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A Pilot Study to Enhance Semi-Urban Tele-Penetration and Services Provision for Undergraduates via the Effective Design and Extension of a Campus Telephony

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ABSTRACT

Inherent challenges in IP-networks constitutes a major milestone in the convergence of info and communication technology. The advent of 3G and IP-telephony birthed Voice over Internet Protocol as a medium to effectively share data resources protocol amongst connected users. IP-telephony provides a range of multi-service technologies allowing the integration of data solutions onto a converged network via supporting hardware, software and open-source protocols used to control and manage data, voice and video sessions. We propose a VoIP-based telephony for the Federal University of Petroleum Resources Effurun – to help improve campus tele-penetration and provide users with a range of benefits while resolving the issues of latency, packet loss and jitters. Its benefits includes rich media streaming support for blended-learning, unified messaging etc – as it provides support network resilience, economy, flexibility, mobility and productivity for users. Result shows framework resolves the issues of latency, packet loss and jitters.

1. INTRODUCTION

The advent of 3G-communications has today, cascaded onto our society the use of interactive services, originally made possible via public-switch telephone network (PTSN) so that transfer is now expansive (over long distances) without interactions (Hiemstra & Brockett, 2012; Oudalov et al., 2009). The robust use of Internet Protocol (IP) continues to now reinvent communications via new technologies (Iyoboyi & Musa-Pedro, 2020; Jayatilaka et al., 2021), allow users exchange of data, which has fast gained worldwide acceptance with open-source solution (Eboka & Ojugo, 2020b; Ojugo & Otakore, 2018). It embeds functionalities previously required by PBXs, and allow organizations reposition their services for effective resource sharing. A robust network automates daily operational activities – if designed to meet specific user needs (Albert & Tom, 2013; Margossian et al., 2015; Ojugo & Eboka, 2018; Oyemade & Ojugo, 2021; Tullis & Stetson, 2004).

Rural/Semi-urban telephony in Nigeria has become crucial – as a nation's economic growth is hinged on it, and measured via its gross national product, which is also strongly correlated to its telephone density and tele-penetration (i.e., the number of lines per 100 persons) (Fan et al., 2022; Pedro, 2020; Yoro, Aghware, Malasowe, et al., 2023). Rural and semi-urban telecoms users do not generate same amount of data traffic and revenue as their urban counterpart. This, often lowers the incentives to invest by many operators. Cost

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of wiring a vast area with low data traffic causes many providers to delay and ignore the provision of services to such areas except with government's intervention (Chen et al., 2018; Gokarn & Choudhary, 2021; Mao et al., 2018; Yoro, Aghware, Akazue, et al., 2023).

1.1 Telephony for Developing Nations

The increased interest worldwide in the growth of rural areas has led to studies aimed at provision of telecommunication services in rural areas for national, economic and social interactions (Liu & Campbell, 2017; Ojugo & Okobah, 2018; Sun, 2019). The International Telecomms Union defines rural area to have these feats: (a) its primary power source is scarce and uncoordinated, (b) the shortage of qualified technical personnel, (c) existence of topographical conditions that hinders the construction of conventional switching and transmission system, and hampers effective performance, and (d) presence of economic constraint on investment that renders service non-profitable due to high-cost construction and maintenance, especially if cost is borne by the dwellers alone (Ojugo, Yoro, Yerokun, et al., 2013; Ojugo & Yoro, 2021; Valaei et al., 2018).

Thus, a common rule to classify an area as rural are: (a) average subscriber density of 50km max, (b) subscribers range from about 5-to50km and (c) communities to be served are isolated with max of 1000-subscribers. With semi-urban area increased in subscriber density, such telephony thus seeks to provide telecomm services in sparsely populated areas with economic and/or geographical disadvantages (Bangor et al., 2008; De' et al., 2020; Kortum & Bangor, 2013).

