DATA EXCHANGE FRAMEWORK TO SUPPORT INTEROPERABILITY AMONG MULTIPLE E-HEALTH RECORDS THROUGH A SINGLE MOBILE APPLICATION: THE CASE OF TANZANIA

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ABSTRACT

Electronic Health (eHealth), particularly in the form of electronic health records (eHRs), has proved to greatly provide to the health sector, a number of benefits such as real time receipt of health-care information and timely addresses health issues. However, many of the eHRs are fragmented as such they face some operational challenges, one of which is eHRs interoperability. The interoperability is caused by lack of architectural guidelines toward eHRs development, and poor collaboration among eHRs development vendors to mention a few. Early efforts to interoperate eHRs suggest that a single mobile app that can access multiple integrated eHRs is among the viable solutions on the way to eHRs interoperability. The research work reported in this dissertation focused to support sharing of information among different eHRs through a single mobile app by creating a data exchange framework. Tanzania as a case study was used to survey issues and challenges facing mobile apps development process when developing mobile app solution for eHRs interoperability. A preliminary study was conducted in mobile app development environment and it was established that the developers have no unified development process to connect multiple databases/repositories. Interviews, questionnaires, and observation were used as data collection tools in two different regions in Tanzania namely; Dar es Salaam and Arusha. The interoperability issues and challenges identified by the survey revealed a demand from mobile app developers of a single mobile app connection to multiple integrated eHRs. The main objective of the reported work was to satisfy this demand - a mobile app connecting to multiple eHRs. As a result, a new Mobile App – Data Exchange Framework (MADE-Framework) has been developed and a prototype implemented and evaluated by mobile app developers and the health practitioners. The framework incorporates a Data Exchange Component (DEC), essentially an exchange engine, acting as its core data exchange and access control mechanism to facilitate data and information sharing among multiple eHRs. The DEC Architecture can integrate multiple eHRs to interoperate and extends the capability into a single mobile app. It involves Open Health Information Mediator (OpenHIM) and MEDIATOR as sub-components to facilitate the data and information sharing mechanism. Based on the evaluation tests, the DEC has successfully proved to connect a single mobile app to multiple eHRs. Therefore, the new MADE framework is a new approach to utilize legacy and newly implemented eHRs without much worry on obsoleteness of database technologies. In this way it will protect investments and providing business continuity within the evolving eHRs.

DECLARATION

I, Frederick Henri Chali do hereby declare to the Senate of Nelson Mandela African Institution of Science and Technology that this dissertation is my own original work and that it has neither been submitted nor being concurrently submitted for a degree award in any other institution.

Frederick Henri Chali ____________________ 10/03/2019

Name and signature of candidate **Date**

The above declaration is confirmed

Dr. Zaipuna O. Yonah ____________________ 11/03/2019

Name and signature of supervisor 1 **Date**

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Name and signature of supervisor 2 **Date**

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CERTIFICATION

The undersigned certify that, they have read and hereby recommend for acceptance by the Nelson Mandela African Institution of Science and Technology a dissertation titled "Data Exchange Framework to Support Interoperability Among Multiple E-Health Records Through a Single Mobile Application: The Case of Tanzania" in partial fulfillment of the requirements for the degree of doctor of philosophy in Information and Communication Science and Engineering of the Nelson Mandela African Institution of Science and Technology.

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DEDICATION

----------To my lovely wife Sophia Agrey Mseli and family----------

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API	Application Programming Interface
App	Application
BLOB	Binary Large Object
CITPH	Center for Innovation Technology in Public Health
DBMS	Database Management System
DBO	Database Object
DEC	Data Exchange Component
EBS	Enterprise Bus Architecture
eHealth	Electronic Health
eHRs	Electronic Health Records
HIE	Health Information Exchange
HIM	Health Information Mediator
HIS	Health Information Systems
HL7	Health Level 7
HRE	Health Record Exchange
HTTP	Hypertext Transfer Protocol
IMT	Internet-Mediated Transaction
iOS	i- Operating System
JDBC	Java Database Connector
MADE	Mobile App – Data Exchange
MADP	Mobile Application Development Framework
MEAP	Mobile Enterprises Application Platforms
mHealth	Mobile Health
MoHSW	Ministry of Health and Social Welfare

NGO	Non-Government Organisation
NHIS	National Health Information System
NoSQL	No Sequentila Query Language
OpenHIM	Open Health Information Mediator
OpenMRS	Open Medical Record Systems
OS	Operating System
RapidSMS	Rapid Simple Messaging Service
REST	Representational State Transfer
RHIS	Rwandan Health Information System
SME	Small and Medium Enterprises
SMS	Short Message Service
SQL	Sequential Query Language
UI	User Interface
UML	Universal Model Language
URL	Universal Resource Locator
URT	United Republic of Tanzania
WHO	World Health Organization
XML	Extensible Markup Language
XP	Extreem Programming

CHAPTER ONE

Introduction

1.1 Background Information

Information and Communication Technology (ICT) in health sectors is currently gaining acceptance due to the demand of quality, efficient and effective health services. Partners such as health workers, funders, technologists etc., in health sectors, are increasing every day. This is due to the growing nature of the sector where the technological innovations are taking a reasonable part on the development of health-care services. Applying ICT capabilities to support health sectors is known as electronic Health (eHealth). E-Health has proved to improve health care services to a big extent both in urban and rural or remote areas (Khan and Sai, 2013; Mugisha and Hrastinsk, 2013).

Apart from their benefits, eHealth systems/records are facing challenges and one of them is interoperability between existing eHealth records (eHRs). Most of these systems are not interconnected (do not exchange data and information between themselves). The systems are fragmented and working independently. According to Douglas, interoperability is the ability of different information technology systems and software applications to communicate, exchange data, and use the information that has been exchanged (Douglas and Peter, 2006).

Parallel to the growing eHealth industry, health-care services are witnessing a wide use of mobile devices such as mobile phones, smart phones and tablets. Utilization of mobile devices into healthcare services provision is generally termed as mobile health (mHealth). The mHealth is one of the innovations that is widely getting acceptance within the health sectors. Many technological innovations on health are now directed to application of mHealth. "The growth of mobile devices has increased access to medical information, which includes eHealth systems, academic medical articles, personal medical data, and other educational resources" (Andrew *et al.,* 2012). Applying mobile devices into health-care services can help on the efforts toward finding solutions to eHRs interoperability problem (Iroju *et al.*, 2013). Currently there are many implementations of mobile applications projects that are focused on supporting provisions of healthcare services (CITPH, 2012).

As mHealth evolve, there is much advancement in programming to support development of mobile applications focusing on the integration with data repositories. Some of these efforts includes; Firebase, RapidSMS, and RwandanNHIS (Ryan *et al.*, 2014; Jembi Health Systems, 2012). Apart from the listed approaches, and to the best of our knowledge it has been found out that, there still no single viable solution for eHRs interoperability through mobile phones. National health strategic plans of Tanzania in 2010, showed that, only 35% of health positions in the country were filled by health workers (URT - MoHSW, 2010). The gap is still there and existing till today. This indicates that, there is a great service delivery crisis to Tanzanians in the health sector, especially the majority who reside in remote areas. The crisis brings about the demand of employing alternative ways of providing and managing health services. eHealth has become one of the best solutions for this situation.

In Tanzania, in the year 2015, the number of mobile phone subscribers reached to mil (Pesa Times, 2015), this goes in hand with mobile phone penetration of 67% (Ng'wanakilala and Macharia, 2015). This is a favorable environment for extending mobile phone capabilities into health services. Boulos *et al.* (2011), confirmed that, opportunity is great on harnessing the potentials of mobile phones to improve health care services and other aspects in the societies.

1.2 Problem Statement

As a case study, the Tanzania's eHealth strategic plan for 2013-2018 shows the need and importance of implementing health information exchange that will support mobile access services (URT - MOHSW, 2013). This study is based on the need to build a Data Exchange Component (DEC) prototype for connecting multiple eHRs and making them interoperable; and at the same time extend the capabilities into a mobile application.

1.3 Research Justification

The health sector in Tanzania is characterized by fragmented eHRs with significant barriers to the effective sharing of information between health-care participants (URT - MOHSW, 2013). The eHealth strategic plan of 2013-2018, identifies the infrastructure building blocks as one of the strategic interventions for eHealth development. The report strongly insists on the eHealth infrastructure as a way to enable electronic sharing of health information across the Tanzanian health sector.

World Health Organization (WHO) lists barriers to mHealth implementation worldwide. The listed barriers are cost effectiveness, technical expertise and infrastructure, to name a few. In Africa, infrastructure is one of the top barriers to deploying eHealth. Over 50% of all African countries are facing this challenge (WHO, 2011). The 2013 Tanzania eHealth strategy identified poor infrastructure as one of the biggest challenges to the implementation of eHealth in the country (URT - MOHSW, 2013).

According to GSMA report of 2014, Tanzania is one of the African countries that has shown to have a high potential for mobile phone utilization (GSMA, 2014). The report revealed that in Tanzania, access to mobile phones is at 63% of the whole population and 55% of the rural population. The mHealth services are estimated to reach 3.3 million people (7% of the population) as per 2016 statistics. Fifty two percent of them use SMS and 48% use internet/installed applications as an access channel.

1.4 Objectives

1.4.1 General Objective

The general objective of this research is to designing a data exchange framework to support sharing of information among multiple eHRs through a single mobile application.

1.4.2 Specific Objectives

(i) To study the development of mobile applications and identify the challenges and issues encountered when integrating mobile application with existing multiple eHRs.

(ii) To identify the basic components and to design data exchange framework.

(iii) To implement a data exchange component prototype.

(iv) To test and evaluate the developed data exchange prototype.

1.5 Research Questions

(i) What are the key design issues which need to be considered during development of a mobile application for seamless integration to a multiple eHRs?

(ii) What are the existing challenges in the integration of mobile applications with existing multiple eHRs in Tanzania?

(iii) What are the necessary design components for building effective data exchange framework?

(iv) What kind of data exchange will facilitate information sharing between different eHRs through a single mobile application in Tanzania?

(v) How does the developed data exchange support mobile app development and the interoperability of eHRs?

1.6 General Research Methodology

The general methodology for this research includes survey, for data collection and analysis by using literarature review, data collection tools, interviews, observation, and questionnaire. The DEC prototype was developed by using Xtreeme Programming (XP) system development approach. Survey was conducted to understand the mobile app development process which was intended to reveal issues and challenges facing mobile apps development process specifically when one wants to connect a single mobile app with multiple heterogeneous/homogeneous databases/systems. The approach was used to develop and test the developed DEC prototype. Figure 1 presents the general methodology.

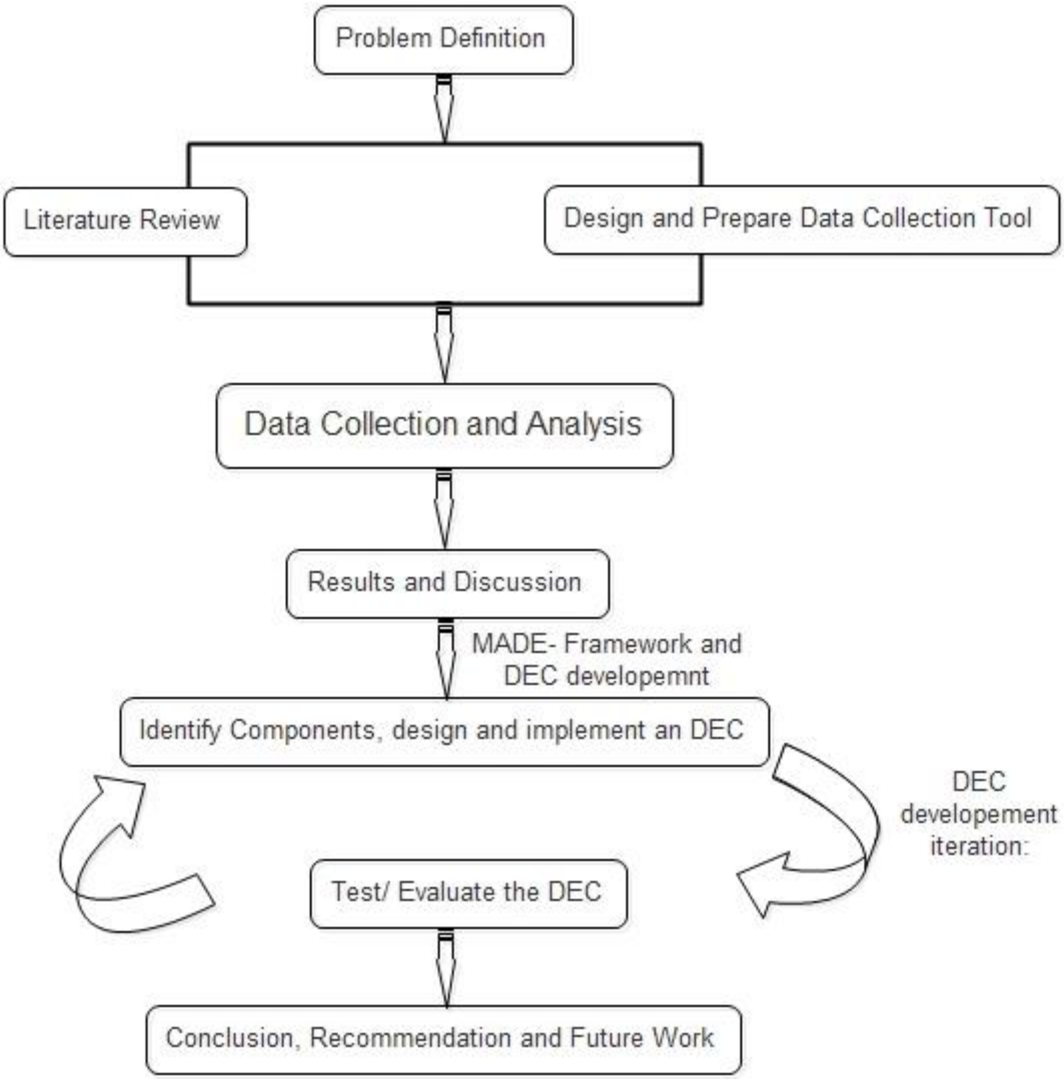

Figure 1: General research methodology

1.7 Structure of the Dissertation

The structure of the dissertation is arranged as follows; Chapter Two presents critical issues and challenges in developing mobile-based health systems in Tanzania. Data exchange architecture for development of mobile applications that support eHRs interoperability in Tanzania is presented in Chapter Three. Chapter Four explain about the framework for eHRs interoperability and the development of mobile applications in Tanzania while Chapter Five gives details about implementation, testing and evaluation processes of data exchange component (DEC) prototype that supports eHRs interoperability and the development of mobile applications. General discussion, conclusion and recommendations are presented in Chapter Six.

CHAPTER TWO

Critical Issues and Challenges in Developing Mobile-Based Health Systems: Case of Tanzania[1]

Abstract

Utilization of mobile devices worldwide is increasing every day. This has created an increasing demand for mobile apps, the development of which is not seamlessly without challenges. A research survey was conducted to identify and confirm the known challenges and issues that are faced by mobile app developers in their development work in developing countries particularly in Tanzania. This survey was done in three regions of Tanzania: Dar es Salaam, Dodoma and Arusha; because most of the mobile apps developers are located in these regions and electronic Health Records (eHRs) were used as a case for this purpose. Methodology used was literature review, interview, questionnaire, and observation. This chapter presents an overview of the identified challenges and issues facing mobile app developers and the proposed data exchange solution. These findings justified the reported research on interoperability of multiple databases through a single mobile application**.**

Keywords: ***Multiple Databases, Data Exchange, eHealth Systems, mHealth, mobile app.***

2.1 Introduction

One survey reports that about 40% of 7 billion people in the world are using internet (Sanou, 2015). Another study recently reported that, 80% among the internet users globally, own smart phones and 47% of them own Tablets (Jason, 2015). Due to the increasing numbers of utilization of mobile devices, the world counts more than 170 million mobile apps in use by 2015 (Statista, 2015).

Said it differently, the potential to utilize mobile phones in developing countries is high. In 2012, about 70% of the global mobile subscribers out of more than 5 billion, belonged to low and mid income communities (SocialCubix, 2015). Banking and healthcare sectors are leading the way on harnessing this available potential in developing countries.

In mobile apps development, challenges such as testing, supporting, security, device

[1] This chapter is based on a published paper titled "Critical Issues and Challenges in Developing Mobile-Based Health Systems: Case of Tanzania" Published on an International Journal of Computer Science and Information Security, IJCSIS ISSN 1947-5500, March 2017 Volume 15 No. 3.

proliferation, development approach, etc. are some of the known challenges that continue to face apps development works (Mona and Ali, 2013; Katz, 2015; Shevchik, 2012). To confirm if these challenges are real, a survey was conducted in the health sector environment as a case specifically to identify and confirm the known issues and challenges in mobile apps development process focusing on connecting to eHRs implemented within an environment having integrated multiple databases. The goal is to establish the design requirements of a data exchange architecture that demonstrates the need for connection/integration between a single mobile app and multiple databases. Section 2.2 reviews the status of eHealth and mHealth systems in developing countries. Methodology used in the study is explained in Section 2.4; and review of major issues and challenges that are generally facing mobile app development process worldwide is presented in Section 2.5. Section 2.6 contains survey results and the proposed DEC architecture that integrates multiple eHRs to be accessed from a single mobile app; and the concept of multiple heterogeneous databases is introduced in Section 2.9. General discussion of the findings from the study is presented in Section 2.10. Finally, Section 2.11 carries the conclusion of this chapter.

2.2 E-Health and M-Health Systems in Developing Countries

The eHRs represent a greater potential to reach large population with quality service provisions. It would easily reach and serve 55% of the population in developing countries where the availability of enough health facilities and health-care services is too low (IFAD, 2011). There are numerous definitions of eHealth from different dimensions worldwide; others have tried to extend the definition to any application of electronic means into the healthcare services. The United Nations health organising body defines eHealth as the transfer of health resources and health-care by electronic means (WHO, 2017). In Jennifer (2002), it is described that, e-health is the application of Internet and other related technologies in the health-care industry to improve access, efficiency, effectiveness, and quality of clinical and business processes utilized by healthcare organizations, practitioners, patients, and consumers in an effort to improve the health status of patients. It is also specifically described by Eysenbach, as an emerging field in the intersection of medical informatics, public health and business, referring to health services and information delivered or enhanced through the Internet and related technologies (Eysenbach, 2001).

Delivery of eHealth by use of mobile app services results into mobile health or mHealth. It is the utilization of mobile apps for the purpose of enhancing provision of health services. In

(Modi, 2013), mHealth is described as the use of mobile phones for the purpose of improving the quality of health-care and efficiency of health services. Further benefits and characteristics of eHealth and mHealth systems are described in the following subsections.

2.2.1 Infrastructure and Benefits of eHealth and mHealth in Developing Countries

Typically, Infrastructure that supports eHealth system architecture include the following (Deluca and Enmark, 2000):

(i) Internet
(ii) Extranet
(iii) Intranet
(iv) Core Data Systems
(v) E-Mail
(vi) Telecommunications
(vii) Hardware

mHealth can provide relevant benefits to health workers, health facilities, healthcare services etc. Modi, identifies the following benefits (Modi, 2013) as retrievable from eHealth and mHealth:

(i) Real time receipt of health-care information
(ii) Timely addresses health issues
(iii) Easy to track the prevalence of diseases and its rate globally
(iv) Helps healthcare officials to be more proactive on addressing health issues rather than being reactive.
(v) Feasibly addresses gaps in health-care in remote areas.
(vi) Provides Health Education Awareness.
(vii) Raises treatment support and medication compliance.
(viii) Improves the performance of healthcare workers.
(ix) Supports diseases surveillance.

2.2.2 Status of eHealth in Some African Countries

Table 1 summarizes the status of eHealth in some African countries. The summary shows the evidence of activity, planning or implementation of eHealth in those countries in terms of national ownership, foundation (Info-structure; the basic physical and organizational structures and Infrastructure) and also health process domain component where it describes the availability of already running eHealth systems in a particular country.

Table 1: Summary of the status of eHealth in selected African Countries.

SN	Country	National Ownership	Foundation		Health Process Domain Component
			Info-structure	Infrastructure	
1	Angola	**E_vP&I**	**E_vP**	**NoE_V**	**E_VI**
2	Botswana	**SE_VP**	**E_vP&I**	**E_VI**	**E_VI**
3	Ethiopia	**E_vN_S**	**E_vP**	**E_vN_S**	**E_VI**
4	Ghana	**SE_VP&I**	**SE_VP&I**	**E_vP**	**E_VI**
5	Kenya	**SE_vN_S**	**E_vP**	**E_vP**	**E_VI.**
6	Nigeria	**E_vP.**	**LE_VI.**	**NoE_V**	**LE_VI**
7	Tanzania	**SE_vN_S**	**E_vP&I**	**E_vP&I**	**E_VI.**
8	Uganda	**SE_vN_S**	**LE_VI.**	**SE_vP&I**	**E_VI.**
9	Zambia	**LE_VP**	**NoE_V.**	**E_VI**	**E_VI**
10	Zimbabwe	**E_vN_S**	**E_vP**	**E_vP&I**	**E_VI**

Key:

- Evidence of = **Ev**
- Strong Evidence of = **SE**v
- Little Evidence of = **LE**v
- Planning = **P**
- Implementation = **I**
- National/Government Support = **N**s
- No Evidence of Planning or Implementation = **NoE**v

Source: Foster (2012**)**

2.3 Deployment of E-Health and M-Health Systems in Tanzania

The Tanzania health sector is witnessing a continuing deployment of eHealth and mHealth systems by health-care institutions including the Government, NGOs and Private sector so as to harness the benefits provided by these systems. Next sub-sections provide details of eHealth and mHealth systems.

2.3.1 eHealth Systems

The deployment of computer or IT systems in the health sector in Tanzania started in the

1990s. Such a deployment has brought revolution of the uses of computer applications from simple formats to complex systems.

However, eHealth is not well and completely implemented in developing countries; due to some challenges that technically need special attention to address. In their survey, Busagala and Kawono identified some of the challenges that are facing e-HRs in Tanzania. The challenges include poor infrastructure for supporting health-care services, insufficient budget for ICT, unreliable electricity supply, and lack of ICT skills for health-care workers (Busagala and Kawono, 2013).

2.3.2 mHealth Systems

In Tanzania, more than 31 mHealth applications are currently providing health-care services countrywide (GSMA, 2014). Among them, the most deployed applications are for data collections and reporting. Currently there are 18 such applications, estimated to be 58% of all mHealth applications in Tanzania. Table 2 lists other applications that are also deployed in Tanzania with their total number.

Table 2: mHealth applications deployed in Tanzania

Application	Total Number
Data collection and reporting	**18**
Client education and behaviour change communication	**15**
Electronic decision support	**14**
Provider work planning and scheduling	**8**
Registries and vital events tracking	**7**
Electronic health records	**7**
Provider training and education	**7**
Provider to provider communication user groups, consultation	**6**
Service use supply chain management	**5**
Financial transactions and incentives	**4**
Sensors and point of case diagnostics (and Monitoring)	**3**
Human resource management	**3**
Tele consultation	**3**

Source: GSMA, (2014)

Some of the active and ongoing mHealth projects in Tanzania are briefly described in the following paragraphs:

(i) SMS for Life: It is an innovative mHealth project piloted in Tanzania under public-private partnership. It helps to reliably support availability of Malaria medication using mobile phone services. The project is led by Novartis and supported by several partners, each bringing specific skills into the project (Novartis, 2014).

(ii) Birth Registration by Mobile Phones: This is a countrywide mHealth platform in Tanzania that gives parents ability to register their children's births by using mobile phones. It allows a health worker to send birth registration information such as baby's name, sex, date of birth and family details by phone to a central database and finally a birth certificate is issued free of charge in a few days (UNICEF, 2015).

(iii) m4RH: Known as Mobile for Reproductive Health (m4RH), is a low-cost innovative system running in Tanzania, Kenya and Rwanda providing information on family planning. It is accessible from every mobile phone through short message service (SMS) or "text messaging" (FHI360, 2015).

From the foregoing, it is hereby acknowledged that, mHealth can have a profound positive impact in health sector. It shows to have the ability to improve delivery of healthcare services even in remote areas and can free other resources for developing the country economy.

2.4 Methodology

2.4.1 Literature review

In depth literature review was conducted to enhance the understanding of issues and challenges on mobile apps development of e-Health systems from multiple database integration point of view. More information was collected from previous researches to gather a wide knowledge about these issues and challenges, as presented in Section 2.5.

2.4.2 Sampling Techniques and Data Collection

Data collection (including questionnaire, interview and observation) was done in three regions: Dodoma, Arusha and Dar es Salaam. To test the questionnaire, a sample questionnaire was circulated to the targeted limited number of mobile apps developers through face to face and also social media.

Data were collected in Dodoma from the HPSS government project based in Dodoma (Swiss TPF, 2015). In Dar es Salaam and Arusha data were collected from 48 programmers from fifteen mobile app development companies and 30 mobile App developer freelancers.

As a stimulus, mobile app utilization in health sector raises the question concerning the technical aspects on the development of mobile apps for health-care delivery. In order to answer the question, it became necessary to examine issues and challenges facing mobile apps development in their integration with medical records. The following section describes major issues and challenges that are facing mobile app development process.

2.5 Major Issues and Challenges that are Generally Facing Mobile App Development Process

Identified from the literature review, is that there are a number of issues and challenges facing mobile application development processes worldwide. The identified issues and challenges are concerned with design, security, user interface, networking, development skills, context etc. Among all these, security issues, user experiences, vendor and device fragmentation are ranked to be the major ones (Katz, 2015). These are further described below.

2.5.1 Security issues

Security in mobile app development is speedily becoming a major concern. The primary concerns are: data upload and download wirelessly using insecure hotspots and from potentially insecure locations and the sizes of devices make them easily misplace-able. The degree level of security in mobile development in enterprises or organizations also depends on the nature of a business. Bank applications for instance, with bill payment feature needs more security measures than an information data application (Katz, 2015).

2.5.2 The User Experience

Mobile user experience could be described as the perception an end user has on a mobile product or service (Rouse, 2014). Mobile devices are characterized by smaller displays and different styles of user interactions. These characteristics have an impact on interaction design for mobile apps. The user experience has a strong influence on application development. The developer has to consider user demands such as user interface, running speed of the application, etc in order for the end product to be well accepted. During development, there are some user experience factors that influence the process of development; these factors are such as widgets, touch, whether through stick or direct by finger, physical motion, keyboard (physical and virtual) for designing user interface, and the context dependencies, such as proximity to other mobile devices and physical location (Wasserman, 2010). Device characteristics such as size and its version are also having an impact on the design of the application. Developers need to consider how to build up an application that could highly meet user's expectations. The user experience could help make an application more successful by maximizing acceptance and usage.

