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Performance Modeling of Software-Defined Networking Paradigm in a Public Health Management System

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Abstract

The improvement in the management of Public Health through the public health management system (PHMS) has become a bottleneck. Although the management of a large number of patients' information has been studied, their networking aspect remains a challenge in prompt assessment of their records. With a view to bringing about an efficient management system, the Software Defined Networking (SDN) Technology came up with an interesting idea to properly manage network operation flow. The SDN technology enables the controller(s) to regulate the control flow in a logical manner through its intelligent control. This paper proposed a framework based on SDN to optimise the performance of large-scale PHMS. As a measure for better healthcare records, the proposed technology provides a reliable system to address huge patients' data request that is imminent. This article motivates experimentally, the need to despise the historical fear of new technology in PHMS as against the conventional/old practices.

Keywords: PHMS, SDN, hierarchical.

1. Introduction

The public health management (PHM) sector was established to address the inherent challenges that have to do with general common health problems contagiously carried from one individual to another. The need for such information to be delivered promptly for proactive actions has been a challenge over some decade due to the deployed system in the PHM (see Michalski et al. [11]). The expectation of any PHM system is to be able to both accelerate and revamp information processing, with the ability to predict prompt cautioning and thorough investigation on any affected part of the community (see Avila et al. [3]). The accuracy, completeness, adequacy and timeliness of a PHM are vital especially in accessing the performance of the system. Thus, for the proper functioning of the PHM system, the network infrastructure that connects various points of accessing data must be reliable, safe, flexible via the advancement in technology and ultimately be able to expand to accommodate increase data collection from clients (see Vest et al. [21]).

In the time past, one of the major challenges with the Public Health Management System (PHMS) is that of lack of adequate infrastructure meant for proper collection and dissemination of public health records. However, with the advent of portable mobile devices and various Internet utilizing devices, it has become relatively easy to access the public health data and information but left with the necessary idea on how to optimise the performance of the system. The common practises is not to destroy the already existing platform currently in practise in PHM but to build on the already existing systems such that there is an improvement in network problem solving capacity. This is envisaged to come along with better knowledge sharing features, coupled with enhanced networking with other network infrastructures or network managers for easy collaborations (see Zhao et al. [24]). One other vital feature entails the need for extendable PHMS for more users as the number of mobile subscribers increases with no deterioration in the users' network experience.

With a view to enhancing all the features above in the PHM, several approaches have been deployed which ranges from active networking to traditional networks (wherein both the control plane and data plane/forwarding elements were fused together on a single device for packet delivery) to the modern day SDN (which stipulated the decoupling of both planes to enhance logical traffic control) (see Bakhshi [4], Bholebawa et al. [5], and Wang et al. [22]). The active networking approach tried to proffer solutions but the solutions are not quite adequate since clear cut deployment scenario cannot be exemplified thus limiting the amount of contribution it made towards networking in general and PHMS also as a typical use-case scenario.

The traditional networks came up with the portable devices whose control and data plane are fused together. This means that the intelligence of the network which is being controlled by algorithms to create shortest paths are all embedded within the network forwarding elements, thus introducing some ambiguity or complexities into the decision-making as it is being distributed all across the entire network. This has over the years hinders the needed robustness expected in a network oriented-environment. It has not encouraged the flexibility, fast deployment of updates and protocols and firm reliability in terms of resistance to packet loss and network latencies (see Masood et al. [10]). However, the gradual and present evolution of a networking platform that logically centralises network control promises to be the long-awaited innovation in the networking environment (see Book of Abstracts, [6], Bakhshi. [4], and Hu et al. [8]).

Considering the rapid growth in the use of mobile devices nowadays, it has warranted that future preparations ought to be in place to anticipate heavy traffics arising from mobile users (see Shooshtarian et al. [17]). Various healthcare organizations are rapidly inculcating the use and connection of many devices into their health IT infrastructures, which calls for an increased network availability, reliability and general management. Many entities are currently dealing with Wi-Fi connectivity which is supported by cloud applications, Internet of Things (IoT) devices and telegraphic programs which are running on the same wireless networks. The flow of these various traffics results into slow connections due to congested bandwidth and gridlock, resulting in health officials being unable to access mission-critical tools at some points of care (see Martini and Paganelli [9]).

While there is certainly the possibility of deploying SDN in healthcare delivery, several organizations are hesitant to embrace the technology behind SDN due to their overall distrust of health IT infrastructure systems that function differently than the traditional/conventional systems. Literature highlighted that based on the historical background of healthcare institutions and organizations, they have always been slow to adopt new technology, as maintaining the status quo was viewed as safer than risking the possibility of disruption from the new technologies (see Rybkowski [15]). As discussed earlier in the abstract, we look ahead to design an improved PHMS with a relatively better performance that forestalls future challenges and will proffer solutions to them, considering the extensibility of the system or scalability as a vital feature (see Martini and Paganelli [9]).

Hence, this article looks to raise an appraisal to healthcare organizations and related institutions of the need to have a positive orientation towards the deployment of SDN technology for optimal network performance for which it promises. We intend to design a Software-Defined Based Networking platform for PHMS with robustness as a vital criterion under which extendibility, flexibility, prompt deployment and interoperability falls under it. Thus, the current paper envisages contributing in the following areas through motivating the need for deploying programmable network control in PHMS, proposing the design of SDN enabled PHMS as well as highlighting the advantages and benefits of SDN enabled PHMS over the traditional approach with respect to PHMS. Technically, we hope to contribute to the current field of networking through:

- Motivating the need for characterization of controllers for efficient traffic flow balancing in PHMS (i.e. Master, Location and Zonal controllers).
- Deployment of hierarchical structured SDN for managing flow PHMS network connections.
- Developing network stability function expression for determining the stability of any network system.
- Proposing a rapid traffic converging algorithm for optimal network performance,
- Finally, Motivating through experimental analysis of the need to adopt SDN technology by healthcare organizations and institutions.

The remainder of this paper is organised as follows: we give a brief background to the origin of SDN in Section II. Section III discusses the proposed network design for the PHMS using SDN approach while Section IV illustrates the design simulation setup for the PHMS Network. Section V shows the design setup for the PHMS service performance, Section VI explains the result and discussion of the experiments while section VII discusses the conclusion and future work of this article.

2. Related Works

Several approaches have been carried out as highlighted in the introduction to emphasise earlier works in the area of PHMS. The impact and the importance of a flexible and robust PHMS cannot be over-emphasised in a fast-growing geographical location for stability and reliability purposes. Some of these works include the simulation experiment of (see Swain et al. [19]) which provided us with both a realism perspective to the spread and effect of various kinds of control measures to INFLU and MEASLES along with some educational values being depicted. As at the time the report was conducted, the evidence of the realism of the simulation with respect to the actual physical situation is still under discussion as the results seem to still be below the expected outputs. Another vast research report (see Mushonga et al. [12]) where web services were deployed to enhance the sharing of disparate databases containing health data. The use of web service coupled with the GIS enabled mobile devices also provided the avenue to make ubiquitous uploading of health information directly into the databases which in addition also captured the location of the device for proper data analysis. The process also had a greater contribution to the prompt delivering of health decision especially during emergency situations. However, the performance and details of the networking functionalities of the exemplified systems were not discussed in the study.

Yuan et al. [23] attributed the success of China in scaling up Cooperative Medical Scheme (CMS) and New Rural Cooperative Medical Scheme (NCMS) to the impact of the health governance systems being deployed. Information from research publications and important policy documents to the development of both schemes were obtained and processed. The processed information was guided by a tested framework which helps in rolling out designs that ensure good coverage and funding mechanisms that is able to strengthen the assessment of rural areas and other informal sectors. Several Low and Middle Income Countries (LMICs) have been motivated through this mechanism to upgrade their approach, but the performance related to the networking section of the framework was not discussed as the assumption could show the framework might not be that effective especially in the context of another country as assumed.

