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AN EVALUATION OF LEGACY 3-TIER DATACENTER NETWORKS FOR ENTERPRISE COMPUTING USING MATHEMATICAL INDUCTION ALGORITHM

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ABSTRACT

In today's internet computing, regardless of the scale of infrastructural integrations, the design cost, QoS, power management etc, largely plays a role in the choice of design. In this paper, we present the limitations of traditional Data Center Networks (DCN) for efficient web application integration in enterprise organisations. We carried out an in-depth study on typical enterprise DCNs viz: University of Nigeria DCN and Swift Network DCN Lagos state-Nigeria, seeking to ascertain the limitations of the traditional DCN with respect to throughput, latency, scalability, efficiency in web application integration, etc in QoS context. Microtic Server and Ethereal Wireshack were employed for traffic trend observation and packet captures on a monitoring Dell Inspiron laptop connected to the UNN DCN. The traffic graphs were captured, computed and analysed. From the results obtained, deductions were derived while articulating on the limitations of these networks. Using mathematical induction theorem, we show that for any introduced network enhancer, this will enable such a network to scale optimally. In this regard, this work opines that for large scale enterprise computing, collapsing a three tier network models into a low cost two-tier model using virtualization and consolidation will be widely celebrated. These forms the basis for our future work on a re-engineered DCN for enterprise web application integrations.

Keywords: Internet, Computing, Efficiency, Application, Ethereal, Wireshack, Enterprise

1. INTRODUCTION

1. Introduction

Large data centres are built around the world to provide various online services [1]. The deployment trend shows that the number of servers in data enters continues to grow exponentially. Companies like Amazon, Google, and Microsoft currently runs mega-data centres for cloud computing services. The recently proposed shipping container data center [2],[3],[4],[5],[6], and [7] takes a modular approach, which is called Modularized Data Center (MDC) houses servers up to a few thousand, which are interconnected and placed on multiple racks within a standard, say 40- or 20-feet, shipping container. Efforts are made to significantly reduce the costs of cooling, powering, and administration in a container [1]. Most enterprise organizations still run a three-tier DCN as shown in figure 1. In these multi-rooted tree topologies, a key limitation of these networks is that two or more large, long-lived flows can collide and end up on the same output port, creating an unavoidable bottleneck [8] as illustrated in Figure 1b. There are a few disadvantages to the three-tier application model [9]. For both large and medium scale DCNs, this work recommends that organizations should leverage optimal approaches to improve the performance of their DCNs.

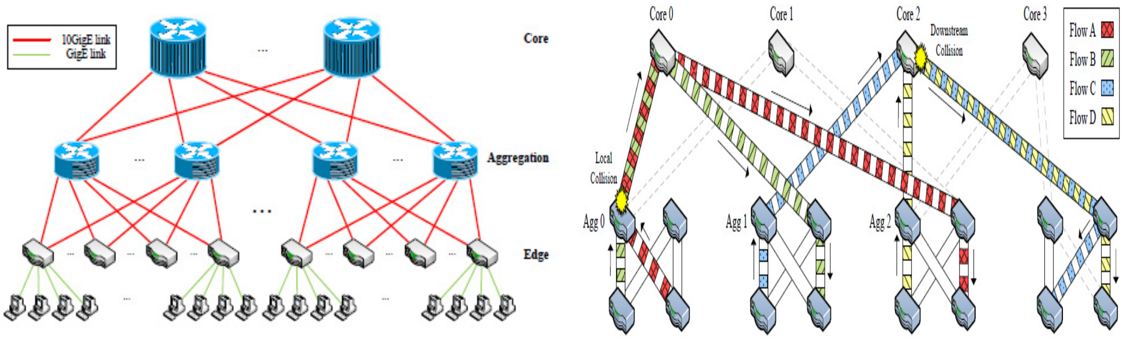


Figure 1: A common multi-rooted hierarchical tree with redundant links, (figure 1a &1b) [8]

The model comprises of the core, aggregation and the edge/access layer. This model does not scale well for computational-intensive applications such as financial modelling, animation, manufacturing and search engines. Another disadvantage is that often complex traffic engineering is required to optimize performance. Finally, the Total Cost of ownership (TCO) of this architecture can be high due to inefficient use of physical server infrastructure with high power, cooling and space requirements [9]. These will be ascertained from a set of selected testbeds where experimental investigations was carried out in this research.