2.5.3 Vendor and Device Fragmentation

Existence of multiple mobile application platforms such as Apple Mobile OS (iOS), Android, Windows Phone etc., is one of the challenge that must not be ignored in the development of mobile apps (Mona and Ali, 2013; Shevchik, 2012; Propelics, 2014). These mobile Platforms, rather than encouraging unification, instead they are heading towards fragmentation (Mona and Ali, 2013). Fragmentation in mobile apps could be grouped into two categories:

(i) Fragmentation across platforms (Vendors/Platforms Fragmentation): This includes a variety of mobile operating systems (OSs) such as Android, iOS, BlackBerry, Windows Phone etc.

(ii) Fragmentation within the same platform (Device Fragmentation): This includes different versions of the same platform (Shevchik, 2012).

Each platform requires different and sometimes separate skills to use in order to develop and deploy an application successfully. This poses as a challenge during development and is known to force developers to base their developing skills mostly on one platform.

2.6 Survey Results

This section presents the results of the survey, which in general, confirm the issues and challenges in mobile application development to achieve connection/integration with multiple databases remotely; particularly within Tanzania as a case study.

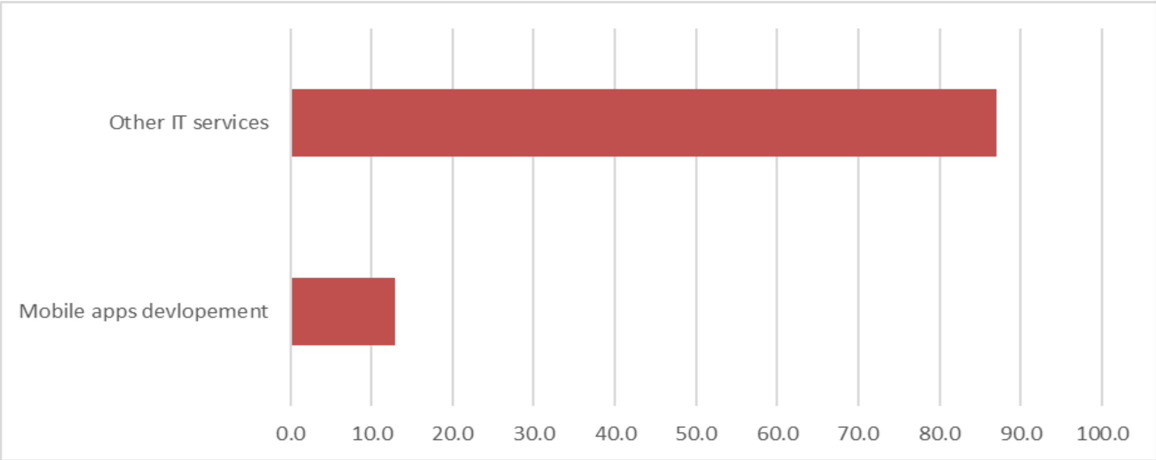

Figure 2: Distribution of IT related service businesses in Tanzania.

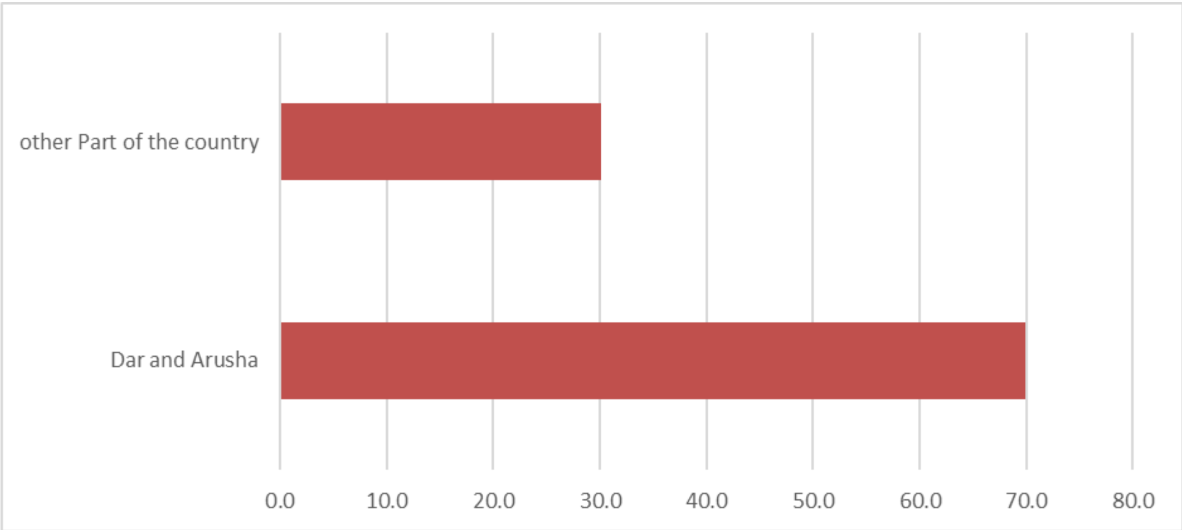

Figure 3: Availability of IT related businesses in Tanzania.

The survey was conducted in three different regions in Tanzania. These regions are Dodoma, Dar es Salaam and Arusha. A total number of 78 mobile app developers from two regions, Dar es Salaam and Arusha were contacted to respond to the data collection tools (interview and questionnaire). Statistics revealed that country wide there are approximately 541 businesses whose services are IT related services such as Network Installation, hardware and software maintenance, IT equipment supplies, IT consultancy, web hosting and mobile app development. Of all these, nearly 70% reside in Dar es Salaam and Arusha (Fig. 1).

Approximately 70 businesses out of 541 (about 12.9%) are doing mobile apps development (Fig. 2). Since a large proportion of these businesses are small and medium enterprises (SMEs), it has been estimated that each has at least 3 developers on average.

This accounts for 210 developers countrywide; the number does not include freelancer developers scattered in big towns and cities in the country who are mostly fresh university and college graduates. Table 3 shows a summary of results that came out of the survey.

Table 3**:** Issues and challenges facing mobile apps development process when connecting the app with remote database(s).

S/N	THEME/ CATEGORY	Percentage (%)
1	Database adapters and incompatibility	2.6
2	Handling BLOB objects/data	6.4
3	Multiple databases integration	20.5
4	Platform consideration	14.1
5	User Experience and Mobile Device Capabilities	24.4
6	Device fragmentation	26.9
7	Vendor/Platform fragmentation	1.3
8	Other Challenges	3.8
	Total	**100**

2.6.1 Platform Consideration and Device Fragmentation

Mobile applications run in mobile operating system (mobile OS) platforms such as Android, iOS, Windows Phone, Black Berry etc. Developers mentioned that they normally choose a particular type of platform when they start the development of an application. This is very important to them since developer's choice is based on own/individual competencies. About 14% of them mentioned this.

Device fragmentation is another not to ignore challenge facing the Tanzanian developers today. Developers, about 27%, confirmed this as their challenge. Notable is that android has the biggest share in sub-Saharan countries, which includes Tanzania (GSMA, 2014), and 85% of the developers are developing mobile apps based on Android. The presence of different versions of Android OS creates difficulty in developing a multiplatform application. Vendor/Platform fragmentation challenge is not faced by most of developers in Tanzania since most of them are working on Android rather than other platforms, Fig. 4 shows the details.

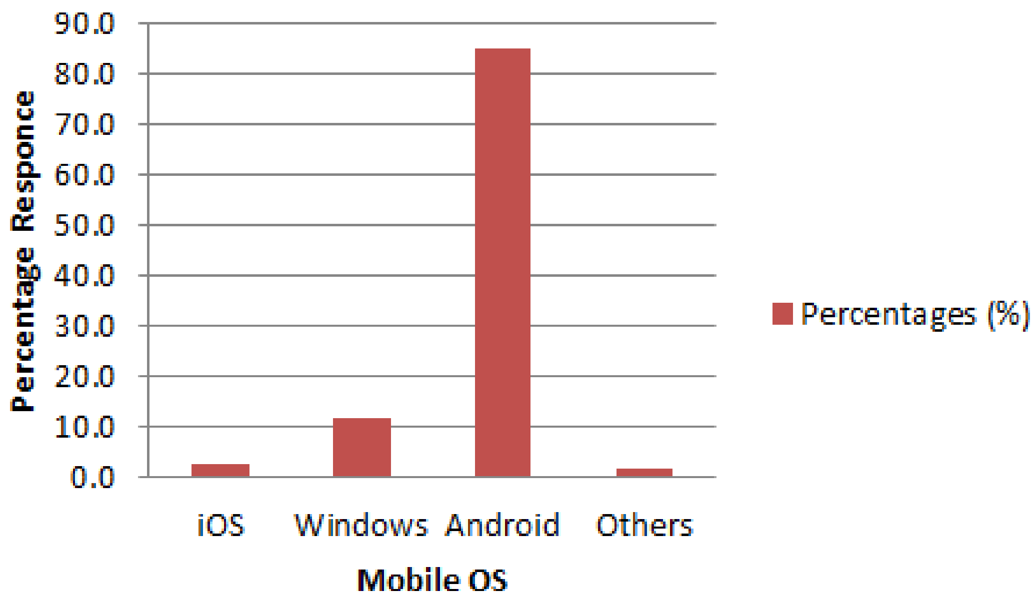

Figure 4: Mobile OS choices of mobile app developers in Tanzania.

2.6.2 User Experience and Mobile Device Capabilities

User experience was also mentioned by developers as one of the issues and challenges to the mobile app development process. From the survey, 24% of developers mentioned this. They utilize different application design tools and techniques to build up an app. They commented that they sketch the User Interface (UI), database model, and User models etc as their techniques of designing good and interactive mobile apps. Others said they normally visit design samples from websites such as materialup, dribbble, material pallet etc. to get a clue on the current graphics, web designing. It is difficult to understand the users taste and experience on the mobile applications.

They usually use adobe Photoshop for UI design, Universal Model Language (UML) tools such as use case, activity and state diagrams as the tools for design. For simplicity and rapidness, they use Java programming language since this language is used by a wider community of mobile developers. Mobile phone capabilities in terms of size, capacity, speed etc, are also challenges mentioned to impact the development of mobile apps. Developers also confirmed that they consider capability of mobile device such as limited power and size during app development.

2.6.3 Multiple Heterogeneous Databases Integration

Databases are available in different types and technologies eg. Oracle, MySQL, SQL Server, etc. For the developer to link with only one among these external databases at a time with mobile app is very possible and in normal practice is always done. For instance when a developer intends to connect the app with MySQL database, it is necessary to configure HTTP post library for the connection to be successful. When the intention is to utilize SQL server database, then the developer must download jTDS (JarFile, JDBC) Libraries, configure it and then connection will be established.

However, a challenge arises when the need is to link two or more databases of both the same or different technologies, with a single mobile app so as they can share information all together. Here, heterogeneity of the databases (Oracle, MySQL, SQL Server etc) was pointed out to be a big challenge. 21% among the developers said this. The following sub-section presents current practices taken by mobile app developers when connecting single mobile app with multiple database systems.

2.7 Current Practice on the Connection Between Single Mobile App to Multiple Homo/Heterogeneous Databases

From the results of the conducted survey, it was confirmed that, there was an existing challenge in mobile application development on integrating a single mobile app with multiple databases (multiple database integration). Also, it was observed that, mobile app developers are comfortably and easily connecting mobile apps with remote databases in one to one connection fashion.

It was further observed that, currently, developers connect a mobile app separately when they have a need to connect it to multiple databases. Figure 5 illustrates the connection of single mobile application to two different databases of two different technologies, MySQL and SQL Server. A developer will not be able to connect it (at the same time) in both databases with a single connection. In this case, two different connections (two pipelines for data flow) using two different components must be established in order to meet this demand.

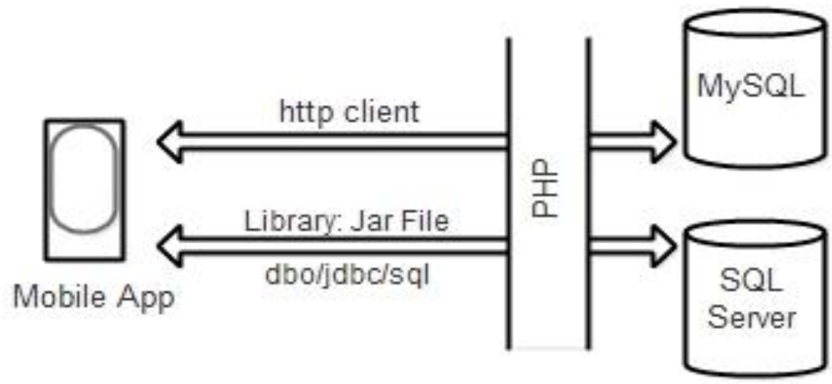

Figure 5: Connection between mobile app and two heterogeneous database systems.

HTTP client, a client side HTTP transport library that provides basic functions for accessing a resource via HTTP protocol (Apache, 2011), is used in the connection between mobile apps with MySQL database. Jar file library is used in the connection between mobile application with SQL server (Oracle, 2016). Other libraries that serve the purpose for this connection are such as DBO (database Object) and JDBC (Java Database connector) (Hopwood *et al*., 2005). All these connections regardless of technologies connect to each database by utilizing PHP functions to enable their connections.

Problems in mobile apps development stem from versioning, incompatibility and open source (Stine, 2013). The focus of the reported research work is to build up a mechanism where connectivity between these components (mobile apps and multiple databases) will become more convenient and seamless regardless of the technology the database is using. The developer should be able to create a mobile app on the client side using same approach without being concerned about the kind of database is connecting to. Figure 6 illustrates concept of desired seamless data exchange.

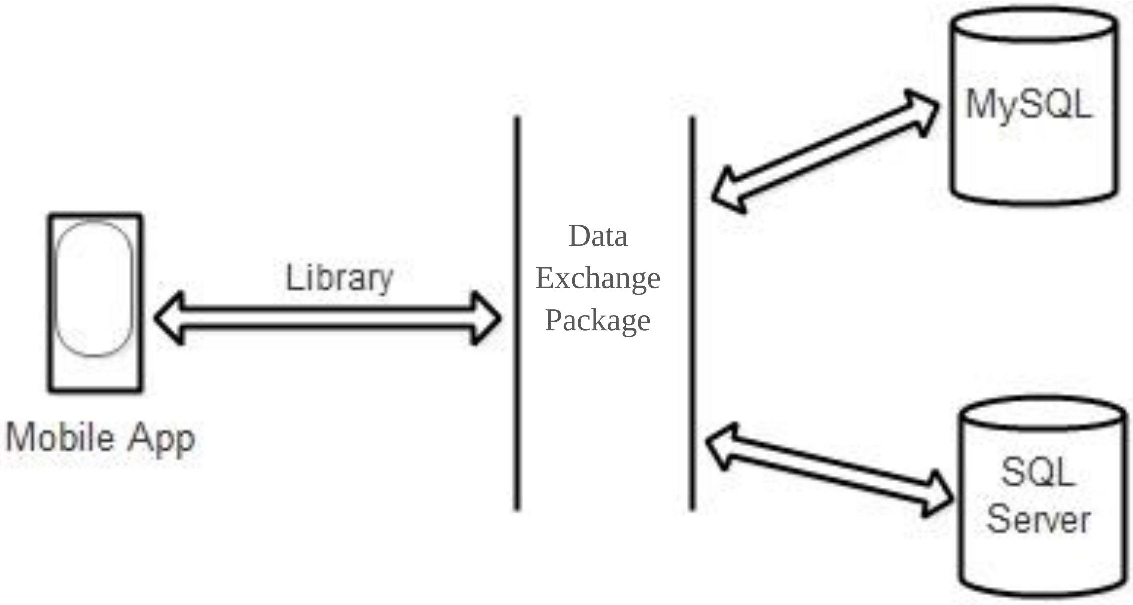

Figure 6: Architecture model for data exchange between single mobile app and multiple databases.

2.8 Proposed Data Exchange Component (DEC) Architecture Between Mobile App and Multiple Heterogeneous Databases

As alluded to in the previous sections, multiple database integration is one of the challenges facing mobile app development such that mobile app developers are not able to connect a single mobile app with multiple databases. As a viable approach, it is proposed to build up a Data Exchange Component (DEC) that will provide a connection interface to mobile applications on one side and on the other side to multiple databases. The DEC was proposed to provide a solution toward multiple system interoperability and also provides an interface to the already developed mobile apps to connect to the already connected multiple databases. Before get deep into proposed DEC details, let's take a look on the interoperability dimension which are very important for interoperability solution development.

2.8.1 Interoperability Dimension

When developing interoperability solutions for different systems, Chen *et al*. (2006) and Guedria *et al*. (2015), suggest three basic interoperability dimensions. In developing interoperations of the systems (interoperability solutions), multiple perspectives, various dimensions and with different types of approaches should be considered (Guedria *et al*., 2015). The three dimensions are; barriers (conceptual, technological, organization), levels (legal, organizational, semantic, technical) and concerns (data, process, service, business).

Figure 7 provides two basic dimensions for enterprise interoperability framework provided by (Chen, 2013; Guedria *et al.*, 2015).

Concerns	**Barriers**		
	Conceptual	Technological	Organizational
Business			
Process			
Service			
Data			

Figure 7: Enterprise interoperability framework.

Interoperability dimensions define the enterprise interoperability research domain and it can be used to structure interoperability knowledge. A piece of knowledge is considered as relevant to interoperability if it contributes to remove at least one barrier at one enterprise concern (Chen, 2013). A concept of connecting multiple systems for the purpose of sharing information and that, the system can use the shared information meaningfully is termed as system interoperability. In this context, interoperability is a demand that is facing disparate information systems today especially in the health sector. It is recognized as the cornerstone for improving quality of healthcare, but currently it's difficult to achieve. Next sub- sections present the three named important interoperability dimensions.

(i) Interoperability Dimensions: Barriers - Barriers in systems interoperability could be categorized into three; conceptual, technological and organizational (Chen, 2013).

Conceptual barriers

Conceptual barriers are concerned with the syntactic and semantic differences of information to be exchanged. Dealing with the enterprise models of a company and as well as the level of the programming (for example XML models).

Technological barriers

Technological barriers refer to the incompatibility of information technologies (architecture & platforms, infrastructure etc). They deal with technical issues related to different technologies involved in the interoperability of the systems.

Organizational barriers

Organizational barriers relate to the definition of responsibility (who is responsible for what?) and authority (who is authorized to do what?) as well as the incompatibility of organization structures (matrix vs. hierarchical ones for example).

(ii) Interoperability Dimensions: Levels - According to Guedria *et al.* (2015), European Interoperability Framework (EIF) defines four levels of interoperability. These levels are legal, semantic, organizational and technological.

Legal Interoperability

Legal interoperability is concerned about legislation relating to data exchange which also includes data protection. It deals with the organization laws and procedures, and the countries legal system etc.

Organizational Interoperability

Organizational interoperability is concerned with how organizations, such as public administrations in different Member States, cooperate to achieve their mutually agreed goals.

Semantic Interoperability

Semantic interoperability ensures that the precise meaning of exchanged information is understood and preserved throughout the exchanges between parties.

Technical Interoperability

Technological interoperability covers the technical aspects of linking information systems such as interface specifications, interconnection services, data presentation and exchange.

(iii) Interoperability Dimensions: Concerns - The interoperability concerns are representing areas concerned with interoperability in an enterprise. Four areas are defined by Guedria and Lamine (2015a) and Chen and Daclin (2006) namely data, services, processes and businesses.

The interoperability of data

The interoperability of data refers to making different data models and query languages work together. That is to find and share information from heterogeneous bases, and which can moreover reside on different machines with different OS and databases management systems (DBMSs).

The Interoperability of services

The interoperability of services requires identifying, composing and making various applications originally designed and implemented independently to function together.

The interoperability of processes

The interoperability of processes makes various processes of different connected systems to work together.

The interoperability of businesses

The interoperability of businesses refers to work in a harmonized way at the level of organization and company in spite of, for example, different modes of decision making, methods of work, legislations, culture of the company and commercial approaches etc. so that business can be transacted between companies.

2.8.2 Data Exchange Component (DEC) Architecture

From the interoperability dimensions described in Section 2.8.1, the reported work addresses the technological barrier by establishing information sharing between heterogeneous eHRs and single mobile app through data exchange framework. In the interoperability levels, the focus is on the technical aspects. In the interoperability concerns dimension, information is shared among different databases i.e data interoperability as illustrated in Fig. 8.

Concerns	Barriers		
	Conceptual	Technological	Organisational
Business			
Process			
Service			
Data		eHR-DE	
Level: Technical interoperability level			

Figure 8: E-Health data exchange (DEC) deal with technological barrier, data interoperability concern and technical interoperability level.

In the design architecture (DEC), shown in Fig. 9, a data exchange package/component is introduced to connect multiple heterogeneous databases to a single mobile app.

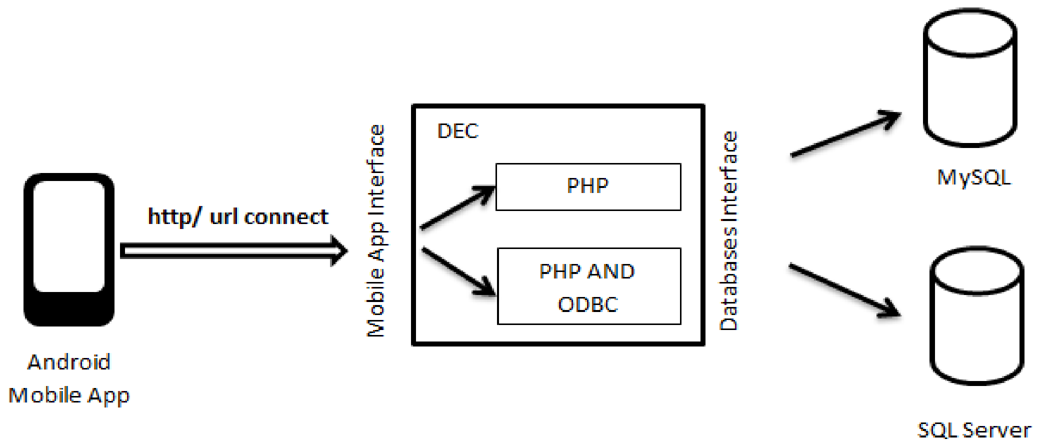

Figure 9: DEC architecture connecting single mobile app with multiple databases.

Utilization of developed DEC is such that: a mobile app developer will download the DEC then connect a developed mobile app into it through an interface provided by the component. The component proposed to contain PHP and ODBC connectivity technologies that provide connection interface to the developed mobile application. The mobile app is connected to the DEC through http/url connect. The provided interface on the other side also has provision to connect multiple databases.

2.9 Discussion

Interoperability is one of the challenges existing in the healthcare domain worldwide. "Interoperability is the ability of different ICT systems and software applications to communicate, to exchange data accurately, effectively, and consistently and to use the information that has been exchanged" (Asuman *et al*., 2006). In Kajirunga and Kalegele (2015), it is reported that lack of coordination at all levels of systems development contribute about 62.5% on the source/causes of interoperability problem among eHealth systems in Tanzania. Another source is the common use (in hospitals and other healthcare facilities) of open source systems that were not specifically designed to meet multiple databases interoperability context and environment and were not created with integration focus in mind.

Achieving interoperability from mobile developers' side is also an existing challenge. The process of integrating two or more health information systems through single mobile app is not easily achievable. Multiple database integration through mobile app is one of the ways to achieve interoperability of eHealth systems. This is now confirmed to be one of the challenges facing mobile app developers.

The main focus of the reported work was to establish/enable interoperability of existing fragmented eHealth systems through mobile apps. In Iroju *et al.* (2013a), a lists of solutions is provided that can be adapted to achieve complete interoperability in health-care. Connection of legacy (existing) systems to healthcare network is among the solutions listed. This is in line with the hypothesis by the authors that "mobile app development could support interoperability of existing/legacy multiple eHealth systems".

The architectural model presented in Fig. 6 provides a possibility toward achieving interoperability in eHealth systems. The DEC architecture proposed in Fig. 9 shows how the integration between a single mobile app and multiple databases could be successfully achieved.

The reported survey results show that, the health sector in Tanzania is characterized by fragmented electronic health information systems (eHealth Systems) with significant barriers to the effective sharing of information between healthcare participants (URT - MOHSW, 2013). The eHealth strategic plan of 2013 - 2018, describes that, infrastructure building blocks is one of the strategic areas of intervention in eHealth development. The report provides a reason to continue researching on the kind of required infrastructure to enable electronic sharing of health information across the Tanzanian health sector. The strategic plan shows the need and importance of implementing health information exchange that leverages mobile technologies (URT - MOHSW, 2013).

2.10 Conclusion

In this chapter, issues and challenges facing mobile application developers in developing countries focusing on connecting multiple eHRs to a single mobile application has been identified and confirmed. Benefits of eHealth infrastructure in developing countries have been reviewed. A DEC architecture for solving the interoperability problem between a single mobile app and multiple databases has been presented. Also discussed is the interoperability challenge among eHealth systems.

It is suggested that multiple database integration through single mobile app is a possible solution towards mitigating the interoperability challenge. Some of the identified and confirmed issues and challenges in mobile app development in Tanzania are; Platform Consideration and Device Fragmentation, User Experience and Mobile Device Capabilities, and Multiple databases integration. These results are subsets of issues and challenges that are facing mobile developers in developing countries particularly in Tanzania. They serve to justify the need for wider efforts to be undertaken by mobile app developers and other stakeholders especially government to provide better environments to the mobile application development processes in Tanzania. Chapter three covers in details the work done to develop the DEC architecture for solving the interoperability problem between a single mobile app and multiple eHRs.

CHAPTER THREE

Data Exchange Architecture for Development of Mobile Applications that Support eHealth Systems Interoperability; A Case of Tanzania[2]

Abstract

Electronic Health (eHealth) especial in the form of electronic health records (eHRs) has proved to greatly improve health care services both in urban and rural or remote areas. However, many of the systems are fragmented and work independently. Therefore, apart from their benefits, these systems are stand alone and as such they face some operational challenges, one of which is interoperability among the eHRs. Early efforts to interoperate eHealth Systems, suggest that a single mobile application that can access multiple integrated eHRs is among the viable solutions on the way to eHRs interoperability. The proposed data exchange design offers a mechanism to integrate a single mobile application with multiple eHRs while mitigating the interoperability problem. The design work builds on the results of a survey previously done to collect preliminary requirements of the data exchange system. System design techniques were used to design the system. In this chapter, the architectural system design of an eHealth Data Exchange that can mitigate interoperability challenge is presented.

Keywords: ***Multiple Databases, Data Exchange, eHealth Records (eHRs), mHealth, Mobile App.***

3.1 Introduction

The global health sector today is enjoying benefits (see Section 2.2.1) enabled by ICT facilities especially eHRs. Many countries globally have reported to continue installing eHRs and some of them creating environment for the implementation. Encouragingly, about 70% of the countries in the world today have national policies for eHealth or have plans to implement such systems. The eHRs technology has proved to improve health care services greatly both in urban and rural or remote areas (Khan and Sai, 2013; WHO, 2017). However, most of these systems are not interconnected as they are fragmented and work independently. They do not exchange data and information among themselves, that is, they are not interoperable.

