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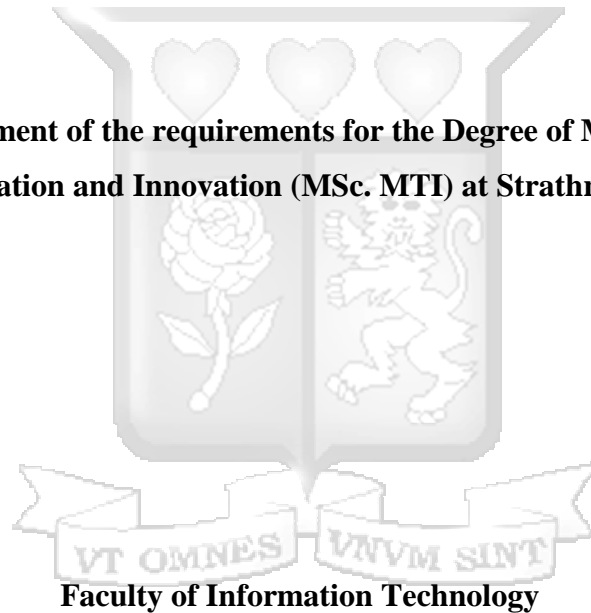
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A Restful E-Health Interoperability Platform: Case of Nairobi County Health Facilities

Rono Kipyegon Derrick

**Submitted in partial fulfilment of the requirements for the Degree of Master of Science in Mobile
Telecommunication and Innovation (MSc. MTI) at Strathmore University**



Strathmore University

Nairobi, Kenya

June, 2016

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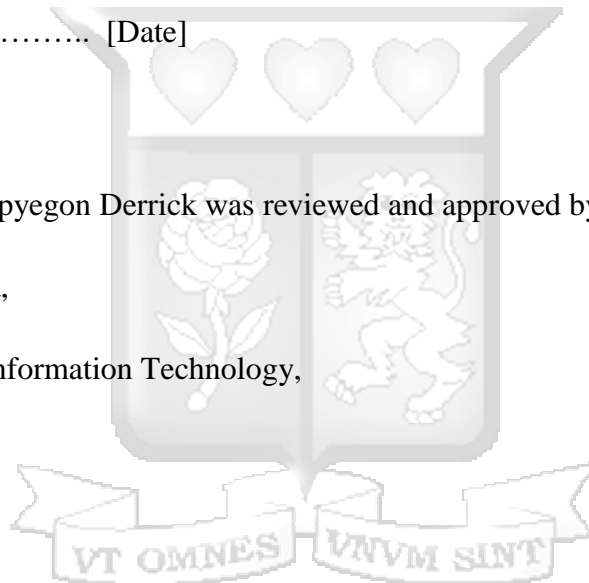
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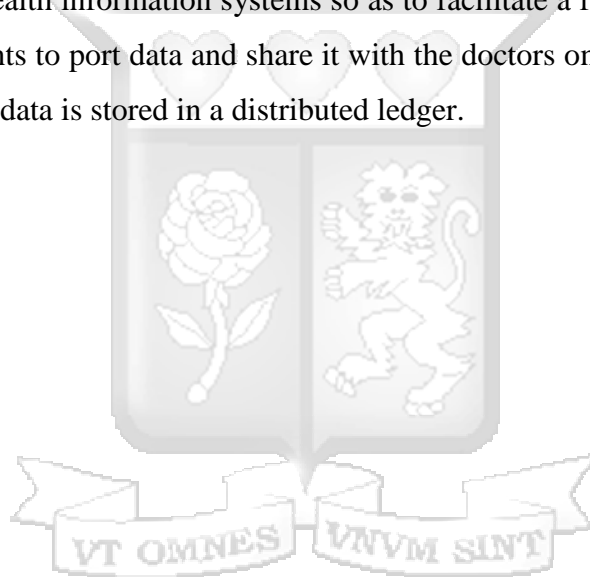
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ABSTRACT

The concept of interoperability is key to information exchange amongst systems running on different platforms. Currently, E-Health systems operate within the hospital domain and they cannot communicate with other health facilities in order to share information. This makes it hard for health practitioners to share patient data and access medical history which facilitate evidence based decision-making at all levels of the system especially at the point of origin. This research sought to investigate why hospitals and developers have had a problem integrating the systems and also to identify some of the technologies used to achieve interoperability. To achieve this, the author conducted interviews to get general information on sharing of patient data. Findings indicated that current systems do not allow sharing of health data. The research developed a platform that uses blockchain technology and distributed file systems. The platform integrates into the existing health information systems so as to facilitate a fast and secure data exchange. The application allows patients to port data and share it with the doctors on demand and also ensure that a permanent reference of the data is stored in a distributed ledger.



DEDICATION

I dedicate this dissertation to God, my family for their encouragement that kept me moving, to all my classmates for the support granted throughout the masters' period, the lecturers for their guidance, the open source community for the resourceful tools they have developed and finally, to my supervisor Dr. Vincent Omwenga, for his advice throughout the research period.



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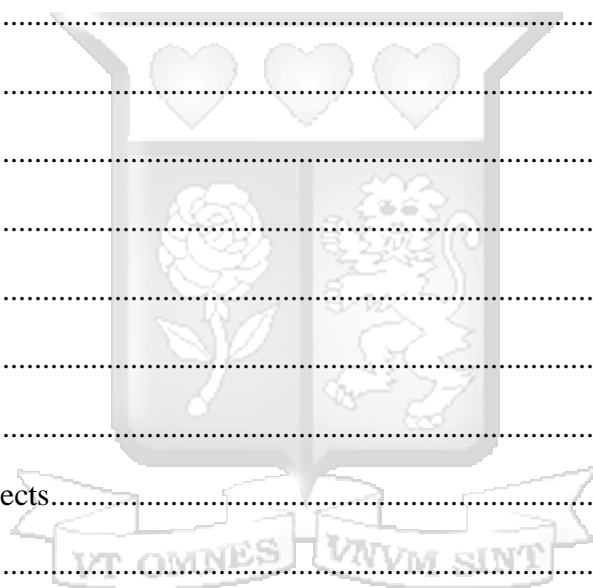
I would like to pass my gratitude to everyone who helped me throughout the project. Your daily encouragements and push helped me to reach completion. A big thank you to my parents and siblings for their prayers and encouragement. I would also like to thank my supervisor Dr. Vincent Omwenga for his tireless efforts that helped me to write a good thesis. Much gratitude goes to Safaricom Ltd for enabling me to pursue my masters. Finally I would like to thank the Strathmore community, they provided a peaceful environment and adequate resources for me to finish my studies



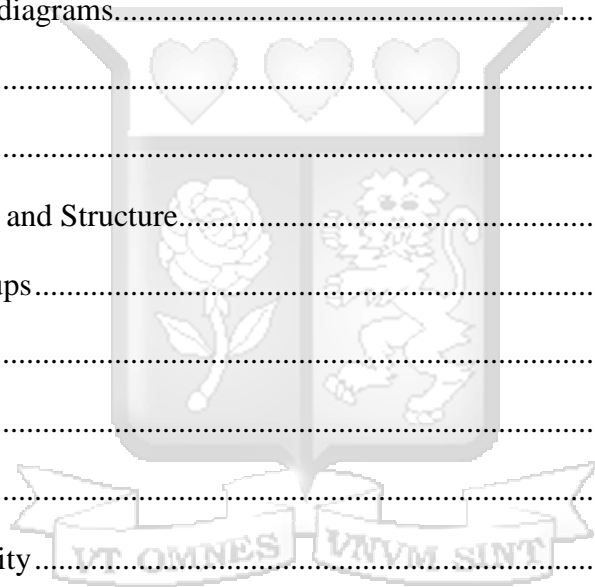
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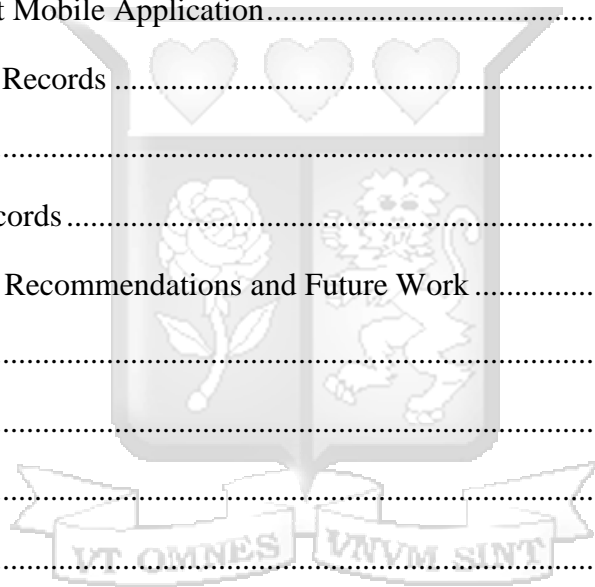
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ABBREVIATIONS AND ACRONYMS

AES- Advanced encryption standard.

API- Application program interface.

E-Health- E-health is the transfer of health resources and health care by electronic means.

EMR- Electronic Medical Records.

HIS- Hospital Information System.

HTTPS- Secure Hypertext transfer protocol.

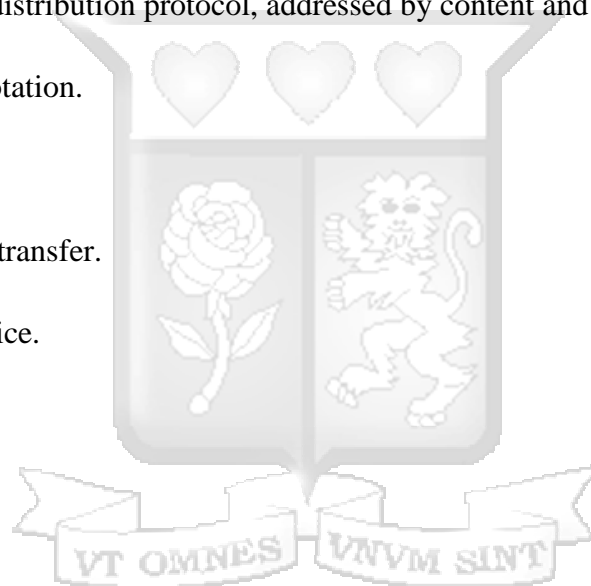
IPFS- is a new hypermedia distribution protocol, addressed by content and identities.

JSON- JavaScript Object Notation.

QoS- Quality of Service.

REST- Representation state transfer.

SMS- Short Messaging Service.



DEFINITION OF TERMS

Bitcoin- Bitcoin is a form of digital currency, created and held electronically. No one controls it.

Blockchain- Blockchain is a technology for a new generation of transactional applications that establishes trust, accountability and transparency while streamlining business processes.

Deserialized – Converting a JSON string into an object.

Healthbitt- Name of the proposed mobile application and platform.

RESTful - A service based on REST is called a RESTful service.

Testnet- The testnet is an alternative Bitcoin block chain, to be used for testing.



Chapter One: Introduction

1.1 Background of the Study

Health is a very critical sector in the building of a country's economy. A healthy nation is a healthy economy. According to a study by European Commission (2005), it is pointed out that health is no longer a mere by-product of economic development but a key determinant of economic development and poverty reduction. The challenges experienced in the health sector emerge because of the way health records are handled. Use of offline mediums i.e. paperwork, tapes, compact tape etc. to store patient data and subsequent history can lead to damage/loss of the data and it does not allow transfer of data from one facility to the other. This therefore calls for deployment of health information system.

The role of the Health Information System (HIS) in the health system is to ensure efficient and safe health data collection and conveyance of the same to the higher levels of healthcare systems. The system is also supposed to facilitate evidence based decision-making at all levels of the system especially at the point of origin (HIS policy, 2007). This therefore makes HIS a key to improving health status of the population within a health system because the subsequent health planning should be based on such information and strategies should be designed to address any identified discrepancies. According Ayub, Jorn, Ola, Jeremiah and Charles (2012), over the years, there has been a great focus in strengthening the national health information system in Kenya. This happened because of the need to create a centre of excellence for quality health and health related-data and also availability of information for all to use. However, the deployment of these systems has not expanded to cover private clinics and other small establishment which therefore default to using their custom made systems or paper records which might take long before it is fed to the central database. This led to emergence of centralized systems which need to be always connected to other centres in order to facilitate information exchange.

This approach is very prohibitive especially when dealing with so many facilities at the same time, given that if a failure occurs in the central server no operations will take place. Currently, there is no mechanism of sharing the health data across facilities because the systems do not have a standard of exchanging the data. The main reasons being lack of fully and evenly developed infrastructure and poor capacity in management of health information among the workforce (Ayub et al., 2012). This therefore calls for development of systems which are evenly distributed and can share data.

This concept where systems are able to share and exchange information to aid decision making is called interoperability (Neil & Jens, 2009). In the case of health care; interoperability refers to the ability of

health care information system and information technology systems to work seamlessly within and across organizational boundaries so as to advance effective delivery of healthcare to communities and individuals. Interoperability is a key component that will enable access to robust patient data and also ensure that there are better health care outcomes while bringing efficiency and cost saving (Kilwake, Matoke, Waliaro, Wanyembi & Ogao, 2012).

According to Kilwake et al. (2012), Kenya has made important steps in creating policies that will guide developers and other solution providers when coming up with interoperable systems. However, the challenge remains on how the systems can be implemented across several levels of the health ecosystem. Table 1.1 shows the EMR systems being used in Kenya and their capability of exchanging electronic. None of the systems have been able to achieve interoperability, the fact that it cannot transmit aggregate information to the national repository makes the systems totally independent. The average rate at which the deployed systems meet the requirements is less than 25%. In this case 17 systems were evaluated as shown in Table 1.1.

Table 1.1 Exchange of electronic information (Adapted from REPUBLIC OF KENYA, 2011).

Functionality	N	Meeting Requirement (%)
Exchanges clinical information and patient summaries	17	4 (23.5)
Electronically transmits prescriptions	17	4 (23.5)
Electronically transmits and receives laboratory orders and results	17	3 (17.6)
Electronically transmits aggregate information to DHIS2	17	0 (0)
Supports HL7 messaging	17	3 (17.6)
Supports XML generation and messaging	17	3 (17.6)
Supports SDMX-HD	17	0

1.2 Problem Statement

Health facilities in Kenya uses either the traditional mediums i.e. paper records of storing patient information or have deployed standalone systems. These systems keep data that is relevant to the clinic and the patients who visit them. Once the patient leaves the clinic, the files/records remain stagnant and are never shared with the patient or any facility unless requested. When patients visit different clinic, they get a new file and progressive treatment is not possible since their previous records are located in a different system. Doctors prescribe examinations in order to allow them to know the state of the patient. This is done even if the records are clear that the patient has some conditions, but since the health facility does not have the records they will have to undergo the compulsory examination. This at times leads to

delayed attention and thus worsening situations. According to Emmanuel and Jamah (2013), statistics collected by medical lawyers and independent pathologist show that three out of ten patients get the wrong diagnosis or medication. This might even lead to prescription of life threatening procedures before the mistakes are uncovered. Also the patient incurs more charges because of the repeated examinations. In case the facility does not have the necessary equipment/laboratories to carry out the procedure the patient is either referred to a high level facility to get same examinations conducted. Many clinics fear exchanging the data of patients because of issues of privacy and confidentiality.

Interoperability is important in the E-Health domain because it increase the quality of healthcare and decreases costs of treatment and data exchange. It also allows unrestricted access to Electronic Health Records of a patient anywhere at any time by authorized personnel. There are several real life cases that will benefit from interoperability, such as being able to share lifelong Electronic Health Records of patients among different healthcare providers; providing clinical decision support through the use of clinical guidelines which require the interoperability of E-Health systems. This data can also be used to conduct research and come up with better ways of delivering healthcare. The purpose of this study was to come up with a solution that will be integrated into the current EMR systems to ensure that there is a seamless and secure exchange of data amongst the systems.

1.3 Research Objectives

The general objective of this study is to come up with a platform that will facilitate seamless exchange of information amongst E-Health systems. Below are the specific objective of the study:

- i. To review the factors that enhance interoperability in E-Health systems.
- ii. To investigate technologies used in achieving interoperability.
- iii. To develop a platform that will support information sharing amongst E-Health systems
- iv. To test the usability and functionalities of the system.

1.4 Research Questions

- i. What are the factors that enhance interoperability between E-Health systems?
- ii. What are the technologies used to achieve interoperability?
- iii. How will the platform developed enhance exchange of data amongst heterogeneous systems?
- iv. How will the usability and functionality test of the system be carried out?

1.5 Justification of the Study

For the past years institutions have been moving from paper work into electronic forms of storing data. Most of them have developed their own systems while others have preferred to buy off-the-shelf software. This has created emergence of several Electronic medical record systems in the ecosystem. Most of these systems have different ways of handling data i.e. Text, csv etc. The challenge comes when it comes to porting the same data from one platform to another. Thus the issue of interoperability. Even though standards have been developed to tackle the issue, most of the native systems which store millions of patient records were not developed using the same standards. Therefore most of the facilities will be resistant to moving into newer platforms which supports interoperability because they fear losing data and also the amount of money they spent on purchasing the software.

So to tackle this problem the study came up with an easier way of integrating most of the native systems into a single ecosystem. Creating a switch at the edge of these systems allows them to feed data into the distributed database and also be able to retrieve data without having to overhaul their current system. The public distributed database is a very important resource for health practitioners, government, insurance firms and researchers who need to develop effective models for healthcare provision. Since the medical data file are public, everyone will be able to tap into the ecosystem but they will not have the identity of the file owner.

This means more precise decisions are made when attending to patients in any hospital in the country. Health practitioners are able to preview the patient medical history and insurance companies have a more transparent reference for the medical history of its clients and thus can create fair premiums for them.

1.6 Scope

The research was conducted in Nairobi County and it targeted outpatient clinics. The reason why Nairobi was chosen is because the rate of the adoption of technology in most clinics is commendable and also proximity to the centre of learning. The study found that a clinic in Nairobi operates is the same as any other clinic in the country and thus this research addressed issues faced by most of the health facilities around the country. The research mostly dwelled on how data is exchanged amongst RESTful system and touched a little bit on the standards and policies that govern the E-Health ecosystem. However there are many use-cases of the platform, a proof of concept mobile application was developed to show how data can be added or retrieved from the platform.

Chapter Two: Literature Review

2.1 Introduction

As discussed in the previous chapter, health is a key pillar of the economy and having quality and standard health leads to prosperity. But this do not come on its own, several measures have to be put in place so that health facilities can be able to exchange patient's data seamlessly. This chapter analyses the current models which have been developed to solve the problem of interoperability. It also goes deeper to analysing block chain technologies and peer to peer file sharing that can be used to enhance the exchange of data in a more secure and seamless way. The role of web, mobile and block chain technologies in solving the issue of interoperability is also discussed in this review.

2.2 Interoperability Concept

According to Adebesei, Foster, Kotz'e and Greunen (2013), there are three levels of interoperability; Technical interoperability, Semantic interoperability and Processes interoperability. Technical interoperability enables heterogeneous systems to exchange data, but the data exchanged might not be used in a meaningful way by the receiving system. Semantic interoperability makes systems to interpret the information that has been exchanged in a similar way through a shared dictionary of concepts. Whereas, processes interoperability focuses on business process between two systems A and B to work together.

Benson (2010), explains that health care is a communication industry, it involve exchange of data at different levels namely:

- i. Within a facility where records of an individual patient are recorded.
- ii. Between specialized diagnostic departments to request data and report results.
- iii. Data sharing between hospitals.
- iv. From health facility to the payer and government agencies.

Information stored by different health facilities involves the use of large data sets, including multimedia diagnostic images, patient records, test results, research samples, and financial. However this data remain in each organizations database (Adebesei, Foster, Kotz'e, & Greunen, 2013). This call for the need for standardization which comes with a number of benefits including single vendor lock-in, promotion of healthy market competition with associated cost savings, reduction in the risks of new technology development and removing the need for expensive customized solutions (DeNardis, 2011). This therefore hints that systems need to be able to talk to each other in order to facilitate the exchange of data at all levels. The main drive of interoperability as discussed by Benson (2010) is towards achieving a patient-

centric health care, he explains that the sole reason for any healthcare activity is because of the patient. Unlike in traditional healthcare model where care was based on discrete visits, the patient centric model is based on a continuous healing relationship which is customized to the patient needs and values putting the patient as the main source of control (Benson, 2010). Figure 2.1, illustrates the difference between a patient centric model and the traditional model.