Further work in public health management system (see Clarke et al. [7]) was manage individuals' health challenges most especially Chronic and urgent care needs. Challenges during transitions of care and poor incorporation of various health schemes to support adequate communications among these providers have been resulting into poor health care delivery performances. The work proposed longitudinal high-risk care management, innovative transition coordination as well as unplanned episodic caregiver were deployed and these approaches have shown positive results. Several existing health resources were to be used along with integrated new models that will incorporate Mobile Healthcare services to address the open gaps through providing twenty-four hours health care services. Moreover, sophisticated equipment with highly professional physicians was deployed to manage the provided platform effectively thus, averting on and off site patient casualties. However, in the whole write up, the network optimization of the system was not discussed with a view to propose a suitable network control management system to appropriately manage the proposed system.

Michalski et al. [11] also demonstrated the impact of a computer network in health information management exclusively in primary health institutions. The authors proposed an improvement in the management of primary health care units through the deployment of a computer network to enable the users in communicating via the personal computer to access the collective database of patients, health diagnostics as well as records of patients, etc. The design in the work aimed at providing an efficient, reliable and inexpensive IT infrastructure that could enhance fast public operations and good record keeping of the patient information. However, the article pointed out security and networking related issues with the devices that are used in accessing the information. It was proposed as a future work to test various security measures for an appropriate recommendation for the PHMS while the performance of a reliable network infrastructure was proposed.

A SOA (Service Oriented Architecture) based architecture that inculcated the use of Web Services was deployed by Avila and others on a SOA architecture in (see Avila et al. [3]). SOA introduced sub-module regulations and functional modules modality system with each performing a specific role which aggregates in a division of labour scenario. Each part of the module or function carried out a singular function which is integrated together as a whole for service provisioning. Thus, having considered several of the articles on PHMS provisioning to users/clients, we found out a gap especially with respect to the network performance of the system which need to be optimized from the present traditional networking approach to the network system which enables optimal network control for better performance in service delivery to the users. So far, none of the articles that has been published has evaluated the deployment of SDN technology into the public health system. The novelty of this article comes from the design of PHMS using the separation of control plane from data plane networking approach.

One of our goals is to evaluate the performance of the PHMS system after deployment of SDN technique in comparison to the traditional network approach especially in network control and management.

3. Proposed Network Design

The proposed design for PHMS is based on SDN technological approach which advocated that the control plane needs to be abstracted from the data plane for enhanced programmability and proper monitoring of the network system environment. This novel technological approach enhances network scalability and faster transmissions of data over the network. With the view to make the control of the network flexible through programming, we devised the network layout as shown in Figure 1. The key features in the figure consists of the control plane which are the controllers and the data plane which are majorly the switches being connected to the network hosts. The Master controller is the feature through which the entire coordination is carried out with the help of some sub-controllers called Zonal and Location controllers.

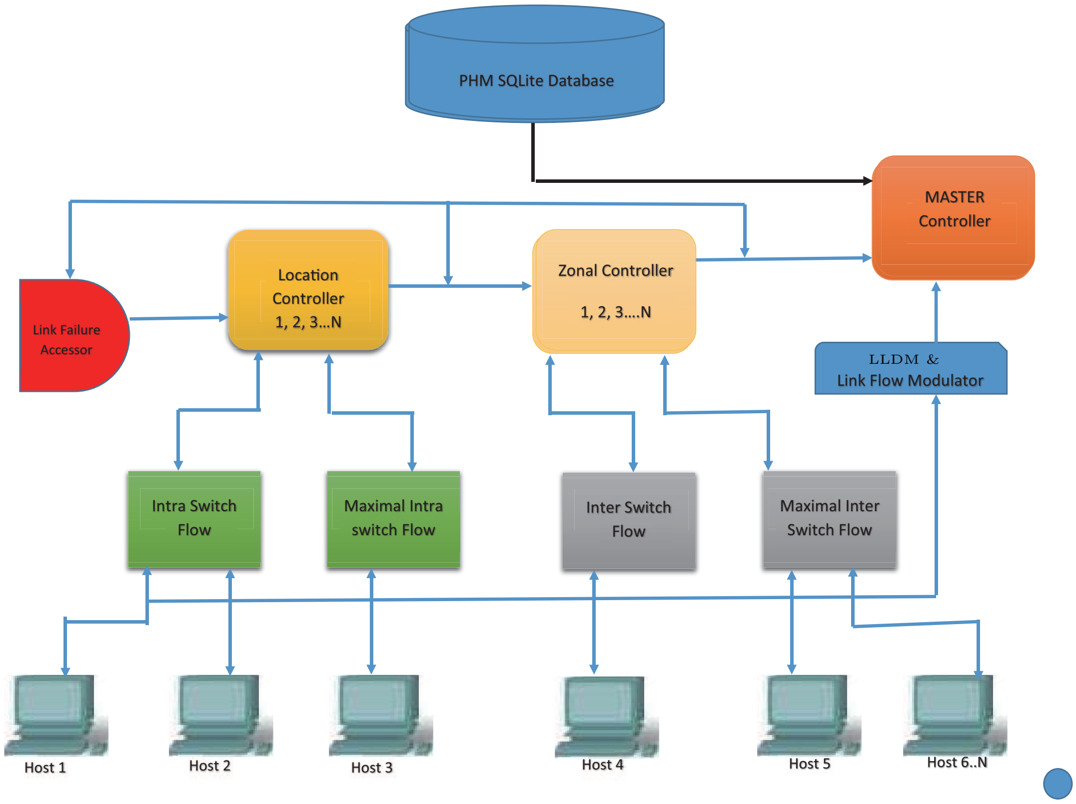

Figure 1: Control Plane Design Model for Robust PHMS Network.

Other network parameters include the Database which house the patients' information and the forwarding elements called switches which helps in forwarding network host data to the appropriate direction. The innovation in the network design here is such that the "controllers" enhance the outright modification of the whole network to behave in a desired manner required by the network administrator. In addition, we innovatively separated the SDN design deployment into three sets of controllers for enhanced coordination of network flow and maintenance of its stability.

Thus, the control planes were structured as shown in Figure 1, containing the location controllers, zonal controllers and the Master Controller in a hierarchical manner. The hierarchical manner of network arrangement was based on our recent findings in our research on controller designs for datacenter (see Akinola et al. [1]). The controllers were aided by two various types of switches being intra and inter switches which forward data traffic from various network hosts to the controllers majorly those around its zones and locations respectively. The maximal intra switch flows are controlled by the Location controllers while inter switch flows are coordinated vis the zonal controllers which are in turns managed by the Master controller. The structured hierarchical arrangements were designed to enable extensible and proper control of the traffic via programming of the