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[2] This chapter is based on the accepted paper for publish titled; Data Exchange Architecture for Development of Mobile Applications that Support eHealth Systems Interoperability; A Case of Tanzania in the International Journal of Advanced Computer Research (IJACR)

Healthcare interoperability is the capability of health information systems to work together within and across organization boundaries (Adebesin *et al*., 2010). Unfortunately, achieving interoperability of healthcare systems remain a daunting challenge (Adebesin *et al*., 2013).

Most of the eHRs, specifically in developing countries, face the challenge of system fragmentation (i.e systems are not interoperable) due to the fact that individual system deployment is done by multiple system contractors and organizations (Mansoor and Majeed, 2010a; URT - MOHSW, 2010). As a case study, Tanzania is among the countries facing both the fragmentation of eHRs and the interoperability challenges. Further, the government of Tanzania through Ministry of Health, Community Development, Gender, Elderly and Children has identified eHRs interoperability as one of the challenges that are facing existing eHRs in Tanzania (URT - MOHSW, 2013). Several benefits accompany the interoperability of eHRs. In Gomez *et al*. (2010), list two general benefits of interoperability of eHRs as: (a) reduces the cost of healthcare, and (b) contributes into more effective and efficient patient care, other benefits include; reduces the incidence of medical errors (Kaushal *et al*., 2010), provides timely access to the healthcare information and enable informed decision and personalized care (Adebesin *et al*., 2013), provides improved communication of health-care by supporting continuity care (Halamka *et al.*, 2005). Hospitals and healthcare facilities in Tanzania are mostly using Open source healthcare software such as OpenMRS, OpenLMIS, Care2x, LIS, TIVA and CTC2. Unfortunately, these software are not interoperable (Kajirunga and Kalegele, 2015).

Interoperability will only be achieved if the two parties exchanging information, understand well the meaning of information being exchanged and they are able to use them properly (Iroju *et al.*, 2013a). Based on this understanding, interoperability of eHRs is confirmed as the fundamental prerequisite for individual health care improvement (Guedria and Lamine, 2015b). But how does this challenge emerge? Some of the causes of eHealth interoperability identified by different researchers in the healthcare sector include the following:

(i) Lack of an architectural guide/framework towards development of eHRs (Adebesin *et al.*, 2010; URT - MOHSW, 2013).
(ii) Lack of standard procedures to guide the lifecycle of eHRs (URT - MOHSW, 2013; Kajirunga and Kalegele, 2015; Nehemiah, 2014).
(iii) Poor collaboration among private companies or vendors in eHRs development (Kajirunga and Kalegele, 2015).

(iv) Different data structures among the developed eHRs (Adebesin *et al*., 2010).

The general objective of this work is to support the ongoing efforts to alleviate interoperability problem of eHRs by designing and implementing a data exchange mechanism that leverages mobile devices deployed in healthcare. The main design principle is that of connecting a mobile application (mobile app) with multiple eHRs. The data exchange resides between multiple eHRs and a single mobile app where connected eHRs can exchange information. The connected mobile app can access and transfer information to and fro eHRs. This chapter presents a detailed design architecture for a Data Exchange Component (DEC), as a way towards realizing interoperability of eHRs. The philosophy around the proposed DEC is that, it is designed to act as a central application/component that can provide a mechanism to make two or more eHRs to interoperate; i.e to exchange data and information, in order to improve health-care delivery and provide access to mobile apps that are used to access information to/fro the interoperable systems.

The rest of the chapter is arranged as follows: Section 3.2 provides materials and methods used to obtain results presented in this chapter. Section 3.3 reports on the alternative set-ups that could be adopted for DEC deployment and the other connected systems. Section 3.4, gives the proposed architectural design of the DEC. Discussion is presented in Section 3.5 and conclusions are in Section 3.6.

3.2 Materials and Methods

In Chali *et al.* (2017), a survey method was used to identify challenges facing mobile app developers during the process of interconnecting multiple eHRs as a way toward alleviating the interoperability problem. Data were collected and analyzed through questionnaires, interviews and observations. The survey was conducted in Dar es Salaam, Dodoma and Arusha regions in Tanzania. Results of this survey revealed that, multiple database integration, user experience and mobile device capabilities, device fragmentation and platform considerations are some of the issues and challenges facing mobile app developers when dealing with the interoperability problem. The results of the survey were considered as a basis for the design of the DEC. Details of the DEC architectural design is presented in Section 3.4.

3.3 Alternative Set-Ups for DEC

This section presents three possible (and considered viable) set-ups showing alternatives on how the DEC and the participating eHRs could be installed. In general, the DEC is designed to run within a web server, such that both eHRs and DEC reside within servers. The set-ups are as follows:

3.3.1 Set-up I: Use of Three Servers

In Fig. 10, it is proposed to utilize three separate servers where DEC is installed in a separate server. The two participating eHRs will reside separately in other two servers. A typical example in a real-life situation is where the two eHRs represent Health Information Systems (HIS) of two different hospitals. When the hospitals agree to exchange data generated and stored in their particular HISs, they will utilize the proposed central DEC to fulfill their goal. HIS from each hospital will remain where they reside i.e within a particular hospital server, and then an additional server would be added to install DEC.

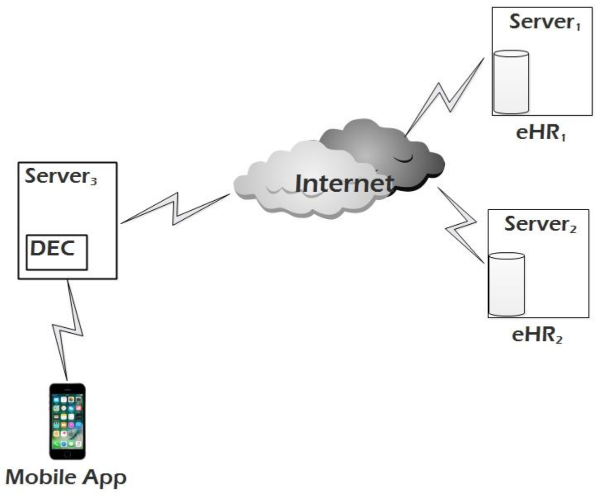


Figure 10: Set-up I - Three Server Set-up for the DEC and participating eHRs.

3.3.2 Set-up II: Use of Two Servers

The second considered set-up is presented in Fig. 11, which shows utilization of only two different/separate servers. This architecture requires DEC and one of the eHR to be installed in a single server and the second eHR installed in the second server. This second architecture allows use of only two separate servers managed by two hospitals, such that one of the hospitals is a host of DEC.

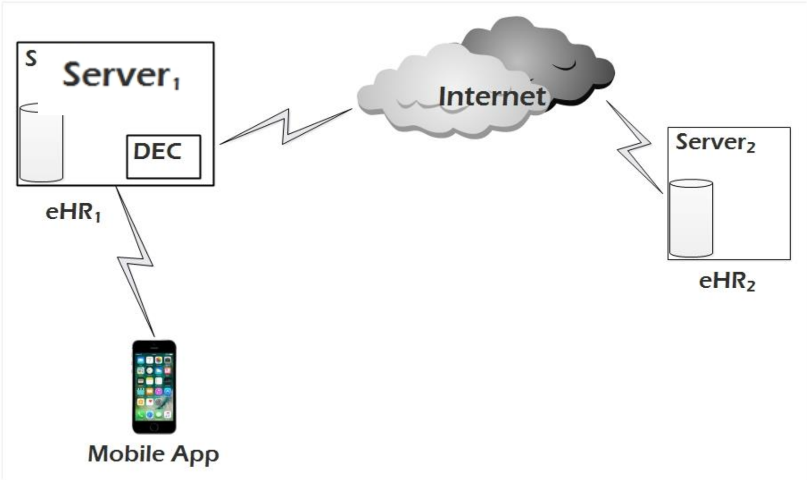


Figure 11: Set-up II – Two Server Set-up for the DEC and participating eHRs.

3.3.3 Set-up III: Use of Single Server; a Local or Cloud Server

The third proposed set-up is such that both eHRs are hosted in the same server with DEC. This architecture can be implemented using two models. One is to host the eHRs and DEC in a physical/local location as illustrated in Fig. 12; the second model is to host them in the Cloud on a virtual server as shown in Fig. 13.

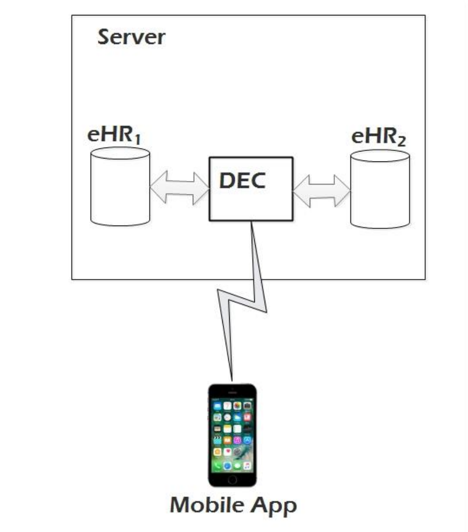


Figure 12: Set-up III A– Single Server; physical/local server host set-up.

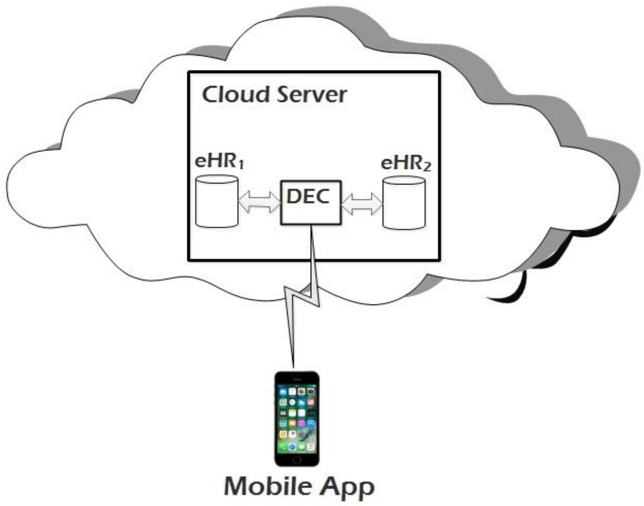


Figure 13: Set-up IIIB – Single Server; Clouds server host set-ups.

3.4 Proposed Architectural Design of the DEC

Fundamentally, the DEC provides a mechanism to connect a single mobile app with multiple eHRs. The architecture presented in Fig. 14 shows an interface to a mobile app, the processing and exchange mechanism where the authentication and data exchange between the mobile app and the connected multiple eHRs occur. Also, the figure shows an interface to eHRs/databases and the connected eHRs.

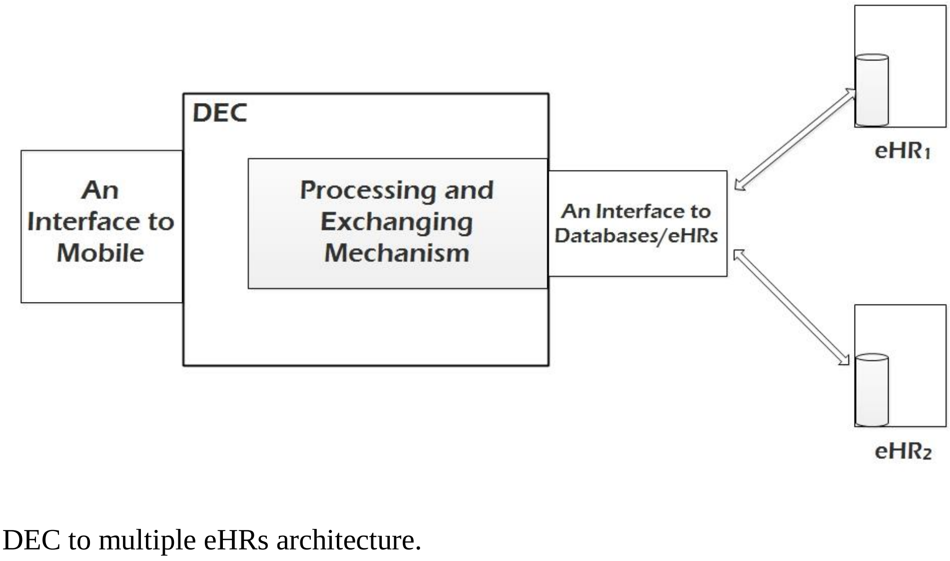


Figure 14: DEC to multiple eHRs architecture.

3.4.1 The DEC Building Blocks

In Chali *et al.* (2017), it is proposed to use the DEC as a solution component toward eHRs interoperability through single mobile app. Figure 15, presents the DEC Architecture's building blocks.

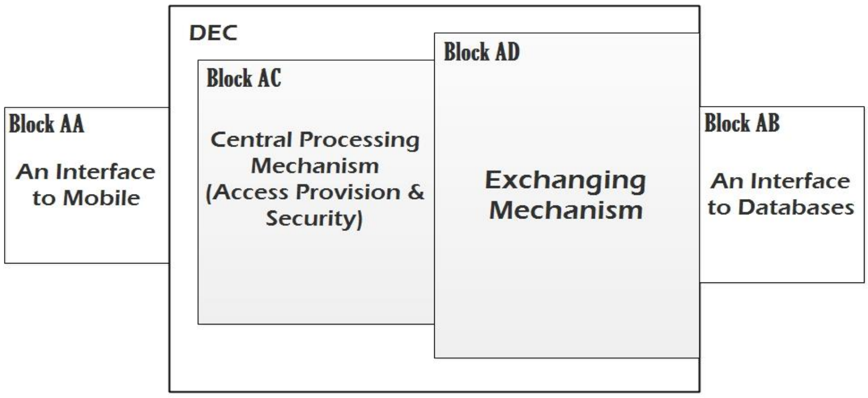


Figure 15: The main building blocks of DEC Architecture.

The following are the details of each building block (Fig. 15):

(i) An Interface to Mobile side (Block AA): This provides a way for the developed mobile app to be connected to the DEC. By being connected to the Data Exchange, mobile app users will have the possibility to access data/info located in the connected eHRs through an authentication process, i.e the user has to be a legal registered user who has been given access to do so. The user has to pass the central processing mechanism, to pull patients info and by the help of DEC application the info-data can be exchanged. To connect the mobile app to the DEC, a mobile app developer will follow the procedures listed in Section 5.4.1 on how to connect and post/retrieve data between the two eHRs.

(ii) An Interface to Database/eHRs side (Block AB): The Interface to databases resides on the side of DEC where it provides an interface to connect eHRs where it gives a way from which they are connected and interact with the DEC. Through this interface, eHRs are connected and can exchange data and information through the exchange mechanism within the DEC.

(iii) Central Processing Mechanism - Access Provision and Security (Block AC): The central processing mechanism provides a mechanism that controls access to the connected eHRs. A user has to be authenticated here and thereafter, allowed to access the eHR databases. The authentication should be controlled by the owner of the connected eHRs, where, before accessing /transferring data from the connected eHRs, the mobile app must be approved by both systems.

(iv) Exchange Mechanism (Block AD): This is a step by step SQL procedure that manipulates the two eHRs. These are codes that perform the exchange of information between the two eHRs.

3.4.2 How DEC Works

The DEC will enable the connected mobile app and web-interface users to access data/information in the connected eHRs. To connect a mobile app to the DEC, a mobile app developer will receive procedures described in Section 5.4.1 on how to connect the app to the DEC. The developer will configure the app to exchange information with the connected eHRs through DEC. After a successful configuration, the mobile app/web-interface user will continue to use the app/web-interface to add, modify, transfer, search, or retrieve data/information to/fro the connected eHRs through DEC. The DEC will allow authentication process when the app/web-interface users login before accessing or transferring data/information. A display flow chart for this process is given in Fig. 16.

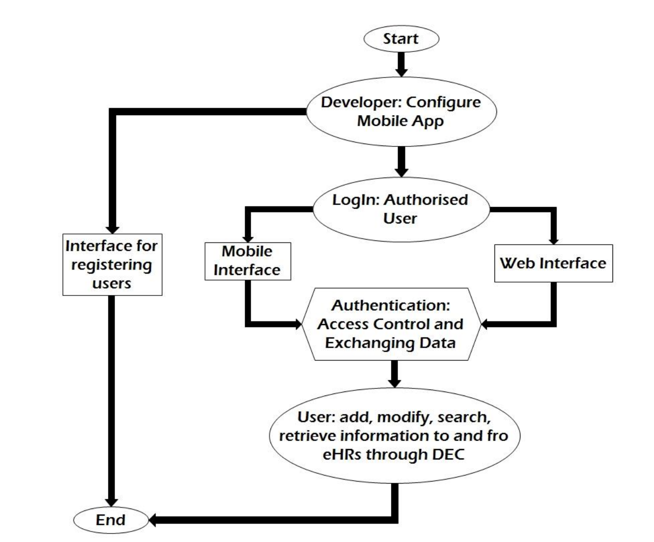


Figure 16: A display flowchart overview.

Essentially, the DEC has two blocks, marked as AC and AD, that control the access (authentication) and facilitate data exchange mechanism as explained earlier in Section 3.4.1. The DEC provides a platform for communication between the two connected eHRs i.e. the connected eHRs will exchange and transfer data/information through DEC.

Users of DEC fall into two main categories;

(i) Category I: Technical Users – Mobile App developers and System Administrators: - Users on this category are those who are responsible for setting up the connections, configuring DEC to work with the intended systems and the mobile app. This category comprises the hospital system/database administrators and mobile app developers. These users are also responsible for the management of the DEC and the system over its lifetime.

A mobile app developer or hospital system administrator will download the DEC, in a compressed folder format and configure it into the intended server and then connect the targeted eHRs. Consider Fig. 17 for more details.

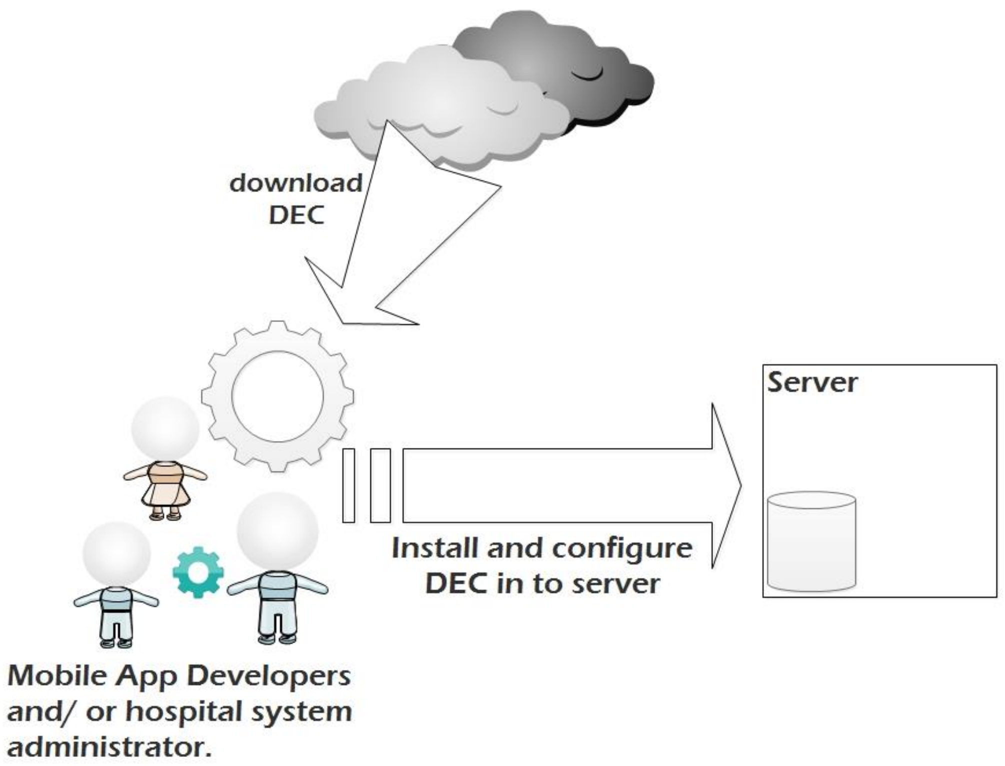


Figure 17: The DEC downloaded by mobile app developer or hospital system administrator and configures it into a sever.

(ii) Category II: Normal Users - The users in this category are mobile app/web-interface users; they are the intended beneficiaries of the DEC. This category includes hospital personnel such as health practitioners, administrators etc. and any other approved users within the participating hospitals. Figure 18 illustrates how category II users interact with DEC.

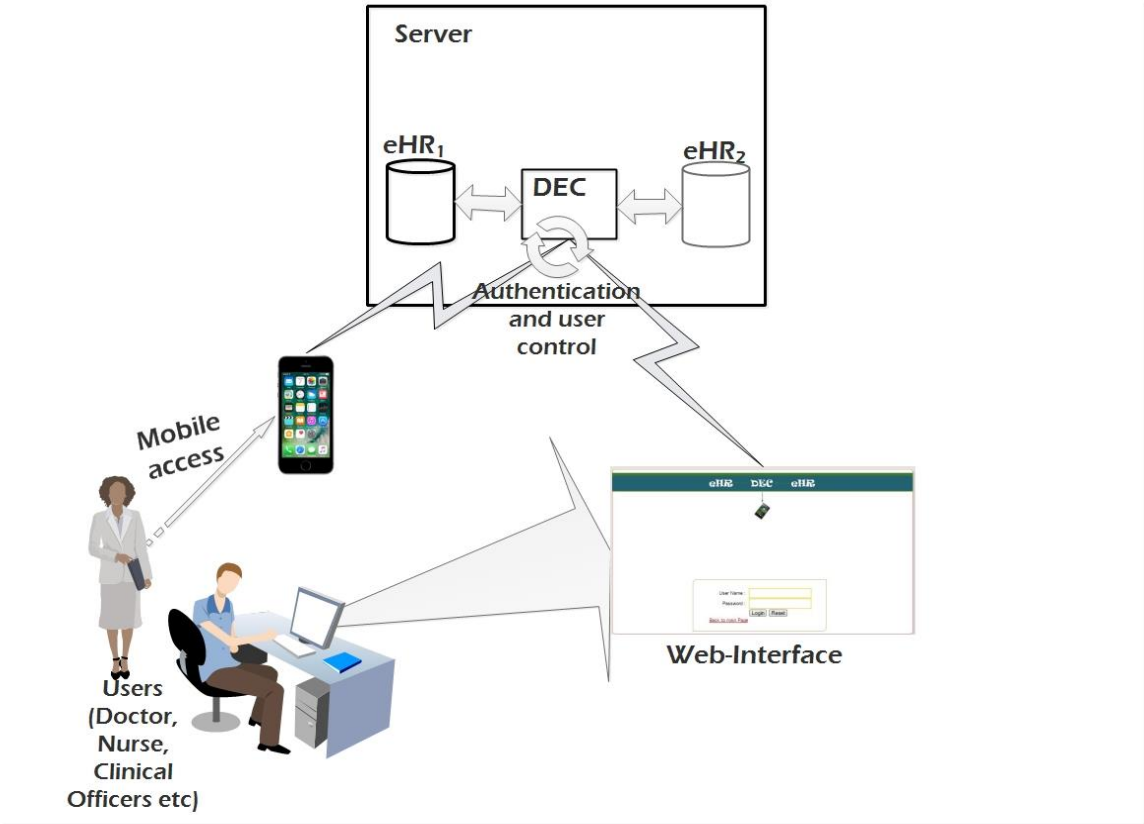


Figure 18: Category II users' interaction with the DEC.

3.4.3 System, DEC Block Diagram and Users' Interaction

Users of the eHRs (doctors, clinical officers, health practitioners etc) will perform actions such as add, modify etc., to the eHRs. The interface to access data will be provided through mobile app and the web-interface. With the interfaces configured and enabled, a user will be able to login to the DEC through authentication processes provided by the DEC and the participating systems (eHRs). Upon successful login, a user will search patient details by using the known patient ID where the details could be transferred to the other connected eHR (the other hospital in this case). Through the data exchange mechanism described in Section 3.4.1, hospitals could exchange medical documents such as discharge summary, referral details, Lab results etc. The block diagram in Fig. 19 illustrates the described interaction.

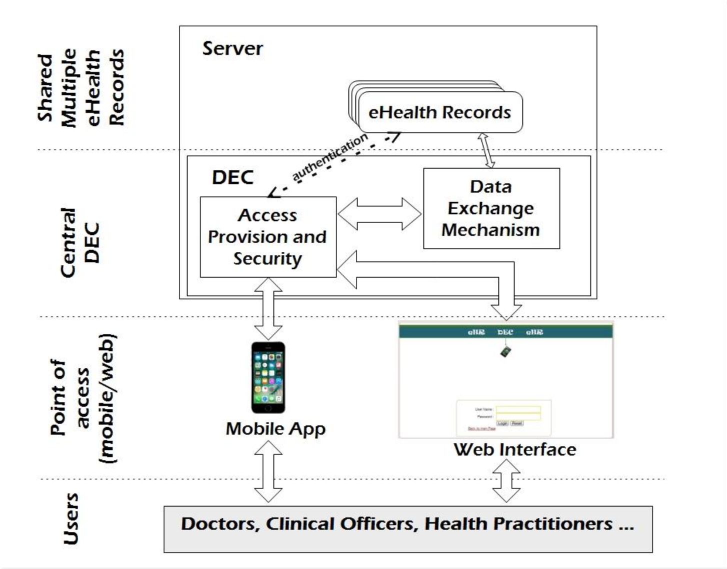


Figure 19: The block diagram for system, DEC building blocks and user interaction.

3.5 Discussion

Three alternative setups for deploying DEC have been presented in Section 3.3. The setups provide possible arrangements on how DEC can be installed and deployed. The arrangements consider options that the hosting institutions could choose based on the cost of implementation as add on to the existing setups, principles and policy. Option of choice by the participating institutions will base on the best viable option that will fit institutional requirements.

In this chapter, the DEC is shown to provide a platform for connecting a mobile app with multiple eHRs. Utilization of mobile devices in health is increasing every day. Deployment of the DEC in this manner is designed to leverage and capitalize on the high penetration of mobile phones (devices) in health-care delivery.

3.6 Conclusion

Achieving interoperability between two or more eHRs is still a challenge in both developing and developed countries. Yet, interoperability of eHRs continues to be an important aspect towards delivering good health-care services. Efforts among health-care stakeholders, practitioners, researchers etc. are still directed toward achieving interoperability among eHRs.

Use of specialized software-based data Exchange Component (DEC) has been suggested as a viable solution to achieve the interoperability of eHRs. The DEC focuses on achieving interoperability of two different eHRs. It has been shown that, the proposed DEC provides a mechanism where two eHRs can share data/information from each other and extends the interoperability capability into a mobile app. Therefore, the realization of DEC is a novel effort and could help to add value in the current efforts towards achieving interoperability of eHRs in hospitals, and health institutions. Actual detailed design of MADE-Framework is covered in Chapter Four.