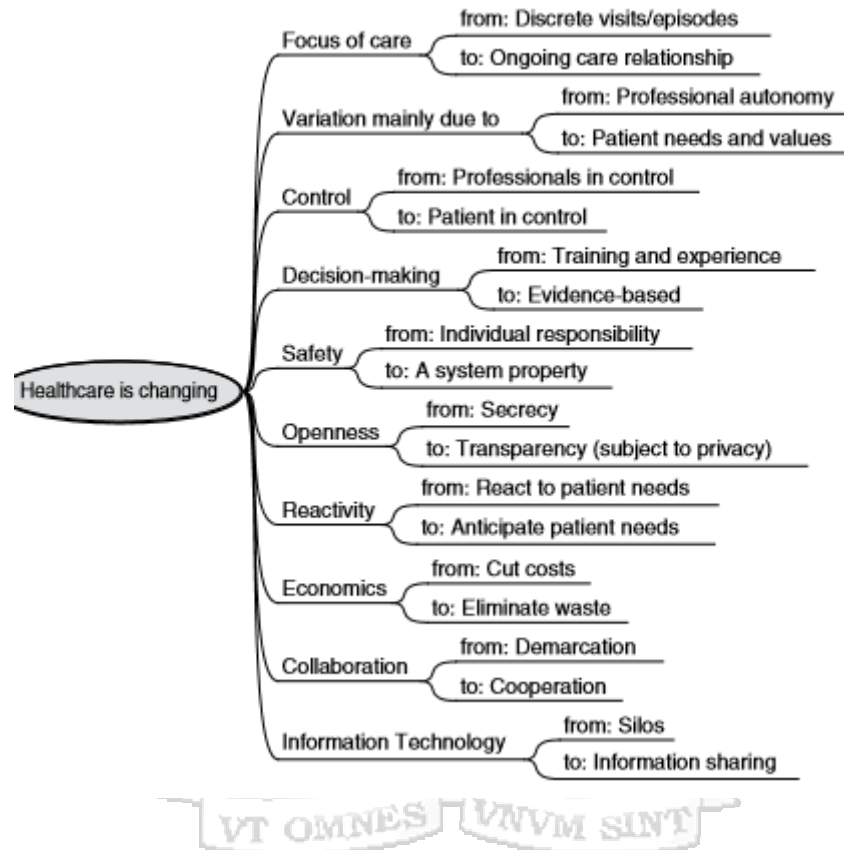


Figure 2.1 Differences Between Traditional and Patient-Centric Health Care (Adapted from Benson, 2010).

Some of the factors that have facilitated interoperability includes standards and models which have been developed for E-Health system. When two computer systems A and B stores data in different ways it become problematic in that the data has to be translated for the systems to communicate. The most suitable way is translating into a standard that both systems understand (Benson, 2010).

2.2.1 Factors That Influence Interoperability of E-Health Systems

Das and Mahapatra (2012), regards e-government as a complex context because it has to deal with policy, legal, politics and sociocultural issues. They identified legal and political factors to be among other things influencing interoperability of systems.

2.2.1.1 Standards

According to ISO (2004), a standard is a document established by consensus and approved by a recognized body that provides for common and repeated use, rules, guidelines or characteristics for activities or their results, aimed at the achievement of the optimum degree of order in a given context. Several institutions in the world have developed standards around medical information exchange, medical terminologies and electronic health record systems processes. Some of the standards have been tailored to cover the security of health information systems (Ministry of Health, 2010).

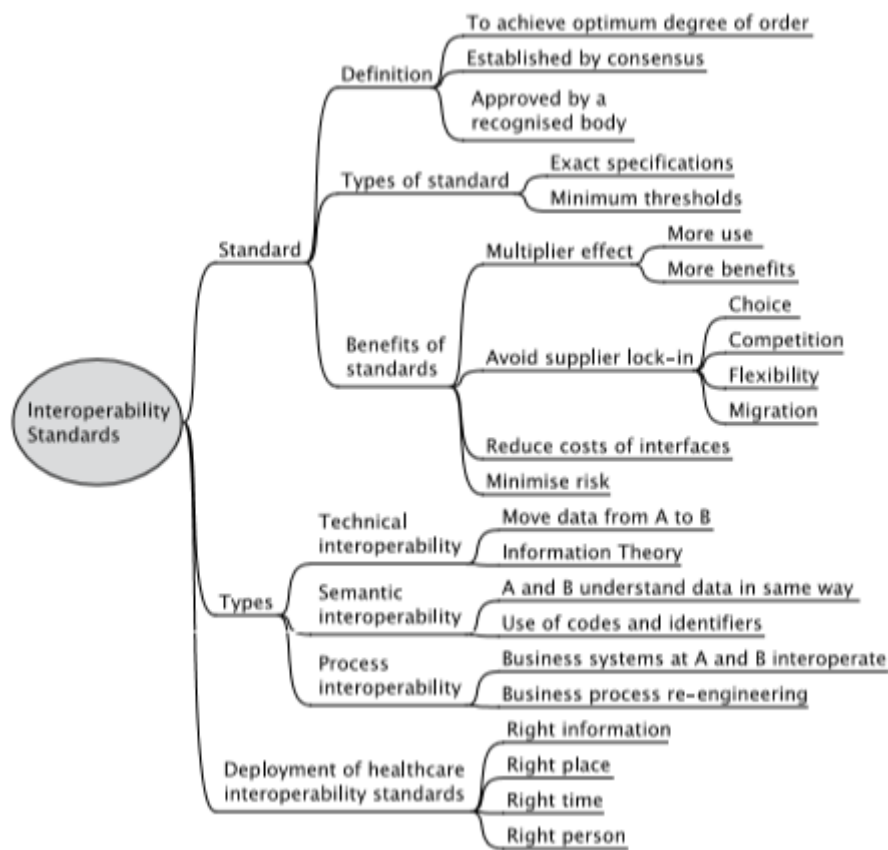


Figure 2.2 Interoperability Standards (Adapted From Benson, 2010).

According to the Ministry of health (2010), these are some of the standards available for the E-Health systems in Kenya:

i. Health level seven standard standards

According to HL7 (n.d.) the Health level seven standard provides a framework for the exchange, integration, sharing and retrieval of electronic health information. The name came from the OSI model, this is because the standard was designed to operate at level seven of the OSI model i.e application layer.

This was to establish semantic interoperability across a diverse number of domains like laboratory, clinical health record data etc. The standard has been used widely in the USA. This increase in integration of enterprise clinical information is receiving a lot of highlights as many clinics and hospitals and medical research centres try to gain insights into existing data. Figure 2.3 shows the key concepts in HL7

SEQ	LEN	DT	OPT	RP/#	TBL#	ITEM #	ELEMENT NAME
1	1	ST	R			00001	Field Separator
2	4	ST	R			00002	Encoding Characters
3	180	HD	O			00003	Sending Application
4	180	HD	O			00004	Sending Facility
5	180	HD	O			00005	Receiving Application
6	180	HD	O			00006	Receiving Facility
7	26	TS	O			00007	Date/Time Of Message
8	40	ST	O			00008	Security
9	7	CM	R			00009	Message Type
10	20	ST	R			00010	Message Control ID
11	3	PT	R			00011	Processing ID
12	8	ID	R		0104	00012	Version ID
13	15	NM	O			00013	Sequence Number
14	180	ST	O			00014	Continuation Pointer
15	2	ID	O		0155	00015	Accept Acknowledgment Type
16	2	ID	O		0155	00016	Application Ack Type
17	2	ID	O			00017	Country Code
18	6	ID	O	Y/3	0211	00692	Character Set
19	60	CE	O			00693	Principal Language Of Message

Figure 2.3 Keys Concepts in HL7 (Adapted from Benson, 2010).

ii. LOINC

According to Bodenreider (2008), LOINC abbreviated Logical Observation Identifiers, Names and Codes and it is a vocabulary for laboratory tests and clinical observations. It has two main entities, the laboratory tests and the clinical observations. It specifies the universal codes, names and other attributes for laboratory results and also clinical reports, physical exam findings, survey instruments and other observations. The standard was developed to enhance exchange and pooling of information across heterogenous sources in order to aid clinical care and decision making (International Health Standards Development Organization, 2014). According to the International Health Standards Development Organization , LOINC community has 34,000 users and is used in 163 countries as at 2014. Accordingly he states that the standard has been adopted by large reference laboratories, health information exchanges, healthcare organizations, insurance companies, research applications and several national standards initiatives and programs. LOINC represent tests with a 6- part LOINC name and is assigned a LOINC code which is a number with a check digit. Figure 2.4 shows the component of a laboratory LOINC test codes and formal names.

LOINC Code	LOINC name (Component name:Property:Time:Specimen:Scale:Method)
2951-2	SODIUM:SCNC:PT:SER/PLAS:QN
2955-3	SODIUM:SCNC:PT:UR:QN
2956-1	SODIUM:SRAT:24H:UR:QN
2164-2	CREATININE RENAL CLEARANCE:VRAT:24H:UR:QN
1514-9	GLUCOSE*2H POST 100 G GLUCOSE PO:MCNC:PT:SER/PLAS:QN
3665-7	GENTAMICIN*TROUGH:MCNC:PT:SER/PLAS:QN
17863-2	CALCIUM.IONIZED:MCNC:PT:SER/PLAS:QN
2863-9	ALBUMIN:MCNC:PT:SNV:QN:ELECTROPHORESIS

Figure 2.4 Examples of Laboratory LOINC Codes and Formal LOINC Names (Adapted from International Health Standards Development Organization, 2014).

iii. SNOMED CT

According to Bodenreider (2008), SNOMED CT is a comprehensive concept system for healthcare with a broad concentration on clinical medicine, diseases and procedures. The standard uses description logic for its representations. International Health Standards Development Organization (2014), regards SNOMED CT as having a broad scope which brings in several benefits because it reduces the speciality boundary that arise from use of different terminologies by different facilities. This therefore allows wider exchange and reuse of structure clinical information. Accordingly the standard provides the capability of manipulating the same data and giving it a totally different presentation. With this in place it means that the information can be selectively retrieved and used to meet different requirements at various levels of generalization.

The government arm responsible for standards in Kenya; Kenya Bureau of Standards (KeBS) has been leading the process of making health institutions to adopt and domesticate the ISO Health Informatics Standards developed by ISO TC 215. Table 2.1 shows the standards KEBS is reviewing or have already reviewed for adoption.

Table 2.1 International Standards (Adapted from Ministry of Health, 2010).

Reference	Category	Scope
ISO 22220	Health Informatics	Identification of subjects of health care
TR 20514	Health informatics	Electronic health record — Definition, scope and context
ISO 13606	Health informatics	Health informatics — Electronic health record communication Parts 1,2,3 and 4 - Part I of ISO 13606 specifies the information architecture required for interoperable communications between systems and services that need or provide EHR data Part II of ISO 13606 specifies the communication of part or all of the electronic health record (EHR) of a single identified subject of care between EHR systems, or between EHR systems and a centralized EHR data repository
ISO/TR 18307:2001	Health informatics	Interoperability and compatibility in messaging and communication standards — Key characteristics
ISO/TS 18308:2004	Health informatics	Requirements for an electronic health record architecture
ISO 27799	Health informatics	Health informatics — Information security management in health using ISO/IEC 27002 This International Standard specifies a set of detailed controls for managing health information security and provides health information security best practice guidelines. By implementing this International Standard, health care organizations and other custodians of health information will be able to ensure a minimum requisite level of security that is appropriate to their organization's circumstances and that will maintain the confidentiality, integrity and availability of personal health information
ISO 17090:2008	Health informatics	Public key infrastructure Parts 1, 2 and 3

The ministry of health in Kenya has adopted HL7 as the typical standard for transmission of patient level data. This is because of its flexibility and adoption by many health systems. According to the Ministry of Health (2010), there are no well-established standards that can be used with aggregated data or indicator transmission. Some of standards which are being considered include:

- i. Quality Reporting Document Architecture (QRDA) is being developed on the HL7 Clinical Document Architecture model.
- ii. Statistical Data and Metadata Exchange (SDMX-HD) is a data exchange format. SDMX-HD has been developed by WHO, based on the ISO SDMX reporting standard, to facilitate exchange of indicator definitions and data in aggregate data systems (Ministry of Health, 2010).

Even with the establishment of these standards, there is still need for a top-level view of standardization efforts that will allow tracking and itemization of various e-health standards and reduce conflicts which

might deter interoperability (DeNardis, E-health Standards and Interoperability, 2012). Most of the standards developed have only addressed the issue of semantic interoperability, technical interoperability remains as a critical area in achieving full interoperability. Adebesei et al. (2013) notes that the legacy systems are posing a bigger challenge to the attainment of technical interoperability because of the different data formats and structures, incompatible operating systems, application servers and databases. Most of the institutions are adamant to pick up new interoperable systems because of the previous investments they made on their current systems. Also you find that people are more concerned about the security, confidentiality and privacy of the patient's data shared in E-Health systems (Adebesei, Foster, Kotz'e, & Greunen, 2013).

2.2.1.2 Infrastructure

The components that forms the foundation for the exchange of health information across different geographical boundaries exist in the physical layer. Therefore this means that availability of computer hardware and network connectivity will be a major driver in interoperability (Adebesei, Foster, Kotz'e, & Greunen, 2013).

2.2.1.3 Service and Application

Adebesei et al. (2013) cites services and applications as some of the components that enables the necessary applications, tools and services to exchange information.

2.2.1.4 Workforce

According to Adebesei et al. (2013), implementation of interoperable systems relies majorly in the presence of a knowledgeable and skilful personnel. The amount of training and education should be enough in order to build a workforce capable of designing, building and operating interoperable e-health systems. Accordingly they discuss that presence of a technical team would come handy in development and localization of international standards to meet local requirements.

2.2.1.5 Political Factors

The Government plays a critical role in influencing interoperability this is because it has the political will and power to organize, manage, and fund an e-government interoperability project in a way that addresses all of the interrelated issues and will have a much better chance for success (Das & Mahapatra, 2012). Adebesei et al. (2013) support this by arguing that governance plays an important role in interoperability by providing the necessary decision making rules and procedures that give direction to, and oversee interoperability initiatives. Accordingly they state that in absence of a governance structure it would really be so hard to coordinate e-health initiatives and align them with national health priorities.

2.2.1.6. Legal Factors

Concerns for privacy, security and confidentiality of any healthcare data was identified as one of the factors which is posing a problem to a widespread adoption of interoperable e-health solutions (Kilwake , Matoke , Waliaro , Wanyembi, & Ogao , 2012). According to Adebesei et al. (2013), these concerns have been addressed by putting in place appropriate legal frameworks which define how an effective exchange of healthcare data is going to take place. Health is one of the domain being managed by the national government, this makes the legal weight of the information exchanged among e-government systems a primary concern. This therefore means that the e-government systems must be legally responsible for these concerns, and this pose a challenge when it comes to the design, development, and maintenance of these systems. Several things have to be put into consideration in order to make sure that the systems comply with the laws and policies (Das & Mahapatra, 2012).

2.2.2 Approaches of Achieving Interoperability in Health

There are several approaches for achieving interoperability, but the main approach which is highly adopted is the use of open standards and service oriented architecture.

2.2.2.1 Service Oriented Architecture

According to David, David, Ed and Pat (2005), a service oriented architecture is defined as software architectural paradigm which constitutes a collection of independent, self-contained services than can be accessed in a standard way. Therefore capabilities provided by a service can be connected to perform required processes. Brown defines a service as a coarse-grained, discoverable, and self-contained software entity that interacts with applications and other services through a loosely coupled, often asynchronous, message based communication model as cited in (David et al., 2005, p. 12). The goodness of SOA is flexibility. The computing ecosystem can be heterogeneous but service can be accessed across the network via simple, well-defined interfaces, and without concern for side effects resulting from dependencies between services. These factors allow applications to use services efficiently and effectively (David, David, Ed, & Pat, 2005). However, SOA does not also guarantee interoperability. David et al. (2005) argues that interoperability can only be achieved by SOA if the following capability is included

- i. Mechanisms for conveying additional semantic information about services such as behaviour, QoS and expected preconditions and post conditions. Currently, we do not have good ways of representing this information such that a user of the service could efficiently and reliably determine whether the service provides appropriate capability for a given context.

- ii. Mechanisms for conveying semantics of data required by and shared by a service. Ontologies provide a good starting point, but new techniques are needed to map between the different ontologies that are likely with independently developed services.
- iii. Ways of achieving optimal and predictable performance and other QoS expectations for the end to end capability provided by sequences of services and other application components.
- iv. Ways of constructing services that have wide application to avoid proliferation of similar, but slightly different, services.

According to IBM (2015), REST defines a set of architectural principles by which you can design Web services that focus on a system's resources, including how resource states are addressed and transferred over HTTP by a wide range of clients written in different languages. This has led to the adoption of REST in the development of web services in the last few years to an extent that it has displaced SOAP and WSDL-based interface design because it's a considerably simpler style to use.

According to Fielding (2000), concrete implementation of a REST Web service follows four basic design principles:

- i. Use HTTP methods explicitly.

One of the key characteristics of a RESTful Web service is the explicit use of HTTP methods in a way that follows the protocol as defined by RFC 2616. HTTP GET, for instance, is defined as a data-producing method that's intended to be used by a client application to retrieve a resource, to fetch data from a Web server, or to execute a query with the expectation that the Web server will look for and respond with a set of matching resources.

- ii. Be stateless.

REST Web services need to scale to meet increasingly high performance demands. Clusters of servers with load-balancing and failover capabilities, proxies, and gateways are typically arranged in a way that forms a service topology, which allows requests to be forwarded from one server to the other as needed to decrease the overall response time of a Web service call.

- iii. Expose directory structure-like URIs.

From the standpoint of client applications addressing resources, the URIs determine how intuitive the REST Web service is going to be and whether the service is going to be used in ways that the designers can anticipate. A third RESTful Web service characteristic is all about the URIs.

- iv. Transfer XML, JavaScript Object Notation (JSON), or both.

A resource representation typically reflects the current state of a resource, and its attributes, at the time a client application requests it. Resource representations in this sense are mere snapshots in time. This could be a thing as simple as a representation of a record in a database that consists of a mapping between column names and XML tags, where the element values in the XML contain the row values. Or, if the system has a data model, then according to this definition a resource representation is a snapshot of the attributes of one of the things in your system's data model.

2.3 Technologies Used in Achieving Interoperability

2.3.1 Distributed Databases

Trends shows that organization have seen a continuous growth in the amount of data they handle and the level of sophistication it has achieved. Therefore the use of a centralized database can no longer serve the organizations effectively. This therefore led to the development of distributed databases. A distributed database is a single logical database that is spread physically across computers in multiple locations that are connected by a data communications network (Tripathi & Tripathi, 2012). The following figures shows the structure of a distributed database.

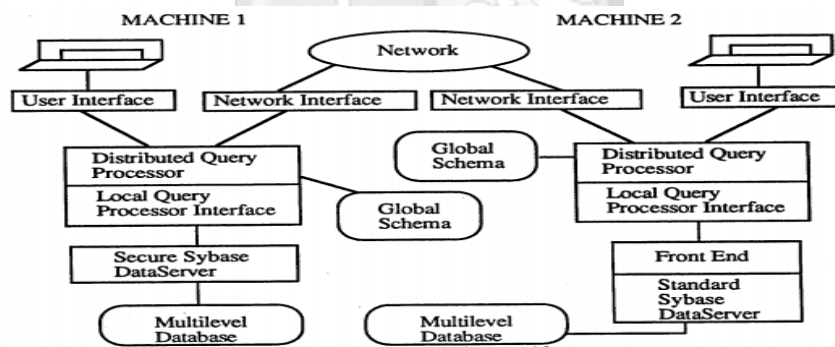


Figure 2.5 Distributed Databases Implementation Architecture (Adapted from Rubinovitz and Thuraisingham, 2010).

According to Özsu and Valduriez (1991) distributed databases have improved the performance of systems tremendously. This is because of the extensive data fragmentation. The fragmentation enables data to be stored in close proximity to the users which benefits the system by reducing the amount of power needed to manage and query the database as compared to centralized databases. This also ensure that there is reduction in the delays caused by delays in the networked environment. K. Tripathi and M. Tripathi (2012), notes that centralized databases run on very complex and expensive mainframes which

pose a great challenge when it comes to scaling. It also does not have capabilities to allow users to add processing and storage capacity. So this therefore means that organizations needs scalable databases that can allow system administrators to handle change in demand with less friction. Accordingly it is noted that replicated database systems provide a level of fault tolerance which cannot be achieved by centralized databases or traditional means such as redundant array of inexpensive disks (RAID). To achieve this level of tolerance K. Tripathi and M. Tripathi (2012) suggests replicating the database so that it is on two separate machines in different physical locations on the network so that the probability of losing it is reduced significantly. These two options for failure recovery are implemented for database replication:

- i. Warm standby uses asynchronous replication to maintain the standby server in a state nearly consistent with that of the primary server. Due to the lag between transactions being committed on the primary server and replication to the standby server, a small number of transactions are normally lost during a primary server failure and switchover to the standby server.
- ii. Hot standby uses synchronous replication to maintain the standby server in a state always consistent with the primary server. From an availability perspective this is the preferred solution, but the higher costs and potential lower performance of synchronous replication databases cause many organizations to select a warm standby solution.