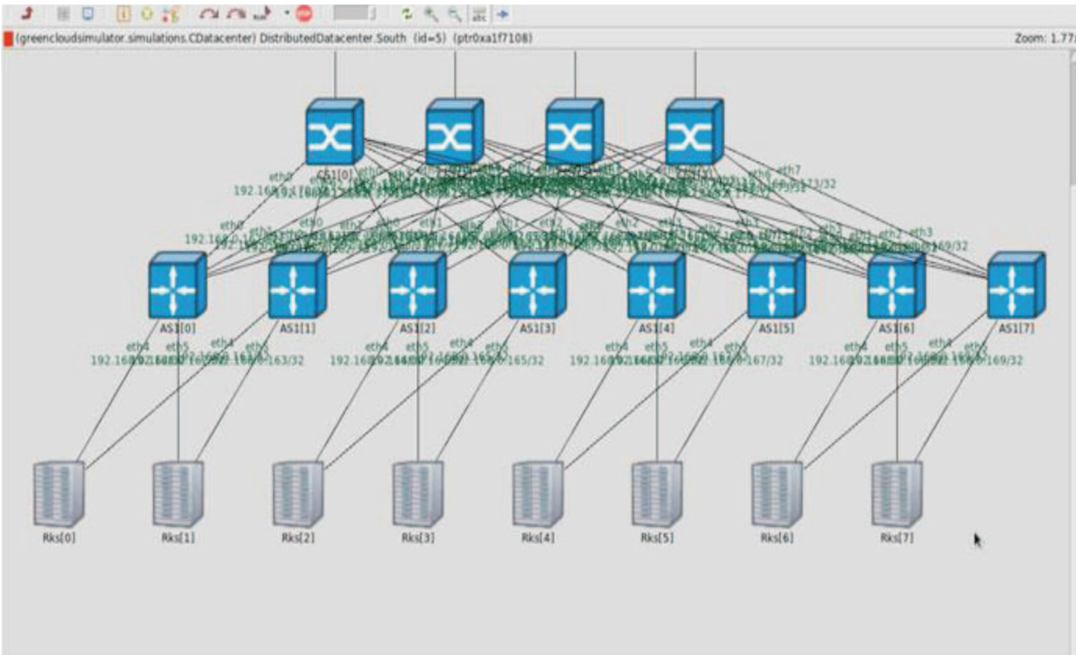

Figure 2: Hierarchical Simulation Setup.

control plane interface. The simulation perspective of the diagram in Figure 1 is shown in Figure 2 depicting the hierarchical arrangement manner for network design using the SDN approach.

Moreover, the link flow modulator links the multiple signal flow with the controllers and ensure that appropriate signals were motivated to achieve a balance in the traffic flow. The link flow counter reports the number of possible traffic failures that were experienced in the course of system operation with the link flow modulator keeping the master controller instructions so as to restrain the possibility of the traffic failure and as well salvage the situation for quick fault recovery. A link layer discovery module (LLDM) protocol is used to discover the link information that interconnect both inter-location and intra-location traffic flows. Thus, multiple switch locations often forestall the need for appropriate link discovery towards network management. The patients' data are finally stored in the database provided at the top of the network design for writing, reading and deleting purposes thus the need for the database to be updated with the current information as permitted by the administrator via the MASTER controller.

The added advantages with the SDN deployed network system is based on the fact that the control section has the interphase which enable the automatic control of the network performance via programming of the control plane. The master control plane is able to provide the network's logical wide view for better decision making to stabilise the network traffic. The design combined the hierarchical and programmability of control plane advantages for the PHMS system thus enabling a scalable, reliable and extendable networking environment.

4. Design Simulation for Network Setup

The setup and experimental testing were carried out on OMNeT++ simulator with INET framework installed to provide the routing protocol for the experiment on core i7, 8G RAM 1T memory Asus PC. The goal is to access the performance of the network design in comparison with the conventional approach under similar packet transmission and routing protocol conditions in respect to the network availability as well as scalability propensity. The switches were arranged in layers to depict the hierarchical format of the design as depicted in Figure 1. We selected OpenFlow-Hybrid switches that enable the switches to perform the characteristic of both flow forwarding task alone as well as the old conventional Ethernet switch bridging and routing tasks. This selection will assist in determining the comparison behaviour of the switches under a different task especially when control functionalities were added to the forwarding elements.

The capacity of the various controllers varies from the Master to the Zonal as well as the Location controllers. The Master controller is directly accessed by the administrator who through the master controller could update new protocols and monitor the whole network. This process ensures that the rapid effect is made on the network states thereby ensuring that the performance of the entire network is rapidly improved. The settings of the controllers and switches were designed according to the Table 1. For the experiment, the maximum number of host (nodes) $N_p = \dfrac{d^3}{4}$ hosts where d is the radix or degree. Using x = number of local switches, y = number of network links, g = the number of hierarchy in the architecture and z as the density. Then, the number of host $N_{p*} = g \cdot x \cdot z = (x \cdot y + 2)x \cdot g = (2z \cdot z) = 4z^4$ under a stable condition of the network state. Assuming that under the balance state of the network, we have $x = 2z = 2y$ while the controller degree $d = z + x + y - 2$. Therefore, we determine the maximum number of hosts that the network can tolerate with the relation $N_p \approx \dfrac{d^4}{64} + \dfrac{d^2}{8}$.

Considering the cost of network setup with respect to software defined networking, representing the number of the switches by $S_{sdn} = \dfrac{6Np}{d}$ due to the fact that we have $\dfrac{d^1}{2}$ master controllers, $\dfrac{d^2}{2}$ sub controllers (Zonal and Location) and $\dfrac{d^2}{4}$ multiple switches in the network.

Similarly, if the number of switches in conventional networks design was given to be $S_{con} = g \cdot x \approx \dfrac{5Np}{d}$. We determine the cost of networking with respect to the number of nodes per switches, and the time frame for packets delivery (PDT) which is given by the addition of transmission (propagation) time (TT) and propagation delay (PD). This is expressed in equation (4.1), (4.2) and (4.3) as:

$$\mathrm{PDT} = \mathrm{TT} + \mathrm{PD}, \tag{4.1}$$

$$\mathrm{TT} = \mathrm{FST} + \mathrm{LMD} + \mathrm{QD} + \mathrm{NPD}. \tag{4.2}$$

FST is the Frame Serialization time, given by the ratio of packet size (bits) to link data rate; LMD is the Link Media Delay, given as the ratio of link distance (m) to processing

Table 1: Simulation Environmental Settings.

SN	Scaling Parameters	Simulator Settings
1	Simulator Name	OMNeT++
2	Numbers of Controllers	8∼155
3	Number of Switches	18∼20,480
4	Simulation duration	1200 seconds, starting packet sending from 1000^{th} second to last for 100 seconds each
5	Number of Nodes	80∼53,248
6	Modules	8∼4096
7	Controller degree	2∼5
8	Switch degree	4
9	Diameter	4∼10
10	Betweenness Centrality	0.06369∼0.00005
11	Assortativity coefficient	-1
12	Spectral radius	4∼6.32455
13	Algebraic connectivity	0.87689∼0.64765
14	Avg. node degree	3.2∼6.15385
15	Density	0.04051∼0.00012
16	Links	128∼163,840
17	Levels	2∼5
18	NC = τ (Normalized network criticality)	1.06899∼0.30542

delay; QD is the queuing delay, given by the ratio of Queue depth (bits) to the link data rate and NPD refers to the Node Processing Delay which is specified depending on the users' machine.

$$\text{PD} = \frac{\text{Link distance}}{\text{Propagation speed}}. \tag{4.3}$$

But the speed of packets in copper wires is $2 \times 10^8 ms^{-1}$ and it is equal to the speed of light in a wireless medium as $3 \times 10^8 ms^{-1}$.