CHAPTER FOUR

eHealth Systems Interoperability in Tanzania; The Framework for Interoperability and Development of Mobile Applications

Abstract

System interoperability in healthcare remains to be a challenge facing both developed and developing countries. In many cases, eHealth records (eHRs) are fragmented and function independently. Syntactic and semantic interoperability for sharing and understanding of the shared data, are among the most useful aspects to consider when dealing with interoperability. Available data standards such as HL7 are important in achieving semantic interoperability. This chapter reviews interoperability frameworks in order to understand previous contributions towards realizing interoperability among eHRs. The chapter presents a design of a solution to extend the interoperability into accessibility of eHRs via mobile applications. The proposed design is a Mobile – App Data Exchange (MADE)-Framework that incorporates OpenHIM architecture to integrate multiple eHRs and a single mobile application consider useful in low and middle income countries environment.

Keywords: ***Interoperability Framework, Interoperability Data Standards, Health Information Exchange, eHealth Records, OpenHIM, Mediator, Low and Middle Income Countries.***

4.1 Introduction

As described in the previous chapters, making eHealth records (eHRs) to interoperate is an ongoing effort in many countries. At the same time, there have been several initiatives worldwide that suggest solutions that focus on achieving interoperability of eHRs (Laplante-Lévesque *et al*., 2016; Hu *et al*., 2015; Zagar *et al*., 2017). Such initiatives include interoperability frameworks and models that propose reference architectures for supporting efforts towards achieving eHRs interoperability (Hu, 2017; Chen and Daclin, 2006; Ryan *et al*., 2014). However, each type of solution is often specific to a particular health facility, business environment, processes, database structures or data being collected (Computer Science Cooperation, 2010). Therefore, there is a need to establish standards that will facilitate the process of making the eHRs to interoperate. Availability of standards will enable integration and guide the interoperability of two or more eHRs. Use of standards will also reduce interoperability problems in multiple eHRs communications (Adebesin *et al*., 2013).

The main goal of establishing eHRs interoperability is to exchange data and share information among connected systems for the intention of improving healthcare delivery. Difference in datasets involved in the sharing process is one of the main obstacles of interoperability among eHRs (DeNardis, 2012; Wikström and Regnér, 2016). These datasets can be categorized in terms of size, type and format, major difference in organization culture, behavior and business processes, presence of legacy systems, and genuine concerns for privacy security and confidentiality of patient information (Wikström and Regnér, 2016; Dawoud *et al*., 2010). For a successful and complete interoperability, one should consider how two or more different systems can be integrated together. A successful interoperability will allow the systems to communicate, which requires compatibility among interfaces of participating systems for smooth handling of datasets.

Interfacing and integration are equally important factors to consider for attaining interoperability (Alvin and Ismail, 2016). An interface is a boundary at which interaction occurs between two systems/processes. Interfaces provide points of integration between systems and allow communication and exchange of data and information. There are three main types of interfaces in computer science namely; user, hardware and software interfaces. Integration is the act of combining diverse applications for joint collaboration of several system components to form a single entity. Interoperability is well when two or more systems of the same or different technologies and architectures are integrated and seamlessly share data and information. In the road toward realizing interoperability, there are three main dimensions to consider, which are; barriers, levels and concerns (Guedria and Lamine, 2015a), also refers into Section 2.8.1. Among these, the most important one is interoperability level. Several researches have suggested a number of different levels of interoperability including legal, organizational, semantic, technical, and syntactical (Guedria and Lamine, 2015a; Chen, 2013). The mostly used levels are syntactic and semantic interoperability (Mansoor and Majeed, 2010b).

Syntactic interoperability is an application level interoperability, allows data exchange and information sharing between different application/systems. In Hu *et al.* (2017), observed that, syntactic interoperability ensures data are successfully shared without requiring a complete understanding of shared data by the participating systems/applications. Some of the efforts to achieve syntactic interoperability are Open Database Connectivity (ODBC), SQL Standards, Service Oriented Architecture (SOA), and XML webserver (Yu *et al*., 2011; Harvey, 1999).

In contrast to syntactic interoperability, semantic interoperability ensures exchange and understanding of shared data by the participating systems. Several efforts have been made to achieve semantic interoperability, one case is data standardization. Authors in Adebesin *et al*. (2013) noted that, standards enhance workflow exchange of data and clinical records and reduce ambiguity of health care providers. They can reduce interoperability problems among eHRs and provide a method of communication among healthcare organizations and providers. To date, several data standards are readily available for use, these are such as OpenEHR, Health-Level-7 (HL7), Digital Imaging and Communication in Medicine (Dicom), CEN/ISO EN13606, International Classification of Disease, and XSAMS (in plasma physics) (Iroju *et al*., 2013b; Hyoung *et al*., 2014). Health-Level-7 (HL7), is the most utilized interoperability standard worldwide and is named as the main international health informatics standard today (HL7 Org, 2016).

HL7 standard supports integration, management and exchange of data. Moreover, HL7 provides reduction of cost, provision of comprehensive clinical framework for message and discharge reports exchange and record sharing (Computer Science Cooperation, 2010). Some of the developed eHRs interoperability middleware and frameworks which utilizes the available interoperability standards include the Open Health Information Mediator (OpenHIM), Rwandan Health Information Exchange (RHIE) and eHealth Interoperability Framework. The OpenHIM architecture is actually one of the most common and promising data exchange middleware suitable for the Low and Middle Income Countries (LMICs) (Jembi Health Systems, 2012). In this chapter, RHIE and several other existing frameworks for eHRs interoperability are reviewed. The review was intended to propose Mobile App - Data Exchange (MADE) – Framework for interoperability between multiple eHRs and extend to mobile application (app) for access to the eHRs.

The organization of the rest of the chapter is as follows; Section 4.2 gives an overview of eHRs interoperability frameworks. Section 4.3 presents the Data Exchange Component (DEC) architecture for MADE-Framework, where in Section 4.4, the proposed MADE-Framework design is presented. Section 4.5 carries the chapter conclusions.

4.2 Overview of eHRs Interoperability Frameworks

A number of eHRs interoperability frameworks have been deployed from different researches both from developed and developing countries. These frameworks include the eHealth European Interoperability Framework, Personal Health System Framework, Health Information Systems Interoperability Framework and eHealth Interoperability Framework (Chen and Daclin, 2006). African countries like Rwanda and South Africa are advanced in the development of eHRs interoperability frameworks. The RHIE is proven as one of the most suitable eHRs frameworks for LMICs (Ryan *et al*., 2014). A brief description of the available frameworks is as follows.

4.2.1 eHealth European Interoperability Framework (eHEIF)

E-Health European Interoperability Framework (eHEIF) is a framework under European Commission that focuses on providing a guideline for interconnecting eHealth systems within European countries (Guedria and Lamine, 2015a). It provides standard architectures when developing eHealth interoperability solutions in Europe.

4.2.2 Australia eHealth Interoperability Framework

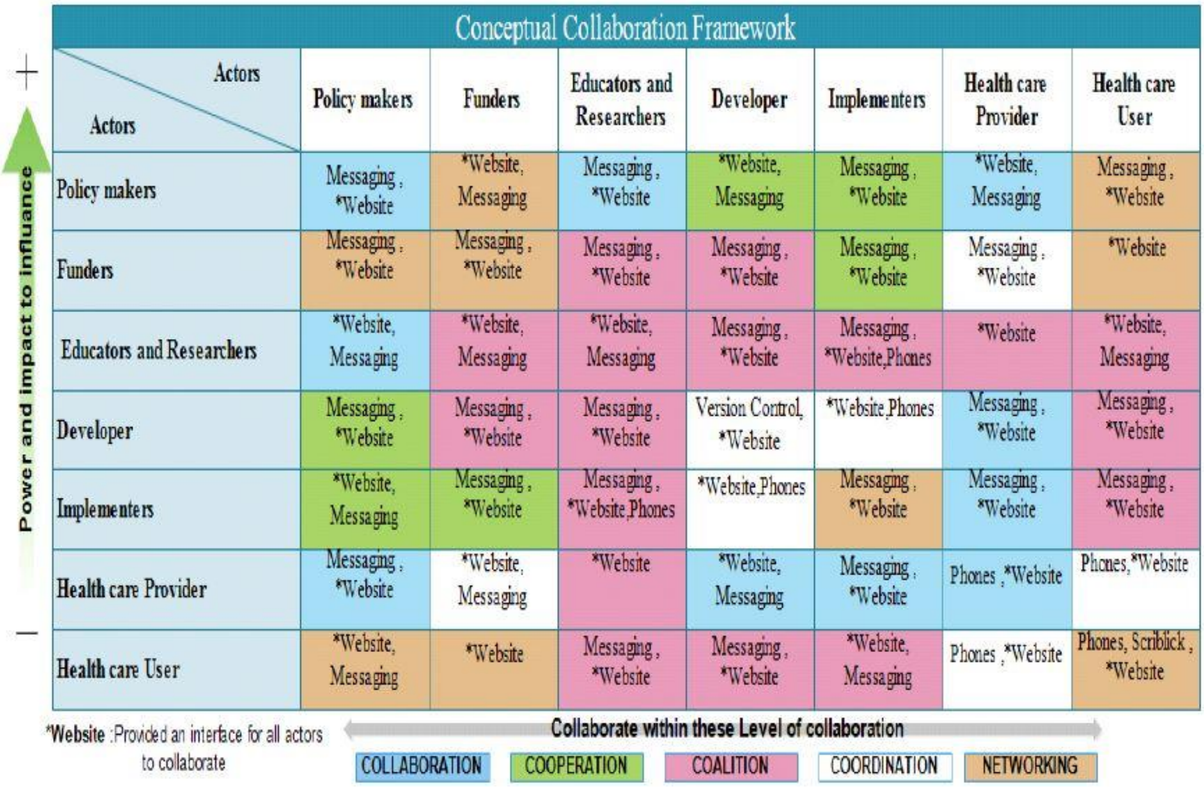
This framework was developed by the National E-Health Transition Authority in Australia (NEHTA). The aim was to facilitate interoperability of eHRs by specifying standards and implementation strategies for successful interoperability (NEHTA, 2005; Chen *et al*., 2008).

4.2.3 Rwanda HIE

The RHIE Framework supports incremental development by allowing disparate systems to be connected through a central HIE with minimal change of the systems (Jembi Health Systems, 2012). It connects local health workers with multiple eHRs through a mobile SMS application. Health workers through RHIE can access patient information and other data located in the connected eHRs.

In Tanzania as a case study, surveys and researches towards eHRs interoperability are being conducted to drive utilization of practical benefits of deploying eHealth information sharing systems. In Nehemiah *et al.* (2014), they conducted a survey about eHRs interoperability in Tanzania's hospitals and concluded that security and privacy of consumer/patient details are very crucial and should be addressed before implementation of interoperable eHRs. Then

Kajirunga and Kalegele (2015), proposed a collaboration tool among eHealth stakeholders (Fig. 20), as one of the frameworks toward achieving systems interoperability in Tanzania.



Conceptual Collaboration Framework

Actors / Actors	Policy makers	Funders	Educators and Researchers	Developer	Implementers	Health care Provider	Health care User
Policy makers	Messaging, *Website	*Website, Messaging	Messaging, *Website	*Website, Messaging	Messaging, *Website	*Website, Messaging	Messaging, *Website
Funders	Messaging, *Website	Messaging, *Website	Messaging, *Website	Messaging, *Website	Messaging, *Website	Messaging, *Website	*Website
Educators and Researchers	*Website, Messaging	*Website, Messaging	*Website, Messaging	Messaging, *Website	Messaging, *Website,Phones	*Website	*Website, Messaging
Developer	Messaging, *Website	Messaging, *Website	Messaging, *Website	Version Control, *Website	*Website,Phones	Messaging, *Website	Messaging, *Website
Implementers	*Website, Messaging	Messaging, *Website	Messaging, *Website,Phones	*Website,Phones	Messaging, *Website	Messaging, *Website	Messaging, *Website
Health care Provider	Messaging, *Website	*Website, Messaging	*Website	*Website, Messaging	Messaging, *Website	Phones ,*Website	Phones,*Website
Health care User	*Website, Messaging	*Website	Messaging, *Website	Messaging, *Website	*Website, Messaging	Phones ,*Website	Phones, Scriblick, *Website

Source: Kajirunga and Kalegele (2015).

Figure 20: Conceptual collaboration framework for eHRs.

4.3 DEC Architecture for MADE-Framework

As it has been described in previous chapters, DEC was proposed as a contribution toward interoperability problem mitigation efforts. DEC building blocks, as illustrated in Fig. 19, integrates multiple eHRs with a single mobile app.

Within DEC, there are two main sub-components, which are access provision and security, and data exchange mechanism. Main functions of these sub-components are to bridge accessibility from the external points of service, and to exchange data and information among the participating systems respectively. In this study, OpenHIM was adopted and incorporated within DEC as core data exchange mechanism. OpenHIM was adopted since it was successfully implemented and tested and proved as a suitable eHRs interoperability mechanism for LMICs. To integrate OpenHIM with points of access, a mediator was used as a sub-component of DEC. In the DEC, the mediator can help to bridge OpenHIM with a mobile app or web page as points of access. In Section 4.4.2 and 4.4.3, more details for OpenHIM and mediator are provided and in Fig. 21 DEC architecture with OpenHIM and mediator sub-components is illustrated.

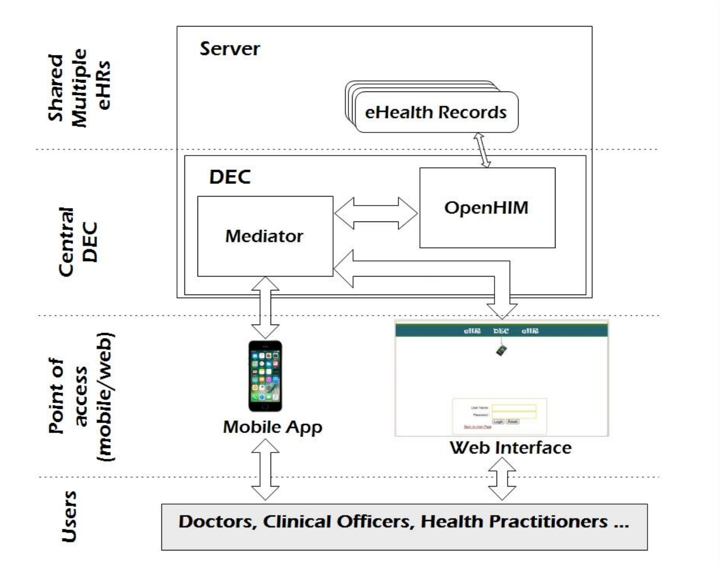


Figure 21: Data Exchange Component (DEC) architecture with OpenHIM and Mediator.

4.4 Mobile App-Data Exchange (MADE) Framework for eHealth Interoperability

MADE-Framework is proposed to support eHRs interoperability and mobile app development. The purpose is to extend interoperability into mobile applications. The framework includes the DEC architecture shown in Fig. 21, with OpenHIM and mediators as core sub-components.

4.4.1 MADE-Framework Requirements

The following requirements were adopted to develop the MADE-framework since they represent LMICs requirements for eHRs interoperability. The requirements were generated during the implementation of RHIE project for eHRs interoperability in Rwanda (Crichton, 2015; Jembi Health Systems, 2012). The descriptions of the requirements are listed as follows.

(i) Facilitate interoperability between existing and future disparate and heterogeneous systems: The MADE-Framework should allow existing and future disparate and heterogeneous systems to be integrated into health Information Exchanges (HIEs) with minimum changes to the system. Also incorporated systems should grow independent of the overall system (HIE).

(ii) Adapt and scale within a changing environment: The MADE-Framework should allow new requirements to be incorporated. Architectural services should be readily expanded as demand arises.

(iii) Local changes should not propagate through the system: The MADE-Framework should allow participating systems to grow and develop independently without affecting other systems. Participating systems should be protected as much as possible such that any change to any participating system will not affect other systems.

(iv) Provide a low entry barrier to connect new and legacy systems: The MADE-Framework should posess minimum barrier for both legacy and new systems to be integrated into the HIE.

The MADE-Framework is composed of five layers namely; users, points of access, central DEC, security, and shared multiple eHRs. Each layer is described as follows.

(i) Users' layer: Allows users to access data/ information through mobile app or web page.

(ii) Point of access layer: Provides the capability for submitting or retrieving data and information to and fro the shared eHRs.

(iii) Central DEC: Is another layer that includes a mediator and OpenHIM general components. The Mediator component provides a mechanism for connecting points of access with OpenHIM, a component which allows data exchange to take place. In this component, the actual exchange of data and information is done. Attached eHRs exchange data/information they store through DEC in this OpenHIM sub-component.

(iv) Shared multiple eHRs layer: Acts as stores/repositories of the data/information. The data repositories share data with each other and with connected user s' points of access through central DEC layer.

(v) Security layer: Provides security mechanism to the whole framework.

The MADE-framework is illustrated in Fig. 22.

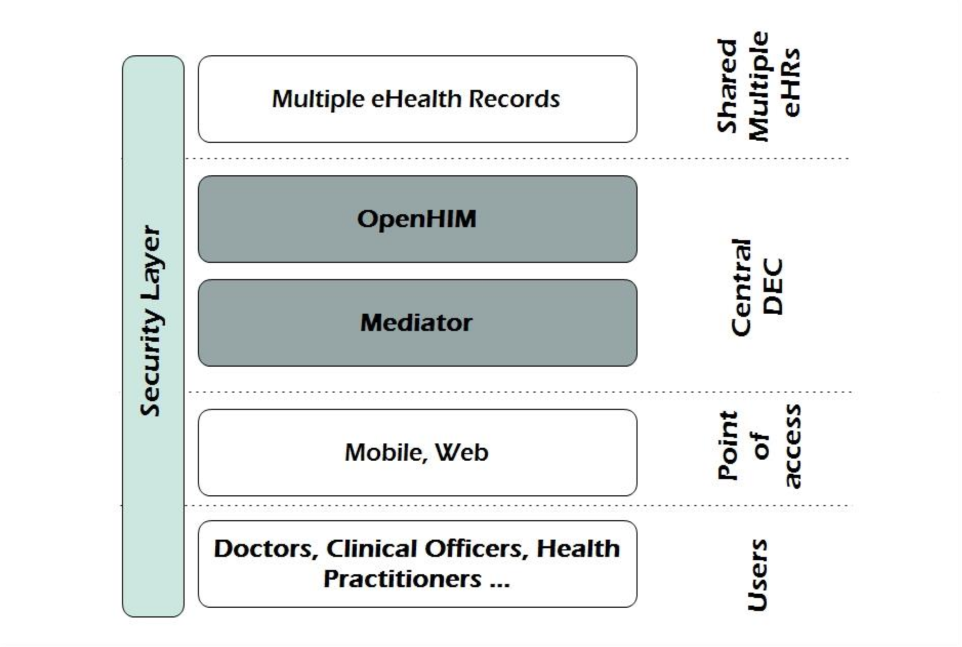


Figure 22: MADE Framework.

4.4.2 Mediator Component

The mediator supports specific implementation processes by extending the functionality of OpenHIM. Its common functions are; (a) Message format adaptation that transforms messages from one format to another. (b) Message orchestration, which involves the execution of business functions that demand services from other systems. As part of DEC, the mediator transforms and orchestrates message formats.

The structure of the mediator is split into three main sub-components to allow easy re-use and mediation. The sub-components are; Normalization, Orchestration and De-normalization.

(i) Normalization**:** Transform transactions into normalized state (i.e canonical form) for particular transaction (Fig. 23). In this sub-component, semantic and syntactic interoperability is achieved and more details on these are presented in Section 4.4.4.

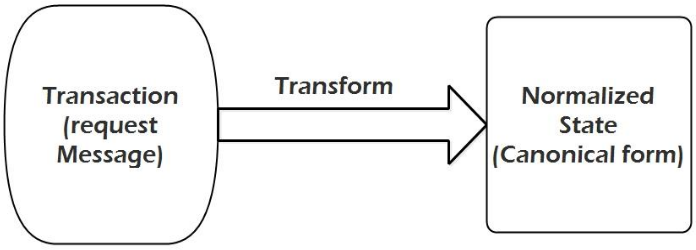


Figure 23: Normalization process of the mediator.

(ii) Orchestration**:** In this sub-component, the mediator receives transactions and performs consequent actions on the orchestration functions. These actions are executions, compiling, and forwarding the responses from the received transaction requests from points of access (external services). Figure 24 illustrates the orchestration function of mediator.

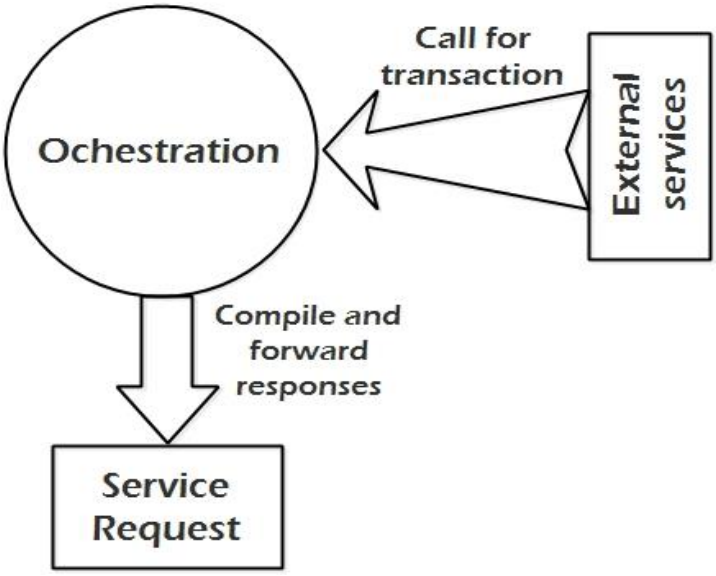


Figure 24: Orchestration process of the mediator

(iii) De-normalization**:** This sub-component helps the mediator to transform service requests into a format that can be understood by the other participating systems. It is a reverse order of normalization process.

4.4.3 OpenHIM Component

OpenHIM is a middleware system that is designed to facilitate interoperability among participating systems in the health infrastructure services. It provides mediation and orchestration functions (Crichton, 2015). The middleware manages orchestrations of transaction of services from participating systems (Jembi Health Systems, 2012).

RHIE successfully implemented OpenHIM and used it as the core architecture for the interoperability of connected eHRs in the data and information exchange (Fourie, 2013). OpenHIM provides an interface that allows systems to make service requests, access controls that prevent access to unauthorized patient information and mediation function among the participating systems. OpenHIM as an interoperability layer was developed based on interoperability concerns/requirements listed in Section 4.4.1 (Crichton, 2015).

OpenHIM is another sub-component of DEC in the MADE-Framework. It performs the core interoperability function among the connected eHRs and extends to mobile app through mediators (Crichton *et al*., 2013). OpenHIM functions support syntactic and semantic interoperability.

4.4.4 Syntactic Interoperability and Semantic Interoperability with OpenHIM

As stated earlier in the Section 4.1, syntactic interoperability involves data exchange and information sharing without considering the meaning of the data under processing. In contrast, semantic interoperability focuses on complete understanding of the shared information by the interoperable systems. Two operations of OpenHIM architecture allow the achievement of syntactic and semantic interoperability. The operations are on-ramp and process transformation.

(i) On-Ramp Transformation: This operation ensures transformation of a process into a canonical form. The process can be handled by OpenHIM for further operations. On-ramp transformation achieves syntactic interoperability. This operation is illustrated in Fig. 25.

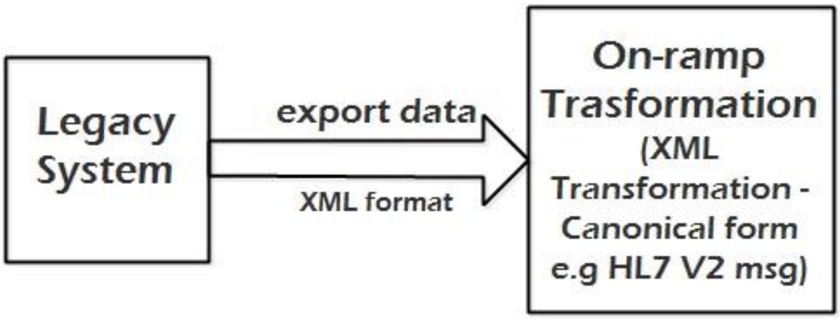


Figure 25: On-Ramp transformation for syntactic interoperability

If a transaction is received from a legacy system and data is exported as XML format, the format will be transformed to a form that will be understood by the OpenHIM i.e canonical form like HL7 and others.

(ii) Process Transformation: This operation ensures code system within a transaction is transformed into a standard set of vocabulary or clinical terms. The operation focuses on achieving semantic interoperability, as illustrated in Fig. 26.

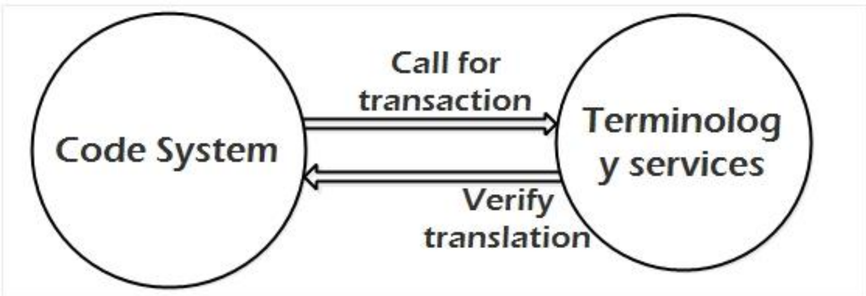


Figure 26: Process transformation for semantic interoperability.

4.5 Conclusion

Interoperability of eHRs remains an operational objective difficult to achieve without considering interoperability dimensions such as barriers, levels and concerns. Syntactic and semantic interoperability levels are considered to be among the most important dimensions. Data standardization is one of the several efforts towards realizing semantic interoperability. HL7 is recognized as the most utilized data standard. In this chapter, several existing interoperability frameworks have been reviewed. Noted is that OpenHIM is one of the popular middleware to facilitate interoperability of multiple eHRs in LMICs.

MADE-Framework has been proposed to contribute towards realizing eHRs interoperability in LMICs. The framework adopts available requirements that fit the needs of eHRs interoperability within LMICs. It incorporates OpenHIM in DEC architecture as a core interoperability mechanism for participating eHRs. This work provides a new contribution and adds value in the efforts towards mitigating the eHRs interoperability challenges. Implementation, testing and evaluation of DEC prototype to realize a guiding framework is presented in Chapter Five.

CHAPTER FIVE

Data Exchange Component (DEC) Prototype: Implementation, Testing and Evaluation.

Abstract

Mobile phones have been used for years for communications purposes. E-Health systems (eHRs) integrate with mobile applications (apps) in mobile phones to deliver healthcare services both in urban and remote places. The new trend in health-care is for eHRs to exchange data/information (interoperability) and extending their service delivery through mobile apps. This chapter reports on the implementation, testing and evaluation of the Data Exchange Component (DEC), a core interoperability mechanism under the MADE-Framework. Usability and acceptance testing techniques were used to test the DEC prototype. The outcome show the success of DEC in interoperating multiple eHRs and it can provide support to the mobile app development process. Therefore, the implementation of DEC can help to support multiple eHRs interoperability through mobile phones.

