JHIA - online.org
Journal of Health Informatics in Africa

11th Health Informatics in Africa Conference (HELINA 2018)
Peer-reviewed and selected under the responsibility of the Scientific Programme Committee

A Scalable Low-Cost Multi-Hospital Tele-Radiology Architecture in Kenya

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In LMIC, radiology image studies are transported across distant geographical locations in an attempt at seeking radiologist's reporting services. This often leads to delayed care, poor patient outcomes and negative monetary implications. The landscape is rapidly changing with improved internet connectivity and availability of advanced radiology equipment. Tele-radiology holds great promise in solving this problem. We describe a tele-radiology architecture that uses the global virtual radiology service model, its implementation, success, challenges and its promise with wide adoption.

Implementation involved several policy, stakeholder, security and workflow integration considerations. Over a 1-year period of implementation from January to December 2017, 80 X-rays (CR studies), 150 MRIs and 1,335 CT Scans were processed and delivered for reporting within a period of three (3 ±1.4) minutes. There was image size variability depending on modality. The total cost of implementation of the architecture was $7,540.

The system demonstrated that it is possible to implement a scalable, low-cost, sustainable, secure and robust tele-radiology architecture in low resource settings. This would help alleviate some of the constraints associated with the sparse number of radiologists.

1 Introduction

There is a general shortage of radiologists in the world [4,5]. This shortage is more marked in the developing countries despite the increasing demand for radiology services. In Kenya, for example, the number of qualified radiologists is only 13-38% of those needed to serve the country's population [6]. The few radiologists tend to be concentrated in urban areas compared to rural areas where a majority of the population lives [5]. To help address the deficiency in radiologists, tele-radiology has been identified as a potential solution to improving the reach and timeliness of radiology services in low- and middle-income countries (LMICs) [3]. Tele-radiology is defined as the exchange of radiological images and patient-related data between geographically separate locations for purposes of primary interpretation, expert consultation and/or clinical review by digital transmission [1].

While services hold great promise in low- and middle-income countries (LMICs), implementation of these systems has been slowed down by several challenges. These challenges include poor internet connectivity, poor understanding of the technology, vendor lock-in, and lack of state of the art equipment. Additionally, there is paucity of data on an appropriate infrastructure setup that would be affordable and scalable to implement without disrupting the workflow of hospitals and radiologists. The demand for services has also been limited by the fact that most of the radiology equipment were initially only available in urban areas, which tended to have radiologists. Rural areas, that could benefit best from tele-radiology services, given lack of radiologists, often also lacked radiology equipment.

However, things are rapidly changing in several LMICs. In Kenya for example, recent developments have increased the demand for tele-radiology services. In 2015, the government invested heavily in equipping at least all county and national referral hospitals with advanced medical imaging equipment [8].

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J Health Inform Afr. 2018;5(2):60-66. DOI: 10.12856/JHIA-2018-v5-i2-207

It involved deploying more than 585 units of diagnostic imaging equipment including digital radiography (X-ray), Computed Tomography (CT) Scan and Magnetic Resonance Imaging (MRI) machines across the country's hospitals. At the same time, the country has experienced significant increase in broadband internet penetration over the last decade after arrival of the undersea fiber optic [7].

Despite these positive developments, Kenya has found itself in the situation where many imaging studies continue to be physically transported across distant geographical regions for interpretation by radiologists. In scenarios where the imaging studies are not transported, the radiologists must shuttle between multiple hospitals to report on the studies. These constraints often lead to delayed care with negative impact on patient outcomes, and negative monetary impact on hospitals and patients.

The chronic shortage of radiologists in the country coupled with rising Internet connectivity rates, ubiquity of computers and accepted communication standards in digital imaging (such as the Digital Imaging and Communications in Medicine [DICOM] standard) have meant that Kenya is in a unique position to benefit greatly from tele-radiology. In this article, we describe the development of a scalable low-cost multi-hospital tele-radiology architecture in Kenya. We also describe its implementation, successes, challenges and the promise of this implementation with broad adoption.