2.3.2 Blockchain Technology

Blockchain technology is one of the radical innovations that have create disruption in how value is exchanged over the internet. This technology eliminates the need for a middleman in any transaction which might come in with a lot of cost, security and delays. According to Needham and Company LLC (2015), blockchain came to the lime light in 2009 as a major backbone for bitcoin. The blockchain is a distributed public ledger which contain blocks that represent the records of all valid network activities done before a succeeding block was added to the chain. The blockchain possess some very unique characteristics. According to BBVA Research (2015), the blockchain is a peer to peer network maintained by a distributed network of computers that require no central authority or third party intermediaries. It contains 3 major components; Transaction, transaction record and a system that verifies and stores the transaction. All these component form blocks. These blocks are generated by open-source software and they record information of when and how the transactions occurred. The “block” stores information of all the transactions that take place in the chain and stores it in a chronological order thus the name blockchain. Therefore blockchain can be defined as a database of immutable time-stamped information of every transaction that is replicated on all servers globally.

According to Barclays (2015), the blockchain exist in two versions:

i. **Permissioned**

The permissioned blockchain technology leverages the blockchain technology from a more closed ecosystem. It allows companies to tailor a newly created blockchain to their needs or group of entities that require it. This kind of blockchain is used mostly by enterprises who do not want to risk by being too open and allowing everyone to tap data stored in the blockchain.

ii. **Unpermissioned (Permissionless)**

According to Steria (2015), a permissionless blockchain allows any entity to post transactions and insert messages using the 40 bytes of space that is allocated to all transactions. This blockchain is open, decentralized ledger and records the transfer of value. Each transaction is cryptographically chained to the previous transaction. The result is always permanent, immutable and verifiable and everyone can see it. This blockchain is very important when there is no trusted authority that verifies the transactions. The users can easily escape censorship and nobody can edit any records which have been created.

The blockchain possess some very unique characteristics as compared to any other ledger. Below are some of its characteristics.

i. Network Effect

Most blockchain rely on the network effect. The greater the adoption of the technology means increased security, robustness, value and attractiveness (Needham & Company LLC, 2015).

ii. Decentralized

Needham and Company LLC (2015), states that blockchain stands-out because it is decentralized, this means that no single entity is in charge of the records. For the blockchain there is no abuse of concentrated power which is normally controlled by a central authority instead the power is distributed among a network of independent nodes and constantly validated by the network participants.

iii. Distributed Consensus

Distributed systems should be reliable and to achieve this, protocols have to be put in place to ensure if failure occurs in one end the system should still be able to run. These protocols and other components need to cooperate, but the problem comes in where systems have to decide which data will be used in a computation (Fischer, 1983). For instance a car control system should be able to be in sync with the sensor

outputs. So in distributed consensus the concern is not what the processes exchange but the fact is that all of them should have the same conclusion. The blockchain was built with this consideration in place. It is able to get distributed system to come to an agreement regarding the state of the data without requiring a central authority. This is achieved by use of peer-to-peer, consensus-based exchange and record keeping (Needham & Company LLC, 2015).

iv. Durability

According to Needham and Company LLC (2015), the public Blockchains operate on decentralized networks as opposed to systems that uses the client-server architecture. With this feature it means there is no central point of failure and thus the distributed ledger will be more durable and in a better position to withstand anything coming from malicious networks apart from power outages. They estimate that the Bitcoin runs on 5000 nodes around the world.

v. Immutability

‘Immutable’ means unable to be changed. In the case of a blockchain, immutability presumably means that it is not possible to go back and rewrite the history. Miners validates records and put it on a distributed public blockchain which is immutable. This makes the processes and applications running on blockchain to operate with a high degree of confidence that they have a complete and original history of activity. This is very critical for applications running on the blockchain (Needham & Company LLC, 2015).

These characteristics have made the potential applications of blockchain technology wider and the most significant applications of the technology are yet to be developed. These are some the developed applications that runs on blockchain.

2.3.2.1 Bitcoin

According to Nakamoto (2007), bitcoin is a chain of digital signatures. Each owner transfers the coin to the next by digitally signing a hash of the previous transaction and the public key of the next owner and adding these to the end of the coin. A payee can verify the signatures to verify the chain of ownership. Bitcoin facilitates a secure, decentralized payment system and provides a tool for the storage, verification and auditing of information, which includes a digital representations of value. The bitcoin forms an intangible unit of account that facilitates the decentralized computer network of Bitcoin users (Scholer, 2016). When a bitcoin user initiates a new transaction, it is added to a block of other transactions which have not been verified. These blocks are then added periodically to the ledger. Thereafter the blocks are distributed to all peers in the network running Bitcoin. The validity of the blocks it then determined using the distributed computing power of the users connected. Once the transactions are approved and sent, it is

not possible to do a reversal or double spend since the only the authorization of the sending party is needed to initiate the decentralized process (Lee, Long, Steiner, Handler, & Wood, 2015). Figure 2.6 illustrates how a Bitcoin blockchain looks like.

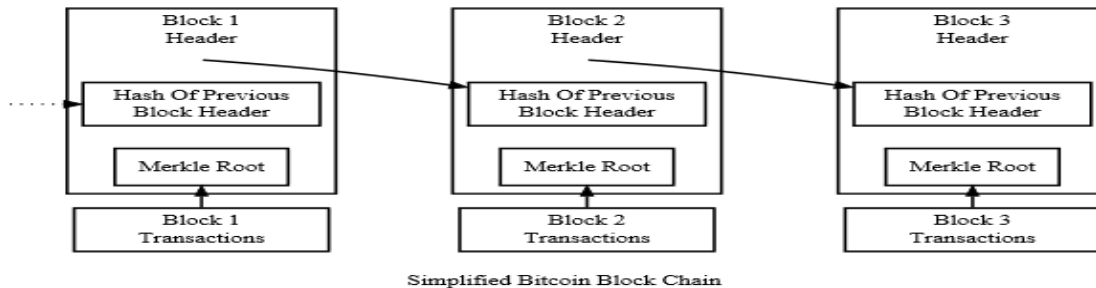


Figure 2.6 Overview of the Bitcoin Blockchain (Adapted from Satoshi, 2007).

According to Goldman Sachs Global Investment Research (2015) the bitcoin transaction as illustrated in Figure 2.7.

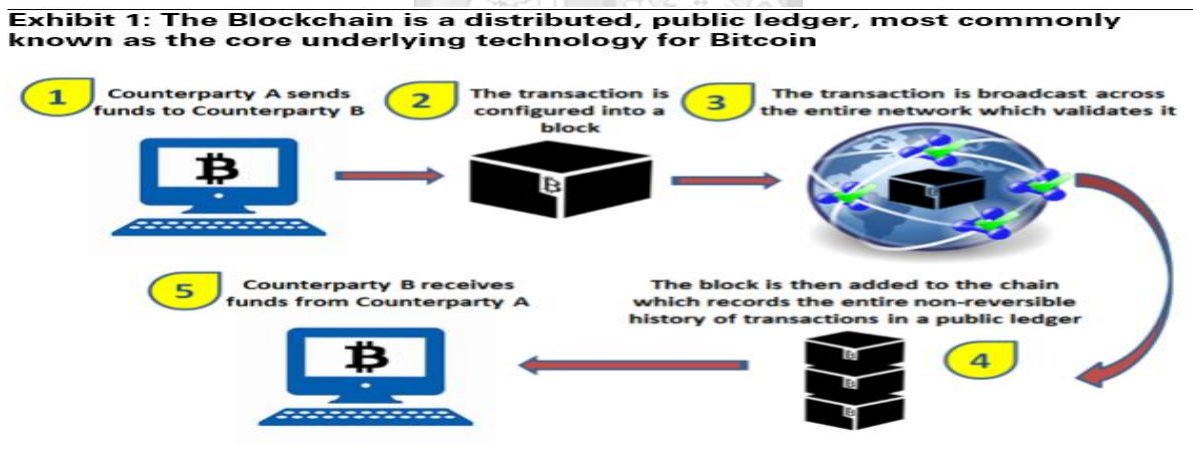


Figure 2.7 Overview of Bitcoin Transaction (Adapted from Goldman Sachs Global Investment Research, 2015).

2.3.2.2 Ethereum

Capgemini (2015) explains ethereum as a platform that takes the blockchain concept a step further. It creates an open secure model for decentralized and generalized-transaction ledger. The creators of ethereum envision it as a world computer that is immune from censorship and anyone can program it and pay exclusively for what they use. The ethereum platform was created mainly to merge and improve the concepts of scripting, alt-coins and metacoin protocols. This would allow developers to create consensus

–based applications which are scalable, standardized, and easy to develop and can be able to exchange information with other systems seamlessly (Buterin, 2015). The platform works by building an abstract foundation layer which lies on blockchain with a built-in Turing complete programming language that allows anyone to write smart contracts and decentralized applications where they can create their own rules, transaction formats and state transition functions. Figure 2.8 illustrates the state transition function of ethereum.

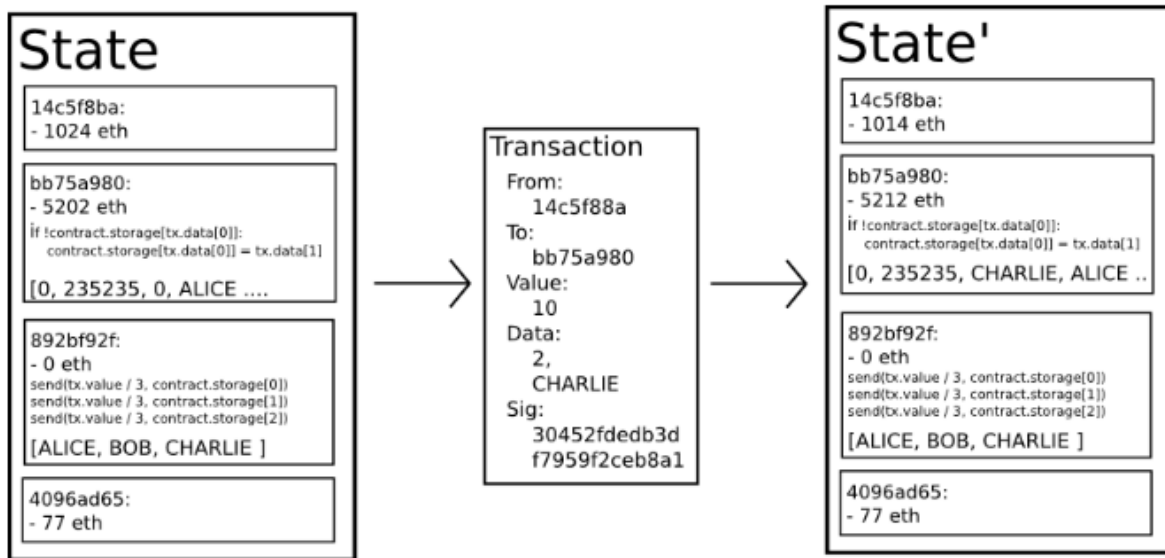


Figure 2.8 Ethereum State Transition Function (Adapted from Vitalik Buterin, 2015).

2.3.2.3 Storj

According to Wilkinson, Boshevski , Brandoff, and Buterin (2014), storj is described as a peer-to-peer cloud storage network that implements end-to-end encryption to allow users to transfer and share data without reliance on a third party data provider. By removing the central authority the traditional data failures and outages are eliminated and security, privacy and data control is improved. To achieve this a peer-to-peer network and basic encryption are used to solve the problem, also users are given incentive in order for them to participate in the network.

2.3.3 Distribute peer-to-peer File System

There has been a growth in research on peer-to-peer systems. The use of large scale distributed network of nodes has becoming an important component of distributed computing due to the increased use by peer-

to-peer platforms such as Napster. Peer-to-peer file systems are becoming popular in the area of research, this is because they offer a decentralized, self-sustained, scalable, fault tolerant and symmetric network of nodes offering an effective balance in storage and bandwidth resources (Ragib, Zahid, William, Larry, & Roy, 2008).

Peer-to-peer architecture has been regarded as a major component for implementing distributed file system. In such a network users share resources via a direct exchange with other nodes, this means the information is distributed among the member nodes instead of being in a single central server (Ragib et al., 2008).

The proposed solution is going to provide a fast and secure means of storing and retrieving medical records for all systems connected to the network. As discussed in the literature there are a number of implementation developed to enhance interoperability, but most of them have dwelled on semantic interoperability. Therefore the combination of blockchain technology, distributed file system, E-Health standards and web services will provide a system that takes care of the semantic and technical interoperability. Table 2.2 shows the strengths and weaknesses of the technologies used in achieving interoperability.

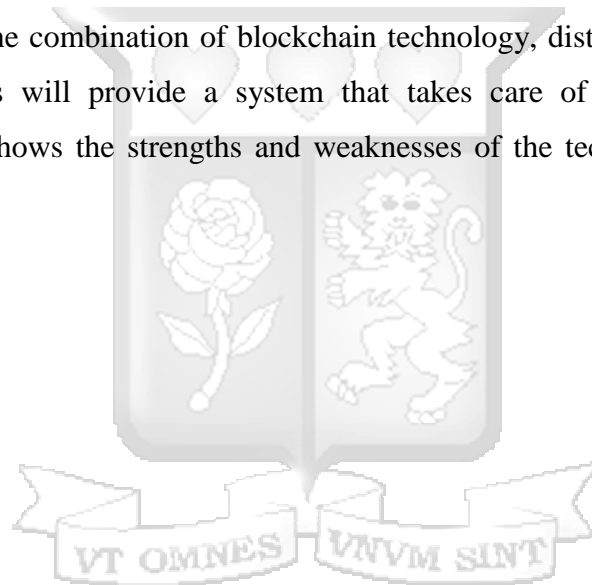
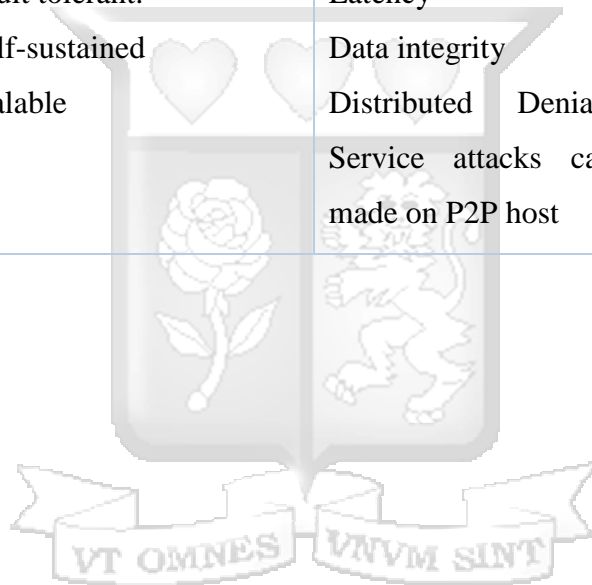


Table 2.2 Comparison of technologies used in achieving interoperability

Technology	Strengths	Weaknesses	Author
Blockchain	Immutable Decentralized Distributed consensus	Latency	(Needham & Company LLC, 2015)
Distributed databases	Decentralized Scalability Fault tolerance Transparency	Concurrency Privacy Costly	(Depardon, Mahec, & S'eguine, 2013)
Distributed File systems	Decentralized. Fault tolerant. Self-sustained scalable	Privacy Latency Data integrity Distributed Denial of Service attacks can be made on P2P host	(Ragib, Zahid, William, Larry, & Roy, 2008)



2.4 Conceptual Framework

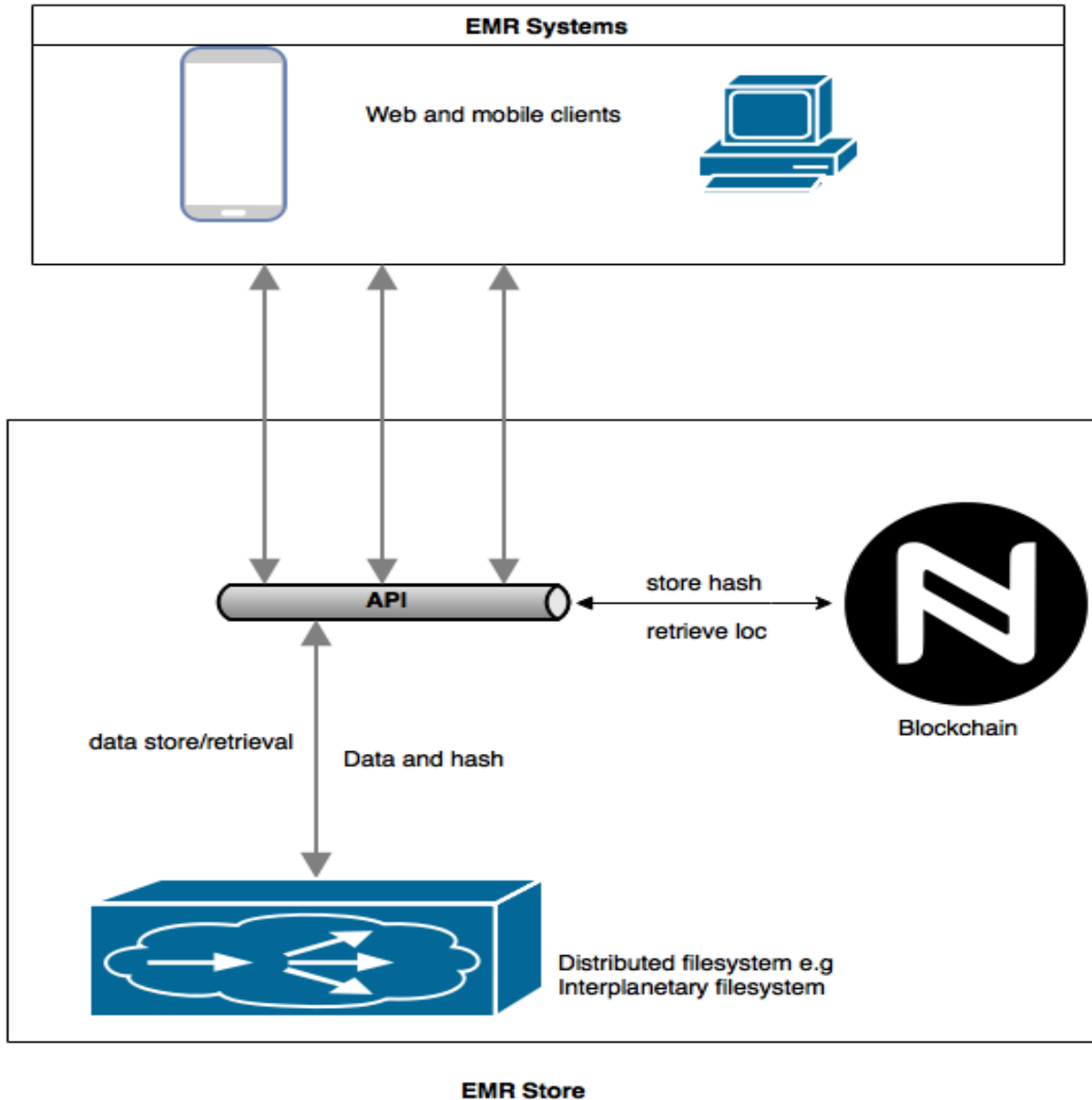


Figure 2.9 Conceptual Framework.

Figure 2.9 shows the main component that works towards creating an interoperable environment. The first layer consist of the electronic medical software. These software run on different platforms and databases. The second layer is composed of three components. The API, Blockchain and the distributed file system. The API act as a glue for all the components in the whole ecosystem, it receives the data and extract the necessary information which is sent to other components. The blockchain act as a public reference ledger, a database that stores a reference of all medical records and the organization that posted the record. The distributed file system stores the real electronic health data which can be obtained from a reference stored

in the blockchain. So when a patient record is closed i.e. the session for the patient ends, the record is submitted to the API in a standard format. The API extracts the information and generate a file which is hashed and stored in a distributed file system. The hash of the file acts as a reference of the health record. This hash is then published on the blockchain and broadcasted to everyone on the network. The patient then receives the reference of his visit in a health wallet. To retrieve the information, the patient supplies the reference to the doctor and then the doctor's system can retrieve the data from the network by querying the API. Third party software can be able to extract data by using the references stored on the blockchain. They extract the references and perform queries on the system to extract the data.