Tele-penetration seeks to measure user percentage covered by telecomm services in a country's entire population; While, tele-density measures percentage of such users with telephone lines (Awotwi et al., 2018; Ogheneruemu et al., 2017). The importance of rural telephony in Nigeria is continually demonstrated via the actions of the Nigerian Communications Commission (NCC) – who seeks to identify existence of rural dwellers (Ojugo & Otakore, 2020; Oyemade & Ojugo, 2021), and continues to campaign on the need to bridge the rural-urban dichotomy through the provision of service extended to unserved and underserved areas in Nigeria (Tetfund, 2019). Nigeria's telecoms steady growth, has been dramatic with highlights of growth rate with over 66% in 2020 alone (Ojugo et al., 2012; Ojugo & Eboka, 2019).

1.2. Converged Telephony/Networks

The foundations of a converged network is in its capabilities and tools that allows for user flexibility, cost effectiveness and secure data transfer services (combined data, voice and video) packets across same transmission links via switching, routing and gateway apps and platforms. Thus, converged networks are more secure, fault tolerable, flexible, scalable, resilient and manageability of resources (Ibor et al., 2023; Udeze et al., 2022). Its network ensures transfer service quality, availability, reliability and security. With ICT, user access becomes tethered to wires – assuring the need for wireless devices. Its merits include: low-cost deployment, broadcast the same data to many locations simultaneously, deployment ease in hostile areas, adoption ease and portability. Its demerit are lesser data rates, lesser reusable frequencies, and they are more susceptibility to interference (Delgadoa et al., 2018; Shelke & Sharma, 2020; Vishwanath, 2015; Yoro & Ojugo, 2019).

IP telephony uses signal technology built on Open IP-standards to provide users with end-to-end communication (file, data, voice and video) – to aid data transfer services for public carrier networks and Internet users in general with an inter-operable networks (Lau et al., 2019; Ustun et al., 2011).

IP-telephony involves a large family of communication standards to deliver voice and video services via open packet network and uses the H.323 protocol to setup, control and manage sessions. Its benefits includes thus: (a) allows call services anywhere on the network and use packet networks rather than TDM, (b) allows service delivery so that dual cabling and network equipment for PBX or IP-PBX connections is not required, (c) can carry data traffic from a variety of vendors and across various nations (Nallaperuma et al., 2019; Parsons et al., 2015) – interfacing a variety of Internet/phone technologies with better flexibly, at reduced implementation and operational cost. A converged network extends the capabilities of an IP network over a PSTN (when built to use underlying the infrastructure) and protocols (Algarni et al., 2017; Zawislak et al., 2022).

Benefits of converged network is derived from its fundamental capabilities to provide these merits (Allenotor et al., 2015; Joloudari et al., 2022; Ojugo et al., 2016; Ojugo & Allenotor, 2017; Oyemade & Ojugo, 2020):

1. Economy – It mitigates the high-cost in traditional legacy PSTN via IP-networks, rendering services via Ethernet economics providing lesser cost connections to other sites and to other apps.
2. Flexibility – PSTN are mostly proprietary, monolithic and restrictive. IP-network has virtual reach with resources distributed on demand anywhere needed, and economies are gained via centralized gateway. It helps facilitate communication via support for broadband voice, office integration app, outsourcing task, mobility, telecommuting, automation etc, and leverages a plethora of emerging web services.
3. Security – It achieves higher degree for secure transfer that is superior over legacy systems; while deploying and integrating wireless LAN apps, video surveillance, IP video on demand, streaming and rich media conferencing applications.
4. Productivity – Its cost savings enables users become more productive with apps to help accomplish higher transfer quality more quickly and easily. Its end-users can benefit from of web services and tools.
5. Resilience – allows for business continuity and disaster recovery to keep an organization connected for survivable services. Its redundancy is built into intelligent layer technologies and apps. Clustering and hot standby technologies, fault tolerant storage technologies like RAID, dual power supply are now common. IP offers superior failover, self-healing and redundant abilities with easy to deploy supports and open-standards communication via feats of reliability, availability and superior alternatives than PSTN.