2 Materials and Methods

2.1 Setting

The tele-radiology architecture and service was implemented among four private facilities in western Kenya in January until December 2017. The private facilities have a combined capacity of 364 beds (i.e. 24, 90, 100 and 127 beds). Radiology equipment within these facilities included: (a) Computed Tomography (CT) scanner in three facilities, (b) a Magnetic Resonance Imaging (MRI) machine in two facilities, and (C) a digital radiography (x-ray) machine in all the facilities. Internet connectivity to each of the hospitals was an upload speed and download speed of 6 megabytes per second (MBps). Before the implementation, none of the hospitals had resident radiologists. The all shared from the same pool of radiologists. The hospitals are situated within a 5-kilometer radius of each other.

2.2 Tele-Radiology Architecture

The goal of the tele-radiology architecture was to: (a) allow images from the various facilities to be efficiently and securely transmitted to a central server accessible to radiologists; (b) allow for notification of relevant radiologists assigned to interpret the image; (c) save the radiology report; and (d) allow for notification and viewing of generated report by facilities.

(a) Policy and Stakeholder Considerations

Development and implementation of the system was done in close collaboration with key stake- holders from the four care facilities. Particular attention was paid to ownership of radiology data files, to ensure that each facility retained ownership of their radiology images at all times, and that other facilities could not have unauthorized access to these images. In essence, the infrastructure established acted as a secured repository for each facility, ensure confidentiality of the patient information. Policies on who could access the images (e.g. radiologists allowed to review images for a hospital) were determined by each individual facility. Mechanisms were also put in place on how to manage space within the central server, delete old studies, manage duplicate studies based on a matching algorithm and to optimize responses to different modalities. Acquisition of images was via Digital Imaging and Communications in Medicine (DICOM) compliant modalities in each of the hospitals. The modalities include a CT scan in three facilities, an MRI in two facilities and a digital radiography machine in all four facilities.

(b) Architecture and Implementation

Existing equipment at the facilities often take digital images that are stored within the equipment and are available for printing. Images are acquired using DICOM standard. We implemented an architecture that allowed for the acquired images to be securely transmitted to a central server. To do this, we set up a central

J Health Inform Afr. 2018;5(2):60-66. DOI: 10.12856/JHIA-2018-v5-i2-207

DICOM server that was hosted on a HP Proliant ML310e-G8 Intel XeonE3-1220v2 (3.1GHz/4-core) with 4GB random access memory and 2 terabytes of hard-disk space. The server was connected to an uninterrupted power supply (UPS) device capable of sustaining 30 minutes of use without electricity. A power generator was also available on standby and we had power-surge protection functionality. The connection speed to the server was 25 MBps regulated by a Mikrotik router with an advanced firewall and port forwarding configured.

The central server ran the ClearCanvas DICOM Server v13.2.19401.1661 software by Synaptive Medical. This server application is available under an opensource license and can be downloaded for free. With this software, the central server could receive and process DICOM images from distinct types of modalities including but not limited to: Computed Radiography (CR), CT, MRI, Nuclear Medicine (NM), Ultrasound (US), Endoscopy (ES), Positron emission tomography (PET), radiographic imaging (conventional film/screen) and X-Ray angiography among others.

The server was configured so that there was a separate partition for images originating from each facility. At each facility, the radiology equipment was also configured to connect to the DICOM central server. With this configuration, the acquisition of an image by an equipment at the facility automatically triggered a storage command to the central server. This allowed the image to be automatically uploaded. The central server processed each incoming image using a set of criteria before storage. As an example, Lossless compression was applied if uncompressed images were received. Each image was then saved to its appropriate partition based on source facility. The images were then available for view by authorized radiologists within minutes of storage into the central server. Figure 1 gives an outline of the architecture implemented.