Chapter Three: Research Methodology

3.1 Introduction

The study aims at finding out the challenges that health facilities experience in exchanging patients medical history amongst themselves and how to develop a platform that interlinks RESTful E-Health systems without requiring major changes on current systems. This chapter explains the research methodology that was used, the stages in the research, location of the research, and purpose of the research, data collection techniques and analysis that were used.

3.2 System Development Methodology

Agile development methodology provides opportunities to assess the direction of a project throughout the development lifecycle. This is achieved through sprints or iterations, at the end of which a potentially stable product increment is released.

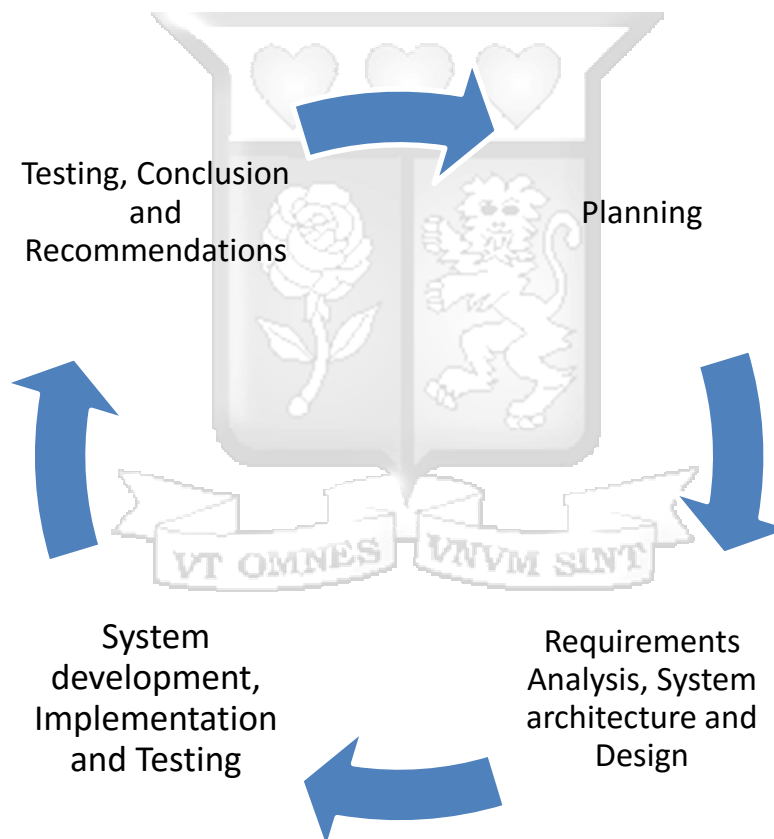


Figure 3.1. Agile Development Methodology.

Figure 3.1 describes the stages of a single iteration that went through the development of the platform and mobile application. The methodology has 4 steps. The first step was planning, the study took the necessary steps to ensure that the processes to be undertaken are outlined clearly so as to achieve the research objectives. This involved reviewing how the problem has been addressed in different

establishments and to come up with new ways of solving the problem. The second step was analysing the data collected through analysing systems in step one and also through interviews, this helped in formulating the requirements for the system to be built. This stage also included the creation of the system architecture. Design phase involved coming up with the application designs based on the requirements gathered, the next step was implementation which involved the actualization of the designs into a working mobile application and platform. Testing was the last step, it encompassed testing the application to make sure that the needed functionalities were working as required and also discuss the application with regards to the set objectives and see whether they were achieved. Conclusions and recommendation were made which also include recommendations for future studies. The process involved several iterations which followed the same circle as illustrated in Figure 3.1.

3.3 Research Design

The study used experimental research design. This design allows one to analyse the prior achievements in order to establish an equivalent solution for the study (Ross & Morrison, nd). To come up with adequate requirements for the proposed system, a number of previous implementations and solutions were analysed. This analysis formed a basis for the system requirements.

3.3.1 System Analysis

The study used Object-oriented analysis approach, this approach combines data and processes into single entities called object (Wang, 2001). This approach was used to create a model of the real-world application. It basically abstracts concepts from the application domain and describes what the intended system must do, rather than how it will be done. This study used use-case modelling and sequence diagrams. It helped in gaining a clear understanding of the functional requirement of the system, without worrying about how those requirements will be implemented.

The system requirements of the system were obtained through analysis of documents and interviews conducted. Experts were interviewed from different fields i.e. doctors, developers and a patient. This was done in order to create a balance in the kind of solution to be developed. The documentation analysed contained specifications and standard guidelines on how past solutions have been implemented. This analysis gave a broad perspective of the solution to be developed including the features that should be added and those that should be deprecated.

3.3.2 System Design

Function-oriented design (FOD) techniques were used to refine the functional requirements identified during system analysis and to decompose the design into sets of interacting units where each unit has

clearly defined functions. Dataflow diagrams were used to show how the system will handle the different data flows between the processes and the entities.

Use case diagrams and its respective use case description was used to model system functionalities. The system functionalities were identified and grouped using the use cases. This enabled the researcher to separate the system into actors and use cases. The use cases were represented in texts and it describes the action a use will perform on the system.

The system sequence diagram shows information passing between the main entities was used to model the system flow. It showed how objects interact with each other, this helped the researcher to explain how the different components of the system work together.

3.3.3 System Implementation

The development tools chosen for this particular project have different component which help in achieving certain functionalities. PHP was chosen because it provides several libraries which can be used to achieve low level functionalities and has so many resources supported by a large community. The scripting language was used to create a REST API which can integrate easily with most of the platforms that run E-Health systems. NodeJs provide server side scripting using JavaScript. The available software development toolkit for interfacing with the Blockchain is based on NodeJs, so it was the most appropriate tool to use for integration purposes. Blockchain was used as a public ledger because of its tamperproof nature and it also cost money to put data on the blockchain, this means the number of people spamming the network will not be many. Android was used to develop the mobile application.

3.3.4 System Testing

Usability testing refers to evaluating a product or service by testing it with representative users. Typically, during a test, participants completed typical tasks while observers watch, listen and took notes. The goal was to identify any usability problems, collect qualitative and quantitative data and determine the participant's satisfaction with the product (Improving the User Experience, n.d.). Usability testing was done to ascertain that the developed application was user friendly and easy to navigate through without any challenge.

3.4 Location of Study

The study was carried Nairobi County in Kenya. The county was chosen because of its massive number of clinics which run different E-Health systems. Also internet coverage in Nairobi is impressive and this means it will facilitate the deployment of the platform without much resistance. The study targeted doctors and developers.

3.5 Target Population

In order to estimate the target population multistage sampling was used. The first stage was to identify the number of health facilities in Nairobi. According to Nairobi county government (2014), the total number of public and private health facilities in Nairobi is 78. For the study 30 facilities were picked randomly. The second stage was to identify the personnel to conduct the study. The study picked 3 people per facility based on the following criteria and availability.

The first group was composed of application developers, they helped to identify the ease with which they could integrate into the platform and raised issues. The application developers were also resourceful experts in system optimization. The second group was composed of doctors who have worked with electronic health records systems. The doctors helped in explaining the challenges they faced when sharing data amongst the several clinics they provide their services. The third group composed patients who visit clinics. The patients helped in determining the feasibility of creating a patient centric application where the patient is in control of all their records.

The target population comprised of 30 patient, 30 doctors and 10 application developers. This resulted to a total of 70 respondents. This formed a representative sample for the county and the respondents helped in filling the usability questionnaires and doing interviews.

3.6 Sample Size

The sample size of the target population was calculated using the binomial probability formula since the data collected was on usability testing. It is based on the chance of seeing the problem and its occurrences. The formula is as follows,

$$\text{Log (1-Chance of Detecting)/log (1-Probability of Occurring)}$$

In this particular study, a problem that impacts more than 10% of the users and have a likelihood of 80% of being detected were chosen. Using the formula $\log (1-0.80)/\log (1-0.1) = 15.2755318478$. Thus the sample size of the study was 15 users.

3.7 Data Collection

Google forms and Google docs were used in the data collection. The data collected was the usability test results and interview feedback. This usability questionnaires results provided insights on how the users felt about the application and whether it solved their problem. There were also interviews conducted. The process involved the use of prepared guidelines in Appendix B and C. The guidelines assisted the

researcher to be able to derive the requirements and limitations of the existing system as per the objectives set.

3.8 Research Instruments

The study was carried out using questionnaires, Observation, reading of documents and interviews. The data collected was used to analyse the current systems, come up with requirements of the proposed system and finally determine the usability of the system developed.

3.8.1 Questionnaires

Questionnaires were administered to a select sample population composed of patients, developers and doctors. The main medium of administering the questionnaires was through emails. Analysis was done using google analytics tools. The questionnaires were used to analyse how doctors and patients interacted with the mobile application and used to gauge usability of the system.

3.8.2 Interviews

Interview guide in Appendix B and C were used to provide a roadmap on the kind of questions to ask so as to determine how doctors and developers interact with the current systems and whether they experience any difficulties when sharing data. The interview was used to identify how the doctors and developers feel about the current system and determine what improvements should be made to make data sharing a seamless process.

3.9 Data Analysis

Exploratory data analysis was performed in order to make connections between the technologies which have been used in the past and how the current technologies can be incorporated to make a difference. Google analytics was used to perform analysis on the usability test data. The tool enables a user to analyse and present data in different styles.

3.10 Research Quality Aspects

Research quality aspects is the degree to which the research was carried out correctly. Validity and reliability were used to test the quality aspects.

3.10.1 Validity

Validity determines whether the research truly measures that which it was intended to measure or how truthful the research results are (Golafshani, 2003). To validate the study, a simulation to depict the nature of transaction that occurs between two E-Health systems was carried out. The simulation shows the

exchange of data between two systems which use the same messaging protocols but runs on different platforms.

3.10.2 Reliability

Reliability is the extent to which results are consistent over time and an accurate representation of the total population under research is referred to as reliability and if the results of a research can be reproduced under a similar methodology, then the research instrument is considered to be reliable (Golafshani, 2003). In this research reliability was attained by giving respondents questionnaires to fill. After a few system features were added, a second survey was issued so as to check the correlation between the two. This gave the researcher a go ahead with the study.

3.11 Ethical Measures

To adhere to ethical codes of conduct, the research ensured that no real patient's medical data was used. Also the respondents were not asked to submit their personal data so that they could act at will and not coerced. Any of their private data they will choose to share will remain private and only used for analysis purposes unless otherwise as was be defined in agreements by the respondents. The research also ensured that the solution proposed only worked for people who choose to share and retrieve data from the platform.

3.12 Tools and Technologies Used

3.12.1 Trello

Trello is an online project management tool that uses cards and a scrum like approach to ensure that your project is in course (Trello, 2016). The tool was used to manage the different phases of the project. It provided a clear view of how the project is progressing.

3.12.2 Draw.io

Draw.io is an online modelling software which integrates with many platforms. This tool was used come up with application designs and mock. The tools provides a diverse set of models which can be used to come up with very high level application designs (Google, 2016).

3.12.3 LAMP Stack

This stack is composed of the apache webserver, MySQL database and PHP (Turnkey Linux, 2016). The stack was used in developing the point of contact between the mobile application and the data exchange platform. The stack run the middleware which handles all the logical operations.

3.12.4 Nodejs

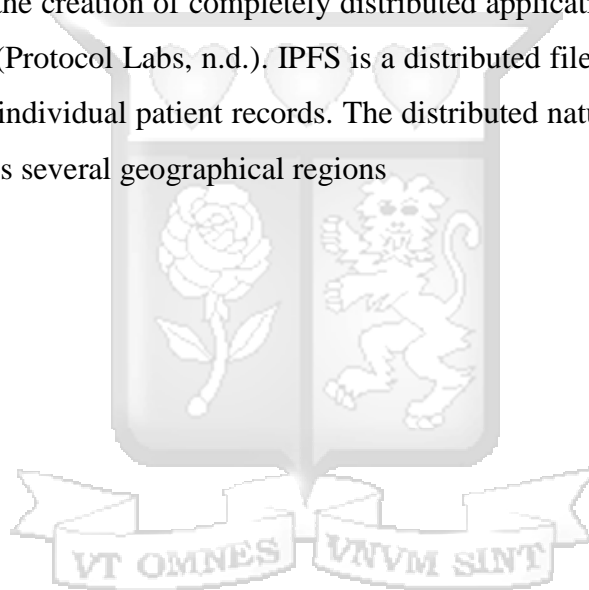
Nodejs is a JavaScript server side scripting language. Nodejs uses an event-driven, non-blocking I/O model that makes it lightweight and efficient (Nodejs Foundation, 2016). The technology was used to interface the middleware application with the Bitcoin Blockchain.

3.12.5 Bitcoin Testnet Blockchain

The testnet is an alternative Bitcoin block chain, to be used for testing (Testnet, 2016). The bitcoin testnet was used to make bitcoin transactions and store the health data references in a permanent public ledger. This Blockchain emulates the real functions of a blockchain.

3.12.6 IPFS (Interplanetary File System)

The Interplanetary File System (IPFS) is a new hypermedia distribution protocol, addressed by content and identities. IPFS enables the creation of completely distributed applications. It aims to make the web faster, safer, and more open (Protocol Labs, n.d.). IPFS is a distributed file system was used to store the electronic health records for individual patient records. The distributed nature of the platform allows the records to be replicated across several geographical regions



Chapter Four: Requirements Analysis, Design and System Architecture

4.1 Introduction

This chapter is going to discuss in detail the data analysis of the data collected from the sample population and then look at system analysis which resulted in the final system design.

4.2 Functional Requirements

Functional requirements describe the processes which the system is going to do. Typically it specifies the behaviour or a function. Table 4.1 shows the functional requirements of the system which represents the actions that can be undertaken by the actors.

Table 4.1 Functional Requirements for Healthbitt Mobile Application

No.	Requirements
1	All users should be able to registers their health wallet.
2	All users should login to authenticate their health wallet.
3	Patient should be able to access his past medical electronic files.
4	Patient should be able to share the health data with doctor.
5	Doctor should be able to scan/enter reference key and authenticate to access a shared health record.
6	All users should be able to logout.
7	Doctor should be able to enter a key to unlock patient records.
8	All users should be able to edit their profile.

To describe the functional requirements in an easy and high level manner we are going to have a use case diagram. The use case diagram shown in Figure 4.1 represents the functional requirements described.

4.3 Non-Functional Requirements

Non-functional requirements are the aspects of the system that are not related with the behaviour of the system. They basically define how the system is supposed to be. The study is created to not only address the functional aspects of the system but to also give emphasis on the components that need to make it usable and valuable to the user. The main goal is to create a mobile application that encompasses all aspects of design with the user in mind. The main source of these requirements is as result of analysing the responses from the interview with the select sample. The table 4.2 shows the non-functional requirements.

Table 4.2 Non-functional Requirement for Healthbitt Mobile Application

No	Non-functional Requirements
1	The application must run on a large set of android devices.
2	The application should be easy and intuitive to use.
3	The application should ensure that the user's data is encrypted.
4	The application should ensure the integrity and verification of the patient's data.
5	The application should provide an intuitive error handling and notification interface.
6	The system should allow the patient to secure their records while sharing.

7	The system should always be available for the user to access their data
8	The system should perform validation for all the data entered.



4.4 System Analysis

4.4.1 Use Case Diagram

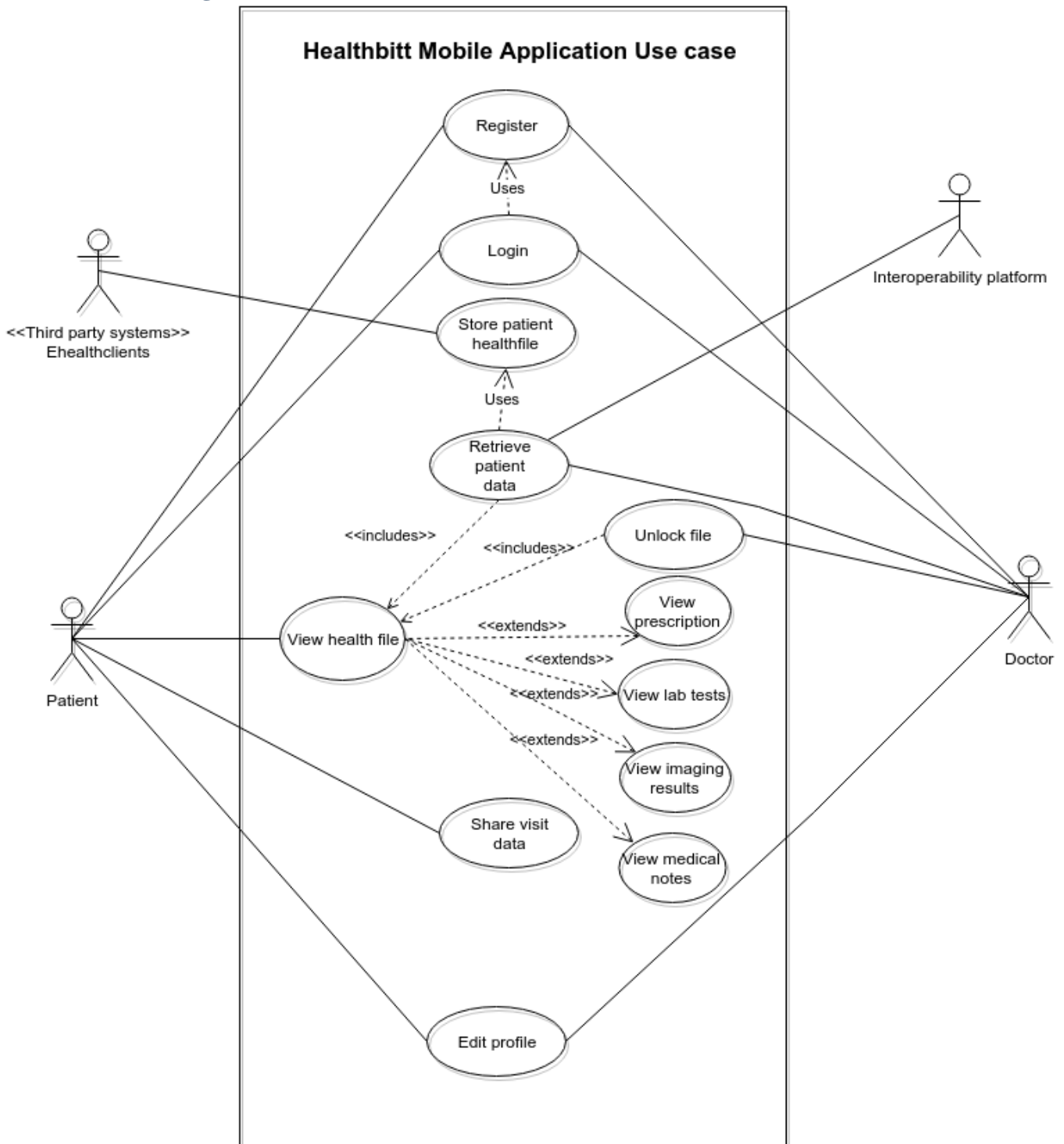


Figure 4.1. Use Case Diagram for Healthbitt Mobile Application.

In the use case the patient is the dominant user of the system. They should be able to view all electronic health files and access the data inside each electronic file. They also should be able to share the same data with the doctor for examination purposes. The doctor can only use the system to access the shared data. The system provides a general function to all actors to be able to edit their profile. The mobile application is a proof of concept that shows how systems can interact with the interoperability platform.

4.4.1.1 Use Case Description

Table 4.3 Registration Use Case

Use case:	Registration
Primary actor:	Doctor/Patient
Stakeholders:	<ul style="list-style-type: none"> a) Patient want to create their own secure wallet. b) Doctor wants to register to be able to access patient’s data.
Preconditions:	<ul style="list-style-type: none"> a) Patient/doctor should have an active mobile number. b) Patient/doctor has not registered with same device.
Post condition:	The patient and the doctor should be able to login function

Table 4.4 Login Use Case

Use case:	Login
Primary actor:	Doctor/Patient
Stakeholders:	<ul style="list-style-type: none"> a.) Patient wants to access their health records. b.) Doctor wants to review patient’s data.
Preconditions:	<ul style="list-style-type: none"> a.) Patient/doctor have already registered b.) Patient/doctor put valid login credentials
Post condition:	Patient/doctor should login successfully and access protected features.

Table 4.5 Retrieve Patient Data Use Case

Use case:	Retrieve patient data
Primary actor:	Doctor
Stakeholders:	a.) The doctor wants to access the shared patient file.
Preconditions:	a.) The patient has shared the file with the doctor. b.) The doctor has the unlock key for the health records. c.) The doctor has logged in and is able to unlock the electronic health file
Post condition:	The doctor is able to access the data stored in the electronic health file.