1.3 Study Motivation and Goal(s)

A critical analysis of the existing system using 4G/5G model (i.e. hybrid PSTN/PBX) at Federal University of Petroleum Resources Effurun implies legacy system has the issues:

Difficulty to accomodate different vendors and their disparate technologies and equipment due to control and local competitions.

a. Diffuculty to traverse geographical area coverages and boundaries
b. Managing sites centrally
c. Change how resources are used on a network
d. Difficulties in thse MTOs in traversing the various regulatory boundaries
e. Inability to deliver new communication services using different media types
f. Provision of the needed levels of integration to ease of telephony use, to ease access to users and management found in IP telephony systems.

The study seeks to address IP telephony at Federal University of Petroleum Resources Effurun over an existing PSTN/PBX system, provisioning an IP-network with a plethora of benefits. Our study x-rays the technical issues of such a hybrid IP/PSTN/PBX telephony.

2. MATERIALS AND METHODS

2.1 Planning the IP Converged-Network

Issues to be addressed by this IP-network falls into three divide: (a) ***Geopolitical*** deals with coverage area's social, educational, political and economic history, (b) ***Economic*** is the initial investment required to deploy such communication services via installation of facilities and equipment in such a remote region, its operational cost and the user's revenue generating capacity – so that such a service can be provided for, supported financially and keeping its subsidies to a negligible minimum, and (c) ***Technical*** is availability of technology to implement such design, regulatory framework, communities' size, expected traffic, type of communication services, and the availability of a technical crew (Ojugo, Yoro, Oyemade, et al., 2013). Thus, the study focuses on all technical issues involved in deployment of an IP-network to enhance rural telephony.

Planning an IP-net on FUPRE existing hybrid PSTN/PBX, the researchers took into account that such network services can and should be accessed by both staff and students. Network is designed to cater for 15000 users (staff/students). The Nigerian Universities Commission stipulates that for effective learning, a department should have a teacher to student ratio of 1:20 for Science and 1:15 for Engineering. With over Fifteen thousand students and close to a Thousand staff, we seek to design a network with a bandwidth that will cater for over 20000subscribers simultaneously. The 2-major issues that threatens service quality are as thus:

1. Packet Loss – results from net congestion, buffer overflow, undesirable transfer, discarded packets, retransmission abilities from protocols etc. Apps using RTP for TCP is more tolerant to packet loss than UDP apps. Bandwidth allocated helps curb this. Deciding how much bandwidth is allocated to a service requires careful consideration such as an organization priorities, available bandwidth and its cost. Thus, selected bandwidth to support 1,000 full-duplex G.711, encoded voice channels, with 20ms packet creation and 200bytes packet size (160B payload + 40B IP header) is computed as thus:

$$Sample\ S = \frac{1000ms}{packet\ creation} = \frac{1000}{20} = 50bps$$

$$Bps = S * Packet\ size * All\ calls * 8bps$$

= 50 * 200 * 1000-calls * 8bps = 80Mbps

The measure of the IP traffic does not account for the overhead time packet used by transport media (i.e. links between the routers) and data link protocol. Thus, we determine the link speed to support the required number of calls by adding this raw value to the overhead. Our bandwidth requirements will vary depending on the rate calls are generated and the signaling protocol used. If a large number of calls are initiated in a relatively short time, the peak bandwidth needs for the signaling can be high. Note the maximum amount of bandwidth required by IP signal protocol is roughly 3% of all bearer traffic. Thus, 1,000-calls can be initiated in 1-sec is approximately 2.4Mbps (3% of 80Mbps).

2. Jitter is difference between expected time and actual arrive time of a packet. With a constant packet transmission rate of 20ms (as in design), new packets are expected to arrive at destination every 20ms. However, jitters are caused by queuing variations resulting from ongoing changes in traffic loads as well as when one or more packets takes a different equal cost link not physically (electrically) the same length as the link used in other voice packets. To curb this, we used media with play-out buffer to buffer packet stream so that the reconstructed voice wave is not affected by jitters (or rather minimized).