2. RESEARCH OBJECTIVE

Our objective in this work is to show the limitations of existing three-tier network implementations for DCNs while arguing that with the collapse of such networks to a two-tier model as well as introducing network enhancement schemes, optimal performance will be derived in the resulting two-tier model

3. METHODOLOGY

3.1. Traditional DCN System Analysis.

In this section, an analysis of the traditional DCNs was carried out to ascertain the extent of efficiency in three-tier architectures. In carrying out this study, two typical traditional DCNs were visited, and their key design features/parameters were gotten. We however carried out our performance analysis on only one of them for the purpose of this work. The first is Swift Network enterprise data center network-a leading regional Internet Service Provider (ISP) situated at No 3 Isaka Tinubu, Victoria Island Lagos, Nigeria. Figure 3.1 shows the DCN setup of the Swift DCN. While Table 3.1 shows the design features and parameter.

Table 3.1: Design Features/parameters of Swift Network DCN

Features/Parameters	Specifications
Link Connection	Fibre Cables
Switch ports	24 and 48
Terminal nodes	4 major nodes
Network Architecture	Three-Tier
Network Topology	Servers-In-Rack
Server Clustering	Yes
Storage Area Network (SAN)	Yes

Figure 3.1: Swift Network Three-Tier DCN (Source: No 3 Isaka Tinubu, Victoria Island Lagos, 2012).

The second typical DCN which is the experimental testbed used in this work is the data center network of University of Nigerian Nsukka. The testbed setup is shown figure 3.2. Table 3.2 was gotten which shows the design features/parameters of the DCN. The DCN supports 500 user sessions with 20 servers (HP proliant 380G5, 370G5 server cluster model), two routers with SAN as a storage technique.

The total number of switches in the DCN is 10 with 48ports each on three-tier architecture. The web applications on the DCN includes: students portal, black board-Library management system (LMS), Koha Library management system. On the

DCN, a Dell Inspiron 1525 with a quad-core Intel Xeon 5520 2.27 GHz processor and 4 GB RAM was connected to port 8 of the DCN switch while running Etheral wireshack on the DCN to capture real life packets.

Figure 3.2: UNN Three-Tier DCN,(Source: University of Nigeria Nsukka, 2012)

As depictd in figure 3.2, the server cluster runs MikroTik RouterOS V2.5 which coordinates the traffic flow on the DCN. The coordinated interfaces are setup with following the TCP IP address viz:

http://10.0.0.1/graphs/iface/Internet/,*http://10.0.0.5/graphs/iface/vlan%2061/*, *http://10.0.0.1/Admin*,
http://10.0.0.5/Admin,
http://10.0.0.5/graphs/iface/Server%2090/,
http://10.0.0.5/graphs/iface/vlan%2061/.

However, two major servers were used viz : *http://10.0.0.1/graphs/iface/Internet/* and *http://10.0.0.5/graphs/iface/Internet/*.

On the server, over 400 requests with allocation time of 0.35ms carry online activities. Users connect to network from 8am-6pm in the DCN. The servers maintain reservations across the network and allocate tenant requests in an on-line fashion. The enforcement module on individual physical machines implements the rate computation and rate limiting functionality. For each user, the server acts as a controller and calculates the rate limits. Enforcement module in the server then use the mikrotic traffic control API to enforce local rate limits on individual machines. The deployment of the DCN server was arranged in a three-tier pattern in the racks.

The servers, switches and wireless/wired routers are all connected with 1GB Ethernet, which is connected to a root switch. Each interface is 1 Gbps. Hence, the testbed has a three-tier tree topology with the end hosts are both wired and wireless devices. Given our focus on quantifying the traffic performance and utilization of DCN resources for a three-tier model, this work then used Wireshark to capture network statistics alongside with the Microtic on the two-server IPs. Each user must be assigned to a distinct VLAN

Table 3.2: Design Features/parameters of UNN DCN

SIMULATION PARAMETERS	Specification
Link Connection	Ethernet GBE
No of Servers	20
No of routers	2
No of switches	10
Switch ports	48
No of server resources	10
No of terminal nodes	Maximum of 500
TCP	Solaris
Server model	HP proliant 380G5, 370G5
Network Architecture	Three-Tier
Network Topology	Servers-In-Rack
Server Clustering	Yes
Fast Network Convergence	Average
Storage Area Network (SAN)	Yes

3.2. Data Collection (UNN DCN)

3.2.1. MicroTik Server [x1]

The main product of UNN DCN server is the MikroTik which is a Linux-based operating system (known as MikroTik RouterOS) installed on a proprietary hardware (Router-BOARD), turning the computer into a network router and implements various additional features, such as firewalling, virtual private network (VPN) service and client, bandwidth shaping and quality of service, wireless access point functions and other commonly used features when interconnecting networks. A Microsoft Windows application called Winbox provides a graphical user interface for the RouterOS configuration and monitoring, while the RouterOS also allows access via FTP, telnet, and secure shell (SSH). Runing on the network servers, as the users transverses across the network, the network traffic trends were captured for 48days as shown in figure 3.3 for few captures.