Table 4.6 View Health File Use Case

Use case:	View health data
Primary actor:	Patient
Stakeholders:	a.) The patient wants to access the electronic medical record for a particular visit,
Preconditions:	a.) The patient has an existing electronic health file b.) The patient has selected an electronic file for a particular visit. c.) The patient is authenticated and has rights to access the health wallet
Post condition:	The patient should be able to read the file and review the records for that particular visit.

Table 4.7 Share Visit Data Use Case

Use case:	Share visit data
Primary actor:	Patient
Stakeholders:	a.) The patient wants to give read access of the electronic file to the doctor
Preconditions:	a.) The patient has an existing electronic health file b.) The patient has selected an electronic file for a particular visit. c.) The patient is authenticated and has rights to access the health wallet. d.) The patient has chosen share and entered the credentials of the user they are sharing the file with.
Post condition:	The doctor should be able to access the shared health file from his client.

Table 4.8 Unlock File Use Case

Use case:	Unlock file
Primary actor:	Doctor
Stakeholders:	a.) The doctor wants to unlock the health file to review patient past history.
Preconditions:	a.) The doctor has logged in and has an electronic health record shared by the patient. b.) The doctor has been given an unlock key by the patient.
Post condition:	The doctor should enter the unlock key and the health record is unlocked.

Table 4.9 Edit Profile Use Case

Use case:	Edit profile
Primary actor:	Patient/Doctor
Brief description:	The patient/doctor wants to view the profile details and make modifications
Preconditions:	a.) The patient has registered with the Healthbitt mobile application and has logged in b.) The patient has an active profile.
Post condition:	The patient should be able to edit and save their profile details.

Table 4.10 Store Patient File Use Case

Use case:	Store patient file
Primary actor:	Third party systems
Brief description:	The system wants to store the patient file on the Healthbitt platform
Preconditions:	a.) The systems are authorized to store health files. b.) The patient details have been captured and bundled into a format supplied by Healthbitt
Post condition:	The patient file is created and distributed to all computers in the network.

4.4.2 Sequence Diagram

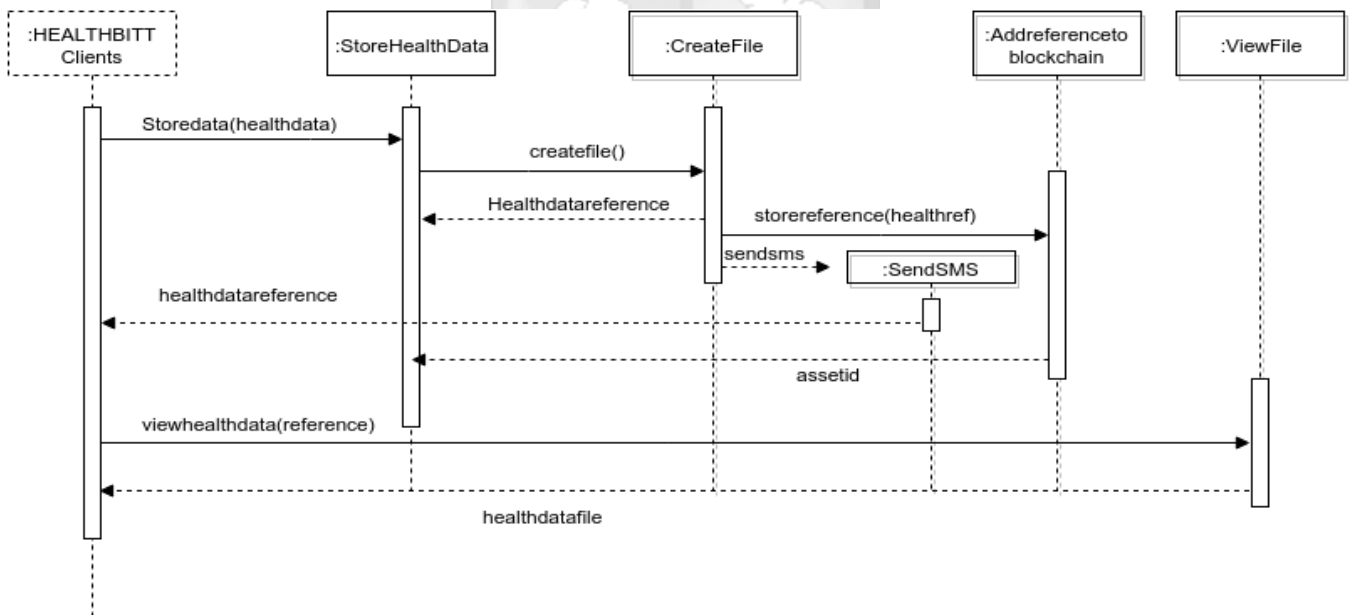


Figure 4.2 Sequence Diagram.

4.5 System Design

4.5.1 Level 0 Data Flow Diagrams

A data flow diagram is used to illustrate how data is processed by a system in terms of input and output. It shows the interactions of the external entities with the system. The figure 14 shows the interaction of the external entities and the system.

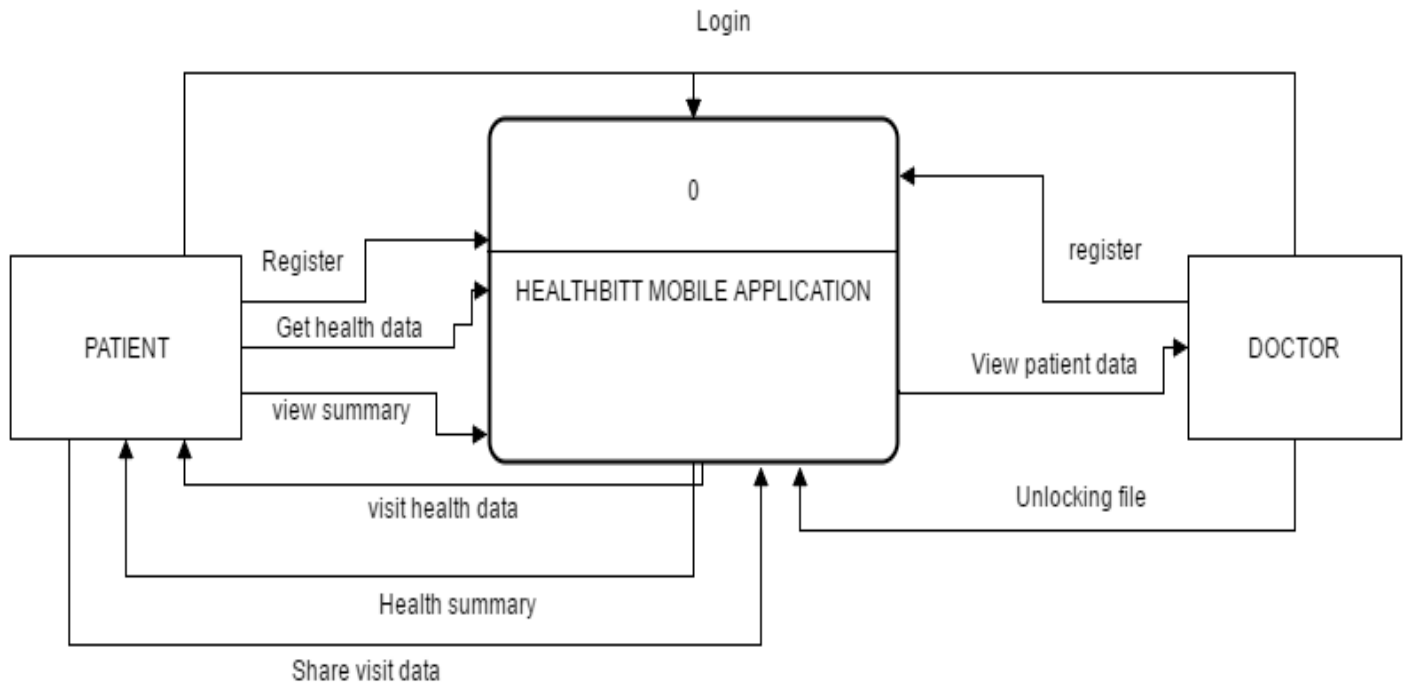


Figure 4.3 Healthbitt Mobile Application Context Diagram.

4.5.2 Level 1 DFD

This DFD shows a more detailed flow of information between processes, the data store and the external entities.

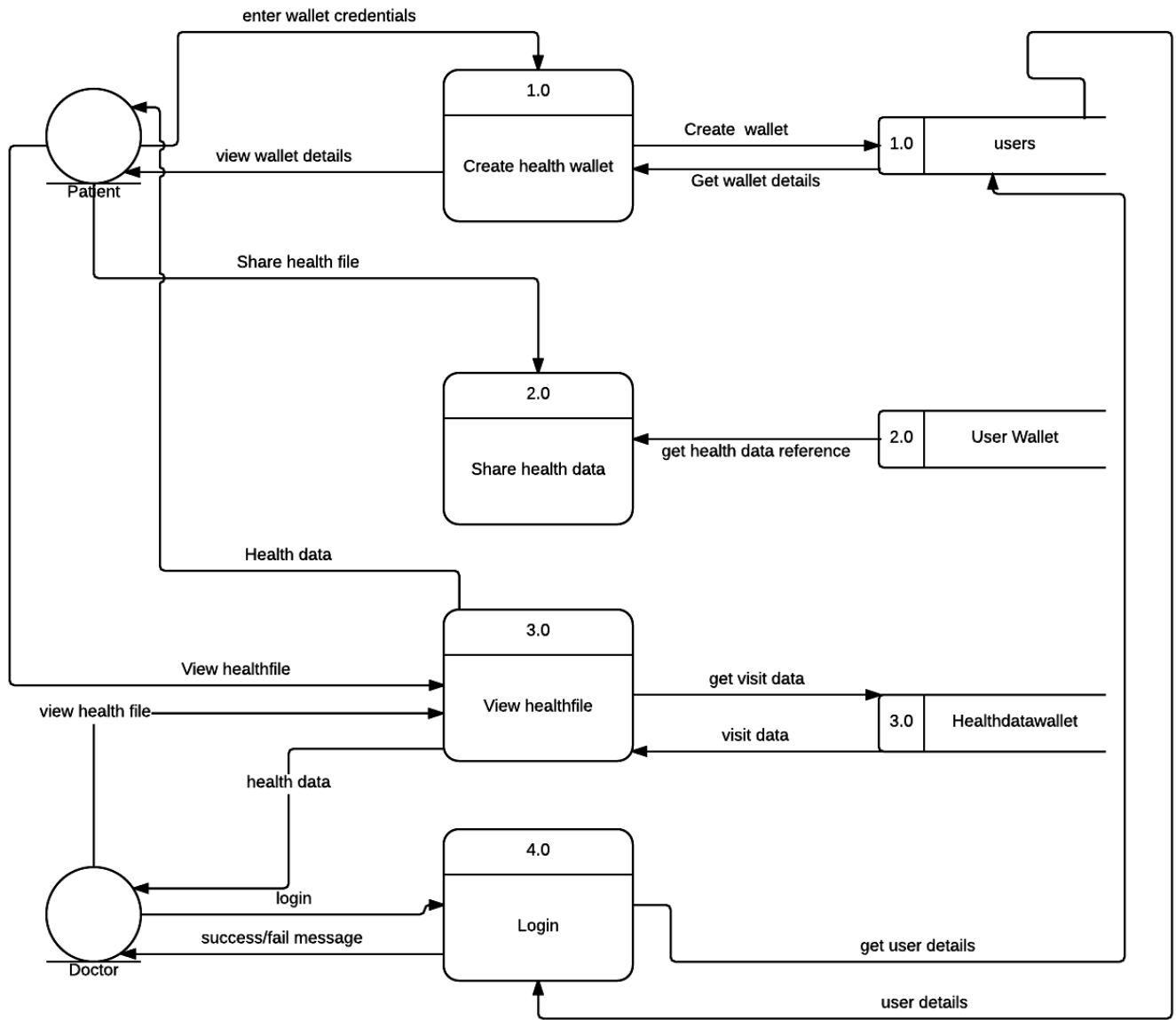


Figure 4.4 Level 1 Data Flow Diagram.

4.5.3. Level 2 DFD

This diagram expand on the view health file process and the share health data process. This are the core processes of the system.

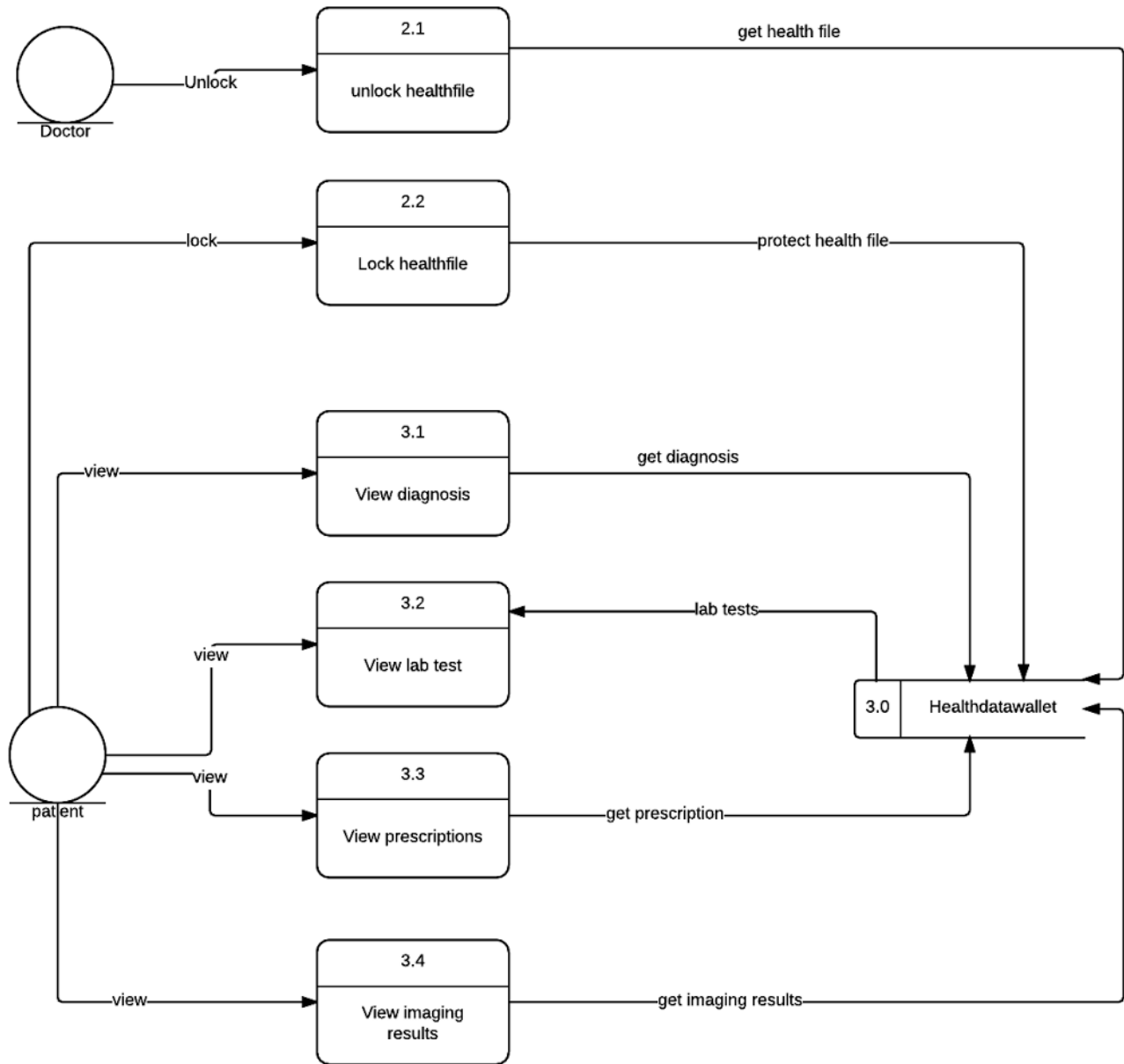


Figure 4.5 Level 2 Data Flow Diagram.

4.5.4 Stored File Format and Structure

Figure 4.6 shows the structure of the data submitted to the platform which creates a JSON file. The JSON schema is described in appendix A.1. All the health data files are stored in JSON format.

```
{
  "patient_history": {
    "prescriptions": [
      {
        "name": "Paracetamol 20 grams"
      }, {"name": "Artheremr lumefatrin"}, {"name": "Piriton"}, {"name": "Asprin"}
    ],
    "lab_test": [
      {
        "name": "stool test",
        "results": {
          "findings": "No palacels found or anything to be scared about"
        }
      }
    ],
    "imaging": [
      {
        "type": "xray",
        "image_location": "QWSDSSERCDFDVG"
      }
    ],
    "observation": {
      "temperature": "37",
      "height": "163",
      "weight": "70",
      "respiratory_rate": "90",
      "systolic_bp": "10",
      "diastolic_bp": "23232",
      "pulse_rate": "88"
    },
    "diagnosis": [
      {
        "presenting_complaints": "headache, diarrhea, fever, nausea and morning sleepiness",
        "examinations_findings": "sign of malaria very acute. might develop high fever and needs to be dewormed",
        "history_of_presenting_complaints": "started one week before visit to tanzania",
        "diagnosis_results": [
          {
            "code": "AFDF34"
          }, {"code": "MATAFS23"}, {"code": "Acute malaria trombositica"}
        ],
        "plan_of_management": "This is a test and not real medical data"
      }
    ]
  },
  "patient_metadata": {
    "organization_code": "432",
    "telecom": "0713038301"
  }
}
```

Figure 4.6 Stored File Format And Structure.

4.6 Application Mock-ups

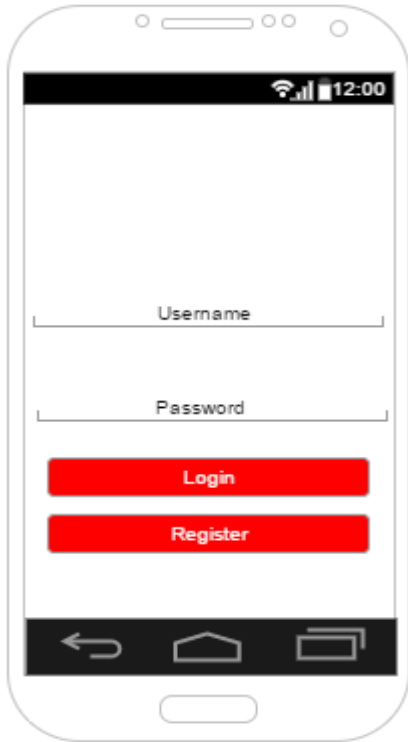


Figure 4.7 Login Screen.

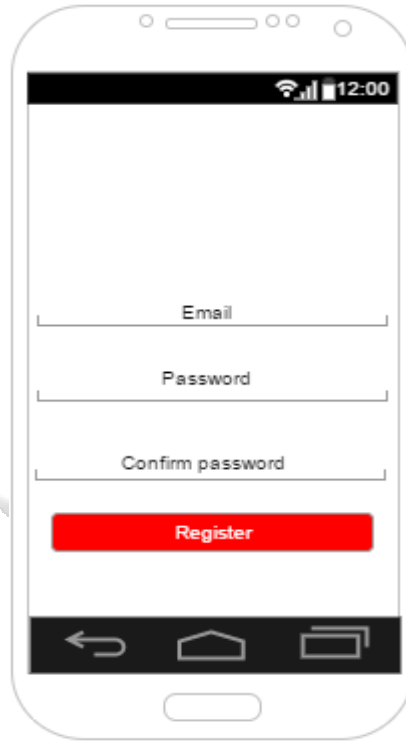


Figure 4.8 Registration Screen.

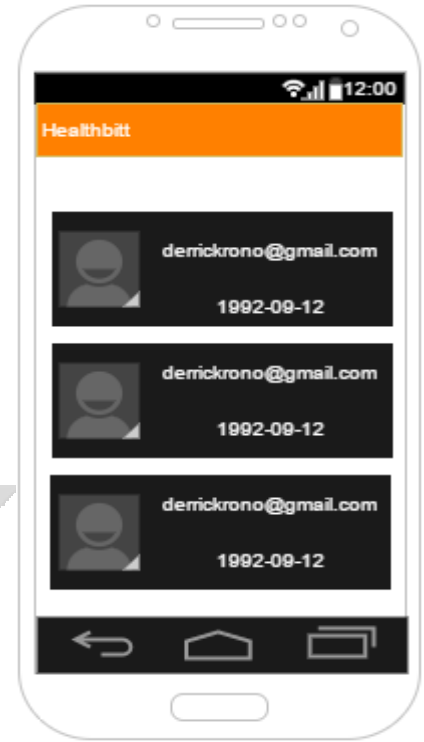


Figure 4.9 Healthbitt Files List.