Evaluating the network criticality (NC) which depicts the performance of a network setup against unpredicted environmental fluctuations like traffic upsurge and topology imbalance with low values signifying better performance of the network. NC showed the convex function of the weighted graphical representation of a network. It is related to the spectral metric that determines network connectivity which is equal to the first nonzero eigenvalue λ_2 or its equivalent second eigenvalue of Laplace matrix. The disconnection of the graphical network expresses the λ_2 as zero, hence NC is metrically proportional to the inverse of λ_2 (see Shooshtarian et al. [17]). This is expressed as $2/(n-1)\lambda_2 \leq$ NC $= \tau \leq 2/\lambda_2$. Thus, the Laplacian matrix of a representative graph G is the $k \times k$ symmetric matrix whose entries are:

$$l_{ij} = l_{ji} = \left\{ \frac{\deg(v_i) \text{ if } j = i}{-\, a_{ij} \text{ if } j \neq i} \right\}. \tag{4.4}$$

Where $\deg(v_i)$ is the diagonal matrix whose entry is d_{ii} and $-a_{ij}$ represents the adjacent matrix. Having analyzed the design simulation for the network setup, we first determine the performance in terms of waiting time using real life data on the hierarchical controller SDN setup as well as the corresponding existing traditional approaches to determine its suitability and recommendation in the first place for PHMS. This is explained more in Section 6. In addition, we finally evaluate the NC of the network setup in relation to our defined stability function expression, i.e. the ratio of switch failures and link failure percentages. This will be discussed further under the Section 6.

5. Design Setup for PHMS Service Performance

This section reported some simulation tests on the performance of the service delivery to the various clients that are connected to the public health management system. They are mostly from mobile devices via the network to the respective destination for appropriate responses. The diagram in Figure 3 shows a typical network setup to issue queries from mobile devices by sending packets to and from the database (DB).

The simulation environment setup was divided into two sections namely the MySQL database and the mobile host devices that sent packets. The MySQL being an open

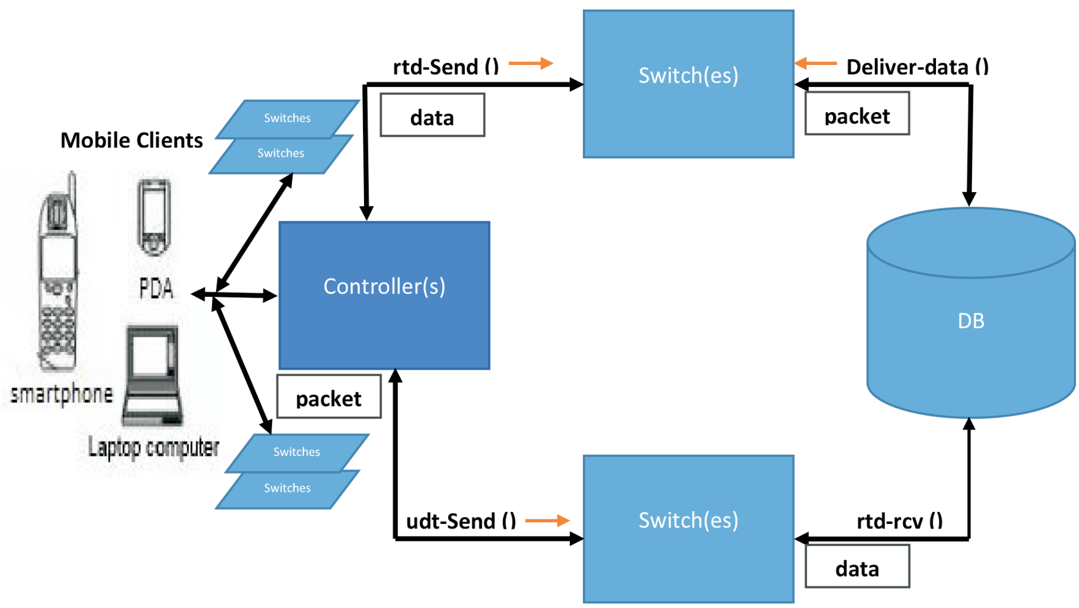

Figure 3: Data Performance Network Setup.

source relational database management system is a secure, scalable, platform independent with easy to use which has a proven guarantee for the safety of patient data and information. The mobile device (host) issues a query which calls a web service that calls the server (Tomcat) wherein the requested information lies. Jersey (JAX-RS) implemented Web services framework that is invoked by the clients.

The experiment was first conducted using 8 mobile devices (HUAWEI Ascend Y330), Dual-core processor @ 1.3 GHz and 512M RAM each, running an Android 4.2 Jelly Bean operating system. These devices help to collect real life data from off the locations as specified in Table 2 and sent to where the data centre for patients are located within the University. The table gives samples of the data that were gathered from different locations. We gathered the information in Table 2 from the literature in (see Primary health care [14]). The devices send the data via the wireless communication and which upload to the database of the framework as shown in Figure 1. The rate of data arrival processes from various users were represented as σ in terms of $\sigma_1, \sigma_2, \sigma_3$, and σ_4 and so on. Using the data received, we determined the degree of variability of the data uploaded. Initially, the issue of latency and attenuation over the distances covered in sending the messages affect the performance of the system, however, the use of hierarchical network design that incorporate the network control design of SDN has brought about improvement in performance. The data arrives at the server with some given predefined rates, which on the other hand varied the utilization of the server appreciably due to the approaches used in network designs. Mathematically, the data sent waiting time is the summation of the time it takes from the sending devices towards the receiving servers of the network. Thus, the waiting time were derived with the expression equation (5.1), (5.2) and (5.3) as

$$W_q^{T\ \text{dispout}} = \sum_{i=1}^{r} W_q^{itot}. \tag{5.1}$$

Table 2: Samples of Data from Users.

Locations	Distances	Diastole	Systole	B. Sugar
Mtuba	45Km	> 200	> 180	≥ 110
R. Bays	25Km	> 180	> 160	100-109
Ongoye	5Km	≥ 156	140	90-99
Empangeni	15Km	130	120	80-89
Mthetwa	45Km	110	115	80
Nongoma	40Km	100	110	75-80
Eshiwini	10Km	96	100	75
Unizulu	500m	95	94	65

Hence, the total waiting time for a particular network approach while sending several varieties of data is given by

$$W_q^{itot} = W_{qdin}^i + W_{qst}^i + W_{qdout}^i. \tag{5.2}$$

Finally, we have the total waiting summarised based on the hierarchical as:

$$W_q = \sum_{n=1}^{m} W_Q^{itot^n}. \tag{5.3}$$

Where these expressions depicted the time it takes to pass a particular data from the source to the destination. The waiting time from provider to devices is represented by W_{qdin}^i, while that from devices to controller is W_{qst}^i, and the one between controller and database is given by W_{qdout}^i. The mobile interface for querying requests were shown in Figure 4, Figure 5 and Figure 6 respectively. In Figure 4, the user is trying to access

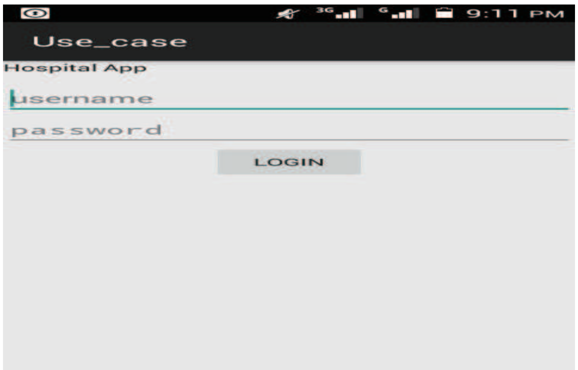

Figure 4: User's Accessing PHMS Account.

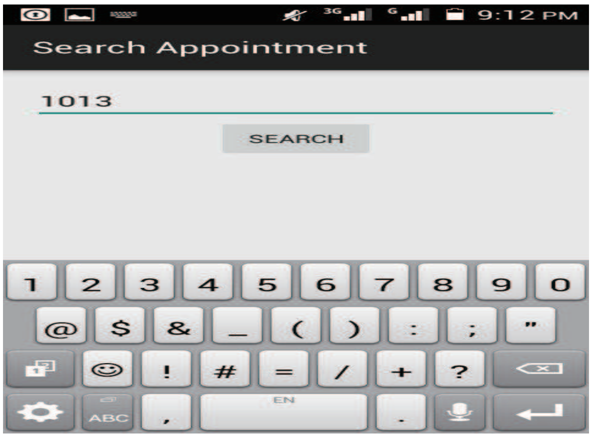

Figure 5: User's confirming the ID Number.