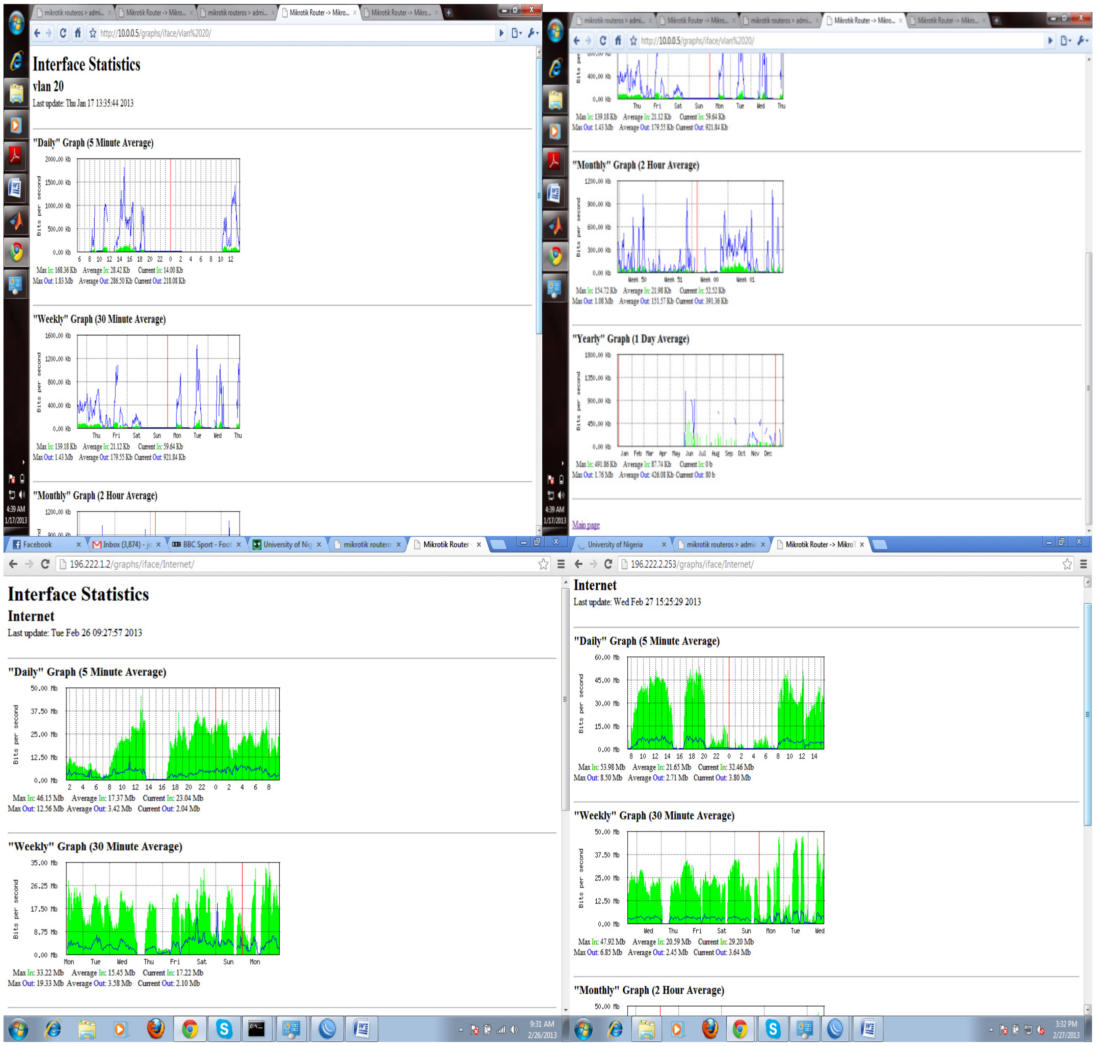
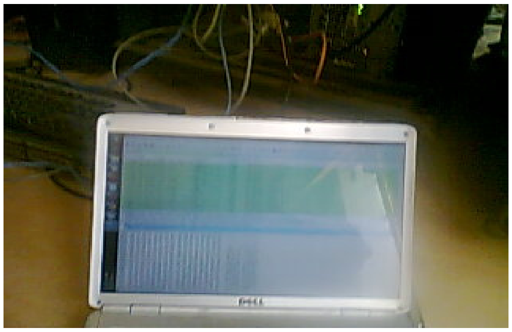


Figure 3.3: Real-time Traffic Statistics on UNN DCN.