Keywords: ***Framework, interoperability, Data Exchange Components, eHealth Systems, mHealth, Mobile App.***

5.1 Introduction

The use of mobile communications in delivering health-care has demonstrated a number of benefits (Modi, 2013). According to ITU, over 85% of the world's population is currently covered by commercial wireless signals including mobile application communications (SANOU, 2015). The highly accessibility and utilization of mobile phone technologies bring about the possibility of greater personalization and citizen-focused public health and medical care (WHO, 2011). The involvement of mobile phone technologies into health-care delivery has matured the idea of extending data exchange between eHRs to mobile devices. Many data exchange applications have been implemented in different countries worldwide. Most of these data exchange focus on the provision of centralized environment for sharing data and information between various point of services and systems including mobile applications. Service Oriented Architecture (SOA) is one of the data exchange which is web based application that helps users to exchange information and share knowledge during an internet-mediated transaction (IMT) (Yu *et al.*, 2011). In plasma physics, there is XSAMS, which provides data exchange mechanism between researchers for validation of data (Hyoung *et al.*, 2014). Open source Health Record Exchange (HRE) platform is another example of data exchange application running in the American National Health Information Infrastructure (NHII). It specifically provides secure interoperable exchange of health records between existing health Information Systems (Douglas and Peter, 2006).

Efforts are in progress to integrate mobile apps with data exchange mechanisms to support interoperability among eHRs. Implementation of data interoperability mechanisms with the extension to mobile application point of access in developing countries is well demonstrated in Rwanda and South Africa (Fourie, 2013). The high utilization of mobile apps in developing countries, about 70% of the global mobile application subscribers (SocialCubix, 2015) is a motivation and a necessity for integration of health systems with the mobile applications. However, development of mobile applications focusing on eHRs interoperability, is facing challenges such as demand of using proprietary programing language, inconsistence experience to some developers, testers and users (Arjit *et al.*, 2013). Most of these developments require developers to understand how to specifically connect a mobile application with a particular information system.

As it has been stated earlier in previous chapters, much effort has already been done to facilitate existing disparate and heterogeneous systems to be interoperable. It has been revealed that, many of these platforms are web-based applications (Section 4.2). Only a few of them are extending their services to mobile based Short Message Service (SMS), example, OpenHIM (Ryan *et al*., 2014). Middleware and some development environment platforms are implemented to offer support to the developments of the mobile applications. Joseph *et al.*, (2012), implemented a cross-platform enterprise mobile framework to provide development environment for mobile applications at Intel enterprises. Other frameworks such as MADP and MEAP are designed to provide support on the same goal (Joseph *et al.*, 2012).

In Alvin and Ismail (2016), it is reported that, there is a need to create a data interoperable/exchange platform that will allow easy integration of mobile applications, other than SMS based applications, from different mobile devices to be integrated with various existing eHealth systems. In Chapter Four, Section 4.4, MADE-Framework was proposed in order to facilitate interoperability process between multiple eHRs extending into mobile apps. Within the MADE-Framework, DEC is proposed to function as a core interoperability mechanism. Presented in this Chapter are the implementation of a DEC prototype, test and evaluation results. The rest of the chapter is organized as follows; next section, Section 5.2, gives the methodology used. Section 5.3 provides reviews of some of the existing architectures and frameworks for eHealth data exchange that support mobile applications. In Section 5.4, results of the DEC Implementation, Testing and Evaluation are given while Section 5.5, MADE-Framework implementation strategy is presented. Lastly, Section 5.6 provides the chapter conclusion.

5.2 Methodology

To test how DEC performs, two kinds of testing techniques were conducted, usability testing and acceptance testing. The techniques were used to test how DEC can be used and being accepted by users for their daily responsibilities. The authors also used observation and questionnaire methods to collect data for DEC evaluation.

5.2.1 Usability Testing

Usability testing is a kind of testing that ensures the intended system provides to the targeted users the intended tasks effectively, satisfactory, and efficiently. The aim is to understand how real users can interact with the intended system and to improve it based on the results (Gaffney, 1999; TechSmith, 2009). The usability testing target the representative users and test host (technical users) and can be attended by intended system developers. The number of test rounds depends on the complexity of the system, budget constraints, and the number of intended users. Data collection methods used during this kind of testing can be observation, interviews, and questionnaire. Usability testing can be conducted during the various stages of development as follows (TechSmith, 2009):

(i) Low-fidelity prototype or paper prototype

(ii) High-fidelity prototype

(iii) Alpha and Beta versions

(iv) Release version

(v) Comparative or A/B

5.2.2 Acceptance Testing

Acceptance testing is a kind of system testing technique that aims to determine whether or not the system satisfies the requirements specified during the preliminary stages of the system development (Tutorial Point, 2017). In Acceptance testing, the system is tested for usability. In general there are two main kinds of acceptance testing namely; internal (Alpha Testing) and external acceptance testing. Internal acceptance testing involves members of the organization where the development of the software project is done. External acceptance testing is performed by the customer who asked the organization to develop the software (STF, 2017).

5.3 Existing e-Health Data Exchange Architectures and Frameworks that Support Mobile Applications

Development of mobile applications with the intention to connect into remote databases/systems is mostly requires developers to generally focus on two main specific areas. One is on developing the particular mobile app. The second area is on how to handle to and fro data exchange mechanism between the application they develop and the systems in the server they intend to integrate. Several existing architectures/programs have been developed for use by developers when developing mobile apps that work with databases. SANA is an open source cellphone-based platform that captures, transmits, and stores complex medical data such as images, videos and other information and physiological signals (MIT, 2014). Its architecture consists of several mobile phones and one web-connected server. A dispatch program that runs on the server provides control on to and fro communication from registered phones in the system. The program has a plug-in that allows it to interface with medical record system within the server (MIT, 2014). On this kind of application, a developer needs to focus on how the application could be integrated with a particular medical record system. Anyone who is in need to use SANA application must install the dispatch program in the server. If it is desired to integrate more than one medical records, one must install the dispatch program into each individual medical record servers.

Another application for mobile app for server connection is e-MOCHA. It is a secure, highly flexible and adaptable mHealth application. It leverages mobile phones to assist health programs, researchers, providers, patient care and data collection. The e-MOCHA consists of two applications: The Device, runs on android-based smartphones, and the Server, this runs on a webserver with MySQL database and application code in PHP format. In addition, it has API, which is handling device authentication and provides a set of functions for devices to transmit data to and from the server (Hopkins, 2014). Other development efforts that support mobile applications development are as follows:

(i) The REST API (Application Programming Interface), a lightweight and scalable API to support mobile development, which is extremely easy to build, integrate, test, extend and maintain (Andry *et al*., 2011).

(ii) The RapidSMS; an application used for extending system servers to SMS applications (Carl, 2014). An evident application of RapidSMS is in data exchange architecture in Rwanda. The HIE API, which resides at the mid of Health Information Mediator (HIM) in the Rwandan NHIS, provides central exchange mechanism that connects with RapidSMS (Ryan *et al*., 2014).

(iii) Firebase, a cloud-based database service that allows mobile app developer to store and sync data across multiple clients. It provides client libraries that enable integration with android, IOS etc. Data sync across all clients in real time using NoSQL database (Poyzner, 2014).

(iv) In Joseph et al., (2012) authors report on a cross-platform enterprise mobile framework implemented to provide development environment for mobile applications at Intel enterprises. Other frameworks such as MADP and MEAP are designed to provide support to achieve the same goal. These efforts are already taking places worldwide.

5.4 DEC Prototype Implementation, Testing and Evaluation

The details of DEC architectural design were presented in Section 3.4. Users can access data/information through point of access (mobile, web devices). The devices are connected to the shared data repositories (eHRs) through DEC. The DEC contains a mediator and an OpenHIM as exchange mechanism components (Section 4.3).

5.4.1 Implementation

In this work, procedures were developed to instruct technical users on how to connect into DEC. The procedures provide step by step instructions to connect and configure the developed mobile app into DEC. The procedures are listed as follows.

(i) Issue HTTP Request to the DEC.
(ii) Parsing the response JSON string.
(iii) Issue the asynchronous task.
(iv) Create a view of the task above (normally custom list View Adapters).

OpenMRS and Care2x health Information systems were used as sample eHRs to demonstrate the applicability of the developed DEC architecture. The DEC, as a web application, resides and runs within a webserver. User of the DEC will download it from online repository as a form of compressed folder. After downloading, the user will un-compress it, install and then configure it in the intended server (Fig. 17).

The following are pieces of codes showing the implementation and testing of the developed DEC.

(i) Data Exchange - Appendix 1 shows the fetch and transfer patient function for data exchange process. Also, it shows scripts for patient data transfer from Care2x to OpenMRS. The transfer patient function is presented in Fig. 27.

```
function transferpatient() {
    var pid=document.getElementById("ppid").value;
    var params="?pid=" + pid;
    sendrequest("transferpatient","page",params);
}
```

Figure 27: Transfer patient function

(ii) Authentication - Shown in Fig. 28 is a screenshot of the authentication form and the login function codes where a user is prompted to enter login details. The sample of login form codes is presented in Fig. 29 and more details are in Appendix 2.


```
function login(){
    var uname=document.getElementById("uname").value;
    var pwd=document.getElementById("pwd").value;
    var params="?uname=" + uname + "&pwd=" + pwd;
    sendrequest("login","page",params);
}
```

Figure 28: A screenshot for user login web page and a sample login function

```
<form id="login" method="post" action="javascript:login()">
    <table>
        <tr><td align="right">User Name :  </td>
        <td><input type="text" id="uname" required></td></tr>
        <tr><td align="right">Password :  </td>
        <td><input type="password" id="pwd" required></td></tr>
        <tr><td align="right"></td>
        <td><input type="submit" id="log" value="Login"/> <input type="reset"
        id="res" value="Reset"/></td></tr>
        <tr>
        <td><a href="index.html">Back to main Page</a></td>
        </tr>
        <tr><td align="right" colspan="2"><span id="sms"></span></td></tr>
    </table>
</form>
```

Figure 29: Sample web-based login form codes

In Fig. 30 are the scripts that provide access control and security within the DEC. The codes are designed to check the data and then secure them before an insert/retrieve action to/fro the MySQL database. Also there is a piece of code that selects a user by using username and password that are inserted by the user through the provided form.

```
<?php

if (isset($_REQUEST))
{
  require_once("conn_mid.php");
  $uname=mysql_real_escape_string($_REQUEST['uname']);
  $pwd=mysql_real_escape_string($_REQUEST['pwd']);


  //If succeded


  $sql="select * from tbl_users where uname='$uname' and pwd='$pwd'";
  $res=mysql_query($sql);


  if ($res) {
      if ($row=mysql_fetch_array($res))
      {
        //require_once("select.php")
            require_once("conn_care.php");
            require_once("objpatients.php");
            $patients=new Patients();
            $patients->LoadPatientsList('');
      }
      else {
        echo  SayThis("Login failed!");
      }
```

Figure 30: Sample login codes

5.4.2 Testing and Evaluation

Testing the DEC prototype was done by using two open sources eHRs namely; OpenMRS and Care2x. The two eHRs were used as data repositories samples. The two eHRs were connected to DEC at the point of access which was a mobile app and the web interface. Patient registration details were transferred from OpenMRS to Care2x; it was a successful transfer of the details from Care2X to OpenMrs. The DEC architectural design adopted for the purpose of this testing was Architecture IIIA, which is discussed in Section 3.3.3.

Through DEC, a user can transfer/ exchange data from either systems i.e to and fro OpenMRS and Care2x. Figure 31 depicts the flow of data to and fro either eHRs through DEC.

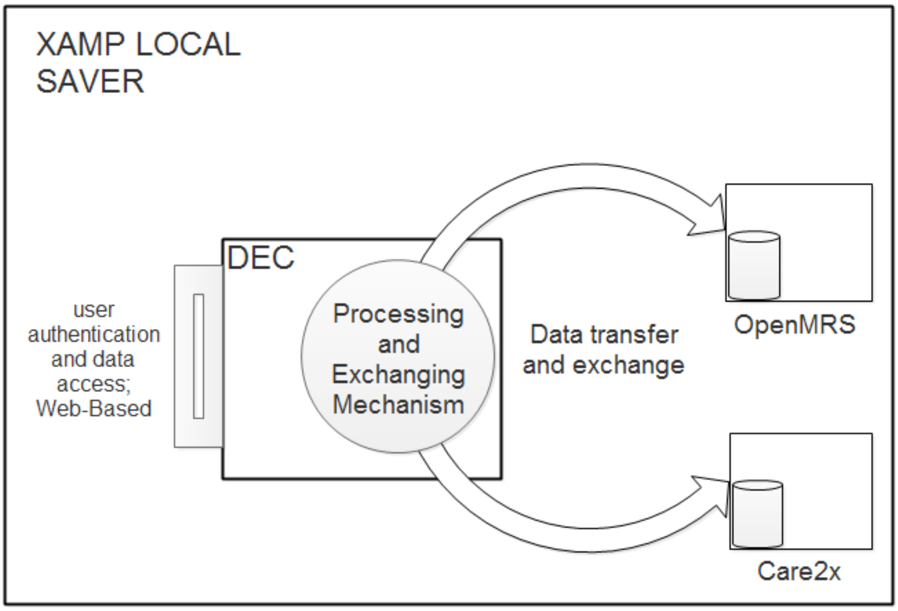


Figure 31:Data transfer/exchange from either system through DEC to XAMP server.

In Section 3.4.2, it was described that, DEC has two different kinds of users namely; technical and normal users. During the testing process, the usability testing involved both technical and normal users to test how DEC can be used. Acceptance testing involved only normal users to understand the acceptability of the DEC. Technical users was represented by mobile apps developers while doctors and nurses represented the normal users. The testing was conducted in two hospitals namely; Dodoma Regional Hospital and UDOM Hospital in Dodoma region in Central Tanzania.

(i) Usability Testing: Involved technical and normal users.

Technical users

This testing was done among mobile app developers of which three (3) were selected purposively. Each developer was given procedures listed in Section 5.4.1 and the DEC source code compressed folder and was instructed to connect the mobile app they have developed to the DEC.

A screenshot of a sample mobile app that was successfully connected into DEC is shown in Fig. 32. The app was able to transfer patient registration details.

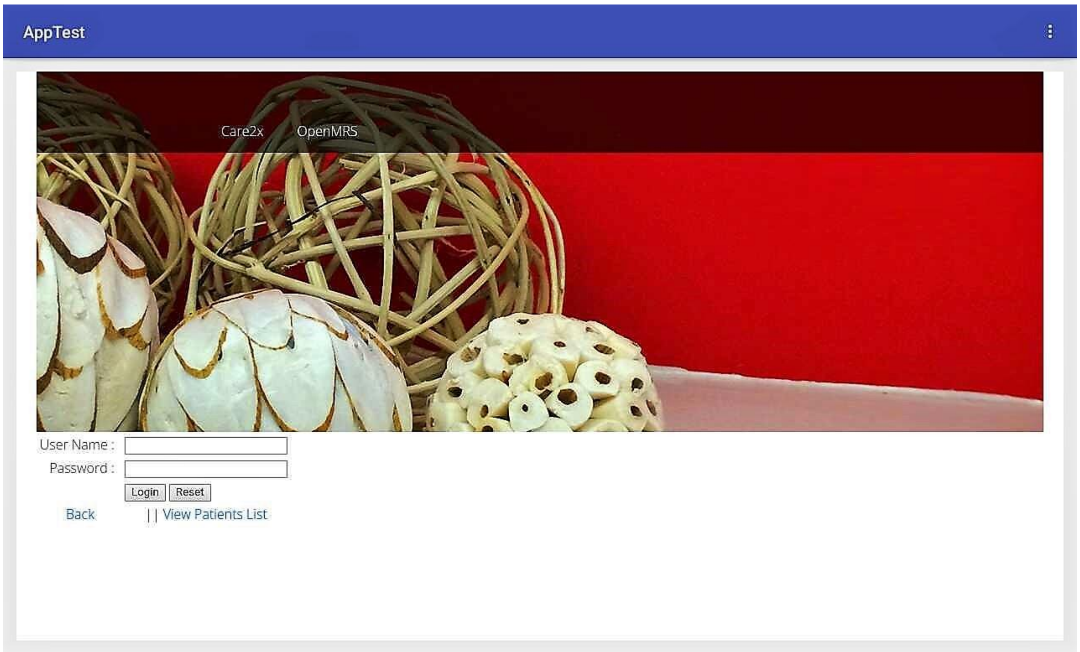


Figure 32: A sample mobile app interface which was successful connected into DEC and access eHRs

Normal Users

A sample developed mobile app as installation file with the name app-*debug.apk,* was distributed to be installed into normal users' mobile devices for evaluation. Fifteen (15) normal users were randomly selected in Dodoma region from Dodoma General Hospital and the UDOM Hospital. The selected users were medical doctors, nurses, and health administrators. The participants were given questionnaire aiming to evaluate the application on how easy to transfer information, its interactivity, compatibility, and its connectivity. During the process, the app were installed and configured on each participant's smartphone where they connect with DEC and the data repositories. As it is described previously in the methodology (Section 5.2.1), usability testing focuses on testing the effectiveness, satisfaction and efficiency of the application under testing, the outcome of this testing is summarized in the following results;

- **Effectiveness**: About 80% of the participants (strongly agree 26.7 and agree 53.3) said that the application is easy to transfer information. Therefore the DEC is effective.
- **Satisfactory**: Users agreed that the DEC is helpful since 66.7% were strongly agreed and 26.7% of them were agreed, this way the DEC proved to satisfy users.

- **Efficiency**: Only two participants of about 6.67% on average, encounter compatibility problem during installation while the remaining 13 participants succeeded to connect to the DEC through internet.

The Fig. 33 shows the effectiveness, satisfactory and efficiency results summary;

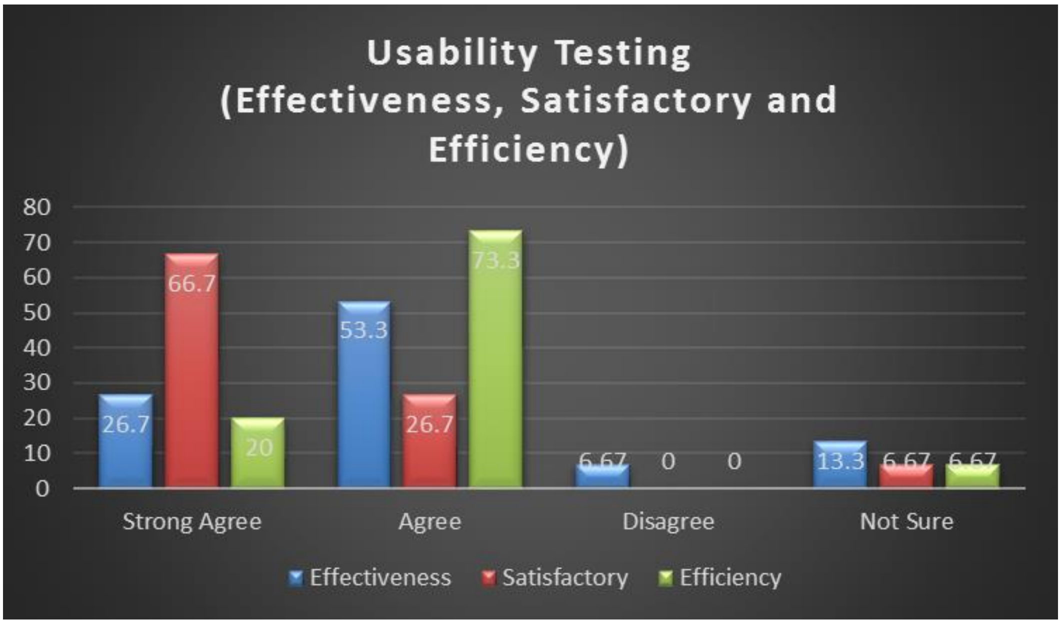


Figure 33: Usability testing (Effectiveness, Satisfactory and Efficiency).

More details of the results are presented in Table 4.

Table 4**:** Usability testing

SNo.	Question	%Results as per question			
		Strong Agree	**Agree**	**Disagree**	**Not Sure**
1	The application is easy to transfer information.	26.7	53.3	6.67	13.3
2	The application is interactive.	20	73.3	0	6.67
3	Compatibility: problem to install an app into your phone was encountered.	6.67	6.67	86.7	0
4	Is the internet connectivity works with the application?	40	60	0	0
5	Is the app helpful?	66.7	26.7	0	6.67

Figure 34 presents results from usability testing in graphics.

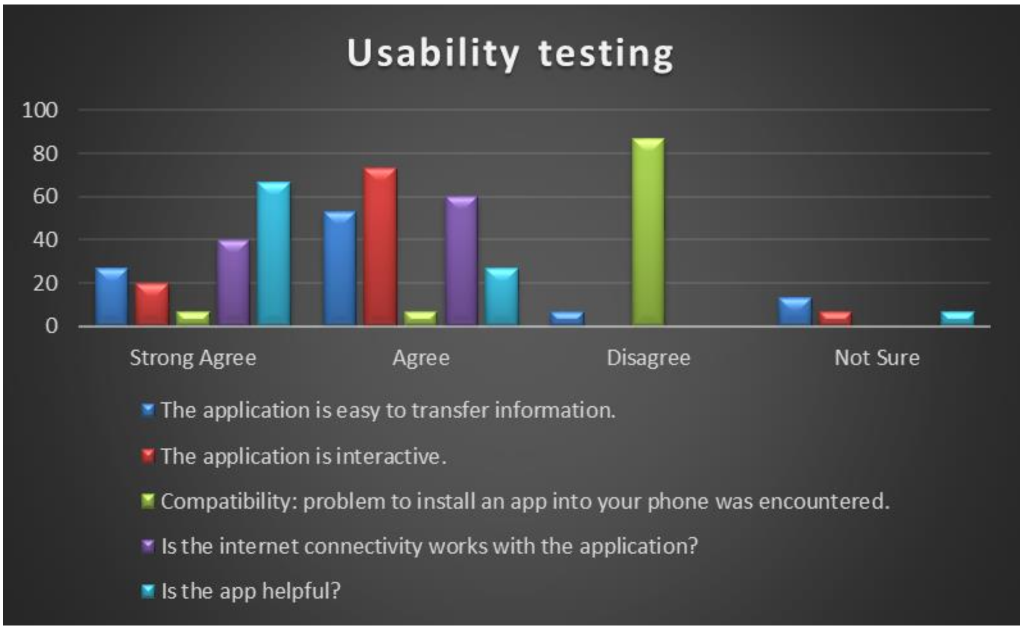


Figure 34: Usability testing

(ii) Acceptance Testing: Another questionnaire was distributed to the normal users to evaluate the users' acceptance of the DEC. This testing was done by the same (previous) selected normal users and their results are in Table 5. Generally, results revealed that, the DEC is acceptable by the normal users. This is signified by 100% of participants whom they strongly agreed to recommend it to others.

Table 5**:** User acceptance testing

SNo.	Statement	%Results as per Question			
		Strong Agree	**Agree**	**Disagree**	**Not Sure**
1	The tool is effective and could be helpfully.	20	80	0	0
2	I think that I would like to use the Application.	66.7	26.7	0	6.7
3	The application will be the helpful in my daily responsibilities concerning patient information transfer and sharing.	46.7	40	6.7	6.7
4	The application will assist me in managing the patient information.	33.3	66.7	0	0
5	The application will provide easy interaction between hospitals.	26.7	60	0	13.3
6	I will recommend this tool to others.	60	40	0	0
7	Overall, I am satisfied with this application.	53.3	40	0	6.7

Figure 35 presents results in Table 5 in graphics.

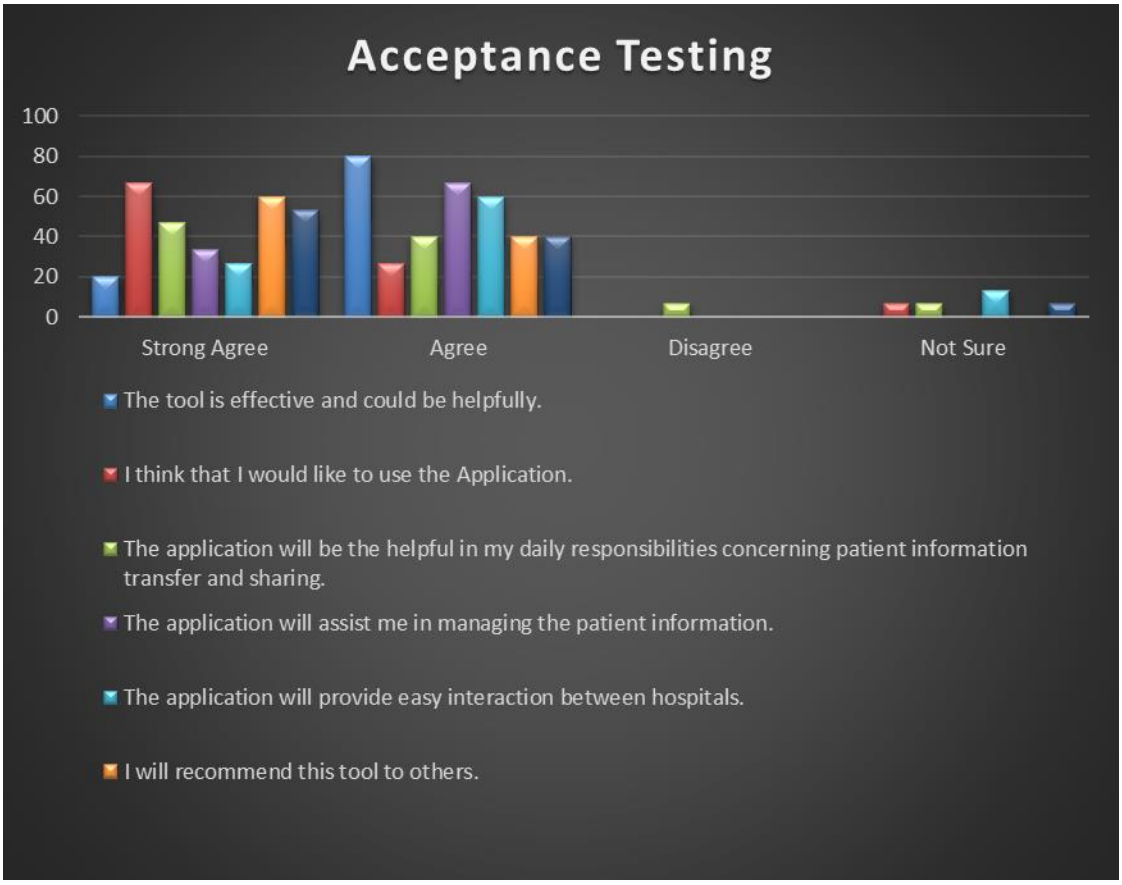


Figure 35: Acceptance testing

5.5 Made-Framework Implementation Strategy

It is suggested that the usability and the acceptance testing performed to the developed DEC prototype in this study should be extended to the implementation testing of the MADE-Framework. The testing processes will focus to test if the framework offers to the users the tasks which it is claimed to provide. Also, the process will test if the framework satisfies its initial requirements. Testing team should be formed to facilitate and coordinate testing process. Generally, steps of testing will include the following:

(i) Setting up DEC by configuring OpenHIM and MEDIATOR.