Figure 6: A user accessing the next health care appointment.

a personal account in the healthcare system through a login with the username and password. In Figure 5, the user is trying to confirm its ID number to have an update of the next healthcare appointment. Figure 6, updated the user with the date, time and the respondent on the day of the appointment. Several other users could be sending such information simultaneously, and several different requests will be sent to the healthcare system. These interfaces typically show examples of the type of request coming from the mobile devices that were used during these experiments. These are the interfaces from HUAWEI Ascend Y330 used in performing these experiments.

We later use Apache JMeter to populate more request that outnumbered the limited available mobile devices to test the performance of the design for data availability and other performance testing metrics such as response time and throughput of the network. We carried out some initial tests to measure the smooth connections existing when few requests were issued. We further carried out the test on data availability when the number of the request was greatly increased and we compare the performance of both network design approaches.

5.1. Network availability for patients' data

The preliminary test is to access the rate at which the network is readily available for use in the PHMS when requests are sent via it. The mobile devices in Figure 3. send requests via the cascaded switches being controlled via the controller and routed through to the data reservoir and forthwith back to the client. The aim of this test is to determine the rate of network availability in the two network design approaches that we are considering in this article. By data availability, we mean the number of successfully completed packets sent via the network and returned to the source of the request. We deployed a random sampling technique for the number of the completed request while considering a subset S being an element of a set X consisting a certain number of services to be accessed, thereby testing the rate of network availability under a randomised data samples (see Olken and Rotem [13]).

Considering a given set of patients' data $I = \{S_1, S_2, S_3, \ldots, S_n\}$ having a subset $I' \in S$ being accessed through some queries from devices. The random sampling approach selected about 30 attributes related to individual patients in the database and similar requests to these selected attributes where checked if the query hit or not. When it is successfully completed, we recorded a hit and when not, we have a null hit for the query that was sent. Hence, we defined the availability of network as the ratio of Mean time between failures to that of the sum of mean time between failure (MTBF) and mean time to repair (MTTR) expressed in equation (5.4), (5.5) and (5.6). Thus:

$$\text{Availability} = \frac{\text{MTBF}}{\text{MTBF+MTTR}}. \tag{5.4}$$

Where we expressed MTBF and MTTR as:

$$\text{MTBF} = \frac{\sum(\text{start of downtime} - \text{start of uptime})}{\text{number of failures}}, \tag{5.5}$$

$$\text{MTTR} = \frac{\text{time to restore to normal operation}}{\text{number of failures}}. \tag{5.6}$$

Hence, we calculated the network availability for the network designs.

5.2. Response time

We determine the time it takes for the network to respond to requested data via each of the approaches. It is measured as the time taken in sending the request and the reception of the response between the database and the client. The expression for the Average response time used for the evaluation of the network design is presented in equation (5.7) as

$$\text{Average response time } = \frac{1}{n}\sum_{i=1}^{n}(T_f - T_o)i, \tag{5.7}$$

where: n represents the number of requests,

T_f represents the time when the request was sent,

i represents the request's index.

Thus, we determine the time taken for each network approach to complete the task when several requests were issued within the network environment.

5.3. Network throughput

Determining the number of transactions processed per given time provides the throughput of the network under consideration. In this particular experiment, the throughput was measured to determine how many requests were completely processed per seconds with an increasing number of clients' requests being issued. The throughput for the network designs was determined by the expression in equation (5.8) as:

$$\text{Average throughput} = \frac{1}{k}\sum_{i=1}^{k} ET. \tag{5.8}$$

Where k in this case represents the number of requests at a particular session and i represents the request index that occur over a time to perform an execution (E) over a number of request sessions. Just like the response time and network availability, we use apache Jmeter (Load generator) to simulate more request to test the performance of the proposed network design.

5.4. Rate of network convergence

We intend to understand the performance of the SDN network setup in PHMS with respect to the rate of network convergence. The convergence of network setup flow is different when comparing between the conventional network setup and the SDN based networks. In SDN, the convergence state is reached when the routing table of the controller possesses an updated record of all the shortest routes to all destination nodes. However, in a conventional network setup, the network convergence is expressed as the state of achieving similar routing information on the routers and as well as possessing all the connecting nodes' shortest accessible routes.

However, determining the convergence of a typical network does not have a standard model as a general rule. Different methods were used in (see [20] and Aslam et al. [2]) but we choose to deploy the approach (see Sankar and Lancaster [16]) based on the fact that we can easily access the time it takes a network to recover when a smooth continuous ping messages were interrupted at one end of the network.

Using the OMNeT++ simulator, we designed a network size that depicted the two types of network approaches we are looking at with nodes ranging from 1 to 200 nodes over a number of network links from $x-1$ to $\left|\frac{x\times(x-1)}{2}\right|$. In addition, we also use the parameters in Table 3 to configure the system for proper evaluation of the network convergence. It is important to understand that the conventional networks were proven to work best on Open Shortest-path First (OSPF) routing protocol as compared with others and hence is the chosen protocol for this study with conventional network connections (see Sankar and Lancaster [16]). We propose a convergent algorithm also, to enhance the performance of the SDN system. We run the algorithm to test the performance with respect to corresponding OSPF that is running on the conventional network. The proposed algorithm is shown under the section with Algorithm 1.

Table 3: Simulation Environment.

Parameter	Symbols	Values
Network link range	NLR	10Mbps
Flow table update delay	D_{FLU}	10 ms
Bandwidth of links btw C & S	linkBW	10^8 bps
Controller load factor	CLF	normrnd(1,1)
Forwarding table update delay	d_{FOU}	10 ms
Instruction per second	IPS	2^{15} instruction/sec
Congestion factor	c	normrnd(1,1)
Detection delay	d_d	1 ms
Link Delay	D_L	1 ms
Network depth at fault location	f	$\mathrm{Log}_2(n)$

Algorithm 1: Find rate of convergence (source, destination, reqRange)

```
waitlist ← empty
visited ← empty
prevLink ← empty
waitlist:add(source)
visited:add(source)
dstFound ← false
while (waitlist is not empty) and (dstFound = false) do
                node ← waitlist:remove()
for link ← topologyLinks:connectedto(node) do
neighbor ← link:getDestination()
if visited:contains(neighbor) then
continue
end if
if getAccessRange(link) < requiredRange then
continue
end if
waitlist:add(neighbor)
visited:add(neighbor)
prevLink[neighbor] ← link
if neighbor = destination then
dstFound ← true
break
end if
end for
end while
if dstFound = true then
route ← empty
node ← destination
while (node ≠ source) do
route:addFirst(prevLink[node])
node ← prevLink[node]:getSource()
end while
return route and do
consider all routes links
end while
return conRoutes
else
return null
        end if
```

6. Results and Discussions

On the general performance of the network approaches that have been discussed, we test the degree of variability in waiting times using real life data between the SDN enabled and traditional networks. Based on this result, we further went ahead to determine other subsections results for the performance Modeling. The master controller acts as the server (Master Controller) within the network environment whose utilization is measured by the amount of flows that it handles with each respective experiment that was performed. Hence, the amount of waiting time in (ms) of each request sent is plotted across the rate of server utilization (ε) as depicted in Figure 7.