Figure 4.10 Medical Notes Screen.

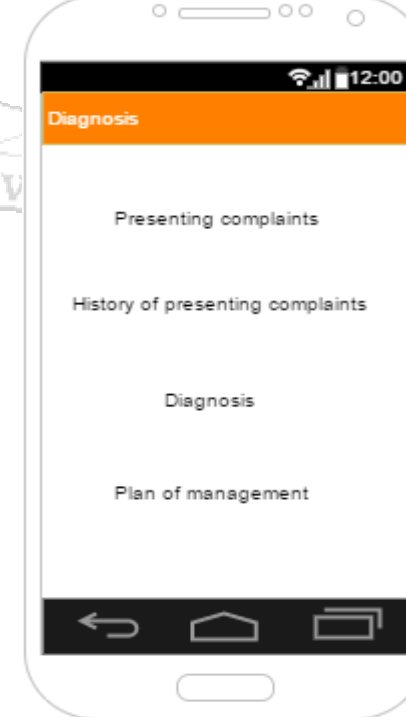


Figure 4.11 Diagnosis Screen.

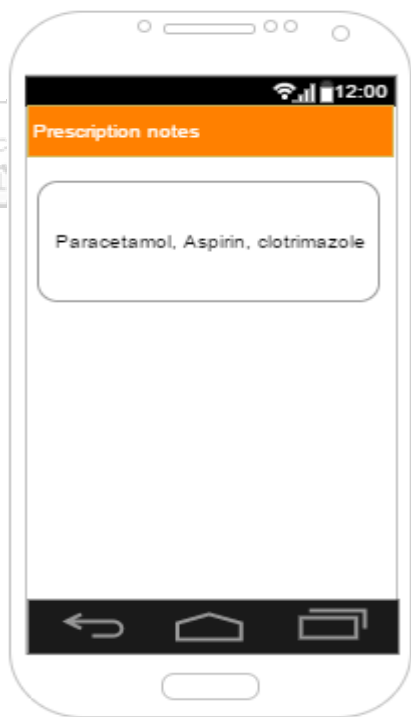


Figure 4.12 Prescription Screen.



Figure 4.13 Lab test notes Screen. Figure 4.14 Imaging notes Screen. Figure 4.15 Unlock Screen.

4.7 Security Design

The data being transmitted on Healthbitt mobile application is sensitive data and by all means it should be secured from eavesdropping during transmission and in storage. Several components have been incorporated so as to ensure total security of the data. AES encryption algorithm is used to encrypt the shared health file. The owner of the health file will use a secret code to encrypt the file, the same code is going to be used to retrieve the content of the file by the recipient. All data that is moved over the internet is transmitted over HTTPS.

4.7.1 Data Integrity

To ensure data integrity the patient wallet stores hashes which act as health data file references. These references are generated when the data is saved from an external system. The integrity of the data is as strong as the hash function used. Another reference is also stored on the blockchain to ensure that the data files cannot be tampered with.

4.7.2 Authentication

All users who want to access patients or own data must be authenticated by the system. They have to login after registering their details on the mobile application. The database that store the user details offline is encrypted using AES.

4.7.3. File System Security

The storage tool used is a distributed file system. This means the health files are not stored on a single machine but are replicated across several geographical regions. This prevents a single point of failure when data in one machine is tampered with. This means the original file can still be fetched from a machine that has not been affected. Also, the file system uses distributed hash tables to ensure integrity of the data stored.

4.8 System Architecture

This section explains the key components that help heterogeneous E-Health systems to interoperate. The Figure 2.9 shows how the different components of system are going to communicate. The system is made up of 4 key components:

a) Healthbitt Client

The first layer consist of the electronic medical software. These software run on different platforms and databases. The main components of this layer are clients that facilities have been using to manage their electronic data.

b) API

The API provide an interface between the EMR clients and the Healthbitt platform. This is the main point of data exchange between the systems and the two components which store the reference (Blockchain) and the real data (IPFS).

c) Blockchain

Blockchain is a public ledger and it is the platform that was used to store permanent references to the health data. This ensured data integrity is in place and a public tamper proof record for every patient file was created.

d) IPFS

IPFS provides a distributed file system that ensured the data stored is accessible in different geographical locations. This provided access to data from any computer that runs on Healthbitt platform.

Chapter Five: System Development, Implementation and Testing

5.1 Introduction

The implementation of Healthbitt mobile application was done using native mobile programming languages and a set of web technologies. The native programming language used is Java while the native system is Android version 4. This allows devices running on Android version 4 and above to run the application. The web technologies used were PHP, JSON, IPFS and Nodejs. PHP was used to create the server scripts which act as the middleware, this is the point of interaction between the mobile application and the platform which is composed of a public ledger and a distributed file system. The data of a patient visit which forms the health data file was stored in JSON format. This data will be deserialized by the mobile application and rendered accordingly. Figure 5.1 shows the implementation.

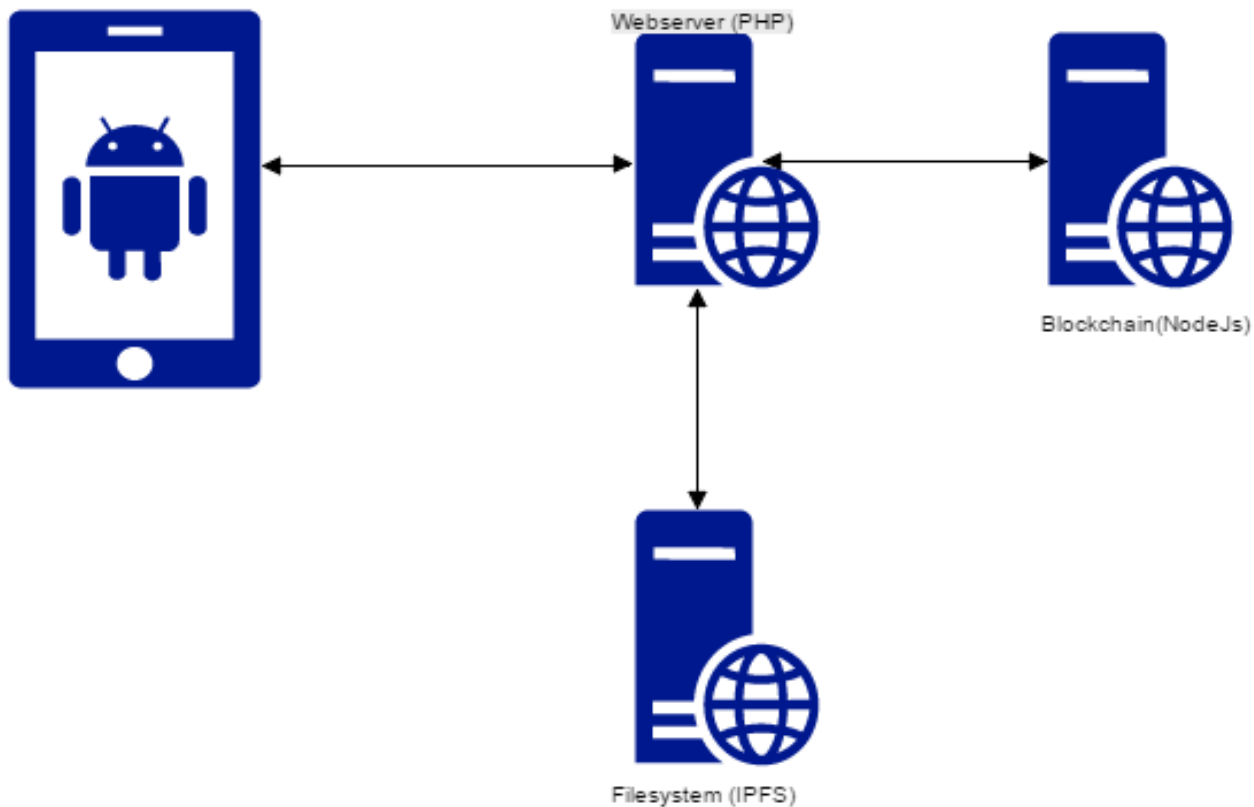


Figure 5.1 Implementation Diagram for the Healthbitt Platform.

5.2 System Development

The system development process used agile methodologies to ensure that the deliverables are handled properly and in a timely manner. It involved creating mock-ups sharing it with a select group of user experience experts and implementing the feedback on the final designs. The final designs were later implemented in the android application. Agile development methodology was chosen so as to ensure that

much time is spent in the development of the product rather than the collection of requirements and documentation.

The development tools chosen for this particular project have different component which help in achieving certain functionalities. PHP was chosen because it is a fast to learn scripting language and has so many resources and a large community. It is also compatible with most of the platforms that run E-Health systems. NodeJs provide server side scripting using JavaScript. The available software development toolkit for interfacing with the Blockchain is based on NodeJs, so it was the most appropriate tool to use for integration purposes. Lastly the Blockchain was used as a public ledger because of its tamperproof nature and it also cost money to put data on the blockchain, this means the number of people spamming the network will not be many.

5.3 System Implementation

5.3.1 Authentication Module

Any user who has installed the Healthbitt mobile application is able to login using the credentials which were used to register. The data they enter includes a username and a password.

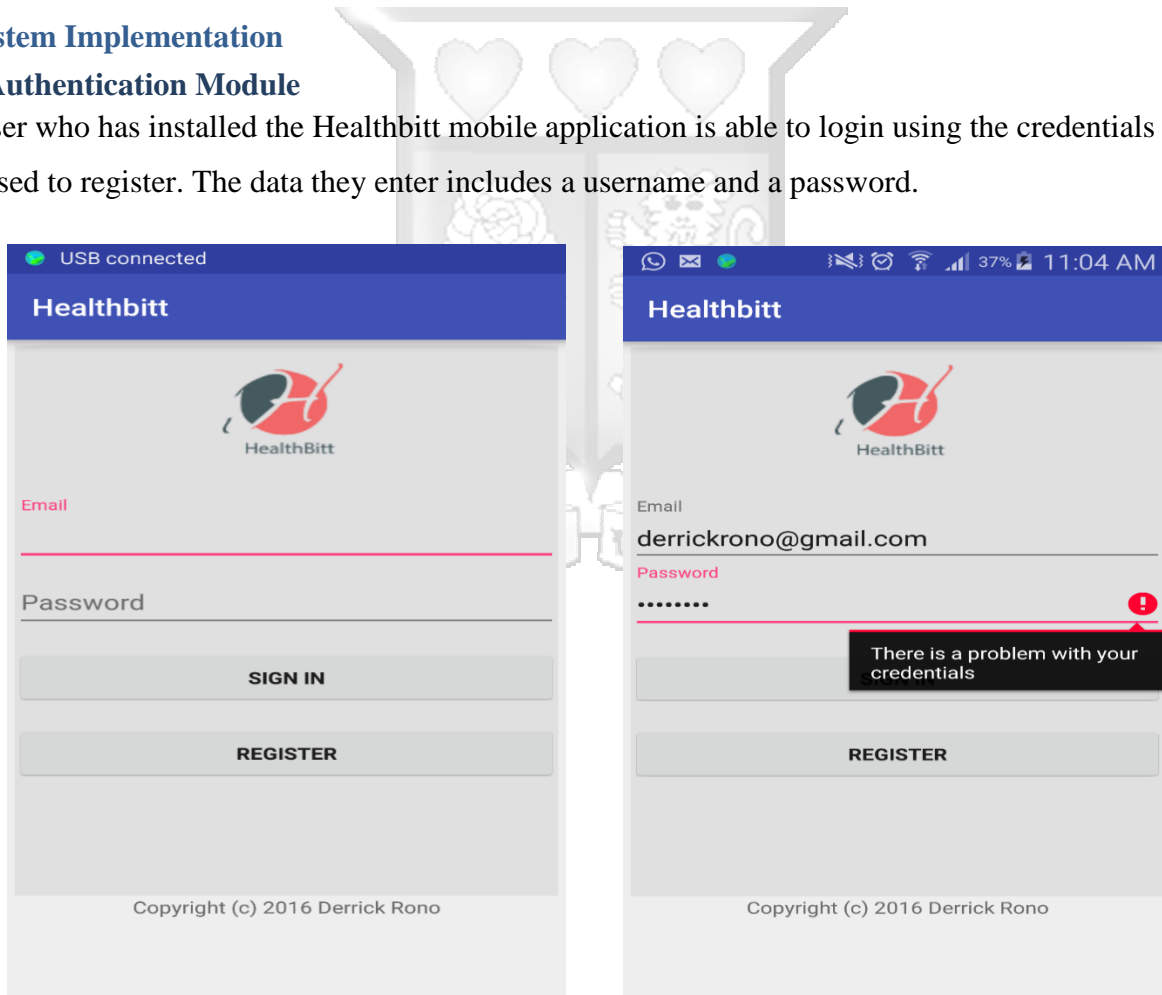


Figure 5.2 Screenshots for the Login Screen with Validation.

5.3.2 Registration Module

This module facilitates the registration of the doctors and the patients. When registering both users must enter their username, email and password.

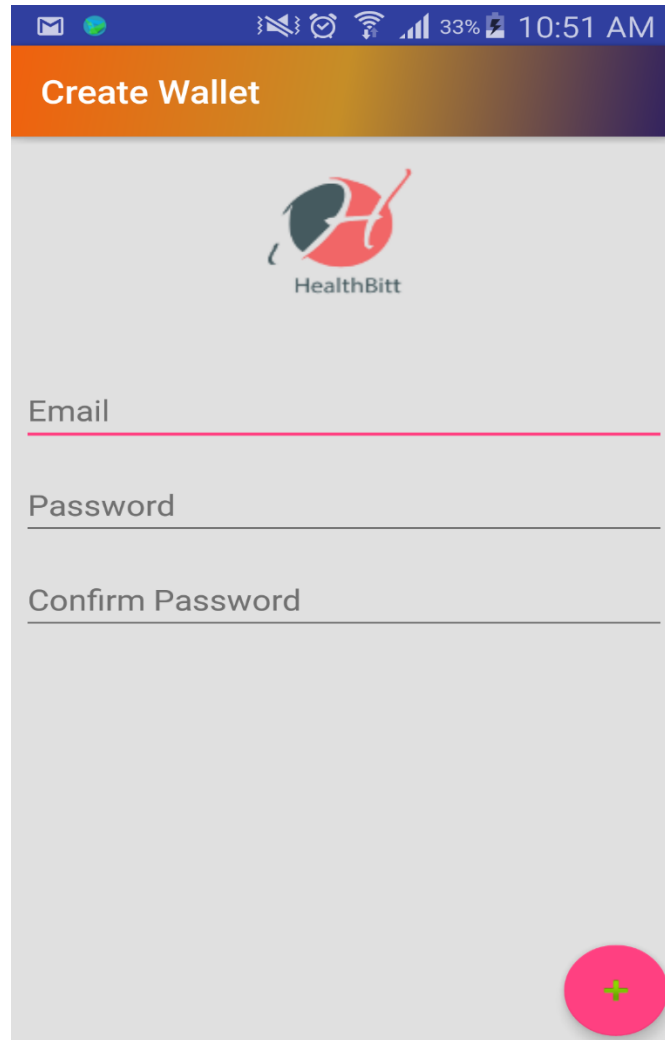


Figure 5.3 Screenshot for the Registration Page.

5.3.3 Health Data Module

The health data module allows the users of the application to be able to view a list of their health files from visits or those shared by the patient. This module also provide a detailed view of each file for the different details captured in that particular visit.

5.3.3.1 Visit Health Files

Figure 5.4 shows the user all the health files available in their wallet.

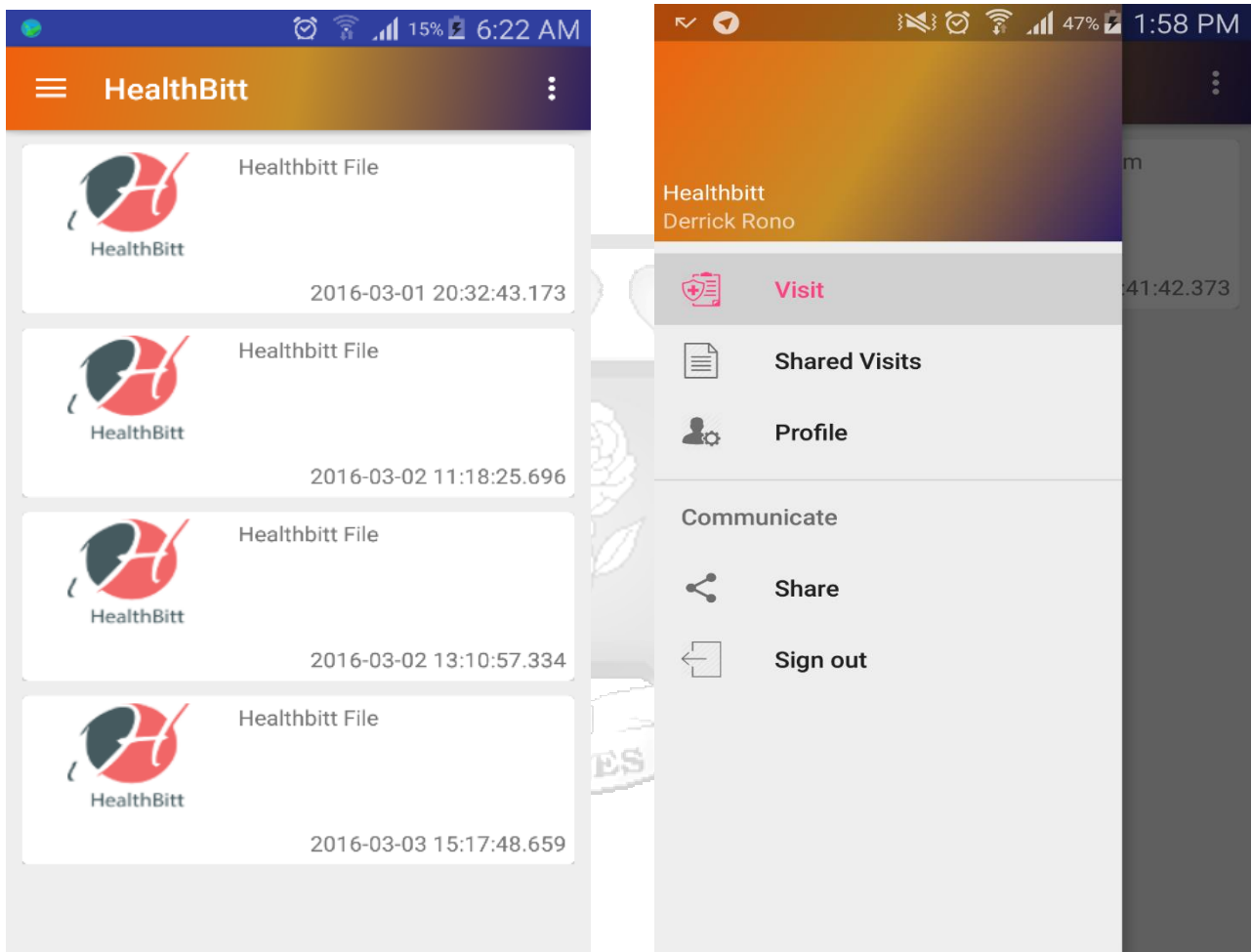


Figure 5.4 Screenshots Showing the Navigation Bar and Visit Health Files.

5.3.3.2 View Medical Notes

Figure 5.5 shows the screen where the doctors/patient can access the details of the medical file.