2.2. Rationale of the Study

The study seeks connectivity of systems to aid effective and efficient resource sharing. Network have ushered in better and unlimited opportunities for resource collaboration and sharing for professionals in different fields both locally and globally. This study seeks to design a scalable and robust network that improves communication and management capabilities for both management, staff and students of Federal University of Petroleum Resources Effurun. It hopes to achieve with the following objectives:

1. Analyse existing network and identify the requirement needs from its initial state.
2. Determine the physical architecture of the existing network and its limitations.
3. Generate a requirements document as the needs list for a proposed network.
4. Compute the estimated data flow as well as recommend appropriate data security and safety measures for the infrastructure.
5. Run simulations of proposed network via the Riverbed Modeler Academic Edition.

2.3 Data Collection & Existing System

The study seeks to modify the existing network infrastructure at Federal University of Petroleum Resources Effurun in readiness for adoption and implementation of the VoIP-based solution. A breakdown of community population size is listed in the Table 1, while Tables 2, 3 and 4 shows available hardware and software in the existing network.

Table 1: Fact-sheet of User Population

No	Population	Number	Training
1	Management Staff	12	Yes
2	Academic Staff	348	Yes
3	Non-Academic Staff	775	Yes
4	Student(s)	2364	Yes
5	Technical ICT Team	14	Yes

Table 2: Fact-Sheets for User Population

No	Population	Status
1	Internet services provider:	Wide coverage with 3Mbps or higher broadband is ideal.
2	10Base-T to connect devices	Upgrade Required
3	100Base-Tx Ethernet Tech Connectivity between servers	Upgrade Required
4	Category six cabling	Still useful
5	3-CISCO ME 3640 24CX Series Ethernet Switches	Still useful
6	1-CISCO 7000 Series Router, reached end-of-life	Still useful for backup
7	1-CISCO Aironet Wireless 1800 Access Points in classes	More Required
8.	Ethernet connectivity in offices	Upgrade Required

Table 3: Fact-Sheets of Server and Devices

No	Hardware	Status
1	HP Pro-Liant DL560 Gen8 Servers with Server, two 750 GB HDD Working on RAID	More Servers required. Upgrade to Hp Proliant Gen-10 Servers.
2	Workstation	Additional Required
3	Network Printers available	More Required

Table 4: Fact-Sheets of Application Software

No	Software	Status /

		Recommended
1	MS Secured Safe Server	Upgrade to Microsoft Visual Studio Team System Server
2	MS SQL Server 2008	Upgrade SQL Server 2012
3	Active Directory	Still Useful
4	MS Exchange Server 2010	Still useful
5	Web Server (MS IIS/8.5)	Still useful
6	MS SQL Server 2008 R2 RTM	Still useful
7	MS Virtual Machine Server 2008 R2	Still useful
8	DHCP Server	Still useful

2.4. Layout Architecture of Existing Design

To reflect applications, device and user requirement, our software requirements and specs document(s) provides the various fact-sheets seen from Table 1 to 6 respectively – to yield a proposed network to withstand the challenges expected by its potential users. Tables 5 and 6 yields the breakdown of these various requirement specifications.

Hp Proliant Gen 10 Servers is proposed to be deployed. HP may not give support to the Gen 8 servers after the year 2023 as the server has reached the end of its service life. Gen 8 servers may not also support some new application and utility software packages which may be installed on the server.

To reduce packet loss and jitters, we suggest thus: (a) Ethernet cabled network is used in the ICT suite and offices, (b) wireless LANs deployed in the classrooms for easy access to students, and (c) cloud storage for data has been proposed. These, will allow for: (i) access to critical data remotely by staff at any time of the day, (ii) quick and efficient recovery due to down time, (iii) seamless data failover due to down-time, and (iv) limited cost on alternate source of power considering poor public supply. The collocation centre ensures constant power supply to network devices being hosted.