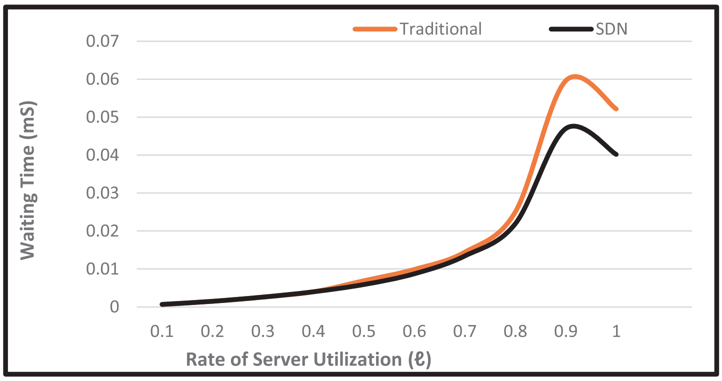

Figure 7: Waiting time against rate of Server Utilization.

The waiting time performance were similar when the initial number of flows were few because the degree of variability is hardly noticed as the rate of utilization is tending towards Zero. However, the coefficient of variation between the two approaches are very small and is less than unity as this point. Considering the rate of utilization of the server, which increases at a linear progression, as against the waiting time in milliseconds, the SDN deployed approach utilizes lesser waiting time in comparison to the traditionally deployed networking approach. Precisely, at the rate of utilization of 0.9, the is a drastic shift in the waiting time, which is higher for the traditional networking approach due to the fact that the capacity of the network can no longer bears the increasing loads, and this is depicted by the increase in waiting time before which the system begins to drop packets and flows.

6.1. Network setup performance

The network setup was carried out using the parameters that were detailed in Table 1. The hierarchical manner of design that was depicted in Figure 1 was used to test the performance of the centralized control system of SDN as against the fused data and control plane conventional system. Our major goal in these simulation scenarios is to quantify, verify and compare the robustness of our design approach with the existing conventional methods thereby determining which of them proffer optimal performance especially in PHMS domain. We coded two different modules. The inputs of these modules are depended on the predefined structures that we formulated in the two different approaches we are considering. In a conventional network, the number of switches is enough to create the whole network setup while for the scalable control plane design, the switch degree and hierarchical levels are also important input parameters.

The performance of the SDN design in terms of its robustness contribution to the efficiency in PHMS networking is evaluated by deploying the graph theory approach to express the mathematical build-up of the network metrics. Hence, the simple programming modules are used to build an adjacent matrix representing the SDN architecture that was designed and set to follow the graph/networks analysis functions. To the fairness of the comparison between SDN designed network and conventional networking approach, the maximum number of controllers are kept at around 30k (32,768) due to the various approaches adhering to their complex default structure and design (see Sridharan et al. [18]). We use network availability, rate of convergence and network stability metrics to measure the degree of robustness and the criticality function of the designed approach. The experiment ensured that the design scale-up by increasing the switch degrees. However, the controller degree is always equal to 2. Ten scenarios were used to test the performance thus achieving a scaling up from 8 to 155 controllers. For this purpose, switch degrees increase from 4 to 16 in these cases.

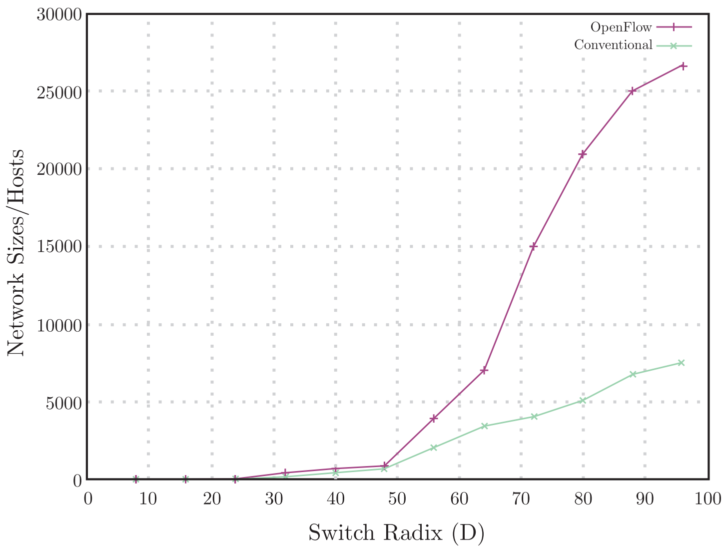

Figure 8: Increasing Network Sizes vs. Switch Radix (D).

Considering the result in Figure 8, we experiment with the performance of the designed SDN approach with increasing switch radix with respect to hosts deployed and the results were depicted in Figure 8. In the situation of low radix switches, the number of ports was few thereby yielding the optimal latency because it has to divide the bandwidths within a minimal number of ports that were available. However, as there was an increment in the switch radix, there is a larger number of ports into which the divisions of bandwidth become easier to carry out and therefore resulting into minimal latency occurrence in the networks. The contribution of our designed SDN based network is seen to yield a lesser latency as well as scaling proportionately than the conventional model even with increasing network sizes or a number of hosts as shown in Figure 7.

Considering the hierarchical order of the network setup, we try to decipher the effect of the network design on the performance of the network. The SDN based network enable the arrangement of the switches in an abstracted hierarchical routing manner that allowed easy resolution of stretching path problem by utilizing intra-switch links and all possible pre-calculated inter-switch links for packet routing. Figure 9 clearly depicted the performance of the hierarchical SDN designed in comparison to the existing conventional network design. Though the hierarchical size of 4 corresponds to the switch radix of 8 for both network designs, the differences began to come into play at hierarchy 50 and 45 respectively against radix 16. Using the hierarchical estimation of $H_{sd} = \frac{\pi d^2}{4}$ where d is the link level for the SDN design as well as linear estimation of the conventional design as $H_{con} = 4d^2$, it was discovered that the hierarchical design is more robust in that it scaled progressively with increasing hierarchical level unlike the conventional approach.

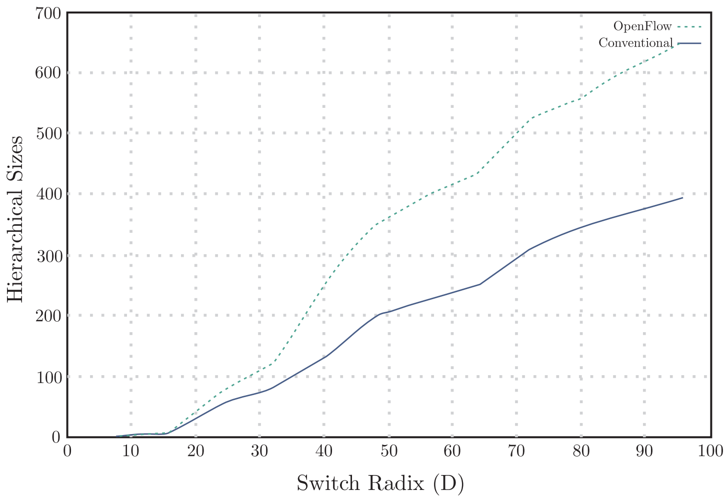

Figure 9: Increasing Hierarchical Sizes vs. Switch Radix (D).

This is purely due to the robustness of the SDN hierarchical design (during network stretch occurrence) to calculate the best path for a packet routing as against the actual route the packet would have taken. The network stretch specifies the best possible path in a network as against the actual path through which the traffic routes. Thus, the stretch problem has purely inhibited the conventional design with the ratio of possible route paths created by the existence of $H_{con} = 4d^2$ multiple links.