3.2.1. Ethereal Wireshack

The Wireshack Protocol Analyzer filter provided excellent tracking information on the DCN. The filter analyzer as shown in figure 3.4 is used to filter TCP traffic like *http.unnportal.com*. The filter enabled extraction of different data flows that occur during an HTTP connection (text/html, application/zip, audio/mpeg, image/gif, etc.). The dataset used in this study comprises of two sets of measurement data. The first data set comprised of Simple Network Management Protocol (SNMP) data extracted from port 7 of the DCN switch.

The data center support a wide range of applications such as search, video streaming, instant messaging, map-reduce, and web applications. SNMP data provides aggregate traffic statistics of every network device (switch or router) in five minute increments and is typically collected because of the infeasible storage overhead required to continually collect detailed packet traces from all devices. The second data set is comprised of packet traces from port 12 of the DCN switch. Figure 3.4 shows the Etheral testbed while figure 3.5 shows the network traffic statistics plots.



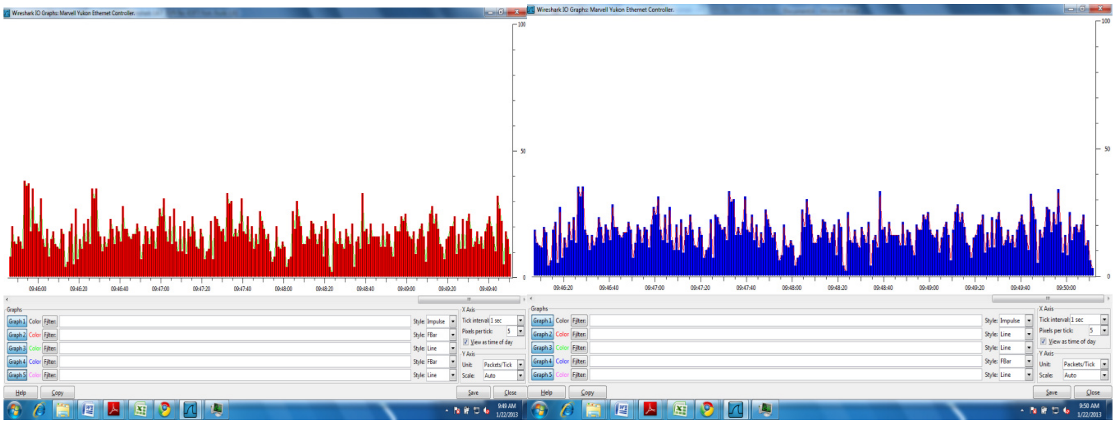
I Figure 3.4: Etheral Wireshack Analyzer (UNN DCN)

3.3. Network Macroscopic View

This work identified the three-tier of data center traffic by first examining the data capture from figure 3.4 while observing the link utilization and packet losses at the core, edge, and aggregation devices. Several captures depicting the patterns of data center traffic was achieved as trace files. The observations made on the three-tier model is very significant for improving the network performance.

In this work the link capacities of aggregation and core links are the same (1GB) except that the Edge links have slightly higher utilization than aggregate links because of their lower capacities (100Mbps) at the edge vs 1Gbps or 10Gbps in the aggregation). Surprisingly, in spite of the higher utilization in the core, core links observe the least loss rates, while links near the edges of the data center observe the greatest degree of losses. This suggests that traffic is more bursty on aggregation and edge links than on the core links in a three-tier model. Another important observation is that a small fraction of the links experiences much bigger losses than the rest of the links. Thus, it is possible to route traffic on alternate paths to avoid most of the losses. Given the large number of unused ports (40% are never used), an ideal traffic engineering scheme would split traffic across the over-utilized and the under-utilized ports.