The office suite proposed is Office 365. This has an online version which is free for educational organisations. It also comes with others server applications. The Offline versions can be purchased at a subsidised rate for only key officers in the organisation. This provides a cost effective option than purchasing Office licenses for individual users or buying an enterprise version for use by the organisation. It also prevents any form of litigation from using unlicensed soft wares as it is popularly done around.

The network topologies used in a design is quite essential as it greatly influences and is responsible in determining the network's overall performance (Eboka & Ojugo, 2020a). There are two types of topologies: physical and logical. Physical topology consists of the device and their cabling layout. The logical topology deals with the pathways data signals undertake as routes from one point to another (Ojugo & Yoro, 2021).

The logical layout for the existing network is a flat network topology – from simplicity of network operation and functionality. Basic operations allow for integration as alternative delivery and result storage system. Course registration forms were accessed from the Web server; while, completed forms are stored back into the database server. The traffic generated in the network was periodic. Thus, network has few issues at peak periods. This can no longer be the case in the event to incorporate new apps and user groups (Akazue et al., 2022, 2023; Ojugo & Okobah, 2017; Okobah & Ojugo, 2018).

Table 5: Fact-Sheet of Proposed Network Specification

No	Type	Description	Gathered At	Location	Status	Priority

1	Device	Cisco ASR1002-X Chassis Routers	Initial Condition	ICT unit	Core	High
2	Device	Cisco Aironet 3600 Series	Initial Condition	See Map	Core	High
3	Device	Hp Proliant Gen 10 (1.5TB) Server for all Servers (and VMs)	Initial Condition	ICT unit	Core	High
4	Device	Cisco Catalyst 6500 Series Switches for distribution layer	Initial Condition	ICT unit	Core	Critical
5	Device	Hikivision CCTV camera to enhance physical security in ICT	Management	See Map	Core	Critical
6	Device	Swipe cards for authentication	Management	ICT unit	Core	High
7	Network	10GB Category 5-E cables for patch panels	Management	See Map	Core	High
8	Network	10GB Category Six cables for host to Servers	Management	See Map	Core	High
9	Network	1GB multimode fiber server backbone	Management	See Map	Core	High
10	Network	Cisco ASA-5550 Adaptive Security Appliance	Management	Server Room	Core	Critical
11	Users	Training of various categories of staff	Management	TBD	Core	Critical
12	Business	Minimal Budget (btw £300,000 - £400,000)	Management	Info	Core	High
13	Business	Minimal disruption of organizational activities	Management	Info	Core	High