Further results depicted in Figure 10 shows the variation of the switch failure experiences in the course of the network setup. The switch failure rate expressed in percentages shows the relative quantity of packet that could not reach its destination or that were dropped over a simulation duration of 100s. This rate of packet sending was also increased with increasing number of nodes via the frequency pulse of the packet transfer in a similar manner for both network designs. The rate of a switch failure in percentages is higher in conventional network approach than the corresponding OpenFlow SDN based network setup. Subsequent to the switch failure rates, is the problem of network stretch being encountered in network setup. As mentioned earlier, the levels of the SDN

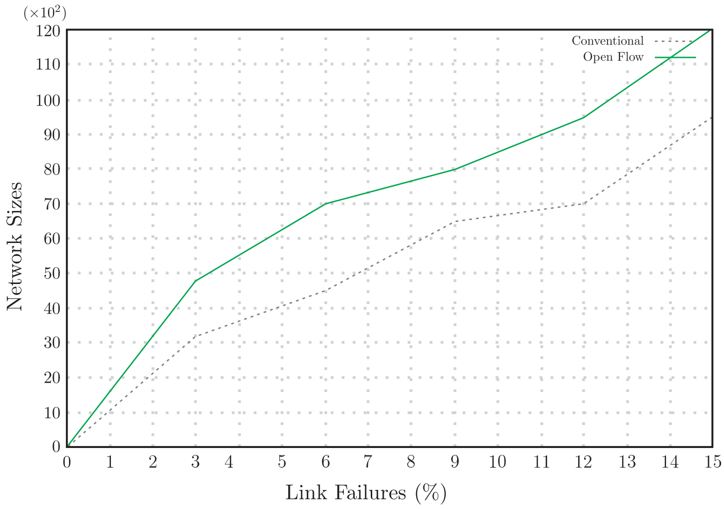

Figure 10: Increasing Network Sizes vs. rate of Switch Failure.

design based network provides the shortest part route through the enabling algorithm, to reduce the stretch value to the minimum possible as an increase in the network stretch presents sub-optimal use of the available resources, thereby predisposing the conventional networking approach to network failure.

We carry out a link failure performance test for the approaches and Figure 11 shows the performance of both approaches to the experiment. It is obvious that as the network size increases, the link failure increases as well. However, the hierarchical approach proved to be a better option at managing the packet loss due to link failure. When

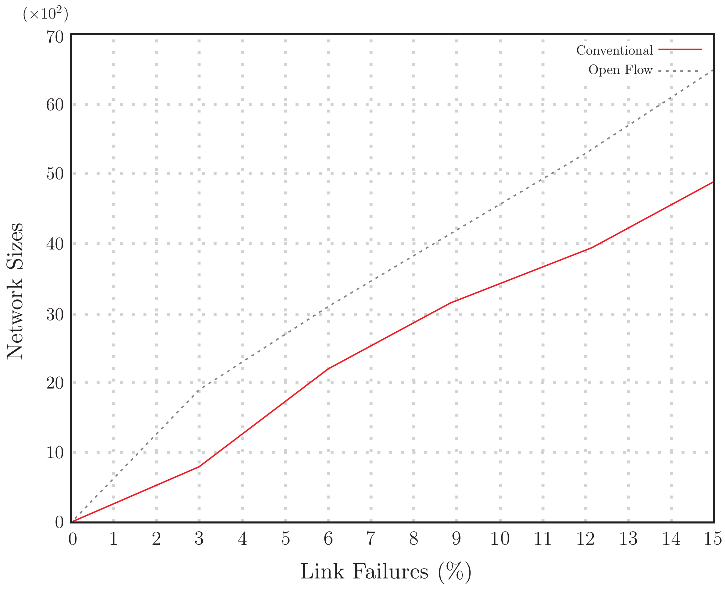

Figure 11: Increasing Network Sizes vs. rate of Link Failures.

there are limited values of network sizes that are sending packets, the conventional approach already recorded higher switch and link failures before corresponding OpenFlow approach. This implies that the conventional or traditional network design is more prone to network instability due to its inability to effectively handle increased or heavy traffic flow coming from the network hosts. It is reasonable to conclude that even though there is an increase in the switch and link failures as the network sizes increases, the trend of SDN based network setup gives a better record of traffic flow performance. One of the major goals of performing the switch and link failure experiments was to determine the stability function of the network approaches whose degree gives us the measure of the performance of the network design.

We defined the stability function (SF) of the network design as the ratio of the rate of link failures to that of the switch failures expressed in percentage thus:

$$SF\% = \frac{\text{rate of } \Delta \text{ in link failures}}{\text{rate of } \Delta \text{ in switch failures}} \times 100. \tag{6.1}$$

Hence, we calculated the stability function for both the conventional network and SDN based network design for evaluation. The result of the stability function for both designs was depicted in Figure 12. We compare the performance of both network designs as we increase the network sizes from 5000 to 25000 nodes. At each level of network sizes, the OpenFlow network design depicted higher stability functions than corresponding conventional network designs. The stability function is a measure of how reliable the network is to avoid the possible or the tendency to be prone to failures. This implies that the higher the value of the stability function of a network, the better is its ability to prevent failure.

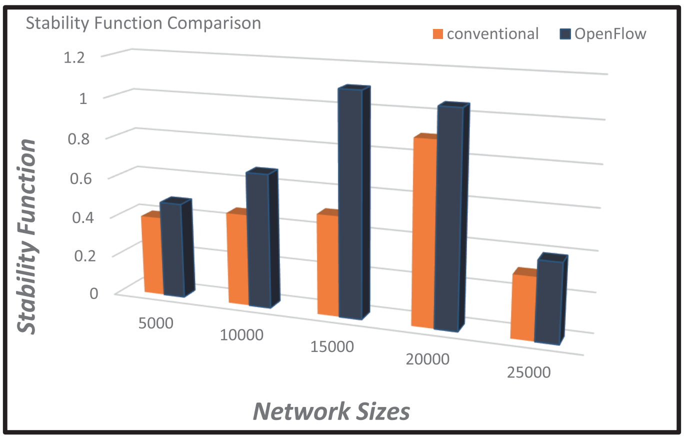

Figure 12: Stability function of conventional and OpenFlow Designs.

Looking at the two approaches, we try to also determine the network criticality which is given as the inverse of network stability. The network, criticality, therefore depicted the tendency for the network to suddenly enter downtime. The inverse of the percentage is expected to be higher in conventional network design compared to the OpenFlow SDN based network design. Hence, this criticality measure of the network is a function of the stability expressed earlier. We can conclude based on the relationship of both stability and criticality that SDN based network has greater stability and lower criticality as against the conventional network approach.

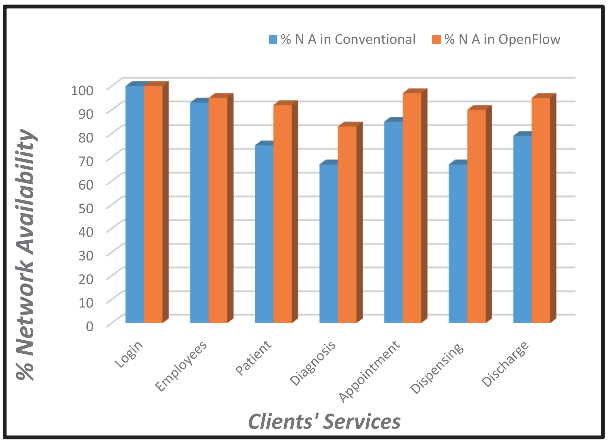

Figure 13: Network Availability Comparison.