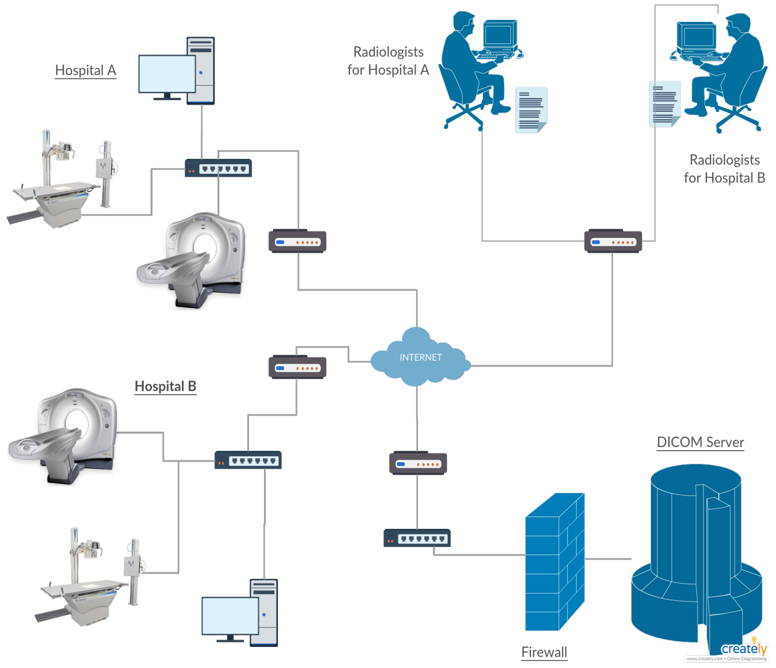

Figure 1. The architecture implemented to interconnect hospitals and radiologists

(c) Workflow Integration

To ensure little interruption to the existing interaction between the radiologists and the hospitals, we implemented a separate workflow tool that was developed using Java and Spring framework. The interface for this tool enabled users with various privileges to log in and monitor the status of the images. The workflow tool actively alerted users on items that needed their attention based on predetermined triggers. As an example, Radiologists assigned to Hospital A would get alerts for new images sent from Hospital A that needed interpretation and reporting. Alerts were pushed to providers and users using verified email addresses in the system. Similarly, hospitals got email alerts for new reports submitted by radiologists. The workflow tool had added functionality such as customizable templates for reports and the ability to generated PDF versions of signed reports.

(d) Security Considerations

Several security measures were implemented given the sensitivity of handling patient-level data. First, the central DICOM server was kept behind a two-tiered firewall - one implemented on the router to only accept traffic through specified ports and a second firewall within the server itself. Second, access to the radiology studies stored on the central server could only be permissible through a virtual private network (VPN). Third, at the application level, the partitions only accepted storage command requests and could not be queried by external applications. The partitions additionally only accepted storage command requests from specified modalities e.g. the partition assigned to Hospital A only accepted commands from the hospitals modalities and rejected those from other modalities.

The system also implemented user-level authentication mechanisms. Secure logins were required for one to be able to view images, create a report or view reports. User level restrictions and privileges for hospital users also ensured that users were only able to view radiology reports and images that they have rights to. Radiologists on the other hand could only view images if they satisfied set criteria. They had to be in the specific hospitals panel of approved radiologists and be certified by the Kenya Medical Practitioners and Dentists Board (KMPDB) as a radiologist allowed to practice in the country for them to be given privileges within the system. Once a radiologist with relevant privileges logged into the secure system and selected an image for interpretation and reporting, the specific study got locked from access and interpretation by other users. Only then were they allowed to view and report on the images. The security measures implemented are summarized below in Table 1.

Table 1. Summary of security measures

Security implemented in the architecture
Router level firewall
Server level firewall for port restriction
Partition restriction to each hospital/facility Secured user logins
User resource restrictions
Only certified board radiologists can report images Locking of images for availability for reporting
Image studies accessible only through a virtual private network (VPN)

3 Results

The tele-radiology system went live in January 2017. The studies that were received and processed from January to December 2017 included 80 x-rays (CR studies), 150 MRIs and 1,335 CT Scans. The breakdown per institution is as shown in Table 2.

Table 3. Number of studies processed over a 1-year period in 2017

Institutions	Hospital A	Hospital B	Hospital C	Hospital D
CR studies	1	15	6	58
MRI studies	-	-	-	150
CT studies	4	-	37	1294

The number of images (or series) sent per patient for each study modality varied based on the modality. On average, CR studies had 2 series, MRI studies had 176 images, while CT scan study had 160 images in each patient study. The number of the images/series also varied depending on the type of equipment used by study type (e.g. 16 slice vs 64 slice CT), the type of study (abdominal CT vs head CT) and study settings.

100% of the studies were fully transferred to the central DICOM server within three (3 ±1.4) minutes of initiation of transfer and were then immediately available for reporting by radiologists. All studies were compressed using the lossless technique. The summary of stored image sizes per modality is shown in Table 3.