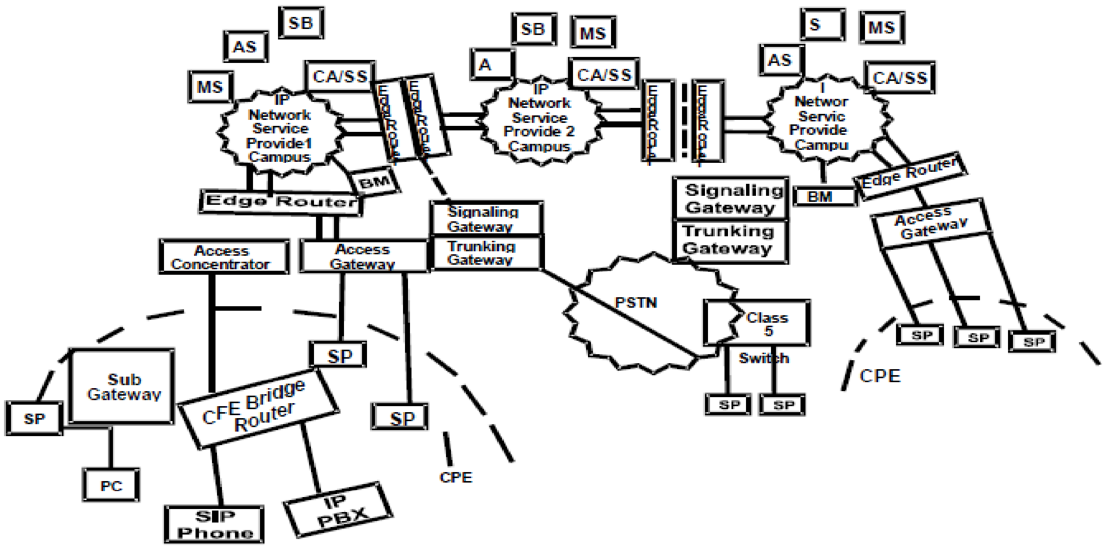

Figure 1: VoIP-solution framework for the Federal University of Petroleum Resource

Table 6. Fact-Sheet of Proposed Application on Proposed Network

No	Type	Description	Gathered	Location	Status	Priority

			from			
1	Application	Active Directory and Domain Controller is installed on main and backup servers	Management	Server Machine	Core	Critical
2	Application	Microsoft SQL Server 2012 to link to the Database Server	Management	Server Machine	Core	Critical
3	Application	MOSS SharePoint 2008 for data and protocol centralization	Management	Server Machine	Core	Critical
4	Application	Office 365	Management	Server	Core	High
5	Application	NovaBack16: Disaster Recovery Backup	Management	Server Machine	Core	Medium
6	Application	Antivirus Software	Management	Server	Core	Critical
7	Application	Payroll Software	Management	Dedicated Machine	Core	High
8	Application	Microsoft Virtual Server 2012	Management	Server	Core	Medium
9	Application	DNS Server	Initial Condition	Server	Core	Critical
10	Application	DHCP Server / Solar Wind Suite	Initial Condition	Server	Core	Critical
11	Application	Cloud server storage		Cloud	Core	High

3. RESULT FINDINGS AND DISCUSSION

The Riverbed Modeller, Academic Edition 17.5 was used for the first sets of test. To effectively run the simulation, we properly configured software with required apps, user population – via an application configuration and profile configuration options.

3.1. Application Response Time

This metric determines the time interval between a user's request and the actual time a response is fed back. To achieve response time of Database Query, HTTP Page, file downloads from FTP and Email Server was tracked as in figures 2. Figure 2 shows the application response time and that of other options for 20,000-users and/or subscribers.

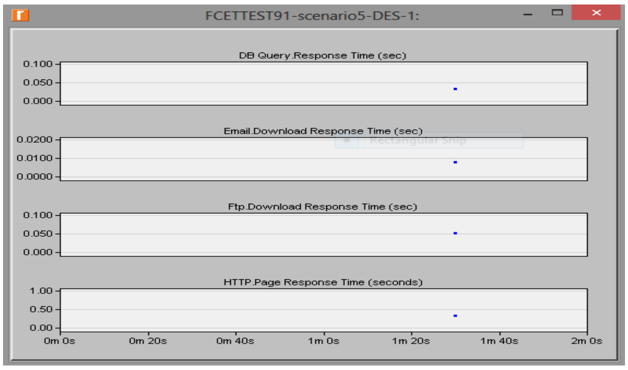

Figure 2: Response time with 20,000-users

Result show Database queries with 0.38secs, 0.008secs for Email, 0.052secs for FTP, and 0.32secs for HTTP retrieval. Thus, network is quite fast, with high scalability. Table 7 is the result for applications response and network scalability test simulation results.

Table 7: Application Response & Scalability

Items	Time	Time

	Secs	Secs
DB Query	0.38	3512
Email	0.008	3512
FTP	0.052	3512
HTTP	0.32	3512

3.3. Availability Test

A ping command is used to reach the different nodes on a network. It sends Internet Control Message Protocol to different devices across the network. Figure 3 shows the execution of a PING command to seek the reachability and availability of the network.