(ii) Connect the intended multiple eHRs to the DEC through OpenHIM.

(iii) Connect web interface and developed mobile app to the DEC through MEDIATOR.

(iv) Test the exchange of information among the connected systems.

However, the testing team will be expected to prepare the testing environment in advance. The team should well communicate the intended testing process to the necessary stakeholders through the proper communication channels. Stakeholders such as policy makers, ministry officers, health practitioners and administrators, mobile app developers, hospital systems administrators and other related government and private officers should be involved to the process from early stage set-ups.

5.6 Conclusion

In this chapter, existing eHealth data exchange architectures and frameworks that support mobile applications development are reviewed. Features of DEC prototype have been presented and described. The proposed MADE-Framework implementation strategy is also presented. This strategy will help to guide the testing process of the framework. The testing will involve two main categories of targeted users identified as normal users and technical users. The chapter also presented results of the usability and acceptance testing which was conducted during the course of this study. The testing was focused to test the applicability and acceptability of DEC prototype. Three mobile apps developers were purposefully selected to represent technical users. Doctors and nurses were randomly selected to represent normal users. Outcome of the testing process showed that, the DEC prototype was effective, satisfactory and efficient. Results further revealed that, the full implementation of DEC can be helpful to the daily responsibilities of the users.

CHAPTER SIX

General Discussion, Conclusion and Recommendations

6.1 General Discussion

In this section a general discussion about the study reported in this dissertation is made regarding supporting sharing of information among multiple eHRs through a single mobile app by designing data exchange framework. The study was arranged into four sub-studies that contributed to the achievement of the general objective of this research work. The sub-studies correspond to four specific objectives:

(i) To study the development of mobile applications and identify the challenges and issues encountered when integrating mobile application with existing multiple eHRs.
(ii) To identify the basic components and to design data exchange framework.
(iii) To design and implement a data exchange component prototype.
(iv) To test and evaluate the developed data exchange prototype.

In Chapter 2, the study identifies the need for a unified central data exchange mechanism that will integrate multiple eHRs with mobile app. Platform consideration and device fragmentation, user experience and mobile device capabilities, and multiple heterogeneous databases integration are some of the issues and challenges revealed by the survey conducted. Data exchange architectural model (Fig. 6) was proposed to support mobile app development process. The chapter proposes a design of DEC architecture intended to connect multiple eHRs to a single mobile app as a response to the research questions one and two;

(i) What are the key design issues which need to be considered during development of mobile application for seamless integration to multiple eHRs?

(ii) What are the existing challenges in the integration of mobile applications with existing eHRs in Tanzania?

[These two research questions address objective one]

In Chapter 3, alternative set-ups for deploying DEC were presented. The set-ups show how DEC and the participating eHRs could be installed within servers. The three different set-ups are proposed in Section 3.3 such that set-up one uses three different servers, set-up two uses two different servers and set-up three uses single server. In this chapter, a detailed architectural design of the DEC is proposed. The design describes how DEC works, identifies the categories of users of DEC and the building blocks and the user interaction with the DEC.

Chapter Four proposes the MADE-Framework (in Section 4.4) to support multiple eHRs interoperability and mobile app development. The requirement used to guide the development of MADE-Framework was adopted from RHIE project for eHRs interoperability in Rwanda. The requirements are presented in Section 4.4.1. The framework uses DEC as its core interoperability mechanism where the DEC involves two basic subcomponents namely OpenHIM and mediator. Chapter three and four addresses research question three;

(iii) What are the necessary components and design for building effective data exchange framework*?"*

[This research question addresses objective two]

In Chapter Five, it was noted that the proposed DEC upon its full implementation is acceptable and helpful to the users. Also DEC works efficiently, effectively and satisfy its users. This chapter presents detailed implementation and evaluation testing of DEC and covers research questions four and five;

(i) What kind of data exchange will facilitate information sharing between different eHRs through single mobile application in Tanzania?

(ii) How does a developed data exchange support mobile app development and the interoperability of eHRs?"

[These two research questions address objective three and four]

The evaluation process to address the stated research questions revealed that 100% of the participants strongly agreed that DEC can be helpful and they are ready to recommend it to others. About 71.3% agreed to be satisfied using DEC. Two papers have been published as a contribution to the body of knowledge;

(i) 1st paper title: Critical Issues and Challenges in Developing Mobile-Based Health Systems: Case of Tanzania.

Journal: International Journal of Computer Science and Information Security (IJCSIS).

(ii) 2nd paper title: Data Exchange Architecture for Development of Mobile Applications that Support eHealth Systems Interoperability; A Case of Tanzania.

Journal: International Journal of Advanced Computer Research (IJACR).

6.2 Conclusion

The health sector in the world today is facing the interoperability problem. The availability and utilization of mobile apps mostly in developing countries has set the opportunity and a demand to extend the applications to the eHRs (Iroju *et al*. 2013a). Due to this demand, several researches and projects that focus on mitigating interoperability problem through mobile apps has been introduced and conducted.

In this study, MADE-Framework's architectural design, and the DEC prototype implementation, testing and evaluation has been presented. MADE-Framework provides a new mechanism that supports mobile apps development process while facilitating multiple eHRs integration. The framework includes five layers namely; users, point of access, central DEC, security layer and shared multiple eHRs. In these layers, a central DEC is composed of OpenHIM sub-component responsible for interoperability process and also the mediator sub-component that facilitates integration of mobile apps with the DEC.

In Section 3.4 of this dissertation, a detailed DEC architecture was proposed as a mechanism for sharing data within multiple eHRs with the extension to mobile apps as a point of access. The prototype was developed and tested, and the results shows that it is efficient, satisfactory to the users and can be helpful as presented in Chapter Five.

The DEC prototype was tested due to the reasons that it is a core part of MADE-Framework and it can simply be tested with minimum resources on its prototype stages. The Scientific and the practical contribution of MADE-Framework are as follows;

Section 5.5 provides implementation strategy for the proposed MADE-Framework. The strategy is focusing to guide testing and implementation of the framework therefore to provide its intended tasks.

6.2.1 Scientific Contribution

The proposed MADE-Framework is promised to provides a mechanism for interoperability between multiple eHRs. The framework is intended to contribute to the current efforts to mitigate interoperability challenges in health sector systems. It also extends the interoperability capability to mobile apps. It supports mobile apps development process by providing procedures to connect into data exchange components. The two published paper provides scientific contribution to the body of knowledge.

6.2.2 Practical Contribution

Practically, MADE-Framework provides support to mobile application development process. It gives a platform that allows fast availability of health data exchange mechanism where a mobile app developer will not invest much energy on creating mechanisms for information exchange. The framework will help health workers and practitioners to easily interchange data between different health systems on the fulfillment of their daily responsibilities.

6.3 Recommendation and Further Research

It is recommended that OpenHIM and mediator for DEC should be implemented to fully realize the benefits of the MADE-Framework. The improvement provided by this study, did not achieve complete implementation of the framework due to limited research time and other resources. Therefore, further research is recommended that should focus on the fully implementation, testing and evaluation of the framework. The implemented framework should be tested and evaluated in real life environment to realize the potential of the DEC introduced in this study. The framework in its full implementation will contribute to the current efforts to mitigate the existing interoperability challenges in multiple eHRs and the mobile apps development.

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APPENDICES

Appendix 1: Fetch and transfer patient function for data exchange process.

```
<?php

class Patients

{       function Fetchandtransferpatient($pid)

        {       require_once("conn_care.php");

                $sql="select    pid, date_reg, name_first, name_2, name_3, name_middle,
                                name_last, name_maiden, name_others, date_birth,
                                blood_group, addr_str, addr_str_nr, addr_zip, addr_citytown_nr,
                                addr_is_valid, citizenship, phone_1_code, phone_1_nr,
                                phone_2_code, phone_2_nr, cellphone_1_nr, cellphone_2_nr,
                                fax, email, civil_status, sex, title, photo, photo_filename,
                                ethnic_orig, org_id, sss_nr, nat_id_nr, religion, mother_pid,
                                father_pid, contact_person, contact_pid, contact_relation,
                                death_date, death_encounter_nr, death_cause,
                                death_cause_code, date_update, status, history, modify_id,
                                modify_time, create_id, create_time, relative_name_first,
                                relative_name_last, relative_phone

                from

                        care_person where pid='$pid'";

                                try

                                {       $res=mysql_query($sql);

                                        if ($row=mysql_fetch_array($res))

                                        {       require_once("conn_openmrs.php");

                                                $sql="insert into care_persontemp

                                                        (pid,  date_reg, name_first, name_2,
                                                        name_3, name_middle, name_last,
                                                        name_maiden, name_others, date_birth,
                                                        blood_group, addr_str, addr_str_nr,
                                                        addr_zip, addr_citytown_nr,
                                                        addr_is_valid, citizenship, phone_1_code,
                                                        phone_1_nr, phone_2_code, phone_2_nr,
                                                        cellphone_1_nr, cellphone_2_nr, fax,
                                                        email, civil_status, sex, title, photo,
```

```
photo_filename, ethnic_orig, org_id,
sss_nr, nat_id_nr, religion, mother_pid,
father_pid, contact_person, contact_pid,
contact_relation, death_date,
death_encounter_nr, death_cause,
death_cause_code, date_update, status,
history, modify_id, modify_time,
create_id, create_time,
relative_name_first, relative_name_last,
relative_phone)

values

('$row[0]', '$row[1]', '$row[2]', '$row[3]',
'$row[4]', '$row[5]', '$row[6]', '$row[7]',
'$row[8]', '$row[9]', '$row[10]', '$row[11]',
'$row[12]', '$row[13]', '$row[14]',
'$row[15]', '$row[16]', '$row[17]',
'$row[18]', '$row[19]', '$row[20]',
'$row[21]', '$row[22]', '$row[23]',
'$row[24]', '$row[25]', '$row[26]',
'$row[27]', '$row[28]', '$row[29]',
'$row[30]', '$row[31]', '$row[32]',
'$row[33]', '$row[34]', '$row[35]',
'$row[36]', '$row[37]', '$row[38]',
'$row[39]', '$row[40]', '$row[41]',
'$row[42]', '$row[43]', '$row[44]',
'$row[45]', '$row[46]', '$row[47]',
'$row[48]', '$row[49]', '$row[50]',
'$row[51]', '$row[52]', '$row[53]'

)";

mysql_query($sql);

echo "<span style='color:green;font-size:12px;margin-left:40px'>Patient transferred!</span>";

echo "<span style='color:green;font-size:12px;margin-left:40px'><a href='index.html'>QUIT</a> </span>";

} }

catch (Exception $ex){ echo $ex->getMessage();

} } } ?>
```

Appendix 2: Login form implementation

```
<?php
if (isset($_REQUEST))
{  require_once("conn_mid.php");
  $uname=mysql_real_escape_string($_REQUEST['uname']);
  $pwd=mysql_real_escape_string($_REQUEST['pwd']);
  //If succeded
  $sql="select * from tbl_users where uname='$uname' and pwd='$pwd'";
  $res=mysql_query($sql);
   if ($res) {       if ($row=mysql_fetch_array($res))
            {  //require_once("select.php")
                        require_once("conn_care.php");
                        require_once("objpatients.php");
                        $patients=new Patients();
                        $patients->LoadPatientsList('');
            }  else {       echo  SayThis("Umekosea!");
            }  }  else {    echo  SayThis("Umekosea!");
 }       }
         function SayThis($sms)
{        $say='<form id="login" method="post" action="javascript:login()">
         <table border="0">
          <tr>    <td align="right">User Name :  </td>
                  <td><input type="text" id="uname" required></td></tr>
         <tr>     <td align="right">Password :  </td><td><input type="password"
                  id="pwd" required></td></tr>
         <tr>     <td align="right"></td>
                  <td><input type="submit" id="log" value="Login"/> <input
                  type="reset" id="res" value="Reset"/></td></tr>
         <tr>     <td align="right" colspan="2" align="left"><span style="color:red;text-
```

```
        align:left">'.$sms.'</span></td></tr>
    </table></form>'; return $say;
}
?>
```

Appendix 3: Research Output Paper 1

Bibiograph

F. H. Chali, Z. O. Yonah, and K. Kalegele, "Critical Issues and Challenges in Developing Mobile-Based Health Systems: Case of Tanzania," IJCSIS, vol. 15, no. 3, 2017.

Critical Issues and Challenges in Developing Mobile-Based Health Systems: Case of Tanzania

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Abstract - *Utilization of mobile devices worldwide is increasing every day. This has created an increasing demand for mobile apps, the development of which is not seamlessly without challenges. We conducted a research survey to identify and confirm the known challenges and issues that are faced by mobile app developers in their development work in developing countries particularly in Tanzania. This survey was done in three regions of Tanzania: Dar es Salaam, Dodoma and Arusha; because most of the mobile apps developers are located in these regions and eHealth information systems were used as a case for this purpose. Methodology used was literature, interview, questionnaire, and observation. This paper presents an overview of the identified challenges and issues facing mobile app developers and the proposed data exchange solution. These findings have justified our ongoing research on interoperability of multiple databases through a single mobile application.*

Keywords-component; **Multiple Databases; Data Exchange; eHealth Systems; mHealth; mobile app.**

I. INTRODUCTION

One survey reports that about 40% of 7 billion people in the world are using internet [1]. Another study recently reported that, 80% among the internet users globally, own smart phones and 47% of them own Tablets [2]. Due to the increasing numbers of utilization of mobile devices, the world counts more than 170 million mobile apps in use by 2015 [3].

Said it differently, the potential to utilize mobile phones in developing countries is high. In 2012, about 70% of the global mobile subscribers out of more than 5 billion, belonged to low and mid income communities [4]. Banking and healthcare sectors are leading the way on harnessing this available potential in developing countries.

In mobile applications (mobile apps) development, challenges such as testing and supporting, security, device proliferation, development approach, etc. are some of the known challenges that continue to face apps development works [5], [6] and [7].

To confirm if these challenges are real, a survey was conducted in the health sector environment as a case specifically to identify and confirm the known issues and challenges in mobile apps development process focusing on connecting to medical record systems implemented within an environment having integrated multiple databases. The goal is to propose a data exchange architecture that demonstrates the need for connection/integration between a single mobile app and multiple heterogeneous databases. Section II reviews the status of eHealth and mHealth systems in developing countries. Methodology used in the study is explained in Section III; and review of major issues and challenges that are generally facing mobile app development process worldwide is presented in Section IV. Section V contains survey results and the proposed data exchange component (DEC) architecture between single mobile app and multiple heterogeneous databases is introduced in Section VI. General discussion of the findings from the study is presented in Section VII. Finally, Section VIII carries the conclusion and suggestions for further works.

II. EHEALTH AND MHEALTH SYSTEMS IN DEVELOPING COUNTRIES

eHealth systems have revealed a greater potential to reach large population for quality service provisions. It would easily reach and serve the population of 55% of the developing countries where the availability of enough health facilities and health care services is too low [8]. WHO define e-health as the transfer of health resources and health-care by electronic means [9]. In [10], It is described that, e-health is the application of Internet and other related technologies in the healthcare industry to improve access, efficiency, effectiveness, and quality of clinical and business processes utilized by healthcare organizations, practitioners, patients, and consumers in an effort to improve the health status of patients. It is also specifically described by Eysenbach, as an emerging field in the intersection of medical informatics, public health and business, referring to health services and information delivered or enhanced through the Internet and related technologies [11]. There are numerous definitions of eHealth from different dimensions worldwide; others have tried to extend the definition to any application of electronic means into the healthcare services.

Delivery of eHealth by use of mobile app services results into mobile health or mHealth. It is the utilization of mobile apps for the purpose of enhancing provision of health services. In [12], mHealth is described as the use of mobile phones for the purpose of improving the quality of care and efficiency of health services. Further Characteristics of eHealth and mHealth systems are described in the following subsections.

A. **Infrastructure and Benefits of eHealth and mHealth in Developing Countries**

Commission for Science and Technology Tanzania – Costech, 2014-2017. (sponsor)

Typically, Infrastructure that supports eHealth system architecture include the following [13]:

a) Internet
b) Extranet
c) Intranet
d) Core Data Systems
e) E-Mail
f) Telecommunications
g) Hardware

Mobile health can provide relevant benefits to health workers, health facilities, healthcare services etc. Modi, identifies the following benefits [12]:-

a) Real time receipt of health-care information
b) Timely addresses health issues
c) Easy to track the prevalence of diseases and its rate globally
d) Helps healthcare officials to be more proactive on addressing health issues rather than being reactive.
e) Feasibly addresses gaps in health-care in remote areas.

f) Provides Health Education Awareness.
g) Raises treatment support and medication compliance.
h) Improves the performance of healthcare workers.
i) Supports diseases surveillance.

B. Status of eHealth in Some African Countries

Table I summarizes the status of eHealth in some African countries. The summary shows the evidence of activity, planning or implementation of eHealth in those countries in terms of national ownership, foundation (Info-structure; the basic physical and organizational structures and Infrastructure) and also health process domain component where it describes the availability of already running eHealth systems in a particular country.

TABLE I. SUMMARY OF THE STATUS OF EHEALTH IN SELECTED AFRICAN COUNTRIES. (SOURCE: [SUMMARY OF THE STATUS OF EHEALTH IN SELECTED AFRICAN COUNTRIES. (**SOURCE:** [14] **-** [15])

SN	Country	National Ownership	Foundation		Health Process Domain Component
			Info-structure	*Infrastructure*	
1	Angola	**EvP&I**	**EvP**	**NoEv**	**EvI**
2	Botswana	**SEvP**	**EvP&I**	**EvI**	**EvI**
3	Ethiopia	**EvNs**	**EvP**	**EvNs**	**EvI**
4	Ghana	**SEvP&I**	**SEvP&I**	**EvP**	**EvI**
5	Kenya	**SEvNs**	**EvP**	**EvP**	**EvI**.
6	Nigeria	**EvP**.	**LEvI**.	**NoEv**	**LEvI**
7	Tanzania	**SEvNs**	**EvP&I**	**EvP&I**	**EvI**.
8	Uganda	**SEvNs**	**LEvI**.	**SEvP&I**	**EvI**.
9	Zambia	**LEvP**	**NoEv**.	**EvI**	**EvI**
10	Zimbabwe	**EvNs**	**EvP**	**EvP&I**	**EvI**

Key:

- Evidence of = Ev
- Strong Evidence of = SEV
- Little Evidence of = LEV
- Planning = P
- Implementation = I
- National/Government Support = NS
- No Evidence of Planning or Implementation = NoEV

C. eHealth and mHealth Systems in Tanzania; its Application

1. eHealth Systems

The application of computer systems in the health sector in Tanzania started in the 1990s. Deployment of information technology has brought revolution of the uses of computer applications from simple formats to complex systems.

However, eHealth is not well and completely implemented in developing countries; it has some challenges that technically need special attention to address. In their survey, Busagala and Kawono established challenges that are facing e-Health systems in Tanzania. The challenges include poor infrastructure for supporting health-care services, insufficient budget for ICT, unreliable electricity supply and lack of ICT skills for health-care workers [16].

2. **mHealth Systems**

In Tanzania more than 31 mHealth applications are currently providing health services countrywide [17]. Among them, the most deployed applications are for data collection and reporting.

TABLE I. MHEALTH APPLICATIONS ADDRESSED IN TANZANIA (**SOURCE**: [17])

Application	Total Number
Data collection and reporting	**18**
Client education and behaviour change communication	**15**
Electronic decision support	**14**
Provider work planning and scheduling	**8**
Registries and vital events tracking	**7**
Electronic health records	**7**
Provider training and education	**7**
Provider to provider communication user groups, consultation	**6**
Service use supply chain management	**5**
Financial transactions and incentives	**4**
Sensors and point of case diagnostics (and Monitoring)	**3**
Human resource management	**3**
Tele consultation	**3**

Currently there are 18 such applications, approximated to be 58% of all mHealth applications in Tanzania. Table II lists other applications that are also deployed in Tanzania with their total number.

Some of the currently available mHealth projects in the country are briefly described in the following paragraphs.

- **SMS for Life**
  It is an innovative mHealth project piloted in Tanzania under public-private partnership. It helps to reliably support availability of Malaria medication using mobile phone services. The project is led by Novartis and supported by several partners, each bringing specific skills [18].

- **Birth Registration by Mobile Phone**
  This is a countrywide mHealth platform in Tanzania that gives parents ability to register their children's births by using mobile phones. It allows a health worker to send birth registration information such as baby's name, sex, date of birth and family details by phone to a central database and finally a birth certificate is issued free of charge in a few days [19].

- **m4RH**

Known as Mobile for Reproductive Health (m4RH), is a low cost innovative system running in Tanzania, Kenya and Rwanda providing information on family planning. It is accessible from every mobile phone through short message service (SMS) or "text messaging" [20].

From the foregoing, it is hereby acknowledged that, mHealth can have a profound positive impact in health sector. It shows to have the ability to improve delivery of healthcare services even in remote areas and can free other resources for developing the country economy.

III. METHODOLOGY

A. **Literature Review**

In depth literature review was conducted to enhance more understanding of issues and challenges on mobile apps development of e-Health systems from multiple database integration point of view. More information was collected from previous researches to gather a wide knowledge about these issues and challenges, as presented in Section II.

B. **Sampling Technique and Data Collection**

Data collection (including questionnaire, interview and observation) was done in three regions: Dodoma, Arusha and Dar es Salaam. Data were collected in Dodoma from the HPSS government project based in Dodoma [21]. In Dar es Salaam and Arusha data were collected from 78 programmers in three mobile development companies in total.

As a stimulus, mobile app utilization in health sector brings about the question concerning the technical aspect on the development of mobile apps for health care delivery. The intention is to examine issues and challenges facing mobile apps development in their integration with medical records. The following section describes major issues and challenges that are facing mobile app development process.

IV. MAJOR ISSUES AND CHALLENGES THAT ARE GENERALLY FACING MOBILE APP DEVELOPMENT PROCESS

Identified from the literature review, is that there are a number of issues and challenges facing mobile application development processes worldwide. The identified issues and challenges are concerned with design, security, user interface, networking, development skills, context etc. Among all these, security issues, user experiences, vendor and device fragmentation are ranked to be the major ones [6]. These are further described below.

A. **Security Issues**

Security in mobile app development is speedily becoming a major concern. The primary concerns are: data upload and download wirelessly using insecure hotspots and from potentially insecure locations and the sizes of devices make them easily misplace-able. The degree level of security in mobile development in enterprises or organization also depends on the nature of a business. Bank application for instance, with bill payment feature needs more security measures than an information data application [6].

B. **The User Experience**

Mobile user experience could be described as the perception an end user has on a mobile product or service [22]. Mobile devices are characterized by the smaller display and different styles of user interactions. These characteristics have an impact on interaction design for mobile apps. The user experience has a strong influence on application development. The developer has to consider user demands such as user interface, running speed of the application, etc in order for the end product to be well accepted. During development, there are some user experience factors that influence the process of development; these factors are such as widgets, touch, whether through stick or direct by finger, physical motion, keyboard (physical and virtual) for designing user interface, and the context dependencies, such as proximity to other mobile devices and physical location [23]. Device characteristics such as size and its version are having a greater impact on the design of the application. Developers need to consider on how to build up an application that could highly meet user's expectations. The user experience could help make an application more successful by maximizing acceptance and usage.

C. **Vendor and Device Fragmentation**

Existence of multiple mobile application platforms such as iOS, Android, Windows Phone etc., is one of the big challenge in the development of mobile apps [5], [7], [24]. These mobile Platforms, rather than Unification, instead they are heading towards fragmentation [5]. Fragmentation in mobile apps could be grouped into two categories:-

1) Fragmentation across platforms (Vendors/Platforms Fragmentation), this includes a variety of mobile OS such as Android, iOS, BlackBerry, Windows Phone etc.

2) Fragmentation within the same platform (Device Fragmentation) This includes different versions of the same platform [7].

Each platform requires different and sometimes separate skills to use in order to develop and deploy an application successfully. This poses as a challenge during development and force developers to base their developing skills mostly on one platform.

V. SURVEY RESULTS

This section presents the results of the survey that, in general, confirm issues and challenges in mobile application development to achieve connection/integration with multiple heterogeneous databases remotely; particularly within Tanzania as a case study.

The survey was conducted in three different regions in Tanzania. These regions are Dodoma, Dar es Salaam and Arusha. A total number of 78 mobile app developers in two regions, Dar es Salaam and Arusha were contacted to respond to the data collection tools (interview and questionnaire). Statistics revealed that country wide there are approximately 541 businesses whose services are IT related services such as Network Installation, hardware and software maintenance, IT equipment supplies, IT consultancy, web hosting and mobile app development. Among them, nearly 70% reside in Dar es Salaam and Arusha (Fig. 1).

Approximately 70 businesses out of 541 (about 12.9%) are doing mobile apps development (see Fig. 2). Since a large proportion of these businesses are small and medium enterprises (SMEs), it has been estimated that each has at least 3 developers on average. This accounts for 210 developers countrywide; the number does not include freelancer developers scattered in big towns and cities in the country who are mostly fresh university and college graduates. Table 3 shows a summary of results that came out of the survey.

A. **Platform Consideration and Device Fragmentation**

Mobile applications run in mobile operating system (mobile OS) platforms such as Android, iOS, Windows Phone, Black Berry etc. Developers mentioned that they normally choose a particular type of platform when they start the development of the application. This is very important to them since developer's choice is based on own/individual competencies. About 14% of them mentioned this.

Device fragmentation is one of the biggest challenges facing the Tanzanian developers today. Developers, about 27%, show this as their challenge. Because Android has the biggest share in sub-Saharan countries, which include Tanzania [17], and most of the developers are developing mobile apps based on Android, 85% of them. The presence of different versions of Android OS creates difficulty in developing a multiplatform application. Vendor/Platform fragmentation challenge is not faced by most of developers in Tanzania since most of them are working on Android rather than other platforms,

Figure 4 shows the details.