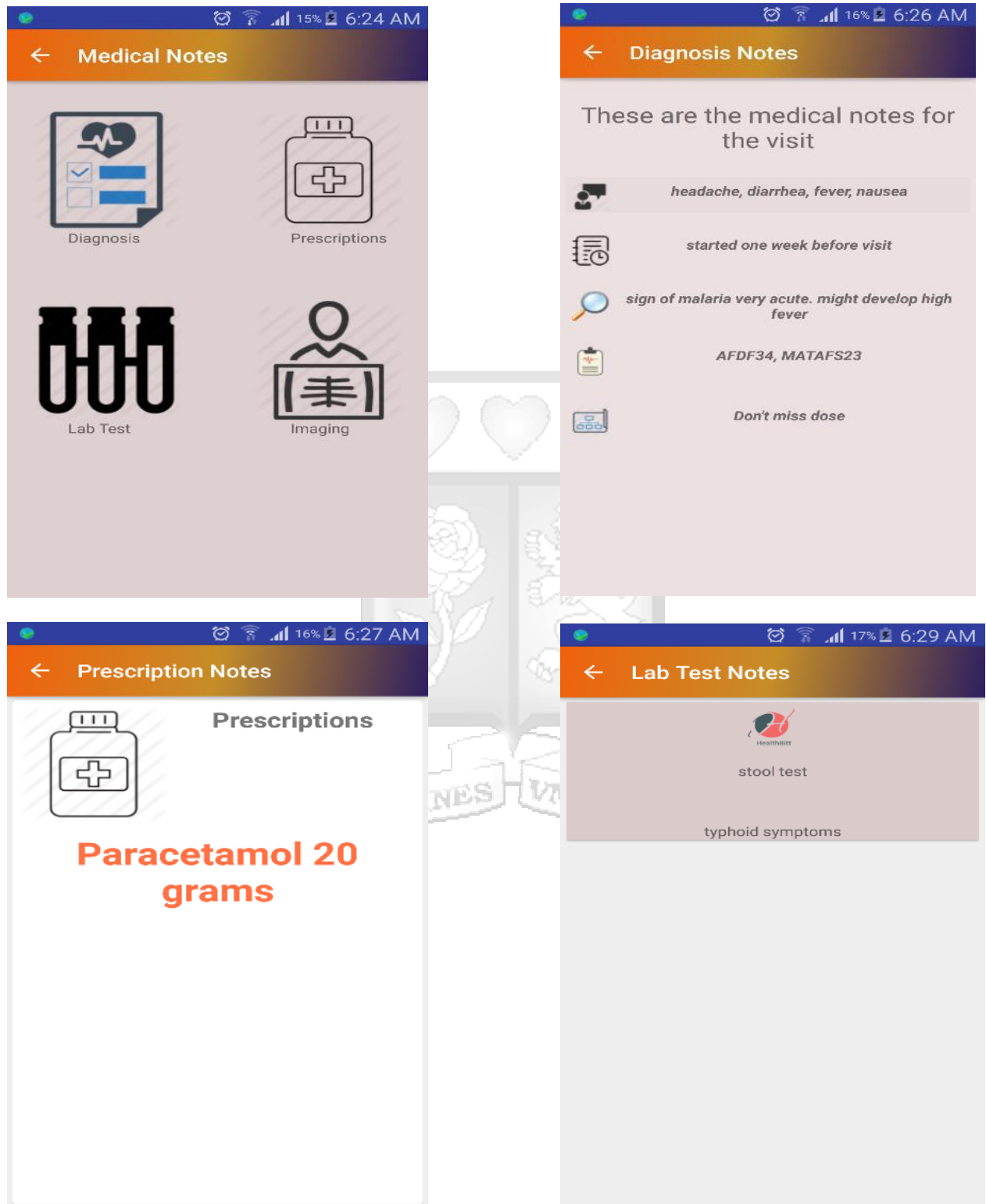


Figure 5.5 Screenshots Showing the Visit Medical Notes.

5.3.4 Sharing Module

Figure 5.6 shows the sharing module which allows the patient to share their health file with anyone using Healthbitt application. The user specifies the key to lock the file and the receiver of the file

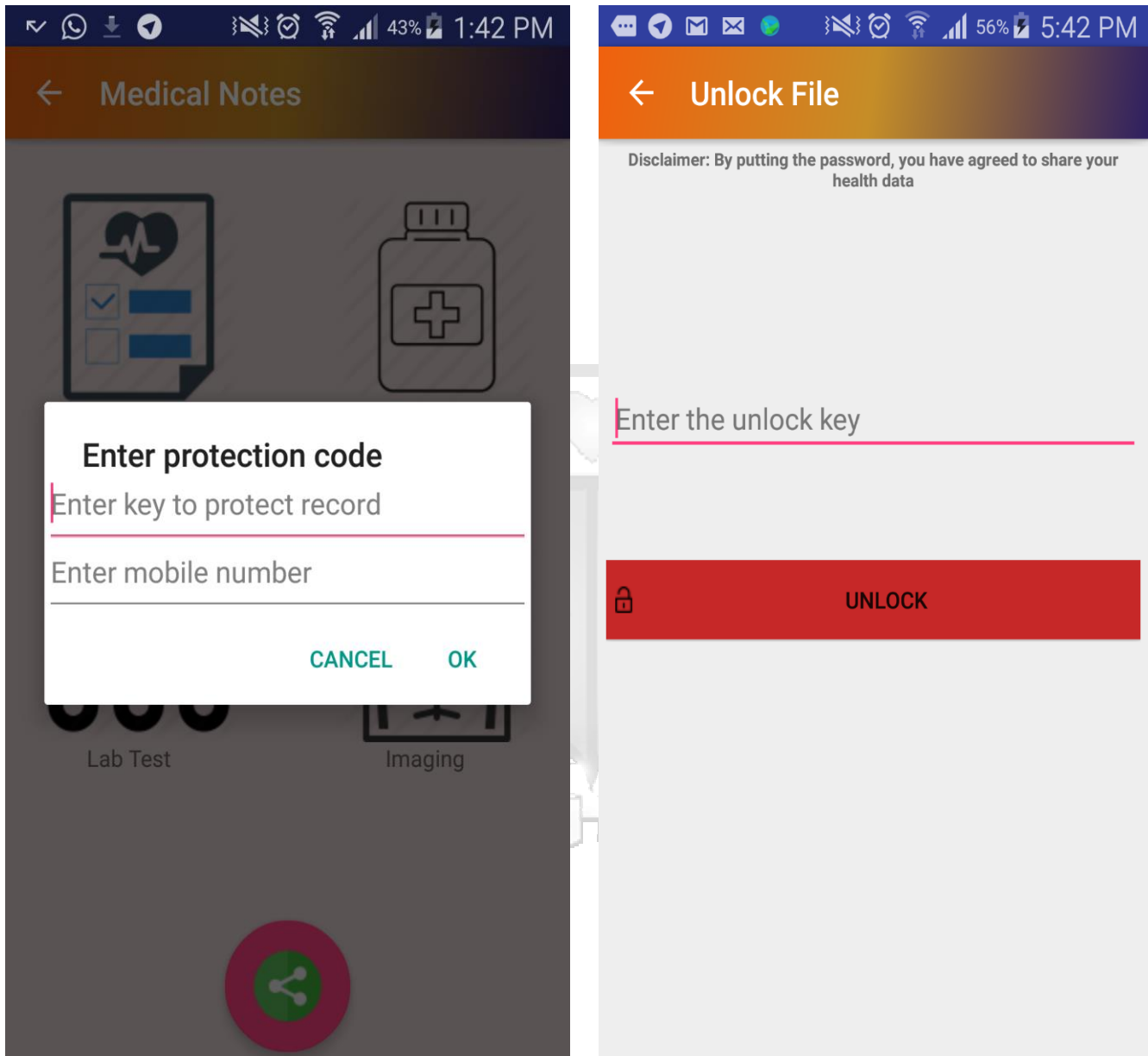


Figure 5.6 Screenshot for Sharing Health Data and Unlocking File.

5.4 Testing

Questionnaires were used to collect test feedback from a section of Strathmore students and a group of select doctors. The tests done were to establish the level of functionality and usability of the mobile application. Functionality testing focused on the functional parts of the system. Usability focused on navigation, look and feel, consistency, responsiveness and speed.

5.4.1 Usability Testing

Usability testing was done to ascertain that the developed application was user friendly and easy to navigate through without any challenge.

5.4.1.2 Installation of Application

Figure 5.7 shows the results of testing the application install process. All the respondents rated the installation to be excellent in all devices.

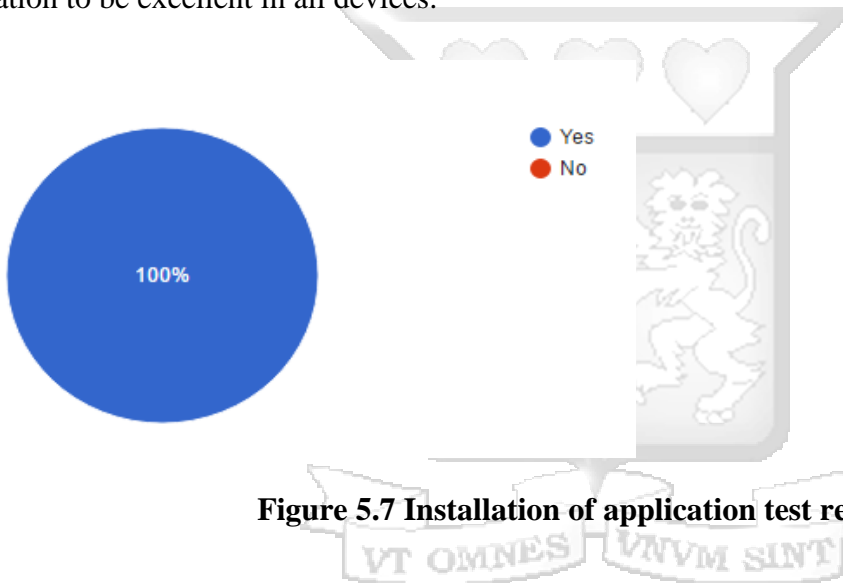


Figure 5.7 Installation of application test results.

5.4.1.2 Application Look and Feel

Most of the respondents gave positive feedback concerning the looks and feel of the application. Figure 5.8 shows the results of the test.

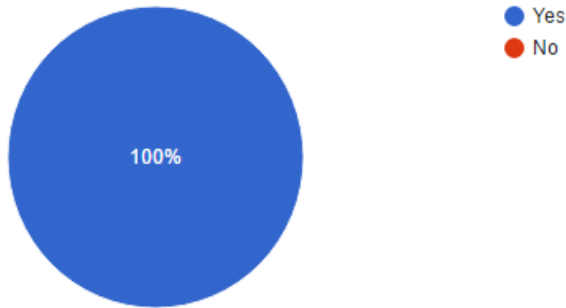


Figure 5.8 Application Look and Feel Results.

5.4.1.3 Usability of the Application

Figure 5.9 shows the response from the test carried out for the usability of the application. Most of the respondents rated the application to be usable.

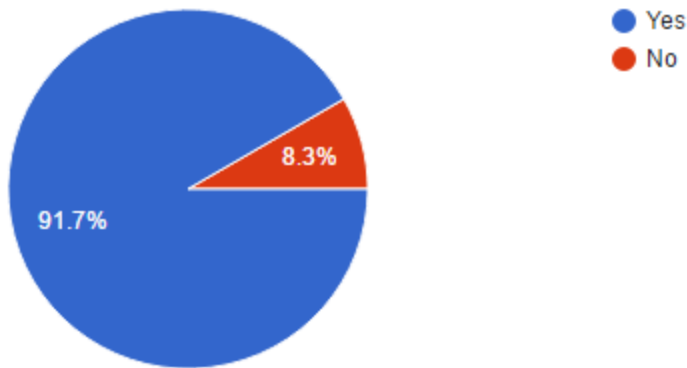


Figure 5.9 Application Usability Test Results.

5.4.1.3 Finding Core Functionalities

Figure 5.10 shows the test carried out to identify the ease with which the users located the functionalities in the system. Majority of the users agreed that it was easy to locate the app functionalities.

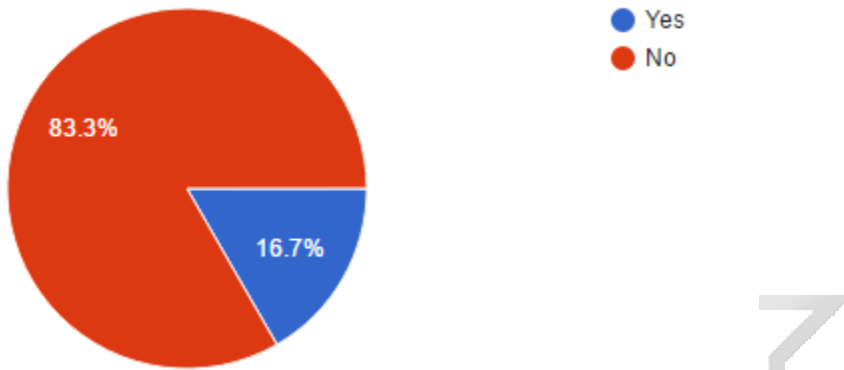


Figure 5.10 Ease with Finding Core Functionalities Test Results.

5.4.1.4 Responsiveness of the Application

When users engage with application, the feedback mechanism on what is taking place is very important in ensuring that the user don't get lost in the application. Figure 5.11 shows the test results for the users with regard to responsiveness.

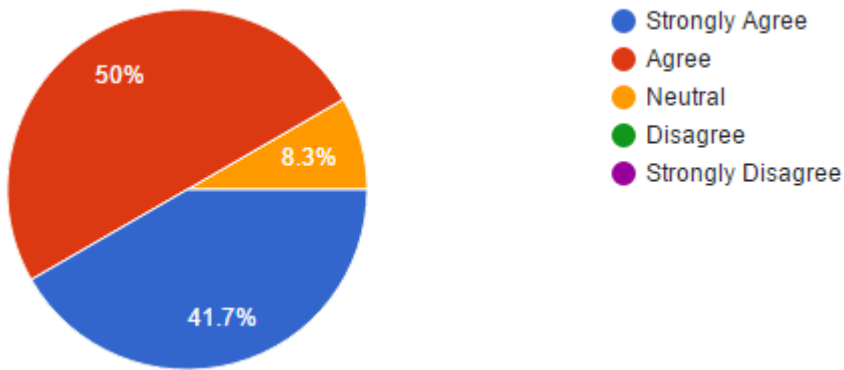


Figure 5.11 Responsiveness of the Application.

5.4.2 Functionality Testing

The functional test results is summarized in the tables below. Based on the feedback the application scored highly in terms of functionality. Some users experience problems logging in but the problem was sorted and that is why all the functional tests were passed.

Table 5.1 Registration Functionality

Test Case Name: Register health wallet				
Testing Date Tested: 31st March 2016				
Tested By: Derrick Rono				
Pre-condition: User has not registered				
Post-condition: User is registered and can login				
Test Steps				
Steps	Action	Expected response	Pass/Fail	Comment
1	Click register on the login page.	See a window with 3 input boxes	Pass	
2	Enter your email, password and confirm password	Successfully registered and redirected to login page.	Pass	

Table 5.2 Login Functionality

Test Case Name: Login				
Testing Date Tested: 31st March 2016				
Tested By: Derrick Rono				
Pre-condition: User has registered				
Post-condition: User is logged in and is able to view all visit files.				
Test Steps				
Steps	Action	Expected response	Pass/Fail	Comment
1	Enter email and password		Pass	
2	Click login	Successfully logged in and user can view all visit files.	Pass	

Table 5.3 View Visit File Functionality

Test Case Name: View visit file				
Testing Date Tested: 31st March 2016				
Tested By: Derrick Rono				
Pre-condition: User has an existing record				
Post-condition: User is see a screen with different component of the file				
Test Steps				
Steps	Action	Expected response	Pass/Fail	Comment
1	Select a file to access by clicking	See a window with several options.	Pass	

Table 5.4 View Diagnosis Functionality

Test Case Name: View diagnosis				
Testing Date Tested: 31st March 2016				
Tested By: Derrick Rono				
Pre-condition: User has selected a visit				
Post-condition: User is able to see diagnosis notes				
Test Steps				
Steps	Action	Expected response	Pass/Fail	Comment
1	Click diagnosis icon on the medical notes page.	User sees a list of items which make up the diagnosis notes.	Pass	

Table 5.5 View Prescription Functionality

Test Case Name: View prescription				
Testing Date Tested: 31st March 2016				
Tested By: Derrick Rono				
Pre-condition: User has selected a visit				
Post-condition: User is able to see prescriptions				
Test Steps				
Steps	Action	Expected response	Pass/Fail	Comment
1	Click prescriptions icon on the medical notes page.	User should be able to view the visit prescriptions	Pass	

Table 5.6 View Lab Test Functionality

Test Case Name: View lab test				
Testing Date Tested: 31st March 2016				
Tested By: Derrick Rono				
Pre-condition: User has selected a visit				
Post-condition: User is able to see lab test and respective results				
Test Steps				
Steps	Action	Expected response	Pass/Fail	Comment
1	Click lab test icon on the medical notes page.	User should be able to view the visit lab test and results	Pass	

Table 5.7 View Imaging Data Functionality

Test Case Name: View imaging data				
Testing Date Tested: 31st March 2016				
Tested By: Derrick Rono				
Pre-condition: User has selected a visit				
Post-condition: User is able to see lab test and respective results				
Test Steps				
Steps	Action	Expected response	Pass/Fail	Comment
1	Click imaging icon on the medical notes page.	User should be able to view the imaging data	Pass	

Table 5.8 Share Health Data Functionality

Test Case Name: Share health file				
Testing Date Tested: 31st March 2016				
Tested By: Derrick Rono				
Pre-condition: User has selected a visit and has an active SMS plan				
Post-condition: User is able to share a protected file				
Test Steps				
Steps	Action	Expected response	Pass/Fail	Comment
1	Click share icon on the medical notes page.	User should see a dialog box requesting for mobile number and protection key	Pass	
2	Click ok	See a message that a share	Pass	

		request has been initiated		
--	--	----------------------------	--	--

Table 5.9 View Shared Data Functionality

Test Case Name: View shared data				
Testing Date Tested: 31st March 2016				
Tested By: Derrick Rono				
Pre-condition: User has is logged in				
Post-condition: User is able to see data of a shared file.				
Test Steps				
Steps	Action	Expected response	Pass/Fail	Comment
1	Open the navigation drawer	View navigation items	Pass	
2	Choose shared visits	User should see the shared file	Pass	
3	Choose a file by clicking	User should be redirected to an unlock scree.	Pass	
4	Enter the password which was used to lock the file.	The file should be unlocked and user redirected to medical notes page	Pass	

Table 5.10 Sign Out Functionality

Test Case Name: Sign out				
Testing Date Tested: 31st March 2016				
Tested By: Derrick Rono				
Pre-condition: User is logged in				
Post-condition: User is logged out				
Test Steps				
Steps	Action	Expected response	Pass/Fail	Comment
1	Open the navigation drawer	View navigation items	Pass	
2	Choose sign out	User should be signed out and redirected to login page	Pass	


```
GET 178.62.158.247/ipfs/QmTB7nsC1WkxhucPJK7Q5sRoke382ZBM2hqiXq3E9KxnV Params Send Save

Body Cookies Headers (14) Tests Status: 200 OK Time: 657 ms

Pretty Raw Preview JSON

1 {
2   "patient_history": {
3     "prescriptions": [
4       {
5         "name": "Paracetamol 20 grams"
6       },
7       {
8         "name": "Artheremr lumefatrin"
9       },
10      {
11        "name": "Piriton"
12      },
13      {
14        "name": "Asprin"
15      }
16    ],
17    "lab_test": [
18      {
19        "name": "stool test",
20        "results": {
21          "findings": "Giardia lamblia"
22        }
23      }
24    ],
25    "imaging": [
26      {
27        "type": "Leg xray",
28        "image_location": "http://previews.123rf.com/images/thailoei92/thailoei921504/thailoei92150400096/39098986-Detail-of-an-x-ray-of-child-1.jpg-Stock-Photo.jpg"
29      }
30    ]
31  }
32 }
```

Figure 5.13 Simulation of Computer B with Address <http://178.62.158.247> Retrieving Data.



Chapter Six: Discussion of Results

6.1 Introduction

This chapter presents a comprehensive view of the study by providing discussion on the findings of test results, the merits of the system, suggestions for improvements and sought to see if the objectives were covered.

6.2 Explanation of Findings

The study had one questionnaire which was handed-out to the respondents and interviews sessions for the selected sample. The questionnaire was used to validate the usability of the current application versus the existing system. The interviews were used to understand the working of the current systems and their limitations. The interviews also provide an opinion on the nature of platform to be built and the protocols to be used. Section 6.3 is a summary of how the objectives were met.

6.3 Discussion

This section discusses in detail how the set objective of the study were achieved. The first objective in section 1.3 was to determine the factors influencing interoperability. The study shows that there are several factors that influence the way systems exchange information. The factors discussed in Section 2.2, explains in detail the interoperability concepts and gives a comprehensive overview of the main factors that influencing interoperability of systems. Standards have been adversely mentioned as a major factor in data exchange. These standards define a common language which systems use to communicate. Apart from that the underlying approach used is service oriented architecture which facilitates the exchange of data for interconnected systems.