Table 3. Image sizes in megabytes (MB) per study

Modality	Minimum size	Maximum size	Average size	Standard deviation
CR studies	7.0	34.0	13.6	8.7
MRIstudies	21.0	242.0	81.9	52.6
CT studies	16.0	1150.0	294.0	260.0

CR studies pushed in the least size of images and needed less storage resources while CT studies required bigger storage needs per study. There was a large variability in image size for CT studies compared with other modalities. This was contributed by the fact that CT images of the abdomen were significantly larger. The significantly smaller image sizes were contributed by incomplete image transfer from the modalities to the server.

The total cost to setup the initial infrastructure capable of supporting the tele-radiology architecture is shown in Table 4. The infrastructure can support an unlimited number of hospitals and modalities with the major limitation being storage, and this can be easily overcome. The business model employed for sustaining this tele-radiology service included the addition of a 10% fee on top of the radiologist's fee for every study that was reported. The resources were used to sustain the architecture through payments for internet and wages to maintain and improve the system.

Table 4. Cost implication of setting up the tele-radiology infrastructure

Component	Amount (USD)
Server - HP Proliant	1,000
Additional storage for images - 2 terabytes	120
MikroTik router	120
Uninterrupted power supply	300
Server internet connectivity 1 year	600
Design and development of workflow tracking tool	2,500
Server and modality configuration costs	500
Tele-radiology support staff wages	2,400
TOTAL	7,540

4 Discussion

We describe an implementation of a tele-radiology solution in a network of four private hospitals in Western Kenya, as a demonstration of a scalable and sustainable health information technology-based approach to improve efficiency and effectiveness of radiology services in settings with limited numbers of radiologists. We demonstrate that this system improves the timeliness to radiologists accessing images from remote sites, enables radiologists to manage their time more effectively by alleviating the need to shuttle between different facilities, and allows for efficient monitoring of turnaround times for reporting on images. The implementation of radiology information systems and picture archiving systems (RIS/PACS) in the western world has been well documented and been shown to be largely beneficial [13,12]. In resource constrained settings the literature is not as comprehensive, and our work adds to the growing body of evidence around the implementation of these technologies within LMICs.

There are four types of business models described in literature for tele-radiology systems: the standalone tele-radiology, the nighthawk/on-call coverage, solo radiologist practice, second opinion tele-radiology and the global virtual radiology [10]. This implementation closely matches the global virtual radiology service model and making it feasibly to alleviate radiology human resource constraints by leveraging approved professionals globally. The attractiveness of this approach is in its ability to potentially allow for cost-reductions for radiology services, and quality monitoring over time. We also demonstrate that through innovative use of open source application, the cost of implementation can be substantially reduced. The cost of obtaining an out of box tele-radiology system is upwards of 20,000 USD [9]. However, the licenses increase exponentially as more modalities are added. The total cost of implementation of this tele-radiology architecture was 7,540 USD, with the infrastructure able to support virtually an unlimited number of facilities and modalities, once storage considerations are accommodated.

In our implementation we demonstrate the importance of using health informatics standards. The architecture implemented is reproducible in different settings with minimal effort. The ubiquity of DICOM standard made it easy to integrate with radiology equipment from different vendors. DICOM use also ensures interoperability with other systems in future e.g. E-learning systems [2], electronic health or personal health records. Most importantly, DICOM is a much more secure standard when combined with the recommended VPN technology as was implemented. Our system also makes use of freely available open source systems, which not only makes the cost of implementation low but also improves on interoperability. Further, we provide evidence of importance of fitting into the users' workflow as a proven way to improve acceptance and utilization of a system [11]. Finally, we highlight the need for multimodal security approaches to protect patient-level information in tele-radiology systems.

This work is the initial stage of a multi-stage implementation. Our manuscript is descriptive, but in the future, we intend to conduct more rigorous evaluation on impact of the system on patient and provider satisfaction, efficiency in care, impact on outcomes and cost effectiveness.

5 Conclusion

In low resource settings where human resources for health are limited, scalable, secure, low cost, sustainable and robust tele-radiology systems promise to alleviate some of the constraints associated with limited numbers of radiologists. We demonstrate the feasibility of such a system using the global virtual radiology service model in the resource limited setting of Western Kenya.

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J Health Inform Afr. 2018;5(2):60-66. DOI: 10.12856/JHIA-2018-v5-i2-207