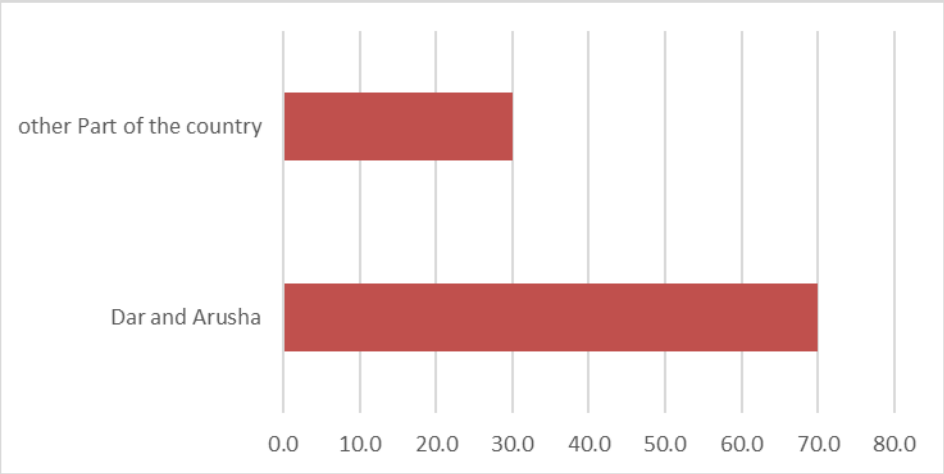

Figure 1. Availability of IT related businesses in Tanzania

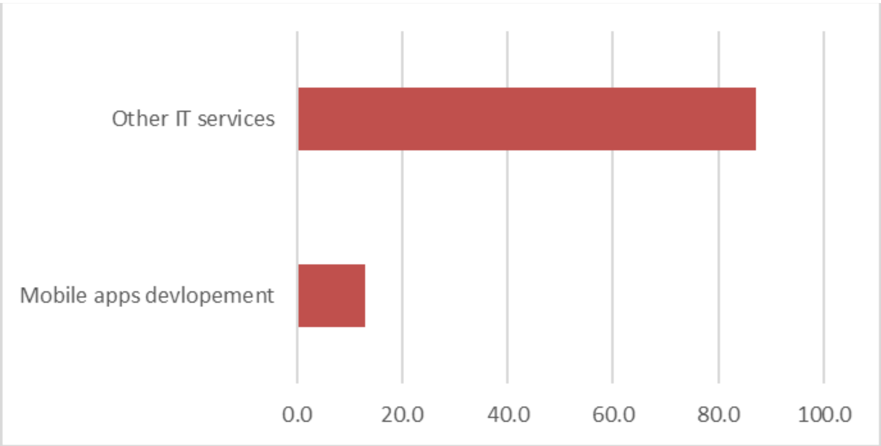

Figure 2: Distribution of IT related service businesses in Tanzania.

B.

User Experience and Mobile Device Capabilities

User experience was also mentioned by developers as one of the issues and challenges to the mobile app development process. From the survey, 24% of developers mentioned this. They utilize different application design tools and techniques to build up an app. They commented that they sketch the UI, database model, and User models etc as their techniques of designing good and interactive mobile apps. Others said they normally visit design samples from websites such as materialup, dribbble, material pallet etc. to get a clue on the current graphic, web designing etc. It is difficult to understand the users taste and experience on the mobile applications.

They usually use adobe Photoshop for User Interface (UI) design, UML tools such as use case, activity, state diagrams etc as the tools for design. For simplicity and rapidness, they use Java programming language since this language is used by a wider community of mobile developers.

Mobile phone capabilities in terms of size, capacity, speed etc, are also challenges mentioned on the development of mobile apps. Developers also confirmed that they consider capability of mobile device such as limited power and size during development.

TABLE II. ISSUES AND CHALLENGES FACING MOBILE APPS DEVELOPMENT PROCESS WHEN CONNECTING THE APP WITH REMOTE DATABASE(S).

S/N	THEME/ CATEGORY	Percentage (%)
1	Database adapters and incompatibility	2.6
2	Handling BLOB objects/data	6.4
3	Multiple databases integration	20.5
4	Platform consideration	14.1
5	User Experience and Mobile Device Capabilities	24.4
6	Device fragmentation	26.9
7	Vendor/Platform fragmentation	1.3
8	Other Challenges	3.8
Total		**100**

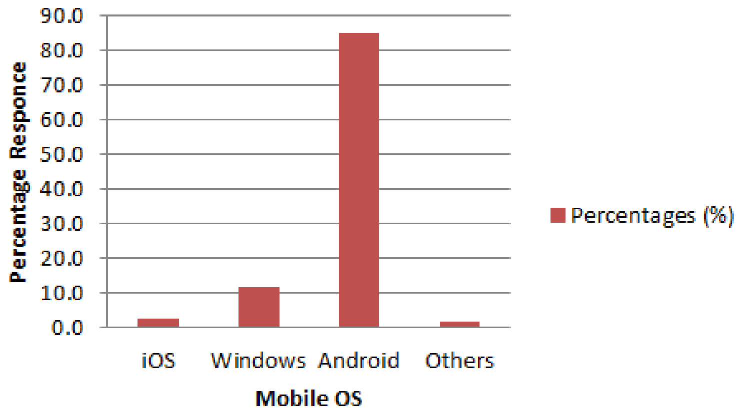

Figure 3: Mobile OS choices of mobile app developers in Tanzania.

C. **Multiple Heterogeneous Databases Integration**

Databases are available in different types and technologies eg. Oracle, MySQL, SQL Server, etc. For the developer to link with only one among these external databases at a time with mobile app is very possible and in normal practice is always done. For instance when a developer intends to connect the app with MySQL database, it is necessary to configure HTTP POST library for the connection to be successful. When the intention is to utilize SQL server database, then the developer must download jTDS (JarFile, JDBC) Libraries, configure it and then connection will be established.

However, a challenge arises when the need is to link two or more databases of both the same or different technologies, with a single mobile app (at the same time) so as they can share information all together. Here, heterogeneity of the databases (Oracle, MySQL, SQL Server etc) was pointed out to be a big challenge. 21% among the developers said this.

The following sub-section presents current practices taken by mobile app developers when connecting single mobile app with multiple database systems.

D. **Current Practice on the Connection Between Single Mobile App to Multiple Heterogeneous Databases**

From the results of the conducted survey, it is confirmed that, there is an existing challenge in mobile application development on integrating a single mobile app with multiple databases (multiple database integration). Also, It was observed that, mobile app developers are comfortably and easily connecting mobile apps with remote databases in one to one connection fashion. It was further observed that, currently, developers connect a mobile app separately when they have a need to connect it to multiple databases. Figure 4 illustrates the connection of single mobile application to two different databases of two different technologies, MySQL and SQL Server. A developer will not be able to connect it (at the same time) in both databases with a single connection. In this case, two different connections (two pipelines for data flow) using two different components must be established in order to meet this demand.

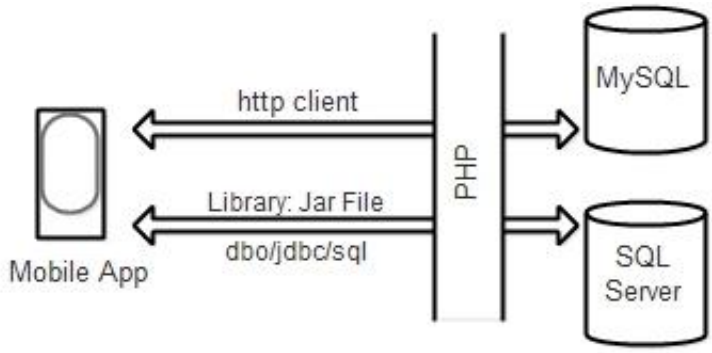

Figure 4: Connection between mobile app and two heterogeneous database systems

HTTP client, a client side HTTP transport library that provides basic functions for accessing resource via HTTP protocol [25], is used in the connection between mobile apps with MySQL database. Jar file library [26] is used in the connection between mobile application with SQL server. Other libraries that serve the purpose for this connection are such as DBO (database Object) and JDBC (Java Database connector) [27]. All these connections regardless of technologies connect to each database by utilizing PHP functions to enable their connections.

Problems in mobile apps development stem from versioning, Incompatibility and Open source [28]. The focus of the reported research work is to build up a mechanism where connectivity between these components (mobile apps and multiple databases) will become more convenient and seamless regardless of the technology the database is using. The developer should be able to create mobile app on the client side using same approach without being concerned about the kind of database is connecting to. Figure 5 illustrates concept of desired seamless data exchange.

E. **Existing Data Exchange Approaches for Single Mobile App - Multiple Heterogeneous Databases/Information Systems**

There is much advancement in programming that currently provide services to support development of mobile apps working with remote databases/information systems. These approaches do not deal with legacy/existing databases rather they provide space to create or connect to the newly created databases [29], [30], and [31]. Firebase is among these approaches [32].

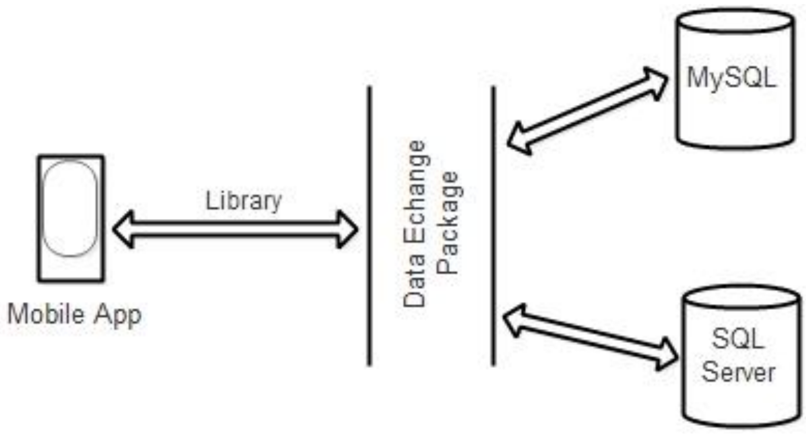

Figure 5: Architecture model for data exchange between single mobile app and multiple databases

Some of these development efforts are such as, the REST API (Application Programming Interface), a lightweight and scalable API to support mobile development, which is extremely easy to build, integrate, test, extend and maintain [29]. The RapidSMS for extending system servers to sms applications [30]. Another one is the HIE API, which resides at the mid of Health Information Mediator (HIM) in the Rwandan NHIS [31]. Firebase, a cloud based database service that allows mobile app developer to store and sync data across multiple clients. It provides client libraries that enable integration with android, IOS etc. Data sync across all clients in real time using NoSQL database [35]; [32].

In [36] authors report on a cross-platform enterprise mobile framework implemented to provide development environment for mobile applications at Intel enterprises. Other frameworks such as MADP and MEAP are designed to provide support to achieve the same goal [36]. These efforts are already taking places worldwide.

VI. PROPOSED DATA EXCHANGE COMPONENT (DEC) ARCHITECTURE BETWEEN MOBILE APP AND MULTIPLE HETEROGENEOUS DATABASES

As alluded to in the previous sections, multiple database integration is one of the challenges facing mobile app development such that mobile app developers are not able to connect single mobile app with multiple databases. As a viable approach, it is proposed to build up an eHR-DE/ data exchange component (DEC) that will provide a connection interface to mobile application on one side and on the other side to multiple databases. The DEC provides a solution toward multiple system interoperability and also provides an interface to the already developed mobile app to connect to the already connected multiple databases.

Three basic interoperability dimensions need to be considered when developing interoperability solutions for

different systems, [33] and [34]. The three dimensions are; barriers (conceptual, technological, organization), levels (legal, organizational, semantic, technical) and concerns (data, process, service, business).
From these interoperability dimensions, the reported work addresses the technological barrier by establishing information sharing between heterogeneous electronic health records and single mobile app through data exchange framework. In the interoperability levels, the focus is on the technical aspects. In the interoperability concerns dimension, information is shared among different databases i.e data interoperability as illustrated in Fig. 6.
In the design architecture (DEC) shown in Fig. 7, a data exchange package/component is introduced to connect multiple heterogeneous databases to a single mobile app.

Barriers / **Concerns**	CONCEPTUAL	TECHNOLOGICAL	ORGANISATIONAL
BUSINESS			
PROCESS			
SERVICE			
DATA		eHR-DE	
* **Level**: Technical Interoperability Level.			

Figure 6: EHealth data exchange (DEC) deal with technological barrier, data interoperability concern and technical interoperability level.

Utilization of developed DEC will be such that: a mobile app developer will download the DEC then connect a developed mobile app into it through an interface provided by the component. The component contains PHP and PHP/ODBC connectivity technologies that provide connection interface to the developed mobile application. The mobile app is connected to the DEC through http/url connect. The provided interface on the other side also has provision to connect multiple databases.

VII. DISCUSSION

Interoperability is one of the challenges existing in the healthcare domain worldwide. "Interoperability is the ability of different ICT systems and software applications to communicate, to exchange data accurately, effectively, and consistently and to use the information that has been exchanged" [37]. In [38], it is reported that, lack of coordination at all levels of systems development contribute about 62.5% on the source/causes of interoperability problem among eHealth systems in Tanzania. Another source is the common use (in hospitals and other healthcare facilities) of open source systems that were not specifically designed to meet multiple databases interoperability context and environment and were not created with integration focus in mind.
Achieving interoperability from mobile developers' side is also an existing challenge. The process of integrating two or more health information systems through single mobile app is not easily achievable. Multiple database integration through mobile app is one of the ways to achieve interoperability of existing eHealth systems. This is now confirmed to be one the challenges facing mobile app developers.

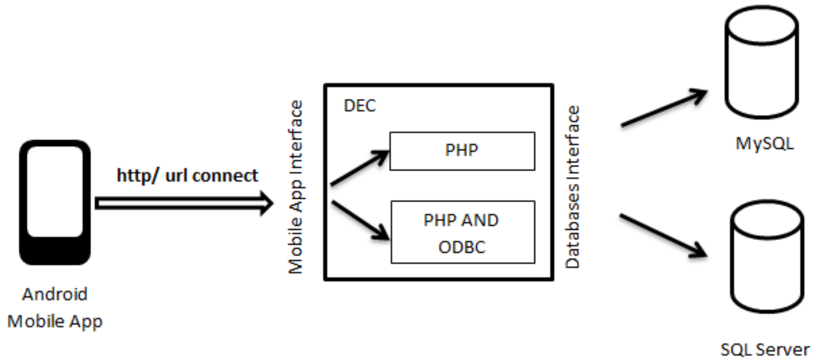

Figure 7: Data exchange (DEC) architecture connecting single mobile app with multiple databases.

The main focus of the reported ongoing work is to establish/enable interoperability of existing fragmented eHealth systems through mobile apps. In [39], a lists of solutions is provided that can be adapted to achieve complete interoperability in healthcare. Connection of legacy (existing) systems to healthcare network is among the solutions listed. This is in line with the hypothesis that “mobile app development could support interoperability of existing/legacy multiple eHealth systems”.
The architectural model presented in Section V provides a possibility toward achieving interoperability in eHealth systems. The DEC architecture proposed in Section VI shows how the integration between single mobile app and multiple databases could be evidently achieved.
Reported survey results show that, health sector in Tanzania is characterized by fragmented electronic health information systems (eHealth Systems) with significant barriers to the effective sharing of information between healthcare participants [40]. The eHealth strategic plan of 2013-2018, describes that, infrastructure building blocks is one of the strategic objective for eHealth development. The report provides a reason to continue researching on the kind of required infrastructure to enable electronic sharing of health information across the Tanzanian health sector. The strategic plan shows the need and importance of implementing health information exchange that leverages mobile technologies [40].

VIII. CONCLUSION AND FURTHER WORKS

In this paper, we have identified and confirmed issues and challenges facing mobile application developers in developing countries focusing on connecting multiple eHealth systems to a single mobile application. Benefits and eHealth infrastructure in developing countries have been reviewed. A DEC architecture for solving the interoperability problem between a single mobile app and multiple databases has been presented. Also discussed is the interoperability challenge among eHealth systems. It is suggested that multiple database integration through single mobile app is a possible solution towards mitigating the interoperability challenge. Some of the identified and confirmed issues and challenges in mobile app development in Tanzania are; Platform Consideration and Device Fragmentation, User Experience and Mobile Device Capabilities, and Multiple databases integration. These results are subsets of issues and challenges that are facing mobile developers in developing countries particularly in Tanzania. They serve to justify the need for wider efforts to be undertaken by mobile app developers and other stakeholders especially government to provide better environments to the mobile apps development processes in Tanzania.

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Appendix 4: Research Output Paper 2

This paper is accepted for publishing in the International Journal of Advanced Computer Research (IJACR) (http://accentsjournals.org/journals.php?journalsId=103 or http://theaccents.org/).

Data Exchange Architecture for Development of Mobile Applications that Support eHealth Systems Interoperability; A Case of Tanzania

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Abstract- *Electronic Health (eHealth) especial in the form of electronic health records (eHRs) has proved to greatly improve health care services both in urban and rural or remote areas. However, many of the systems are fragmented and work independently. Therefore, apart from their benefits, these systems are stand alone and as such they face some operational challenges, one of which is interoperability among the eHRs. Early efforts to interoperate eHealth Systems, suggest that a single mobile application that can access multiple integrated eHRs is among the viable solutions on the way to eHRs interoperability. The design system offers a mechanism to integrate a single mobile application with multiple eHRs while mitigating the interoperability problem. The design work builds on survey previously done to collect preliminary requirements of the data exchange system. System design techniques were used to design this system. In this paper, an architectural system design of an eHealth Data Exchange that can mitigate interoperability challenge is presented.*

Keywords: ***Multiple Databases, Data Exchange, eHealth Records (eHRs), mHealth, Mobile App.***

I. INTRODUCTION

The global health sector today is enjoying benefits enabled by ICT facilities especially eHR. Many countries globally have reported to continue installing eHRs and some of them creating environment for the implementation. About 70% of the countries in the global today have national policy for eHealth or having strategies to implement such systems. The eHRs technology has proved to improve health care services greatly both in urban and rural or remote areas [1]; [2]. However, most of these systems are not interconnected. They are fragmented and work independently. They do not exchange data and information among themselves, that is, they are not interoperable. Healthcare interoperability is the capability of health information systems to work together within and across organization boundaries [3]. Unfortunately, achieving interoperability of healthcare systems remain a daunting challenge [4].

Most of the eHRs, specifically in developing countries, face the challenge of system fragmentation (i.e systems are not interoperable) due to the fact that individual system deployment by multiple system contractors and organization [5], [6]. As a case study, Tanzania is among the countries facing both the fragmentation of eHRs and the interoperability challenges. Further, the government of Tanzania through Ministry of Health, Community Development, Gender, Elderly and Children has identified eHRs interoperability as one of the challenges that are facing existing eHRs in Tanzania [7]. Several benefits accompany the interoperability of eHRs. In [8], Gomez *et. al.*, list two general benefits of interoperability of eHRs as: (a) reduce the cost of healthcare, and (b) contribute into more effective and efficient patient care. Hospitals and healthcare facilities in Tanzania are mostly using Open source healthcare software. Examples of these systems/software are OpenMRS, OpenLMIS, Care2x, LIS, TIVA and CTC2. Unfortunately, these software are not interoperable [9].

In expanded form, interoperability is the ability of different ICT systems and Software applications to communicate, to exchange data accurately, effectively and consistently and to use the information that has been exchanged [10]. Therefore, interoperability will only be achieved if the two parties exchanging information, understand well the meaning of information being exchanged and they are able to use them properly [11]. Based on this understanding, interoperability of eHRs is confirmed as the fundamental prerequisite for individual health care improvement [12].

A. Why eHealth Interoperability Exist?

As stated earlier, eHealth interoperability is an enabler towards achieving a better healthcare. Apart from its importance, interoperability is still among the challenges facing healthcare delivery in the world today. But how does this challenge emerge? Some of the causes of eHealth interoperability identified by different researchers in the healthcare sector include the following:

i. Lack of an architectural guide/framework towards development of eHRs [3][7].
ii. Lack of standard procedures to guide the lifecycle of eHRs. [7][9][13].
iii. Poor collaboration among private companies or vendors in eHRs development [9], and
iv. Different data structures among the developed eHRs [3].

B. Benefits of eHealth Interoperability

So many advantages of interoperability environment on eHRs have been identified by several researchers, some of which include:

i. Reduces the cost of healthcare.
ii. Reduces the incidence of medical errors [14].
iii. Contributes to more effective and efficient patient care.
iv. Provides timely access to the healthcare information and enable informed decision and personalized care [4].
v. Provides improved communication of healthcare by supporting continuity care [15].

The general objective of this work is to support on going efforts to alleviate interoperability problem of eHRs by designing and implementing data exchange mechanism that leverages mobile devices deployed in healthcare. The main design principle is that of connecting a mobile application (mobile app) with multiple eHRs. The data exchange resides between multiple eHRs and single mobile app where connected eHRs can exchange information. The connected mobile app can access and transfer information to and fro eHRs. This paper presents the proposed a design architecture for a Data Exchange Component (DEC), as a way towards realizing interoperability of eHRs. The philosophy around the proposed DEC is that, it is designed to act as a central application/component that can provide a mechanism to make two or more eHRs to interoperate; i.e to exchange data and information, in order to improve healthcare delivery and provide access to mobile apps that are used to access information to/fro the interoperable systems.

The rest of the paper is arranged as follows: Section II provides materials and methods used to obtain results presented in this paper. Section III reports on results and alternative set-ups that could be adopted for DEC deployment and the other connected systems. Section IV, gives the proposed architectural design of the DEC while in section V is DEC implementation and testing. Discussion is presented in section VI and conclusions are in Section VII.

II. MATERIALS AND METHODS

In [16] a survey method was used to identify challenges facing mobile app developers during the process of interconnecting multiple eHRs as a way toward alleviating the interoperability problem. Data were collected and analyzed through questionnaires, interviews and observations. The survey was conducted in Dar – es – Salaam, Dodoma and Arusha regions in Tanzania. Results of this survey revealed that, multiple database integration, user experience and mobile device capabilities, device fragmentation and platform considerations are some of the issues and challenges facing mobile app developers when dealing with the interoperability problem. The results of this study were considered as a basis for the design of the DEC. Details of the DEC architectural design are presented in section IV.

III. RESULTS: ALTERNATIVE SET-UPs FOR DEC

This section presents three possible (and considered viable) set-ups showing alternatives on how the DEC and the participating eHRs could be installed. In general, the DEC is designed to run within a web server, such that both eHRs and DEC reside within servers. The set-ups are as follows:

A. Set-up I: Use of Three Servers

In Figure 1, it is proposed to utilize three separate servers where DEC is installed in a separate server. The two participating eHRs will reside separately in other two servers. A typical example in a real life situation is where the two eHRs represent Health Information Systems (HIS) of two different hospitals. When the hospitals agree to exchange data generated and stored in their particular HISs, they will utilize the proposed central DEC to fulfill their goal. HIS from each hospital will remain where they reside i.e within a particular hospital server, and then an additional server would be added to install DEC.

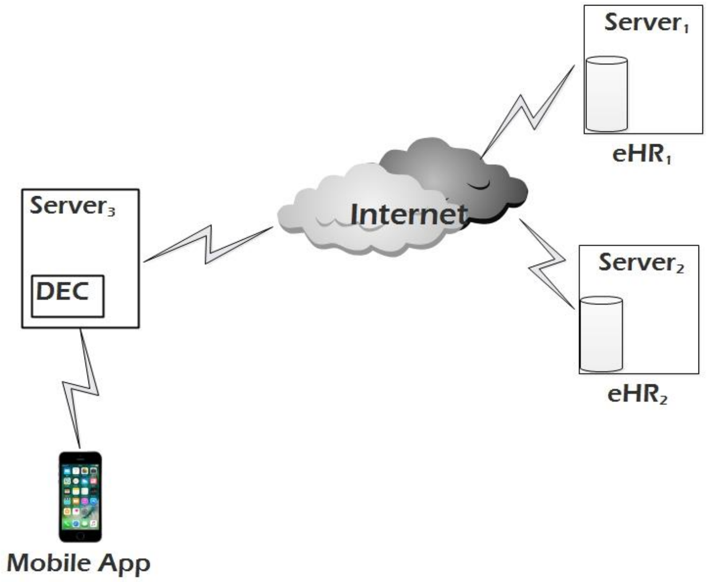

Figure 1: Set-up I - Three Server Set-up for the DEC and participating eHRs.

B. Set-up II: Use of Two Servers

The second considered set-up is presented in Figure 2, which shows utilization of only two different/separate servers. This architecture requires DEC and one of the eHR to be installed in a single server and the second eHR installed in the second server. This second architecture allows use of only two separate servers managed by two hospitals, such that one of the hospitals is a host of DEC.

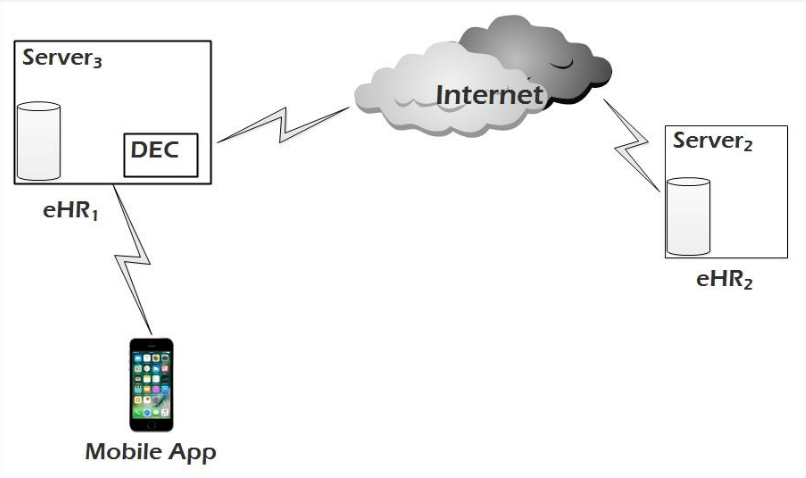

Figure 2: Set-up II – Two Server Set-up for the DEC and participating eHRs.

C. Set-up III: Use of Single Server; a Local or Cloud Server

The third proposed set-up is such that both eHRs are hosted in the same server with DEC. This architecture can be implemented using two models. One is to host the eHRs and DEC in a physical/local location as illustrated in Figure 3; the second model is to host them in the Cloud on a virtual server as shown in Figure 4.

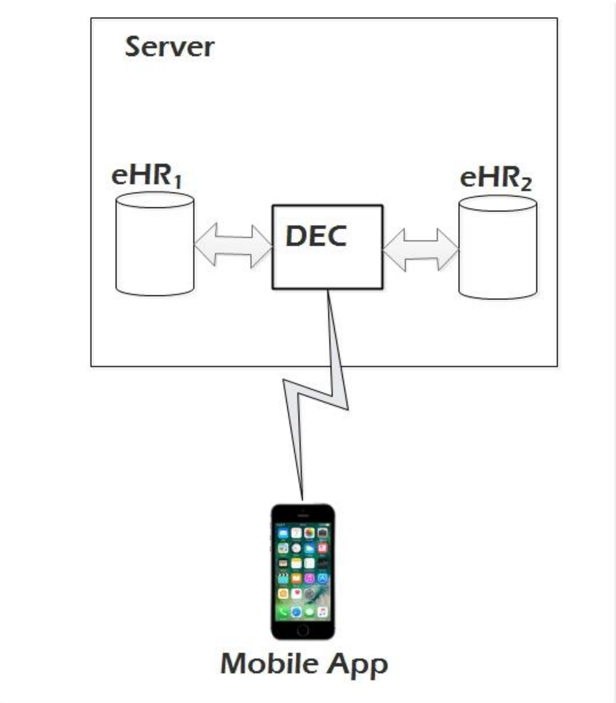

Figure 3: Set-up III – Single Server; physical/local server host set-up.