From the interviews conducted most of the respondent expressed concerns over the security of data shared and lack of a technology stack that combines all the aspects during data exchange. This is because most facilities have deployed different systems. These factors contributed to the development of a platform that combines all of the elements mentioned and the approach discussed. The factors addressed most of the generic issues systems face when exchanging data. Some factors like the standards were mainly targeting health systems.

The second objective was to determine the several technologies used to achieve interoperability. This helped in understanding the technologies which have been used in the past and know their strengths and weaknesses. Section 2.3 elaborates most of the technologies which are used in current system setting. The major one being the use of distributed databases. This means data is stored in multiple locations and if there

is failure in one location the system can still be accessed from elsewhere. Other technologies which are still underutilized were also discussed and their role in solving the issues of interoperability. Most of the developer respondents expressed a problem in developing several web services for the different systems deployed to exchange information.

This informed the use of a distributed file system which ensured systems have a single point of integration. The third objective was to develop a platform that facilitates information sharing across E-Health systems. Section 2.4 shows the conceptual framework and give a detailed description of how the proposed solution works. The development methodology is further explain in Section 3.3. The application was developed and the main advantages are discussed in Section 6.3.

This objective focused on design and development of the application, it sought to establish way to create a design and develop the health data exchange system. In Section 2.3 the study showed the various ways through which a distributed system can be designed. In Section 4.5 the study shows how the application was designed with regards to the requirements generated from the data collection stage in Section 4.2-4.3. The application was then developed and the post questionnaires given to the sample population that tested the application their views are given in Section 5.4.1-5.4.2, the main advantages of the application are discussed in detail in Section 6.3.

The final objective was to test the usability of the application and see that the various functionalities work as required. The developer did a lot of functional testing while doing development for the application and the results are show in Section 5.4.2. The users were also given the application to test and their results are highlighted in Section 5.4.1 it was concluded that the application's functionalities worked as required and any corrections or errors that were found were rectified.

6.4 Merits of the Healthbitt Mobile Application

6.4.1 Distributed Health Records

The implementation of a distributed file system enables the system to have a 99% uptime because there is no single point of failure. This also means that the access speeds of the data is commendable since the data is fetched from the computer which is next to the client on the network.

6.4.2 Data Integrity

The data stored in the distributed file system cannot be altered. This is because the naming convention is based on a hash function which generates the name of the file by hashing the data of the file. To add on that the filename is stored on the blockchain which becomes a permanent record and is not modifiable.

6.4.3 Sharing Health Records

The mobile application provides the user an option of sharing health record with anyone. The data shared is encrypted using a key which can be used to open the file by the receiving party. AES encryption is used. This ensures that the record cannot be redistributed by unauthorised third parties or intercepted during transmission.



Chapter Seven: Conclusions, Recommendations and Future Work

7.1 Conclusion

The study reveals that a lot of effort has been put to ensure E-Health systems interoperate. Several consortiums have come up with standards and technologies to ensure data is exchanged seamlessly. Doctors insisted that this data is very important in making key decisions about the patient health status. Nonetheless most doctors and developers haven't been able to implement this standard in their systems. From the interviews conducted most developers expressed a difficulty in integration because of the different systems deployed in the health facilities and also different infrastructure. On the other side doctors were fearful of losing data hence the deadlock, this is because the cost of porting the data is also another barrier.

The use of the technologies mentioned in section 2.3 led to creation of a platform that is scalable, immutable and easy to do integration with. The solution plugs in to the existing compatible E-Health systems. During the development of the system several factors had to be considered in order to answer the research questions. To create an interoperable ecosystem, the study consider the use of distributed file systems. But then again another problem emerged concerning the integrity of the data, this is because someone can put false information into the platform or modify the existing records. To curb this problem a distributed file system that uses distributed hash tables was incorporated. Apart from the integrity of records, the issue of locating health records brought in the use of an immutable distributed public ledger (Blockchain) which allows stakeholders to get location of the health data by searching the using supplied identifiers.

If adopted this platform enables health facilities who either own E-Health systems or are developing new ones to have a common data exchange point. By employing the platform the health facilities and other stakeholders creates an ecosystem of interoperable systems. The proof-of-concept mobile application was put to test and respondents found it useful and that all functionalities were working.

7.2 Recommendation

The findings of the study carried out were a success in an effort of evaluating the use of web/mobile technologies to enhance E-Health interoperability for health facilities. The system was able to simulate a successful creation of sample health records which were replicated to different servers across the globe. However the research felt the need to have more features and made the following recommendations:

- i. Inclusion of bar codes for sharing health data. Most of the users suggested that instead of using SMS to share the information, one could easily share a QR code which the other party can scan and get details. This is because SMS is costly and can be easily leaked to other parties.
- ii. Protection of shared health records. Since the data is shared using SMS, the doctors suggested that people could easily share the records with others. Since there is no central store for the health data references, the users suggested that a secure vault should be included to ensure that patients can be able to retrieve their health wallets even if they lose data.
- iii. Include the use of soap messaging. This will make integration with other web platforms easy and more Robust. This will also give developers an easy time to understand the way messages are exchanges and the kind of response they will receive. The code snippets and sample messages are included in the Appendix A

7.3 Future Work

This study had its own limitations. The main focus was developing the platform which can be used to enhance E-Health interoperability and a proof-of-concept mobile application. For further research the following aspects should be put into consideration:

- i. Development of analytic tools that can present the summary of health data files in an intuitive way by tapping into the Healthbitt blockchain.
- ii. To develop systems that can help in performing health data forensics.
- iii. To develop a secure vault which the patient can use to keep their health data references.
- iv. Develop a messaging system based on the health data exchange standards put in place e.g. HL7, SNOMED

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Appendix A: Code Snippets and Messages

Appendix A.1: Sample JSON Schema for Storing Health Data

```
{
  "$schema": "http://json-schema.org/draft-04/schema#",
  "id": "/",
  "type": "object",
  "properties": {
    "patient_history": {
      "id": "patient_history",
      "type": "object",
      "properties": {
        "prescriptions": {
          "id": "prescriptions",
          "type": "array",
          "items": {
            "id": "0",
            "type": "object",
            "properties": {
              "name": {
                "id": "name",
                "type": "string"
              }
            }
          },
          "required": [
            "name",
            "results",
            "type",
            "image_location",
            "presenting_complaints",
            "examinations_findings",
            "history_of_presenting_complaints",
            "diagnosis_results",
            "code",
            "plan_of_management"
          ]
        }
      }
    }
  }
}
```



```

    "0"
  ]
},
"lab_test": {
  "id": "lab_test",
  "type": "array",
  "items": {
    "id": "0",
    "type": "object",
    "properties": {
      "name": {
        "id": "name",
        "type": "string"
      },
      "results": {
        "id": "results",
        "type": "object",
        "properties": {
          "findings": {
            "id": "findings",
            "type": "string"
          }
        }
      }
    }
  }
},
"imaging": {
  "id": "imaging",
  "type": "array",
  "items": {
    "id": "0",
    "type": "object",
    "properties": {
      "type": {
        "id": "type",
        "type": "string"
      }
    }
  }
}

```



```

    },
    "image_location": {
      "id": "image_location",
      "type": "string"
    }
  }
},
"observation": {
  "id": "observation",
  "type": "object",
  "properties": {
    "temperature": {
      "id": "temperature",
      "type": "string"
    },
    "height": {
      "id": "height",
      "type": "string"
    },
    "weight": {
      "id": "weight",
      "type": "string"
    },
    "respiratory_rate": {
      "id": "respiratory_rate",
      "type": "string"
    },
    "systolic_bp": {
      "id": "systolic_bp",
      "type": "string"
    },
    "diastolic_bp": {
      "id": "diastolic_bp",
      "type": "integer"
    },
    "pulse_rate": {

```



```

        "id": "pulse_rate",
        "type": "integer"
    }
}
},
"diagnosis": {
    "id": "diagnosis",
    "type": "array",
    "items": {
        "id": "0",
        "type": "object",
        "properties": {
            "presenting_complaints": {
                "id": "presenting_complaints",
                "type": "string"
            },
            "examinations_findings": {
                "id": "examinations_findings",
                "type": "string"
            },
            "history_of_presenting_complaints": {
                "id": "history_of_presenting_complaints",
                "type": "string"
            }
        },
        "diagnosis_results": {
            "id": "diagnosis_results",
            "type": "array",
            "items": [
                {
                    "id": "0",
                    "type": "object",
                    "properties": {
                        "code": {
                            "id": "code",
                            "type": "string"
                        }
                    }
                }
            ]
        }
    }
}

```



```

    },
    {
      "id": "1",
      "type": "object",
      "properties": {
        "code": {
          "id": "code",
          "type": "string"
        }
      }
    }
  ]
},
"plan_of_management": {
  "id": "plan_of_management",
  "type": "string"
}
}
},
"required": [
  "prescriptions",
  "lab_test",
  "imaging",
  "observation",
  "diagnosis"
]
},
"patient_metadata": {
  "id": "patient_metadata",
  "type": "object",
  "properties": {
    "organization_code": {
      "id": "organization_code",
      "type": "integer"
    },
  },
  "telecom": {

```



```
        "id": "telecom",
        "type": "string"
    }
}
},
"required": [
    "patient_history",
    "patient_metadata"
]
}
```



Appendix A.2: Sample Response for a Successful Blockchain Post Request

```
{"response": {"txHex": "010000001530222f23e046343dfc720f93bc6bd10b26e5b53c375403add5694b2744b10f6030000000ffffffffff0358020000000000001976a914d26a131b9d655cf95cc7a0cce1db49cf92ec965f88ac00000000000000406a3e43430201437eba034a6fd247add2bda84dd1eee5cc97894efe1b5708d05fe1791dcecb4778172a84b75b8a9de854c21b1e0eb7acea2e7d32201200201210fcd80000000000001976a914d26a131b9d655cf95cc7a0cce1db49cf92ec965f88ac00000000", "assetId": "LHXwKjBAFf9fxTqx93FsCGuphG35zExkASnuX", "coloredOutputIndexes": [0]}}
```



Appendix A.3: Sample Health Data Record

```
{
  "patient_history": {
    "prescriptions": [
      { "name": "Paracetamol 20 grams"}, { "name": "Artheremr lumefatrin" },
      {
        "name": "Piriton"
      },
      {
        "name": "Asprin"
      }
    ],
    "lab_test": [
      {
        "name": "stool test",
        "results": {
          "findings": "No palacels found or anything to be scared about"
        }
      }
    ],
    "imaging": [
      {
        "type": "xray",
        "image_location": "QWSDSSERCDFDVG"
      }
    ],
    "diagnoses": [
      {
        "presenting_complaints": "headache, diarrhea, fever, nausea and morning sleepiness",
        "examinations_findings": "sign of malaria very acute. might develop high fever and needs to be dewormed",
        "history_of_presenting_complaints": "started one week before visit to tanzania",
        "diagnosis_results": [
          {
            "code": "AFDF34"
          },
          {
            "code": "MATAFS23"
          },
          {
            "code": "Acute malaria trombositica"
          }
        ]
      }
    ],
    "plan_of_management": "This is a test and not real medical data"
  }
}
```

```
}  
]  
},  
"patient_metadata": {  
  "organization_id": 432,  
  "visit_date": {  
    "date": "2016-04-04 06:24:44",  
    "timezone_type": 3,  
    "timezone": "UTC"  
  }  
}  
}  
}
```



Appendix A.4: Code Snippet for Creating a Digital Asset for the Health Data Reference

```
var asset = {
  'issueAddress': 'mzhXGXuKvW4j34yJNszVRwkhd7XSFiG37h',
  'amount': 1,
  'divisibility': 0,
  'fee': 10000,
  'reissueable': false,
  'transfer': [{
    'address': 'mzhXGXuKvW4j34yJNszVRwkhd7XSFiG37h',
    'amount': 1
  }],
  'metadata': {
    'assetName': organization_id,
    'issuer': organization_id,
    'description': data_reference
  }
};

postToApi('issue', asset, function(err, body){
  if (err) {
    console.log('error: ', err);
  }

  //Sign Transaction
  var key="Kzpwk9wVERbkQzxHKKLmy1escmfjAr1PxdsdkZLbG1UJVtdcFdt";
  var txHex=body.txHex;

  var signedTxHex = signTx(txHex, key);
  var transaction = {
    'txHex': signedTxHex
  }

  postToApi('broadcast', transaction, function(err, body){
    if (err) {
      console.log('error: ', err);
    }
    //console.log("signedTxHex: ["+signedTxHex+"]");
  });

  res.setHeader('Content-Type', 'application/json');
  res.end(JSON.stringify({ response: body }));
});
```

Appendix A.5: Code Snippet for Storing the Health Data

```
$healthData=array(
    'patient_history'=>array(
        'prescriptions'=>$prescriptionData,
        'lab_test'=>$labData,
        'imaging'=>$imagingData,
        'diagnoses'=>$diagnosesData,
    ),
    'patient_metadata'=>array(
        'organization_id'=>$organizationData,
        'visit_date'=>Carbon::now()
    )
);

/**
 * Invoke command to send the health reference id to the patient.
 * @var [type]
 */

$reference=md5(base64_encode(json_encode($healthData)));

Storage::put($reference,json_encode($healthData));
$process = new Process('curl -F "file=@'.storage_path('app')."/".$reference.'"
http://127.0.0.1:5001/api/v0/add?encoding=json');
$process->run();
//File::delete($reference);
// executes after the command finishes
if (!$process->isSuccessful()) {
    throw new ProcessFailedException($process);
}
Storage::delete($reference);
$response=$process->getOutput();

//Obtain the hash from the command output
//echo substr($response, 59, -3) .$response;
$ipfs_hash=substr($response, 51, -3);
//return $ipfs_hash;
```

Appendix A.6: Code Snippet for Retrieving the Health Data File

```
//Retrieve data stored by ipfs
$process = new Process('curl http://127.0.0.1:5001/api/v0/get?arg='. $id. '&encoding=json');
//$process->run();
$url='http://127.0.0.1:5001/api/v0/get?arg='. $id. '&encoding=json';
$ch = curl_init();
// Disable SSL verification
curl_setopt($ch, CURLOPT_SSL_VERIFYPEER, false);
// Will return the response, if false it print the response
curl_setopt($ch, CURLOPT_RETURNTRANSFER, true);
// Set the url
curl_setopt($ch, CURLOPT_URL,$url);
// Execute
$result=curl_exec($ch);
// Closing
curl_close($ch);
$results=file_get_contents($url);
/*if (!$process->isSuccessful()) {
    throw new ProcessFailedException($process);
}*/

$items=strstr($results, '{');
$decoded=json_decode($items, true);

$results=array(
    'patient_history'=>$decoded['patient_history'],
    'patient_metadata'=>$decoded['patient_metadata']
);

return Response::json($results,200);
```



Appendix B: Guideline Questions for Developer Interview

These are guidelines which were used to guide in the interviewing process.

1. How do you understand the concept of interoperability in systems?

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.....
.....
.....

2. What factors do you consider before developing an interoperable solution?

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.....
.....

3. Which technologies have you used to achieve interoperability?

.....
.....
.....
.....

4. What are the main challenges with the technologies you have used?

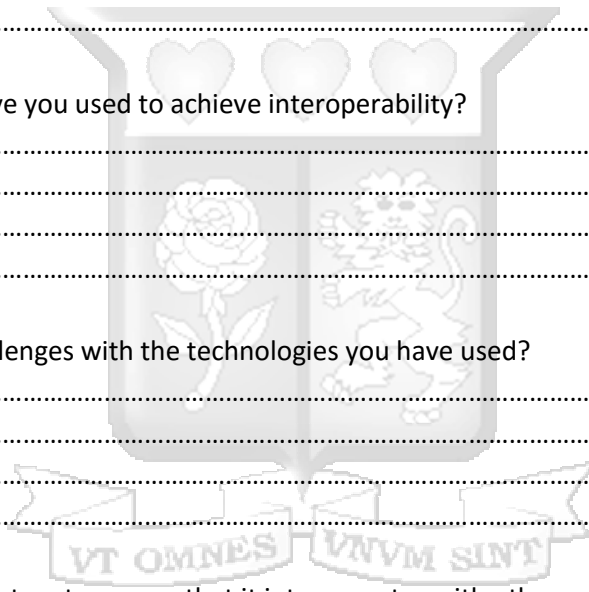
.....
.....
.....
.....

5. How did you test the system to ensure that it interoperates with other systems?

.....
.....
.....
.....

6. If a solution was to be developed what component would you like incorporated?

.....
.....
.....
.....



Appendix C: Guideline Questions for Doctor Interview

These are guidelines which were used to guide in the interviewing process.

1. How do you exchange health data with other clinic/doctors/hospitals?

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.....
.....

2. Does the current system allow you to access patient's data from other facilities?

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.....

3. What are the main challenges and concerns when it comes to exchanging data?

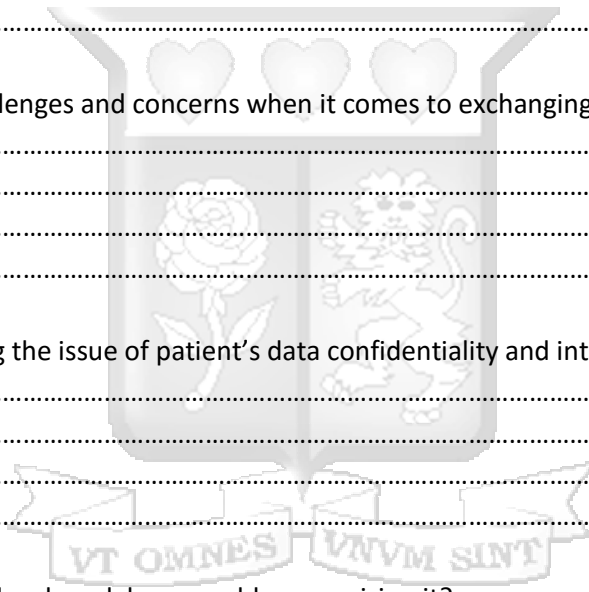
.....
.....
.....
.....

4. How are you addressing the issue of patient's data confidentiality and integrity?

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.....
.....

5. If a solution was to be developed, how would you envision it?

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.....



Appendix D: User Testing Questionnaire

This is a questionnaire designed to get your response on the application and help enhance it, please follow the steps below to install the post office application. This is a prototype and you will be required to register your own health wallet.

Installation Instructions

- i. Download the application sent to you via email.
- ii. Create an account by clicking on the register button.
- iii. Login using the registration credentials.
- iv. A doctor request will be simulated once you confirm installation.

The main functionalities after login are;

- i. Visit.
- ii. Shared visits.
- iii. View medical record.
- iv. View prescription notes.
- v. View imaging results.
- vi. View lab test.
- vii. View prescriptions.
- viii. Share health data.

Immediately you login you will not be able to access any records because the system has not processed any of your records.

Test Questions

1. Were there any issues with downloading the application?

Yes No

2. If you had issues with downloading please list them.

3. Did the application install correctly?

Yes No

4. If you had issues with installation please list them

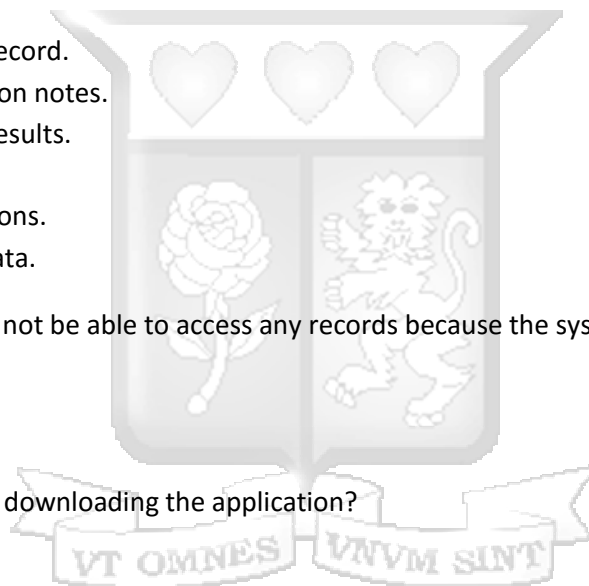
5. Do you like how the application looks?

Yes No

7. If not please give your reasons.

8. Were there challenges logging in?

Strongly Agree



- Agree
- Neutral
- Disagree
- Strongly Disagree

9. Did you have issues with finding the functionalities?

Yes No

If yes please give your reasons

10. Would you consider the application effective as compared with the current system?

Yes No

11. Is the responsiveness of the functionalities okay?

- Strongly Agree
- Agree
- Neutral
- Disagree
- Strongly Disagree

12. Would you say the application is usable?

Yes No

If No please give your reasons.



Appendix E: Turnitin Report

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EHEALTH INTEROPERABILITY PLATFORM: Case of Nairobi County Health Facilities

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