6.2. PHMS performance testing

The performance of the PHMS was tested for Network availability, Response time and throughput. The designs were to be evaluated to see how readily available is the network connection to carry out some basic healthcare services amongst the clients and the network servers. We first tested the reaction of the networks when a login service were accessed and due to the relatively simple matching processes involved, an availability record of 100is carried out, there is little or no effect being felt with respect to the network setup. However, when carrying out other health care activities that involve more computational processes and matching of data, it was discovered that the availability of the network to carry out the requested tasks varies with the SDN based network setup providing a better network setup availability. Figure 13 shows the percentages recorded by each of the clients' services with respect to both SDN and conventional network setup.

Additional test which specifies the response time used to carry out each specific tasks with increasing number of requests were provided in Figure 14. The figure depicted the performance of the conventional, and SDN based network design setup. At every instance of time, the SDN hierarchical approach takes lesser time in milliseconds to retrieve the query sent by the devices compared to the corresponding conventional approach. This can be explained by the fact that the SDN approach often bypasses the occurrence of network stretch problem that takes longer route towards achieving packet transfer. The local network routing is restricted only to the premises as controlled by the control plane rather than going via other components when it is supposed to be routed to another network. The conventional approach route the packets outside its domain thus taking a longer time before the requested feedback is returned. Similarly, the result from the throughput for the network design follows a similar output as the number of data that

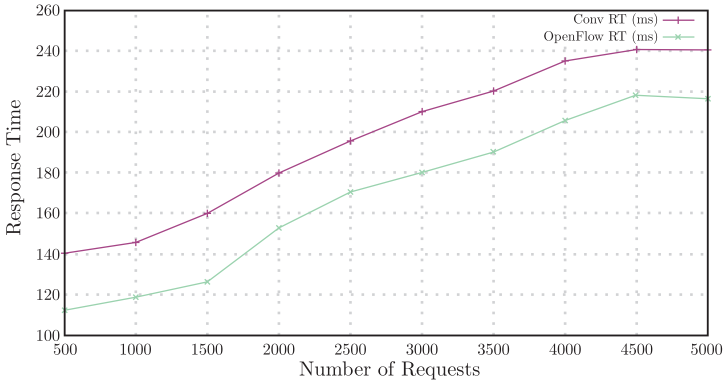

Figure 14: Response Time Comparison.

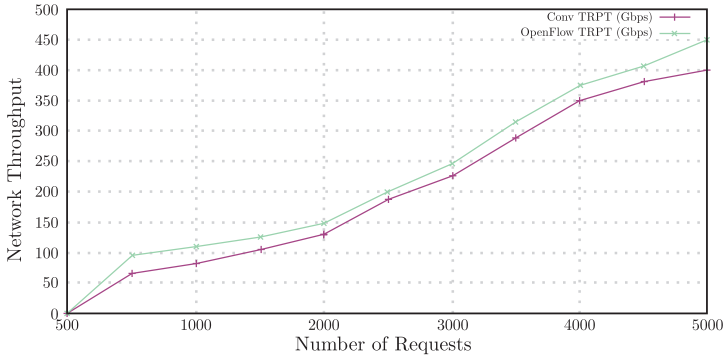

Figure 15: Throughput Comparison.

were successfully routed from one node to the other over a given period of time varies for both designs.

Figure 15 depicted the graphical representation of the performances with respect to network throughput for the designs. As the number of service request increases, the hierarchical oriented SDN based network was able to outperform the convectional approach. The closeness at the mid of the graph typifies the fact that when an average number of the request was made with both approaches, the performance of the designs come close though it is not relatively the same. However, when there is a fewer requests which could just be within the domain and also when there is a larger request which obviously will be both inside and outside the domain, the OpenFlow SDN based network resolves the traffic perfectly without flow interference that usually result into packet loss.

The result depicted in Figure 16 compared the performance of the SDN enabled network with the conventional OSPF routing protocol. Considering the fact that the location of the fault affects the rate of convergence in a conventional network, the speed at which the smaller number of nodes converges in the conventional network is faster than the corresponding SDN based networks. That accounted for the reason while the performances of the OSPF routing protocol in the conventional network performs better at the beginning or initial stages with few nodes/hosts. However, as the number of nodes increases appreciably, the impact of the fault location which invariably has little or no

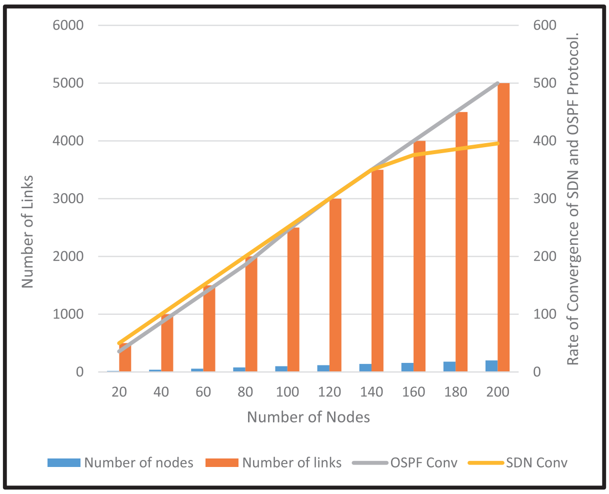

Figure 16: SDN and OSPF-Based Network Convergence Comparison.

effect on the SDN based networks becomes a comparative advantage. This accounted for the OSPF taking longer time than usual towards the end.

Generally, considering the approaches to network design, which could be centralized and or decentralized as seen in the case of SDN and traditional design respectively, the number of experiments conducted in this study shows to us that the deployment of SDN in PHMS network enhance better network performance. This includes prompt deployment of network update, better network stability function, lower network criticality as well as higher network availability function as compared with conventional approach to network design. The ability to perform comparably well especially with the increased number of network hosts in almost all conditions provides a better appraisal and motivation for several healthcare institutions and organizations to develop a greater interest in deploying SDN for better network performance.

7. Conclusion and Future Works

The study in this article proposed the design of public health management system based on SDN approach. We designed a hierarchical network management system that deploys controllers and switches in a network with the controllers being classified into location, zonal and master controllers. Each specific controller is assigned with a unique role in the network to enhance an improved substantial performance compared with the conventional equipment by improved failover time of network path and rate of network stability. The work understood that health care system was rapidly joining the IoT system of interconnected multiple endpoints from various mobile devices. This involves observed objects among which includes image modalities, body monitors, human, medical equipment such as monitors and pumps along with network equipment like IDS, Wi-Fi AP, Routers and Switches as well as some servers which are expected to acts independently and forward some data in form of packets through the network.

The designed SDN-based network in this study enables the separation of the data flow from the control flow of the network. This makes the users benefit from logically centralized monitoring of data flow, defining the performance of data flow and instructing of switches to realize efficient routing of data flows. Some of the experiments conducted on both the conventional/traditional approach and OpenFlow SDN based networking includes testing the effect of Switch radix, increasing hierarchical size against switch radix, the rate of switch failures, link failures, network stability, network availability, response time and the throughput were used to evaluate their performances. It was shown from the results of these experiments that the network resources like bandwidth, ports, and radix were optimised to realise appropriate and appreciable better network performance and recovery from possible failure.

Not only does the SDN approach reduces the cost in term of time needed for carrying out network maintenance, our work showed that there is reduction in waiting time under a relatively controller memory utilization. There is reduction of complexity involved in network troubleshooting, enhances more network consistency and proffers a reliable network convergence in terms of recovery from a fault which is a desirable feature that is required in a PHMS environment.

Conflict of Interest

The authors declare that there are no conflicts of interest arising from the funding received via Telkom SA Ltd, regarding the publication of this paper.

Data Availability

The authors declare that the data used for this study were basically those that were received while the system is opened to students of the University of Zululand for experimentation as well as the primary health care publication in South Africa. The students' data were to test the functionality and efficiency of the adopted approaches.

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