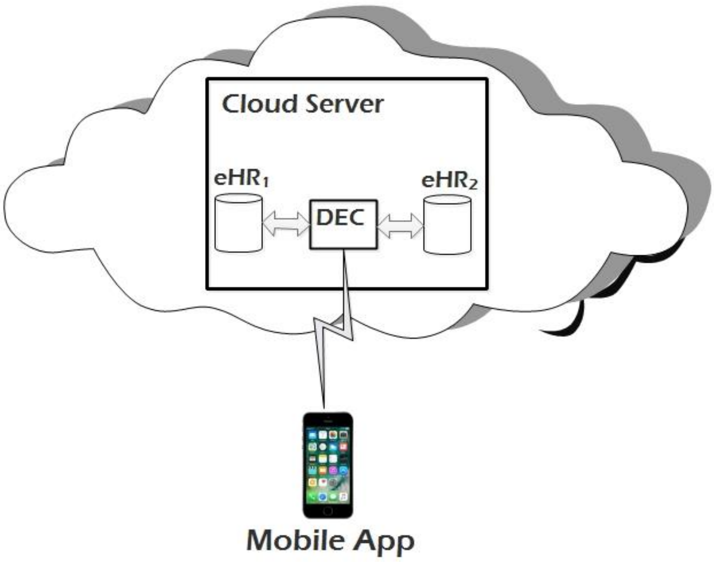

Figure 4: Set-up III – Single Server; Clouds server host set-ups.

IV. PROPOSED ARCHITECTURAL DESIGN OF THE DEC

Fundamentally, the DEC provides a mechanism to connect a single mobile app with multiple eHRs. The architecture presented in Figure 5 shows an interface to a mobile app, the processing and exchange mechanism where the authentication and data exchange between the mobile app and the connected multiple eHRs occur. Also, the figure shows an interface to eHRs/databases and the connected eHRs.

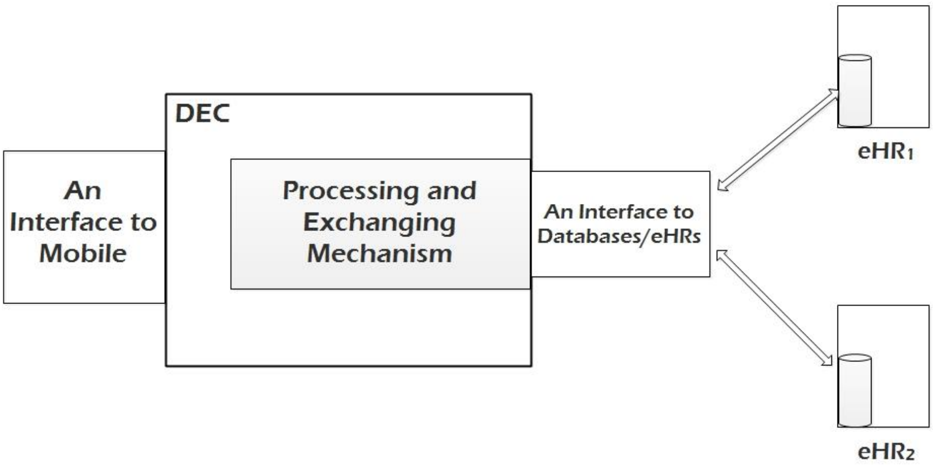

Figure 5: DEC to multiple eHRs architecture.

A. The DEC Building Blocks

In [16], the authors propose use of DEC as a solution component toward eHRs interoperability through single mobile app. Figure 6, presents the DEC Architecture's building blocks.

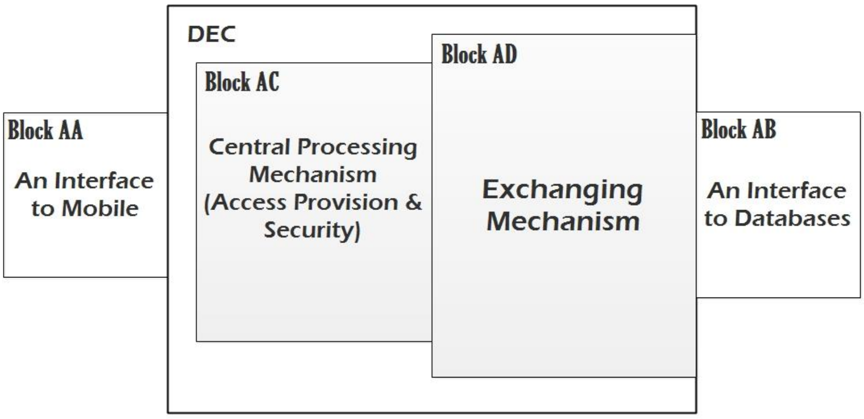

Figure 6: The main building blocks of DEC Architecture.

The following are the details of each building block: (See Fig. 6).

a) *An Interface to Mobile side (Block AA):* This provides a way for the developed mobile app to be connected to the DEC. By being connected to the Data Exchange, mobile app users will have the possibility to access data/info located in the connected eHRs through an authentication process, i.e the user has to be a legal registered user who has been given access to do so. The user has to pass the central processing mechanism, to pull patients info and by the help of DEC application the info-data can be exchanged. To connect the mobile app to the DEC, a mobile app developer will follow the steps on how to connect and post/retrieve data between the two eHRs.

b) *An Interface to Database/eHRs side (Block AB):* The Interface to databases resides on the side of DEC where it provides an interface to connect eHRs where it gives a way from which they are connected and interact with the DEC. Through this interface, eHRs are connected and exchange data and information through the exchange mechanism within the DEC.

c) *Central Processing Mechanism - Access Provision and Security (Block AC):* The central processing mechanism provides a mechanism that controls access to the connected eHRs. A user has to be authenticated here and thereafter, allowed to access the eHR databases. The authentication should be controlled by the owner of the connected eHRs, where, before accessing /transferring data from the connected eHRs, the mobile app must be approved by both systems.

d) *Exchange Mechanism (Block AD):* This is a step by step SQL procedure that manipulates the two eHRs. These are codes that perform the exchange of information between the two eHRs.

B. How DEC Works

The DEC will enable the connected mobile app and web-interface users to access data/information in the connected eHRs. To connect a mobile app to the DEC, a mobile app developer will receive procedures on how to connect the app to the DEC. The developer will configure the app to exchange information with the connected eHRs through DEC. After a successful configuration, the mobile app/web-interface user will continue to use the app/web-interface to add, modify, transfer, search, or retrieve data/information to/fro the connected eHRs through DEC. The DEC will allow authentication process when the app/web-interface users login before accessing or transferring data/information. A display flow chart for this process is given in Figure 7.

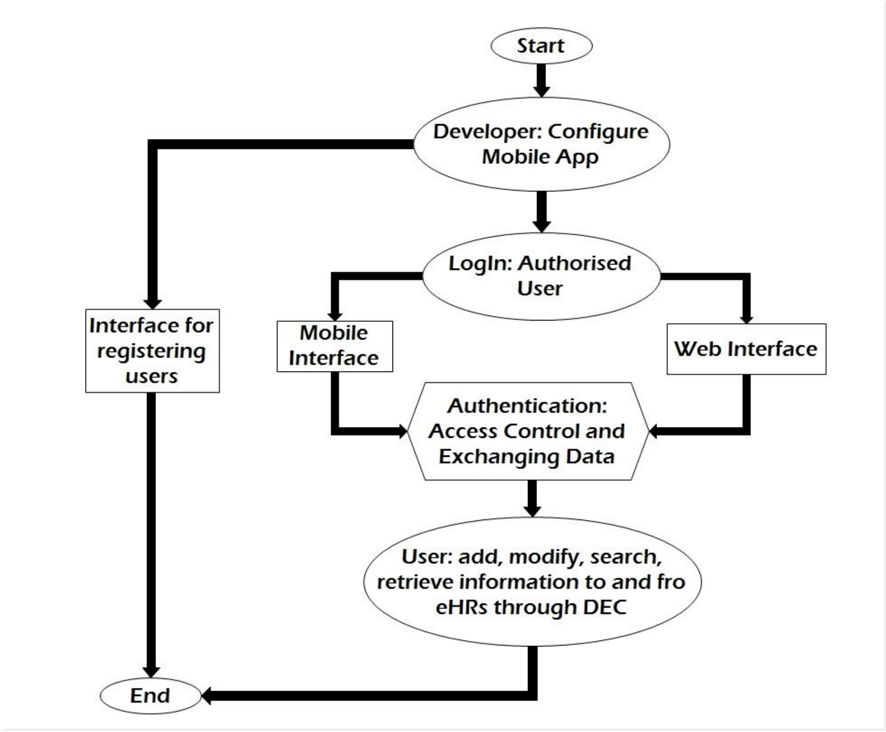

Figure 7: A display flowchart overview.

Essentially, the DEC has two blocks, marked as AC and AD, that control the access (authentication) and facilitate data exchange mechanism as explained earlier in this Section. The DEC provides a platform for communication between the two connected eHRs i.e. the connected eHRs will exchange and transfer data/information through DEC.

Users of DEC fall into two main categories;

i. *Category I: Technical Users – Mobile App developers and System Administrators:*- Users on this category are those who are responsible for setting up the connections, configuring DEC to work with the intended systems and the mobile app. This category comprises the hospital system/database administrators and mobile app developers. These users are also responsible for the management of the DEC and the system over its lifetime.

A mobile app developer or hospital system administrator will download the DEC and configure it into the intended server and then connect the targeted eHRs. Consider Figure 8 for more details.

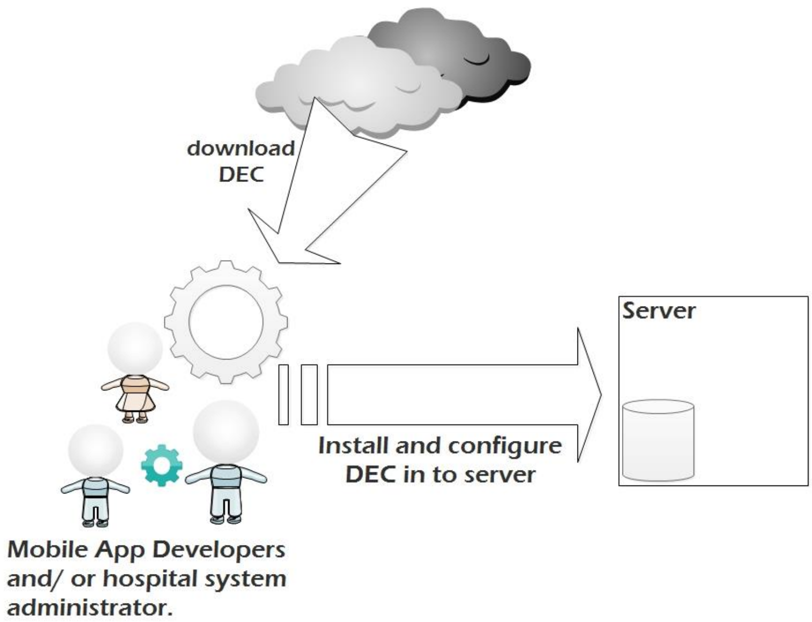

Figure 8: The DEC downloaded by mobile app developer or hospital system administrator and configures it into a sever.

ii. *Category II: Normal Users:-* The users in this category are mobile app/web-interface users; they are the intended beneficiaries of the DEC. This category includes hospital personnel such as health practitioners, administrators etc. and any other approved users within the participating hospitals. Figure 9 illustrates how category II users interact with DEC.

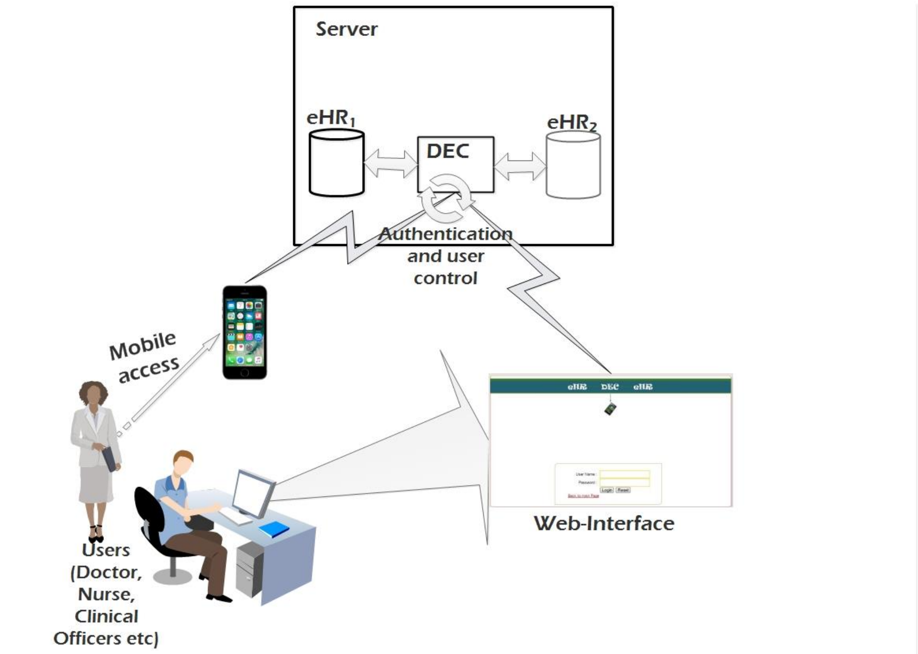

Figure 9: Category II users' interaction with the DEC

C. Data Repositories for the Participating eHRs

The participating eHRs used to demonstrate interoperability between eHRs through the developed DEC. These systems will be stored in repositories such as MySQL, Oracle etc. The repositories in are relation to DEC are planned to resides in the single, two or three different servers as explained in section III.

D. System, DEC Building Blocks and Users' Interaction

Users of the eHRs (doctors, clinical officers, health practitioners etc) will perform actions such as add, modify etc. to the eHRs. The interface to access data will be provided through mobile app and the web-interface. With the interfaces configured and enabled, a user will be able to login to the DEC through authentication processes provided by the DEC and the participating systems (eHRs). Upon successful login, a user will search patient details by using the known patient ID where the details could be transferred to the other connected eHR (the other hospital in this case). Through the data exchange mechanism described in sub-section A of this section, hospitals could exchange medical documents such as discharge summary, referral details, Lab results etc. The block diagram in Figure 10 illustrates described the interaction.

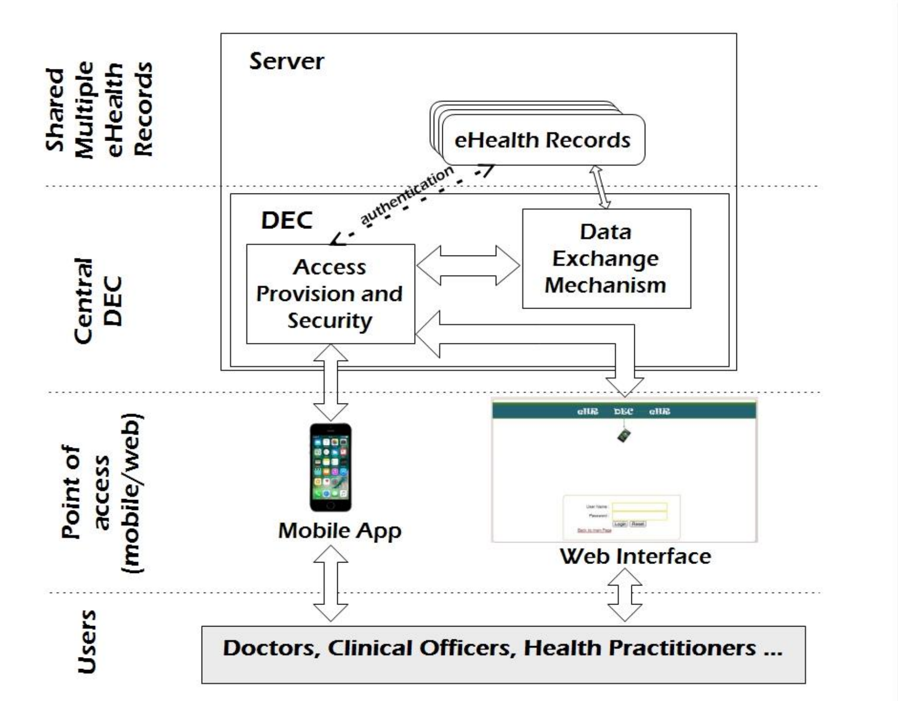

Figure 10: The block diagram for system, DEC building blocks and user interaction.

V. DEC IMPLEMENTATION AND TESTING

OpenMRS and Care2x Information systems were used as sample eHRs to demonstrate the applicability of the developed DEC architecture. The DEC, as a web application, resides and runs within a webserver. User of the DEC will download it from online repository as a form of compressed folder. After downloading, the user will un-compress it, install and then configure it in the intended server (see Figure 7).

The following are pieces of codes showing the implementation of the developed DEC.

A. Data Exchange

Figure 11 shows the fetch and transfer patient function that illustrating the data exchange process. Also, it shows scripts for patient data transfer from Care2x to OpenMrs. The transfer patient function is presented in Figure 12.

```
<?php
class Patients
{
    function Fetchandtransferpatient($pid)
    {
            require_once("conn_care.php");
            $sql="
                select pid, date_reg, name_first, name_2, name_3, name_middle,
                name_last, name_maiden, name_others, date_birth, blood_group,
                addr_str, addr_str_nr, addr_zip, addr_citytown_nr, addr_is_valid,
                citizenship, phone_1_code, phone_1_nr,  phone_2_code, phone_2_nr,
                cellphone_1_nr, cellphone_2_nr, fax, email, civil_status, sex,
                title, photo, photo_filename, ethnic_orig, org_id, sss_nr,
                nat_id_nr, religion, mother_pid, father_pid, contact_person,
                contact_pid, contact_relation, death_date, death_encounter_nr,
                death_cause,  death_cause_code, date_update, status, history,
                modify_id, modify_time, create_id, create_time, relative_name_first,
                relative_name_last, relative_phone
                from
                care_person where pid='$pid'";
            try
            {
                $res=mysql_query($sql);
```

Figure 11: Part of Fetch and Transfer Function; Sample codes showing fetch patient data and transfer it from Care2x to OpenMrs.

```
    var pid=document.getElementById("ppid").value;
    var params="?pid=" + pid;
    sendrequest("transferpatient","page",params);
}
```

Figure 12: Transfer patient function

Figure13 shows the fetch and transfer patient's data function, these codes display the process of transferring patient data in to OpenMrs system.

```
    if ($row=mysql_fetch_array($res))
    {
        require_once("conn_openmrs.php");
        $sql="insert into care_persontemp
        (
            pid, date_reg, name_first, name_2, name_3, name_middle, name_last,
            name_maiden, name_others,  date_birth, blood_group, addr_str, addr_str_nr,
            addr_zip, addr_citytown_nr, addr_is_valid, citizenship, phone_1_code,
            phone_1_nr, phone_2_code, phone_2_nr, cellphone_1_nr, cellphone_2_nr,
            fax, email, civil_status, sex, title, photo, photo_filename, ethnic_orig,
            org_id, sss_nr, nat_id_nr, religion, mother_pid, father_pid,contact_person,
            contact_pid, contact_relation, death_date, death_encounter_nr, death_cause,
            death_cause_code, date_update, status, history, modify_id, modify_time,
            create_id, create_time, relative_name_first, relative_name_last, relative_phone
            )values
            (
                    '$row[0]', '$row[2]', '$row[3]', '$row[4]', '$row[5]', '$row[6]', '$row[7]', '$row[8]',
                    '$row[9]', '$row[10]', '$row[11]', '$row[12]', '$row[13]', '$row[14]', '$row[15]', '$row[16]',
                    '$row[17]', '$row[18]', '$row[19]', '$row[20]', '$row[21]', '$row[22]', '$row[23]', '$row[24]',
                    '$row[25]', '$row[26]', '$row[27]', '$row[28]', '$row[29]', '$row[30]', '$row[31]', '$row[32]',
                    '$row[33]', '$row[34]', '$row[35]', '$row[36]', '$row[37]', '$row[38]', '$row[39]', '$row[40]',
                    '$row[41]', '$row[42]', '$row[43]', '$row[44]', '$row[45]', '$row[46]', '$row[47]', '$row[48]',
                    '$row[49]', '$row[50]', '$row[51]', '$row[52]', '$row[53]'
            )";
            mysql_query($sql);
            echo "<span style='color:green;font-size:12px;margin-left:40px'>Patient transferred!</span>";
            echo "<span style='color:green;font-size:12px;margin-left:40px'><a href=''>Back</a> </span>";
    }
}
catch (Exception $ex){
        echo $ex->getMessage();
}
```

Figure 13: Part of Fetch and Transfer Function; Sample codes showing transfer patient data in to OpenMrs

B. Authentication

Shown in Figure 14 is a screenshot of the authentication form and the login function codes where a user is prompted to enter login details. The sample of login form codes is presented in Figure 15.


```
function login(){
    var uname=document.getElementById("uname").value;
    var pwd=document.getElementById("pwd").value;
    var params="?uname=" + uname + "&pwd=" + pwd;
    sendrequest("login","page",params);
}
```

Figure 14: A screenshot for user login web page and a sample login function

```
<form id="login" method="post" action="javascript:login()">
    <table>
        <tr><td align="right">User Name :  </td>
        <td><input type="text" id="uname" required></td></tr>
        <tr><td align="right">Password :  </td>
        <td><input type="password" id="pwd" required></td></tr>
        <tr><td align="right"></td>
        <td><input type="submit" id="log" value="Login"/> <input type="reset"
        id="res" value="Reset"/></td></tr>
        <tr>
        <td><a href="index.html">Back to main Page</a></td>
        </tr>
        <tr><td align="right" colspan="2"><span id="sms"></span></td></tr>
    </table>
</form>
```

Figure 15: Sample web-based login form codes

Figure 16 shows the scripts that provide access control and security within the DEC. The codes are designed to check the data and then secure them before an insert/retrieve action to/fro the MySQL database. Also there is a piece of code that selects a user by using username and password that are inserted by the user through the provided form.

```
<?php

if (isset($_REQUEST))
{
  require_once("conn_mid.php");
  $uname=mysql_real_escape_string($_REQUEST['uname']);
  $pwd=mysql_real_escape_string($_REQUEST['pwd']);


  //If succeded


  $sql="select * from tbl_users where uname='$uname' and pwd='$pwd'";
  $res=mysql_query($sql);


  if ($res) {
      if ($row=mysql_fetch_array($res))
      {
        //require_once("select.php")
            require_once("conn_care.php");
            require_once("objpatients.php");
            $patients=new Patients();
            $patients->LoadPatientsList('');
      }
      else {
        echo  SayThis("Login failed!");
      }
```

Figure 16: Sample login codes

Through DEC, a user can transfer/ exchange data from either system i.e to and fro OpenMRS and Care2x. Figure 17 depicts how data are transferred or exchanged from either eHRs through DEC.

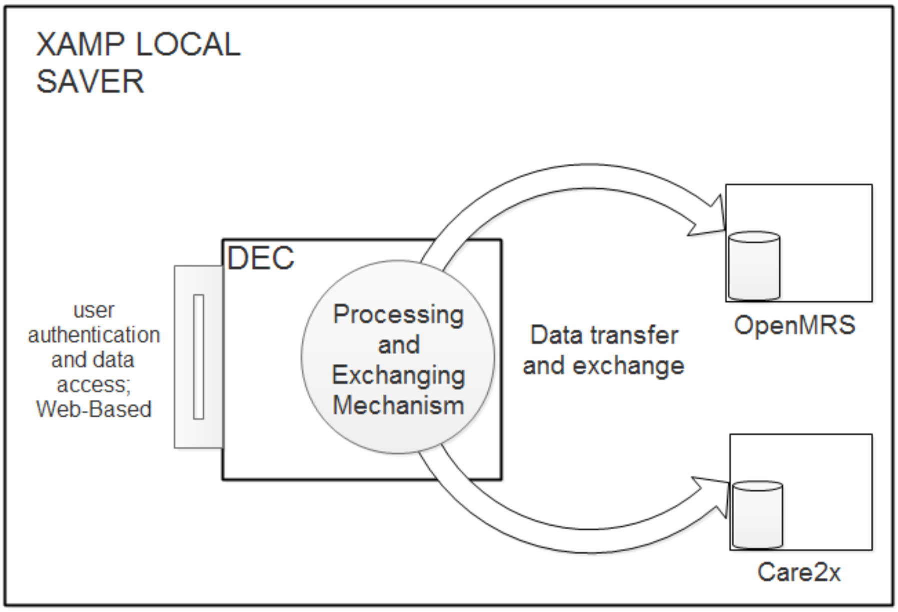

Figure 17: Data transfer/exchange from either system through DEC to XAMP server.

In the first round of testing process, data access by a mobile app is not included since the goal in this round is to ensure a successfully data exchange process between connected eHRs. Instead, a web-based platform was used where a user can login to the DEC through a web-based login form. Work is in progress to test the process using a mobile app.

In the testing process, patient registration details were successfully transferred from Care2X to OpenMrs. The architecture adopted for the purpose of this testing was Architecture IIIA which is discussed in Section III of this paper.

VI. DISCUSSION

Three alternative setups for deploying DEC were presented in section III. These setups provide possible arrangements where DEC can be installed. The arrangements consider options that the hosting institutions could choose based on the cost of implementation on the existing setups, principles and policy. Option of choice by the participating institutions will base on the best viable option that will fits institutional requirements.

In this paper, authors propose DEC to provide platform to connect mobile app with multiple eHRs. Utilization of mobile devices in health is increasing everyday. This is due to the wide range uses of mobile devises especially mobile phones. Subscription of the mobile phones globally has reached to 4.8 billion in 2016 where 8.8% are from Sub-Saharan Africa projected to hit 543m in 2020 [2]. Health sector harness the advantage of the availability and utilization of the mobile devices to extend its services [17]. Integrating mobile app with eHRs became one of the research areas in health sector.

Implementation and testing of DEC were done and results presented in section V. Two open sources eHRs were used as samples. OpenMRS and Care2x health systems were connected to DEC. Point of access used was a web interface where patient registration details were transferred from OpenMRS to Care2x. Results were successful transfer of the patient registration details.

VII. CONCLUSION AND FUTURE DIRECTIONS

Achieving interoperability between two or more eHRs is still a challenge in both developing and developed countries. Yet, interoperability of eHRs continues to be an important aspect towards delivering good healthcare services. Efforts among healthcare stakeholders, practitioners, researchers etc. are still directed toward achieving interoperability among eHRs.

Use of specialized software-based data Exchange Component (DEC) has been suggested as a viable solution to achieve the interoperability of eHRs. The significant contribution of this work is to join efforts towards complete interoperability of eHRs by presenting a DEC design architecture, implementation and web-based interface testing. The DEC focuses on achieving interoperability of two different eHRs. It has been shown that, the proposed DEC provides a mechanism where two eHRs can share data/information from each other through it. Therefore, the realization of DEC is a novel effort and could help to add value in the current efforts towards achieving interoperability of eHRs in hospitals, and health institutions.

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