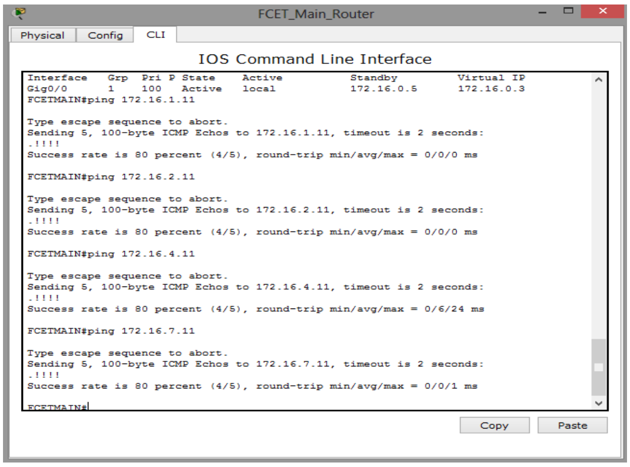

Figure 3. Reachability/Availability Test

From figure 3, we clearly see different nodes were sent echo request, and an eighty per cent (80%) response rate was gotten. This was solely because it was the first time. Subsequent echo request had a success rate of a hundred per cent. This clearly shows that the different nodes were reachable.

3.2. Throughput Testing

It is defined as the actual transfer rate of data in a medium over given a period of time. Being another performance metric test, throughput test is essential because the capacity of a network can be affected by interference and errors, thus making the stated capacity quite different from the actual capacity. The data transfer rate of the four LAN segments were analyzed as in Figure 4.

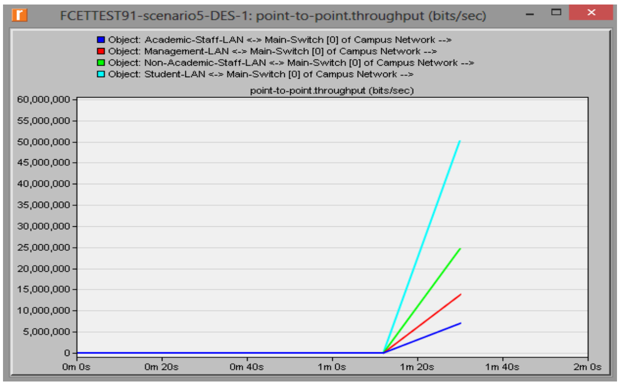

Figure 4. Throughput test for Data Transfer

The highest transfer rate or throughput is about 50,000,000 bps (i.e. about 47.68mbps) – coming from student LAN; while, lowest came from the management LAN with about 7,000,000 bps (i.e. about 6.68 mbps) as in figure 3. Our cabling from the various LAN to the main switch uses the multimode fibre optic cabling with a bandwidth capacity of 9.92Gps. As such, the effect of the highest throughput has no negative consequence on the network. With our LAN cabling capacity, optimal performance is expected.

4. CONCLUSİON

Study explored standardized approaches to network analysis, design, architecture, modelling, testing and optimization to deliver a network that met the requirements of the stakeholders of the client organization. To ensure that users' requirements were met, hierarchical design was employed. It ensures the requirements of the various stakeholders formed the basis for which diverse network topologies, apps, protocols and devices were chosen. The constraints of resources, time and energy made it impractical to explore many more opportunities from a technical viewpoint. Study implements four apps on the designed networks namely centralized data storage, file transfers, web services and e-mail services.

We recommend implementing the voice over internet protocol (VoIP) and campus-cloud for internal communication and external data storage respectively. VoIP will guarantee an optimal utilization of the network infrastructure; while, campus cloud in its variations will provide a reliable platform for data recovery and network agility required by organizations in today's competitive world. In a nutshell and from the various test carried out on the network, the basic functions of the proposed network were working as stipulated and in tandem with the project objectives. We opine that the deployment of this network as stipulated will meet the needs of the various stakeholders.

Conflict of Interest

The authors declare that there is no conflict of interest.

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