Again, by examining the link idleness in one of the data center switches, it is observed that although a large number of ports are unused, the exact set of ports that are unused remain passive. From figure 3.7, this work observes that 80% of the unused links are idle for the duration of two months but this have no effect of the DCN traffic flow. As shown in the statistics graphs (figure 3.5), the traffic in the data center can be quite bursty, which accounts for the unpredictability of idle links, low bandwidth scalability and makes existing traffic engineering schemes less applicable and insufficient to serve the myraids of web services and end users. The network utilization plot like bandwidth, service availability, and throughput are shown for the two servers in figure 3.5



Wireshark IO Graphs: Marvell Yukon Ethernet Controller

Graph 1 Style: Impulse
Graph 2 Style: FBar
Graph 3 Style: Line
Graph 4 Style: FBar
Graph 5 Style: Line
X Axis: Tick interval: 1 sec; Pixels per tick: 5; ☑ View as time of day
Y Axis: Unit: Packets/Tick; Scale: Auto

Wireshark IO Graphs: Marvell Yukon Ethernet Controller

Graph 1 Style: Impulse
Graph 2 Style: Line
Graph 3 Style: Line
Graph 4 Style: FBar
Graph 5 Style: Line
X Axis: Tick interval: 1 sec; Pixels per tick: 5; ☑ View as time of day
Y Axis: Unit: Packets/Tick; Scale: Auto

Figure 3.5: Real-time Statistics Graphs of Network Devices in UNN DCN.

3.4 Data Analysis and Results (UNN DCN).

For the purpose of this analysis, the frame data capture from figure 3.4 was tabularized in Table 3.3 which features: frame number, frame data capture time, source address, destination address, throughput and latency.

Figure 3.6 which is a throughput plot shows a high level of fluctuation and irregularity in the throughput as frame data capture time increases. Such fluctuations and irregularities together with the sharp fall in the throughput at 160 seconds are totally unacceptable for efficient web application integration in enterprise organizations. Similarly, in the latency plot of figure 3.7, the DCN maintained a desirable latency until around 150 seconds when it rose so sharply.

Table 3.3: Frame Data Capture (UNN DCN).

Frame Number	Time (s)	Source	Destination	Latency (seconds)	Throughput
1	10.000000	192.168.0.1	239.255.255.250	0.000000000	304.8
2	20.000004	192.168.0.1	239.255.255.250	0.000004000	296.8
3	30.000006	192.168.0.1	239.255.255.250	0.000002000	252.8
4	40.000315	192.168.0.1	239.255.255.250	0.000309000	295.2
5	50.000318	192.168.0.1	239.255.255.250	0.000003000	296.8
6	60.000319	192.168.0.1	239.255.255.250	0.000001000	304.8
7	70.000745	192.168.0.1	239.255.255.250	0.000426000	300.0
8	80.000747	192.168.0.1	239.255.255.250	0.000002000	252.8
9	90.000749	192.168.0.1	239.255.255.250	0.000002000	309.6
10	100.000905	192.168.0.1	239.255.255.250	0.000156000	284.0
11	110.000974	192.168.0.1	239.255.255.250	0.000069000	252.8
12	120.001041	192.168.0.1	239.255.255.250	0.000067000	296.8
13	130.001397	192.168.0.1	239.255.255.250	0.000356000	303.2
14	140.001399	192.168.0.1	239.255.255.250	0.000002000	252.8
15	150.001401	192.168.0.1	239.255.255.250	0.000002000	245.6
16	163.290139	Fe80::680f:45cc:7818:3c	Ff02::c	3.288738000	166.4
17	176.291966	Fe80::680f:45cc:7818:3c	Ff02::c	3.001827000	166.4
18	189.292088	Fe80::680f:45cc:7818:3c	Ff02::c	3.000122000	166.4

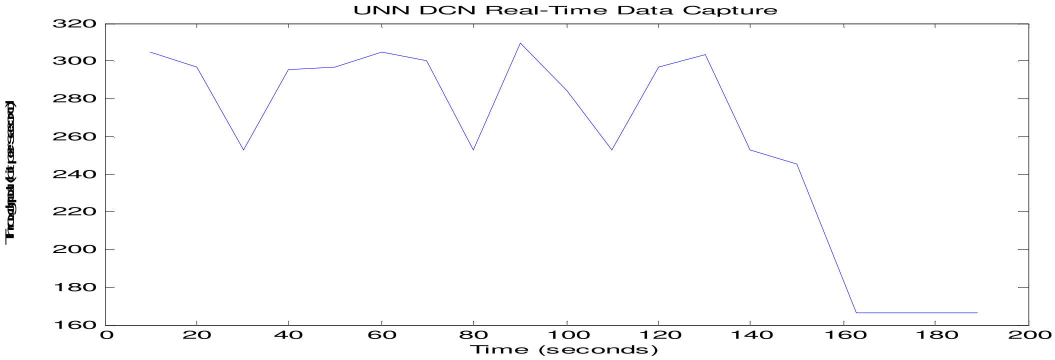


Figure 3.6: Throughput Response of Frame Data Capture (UNN DCN)

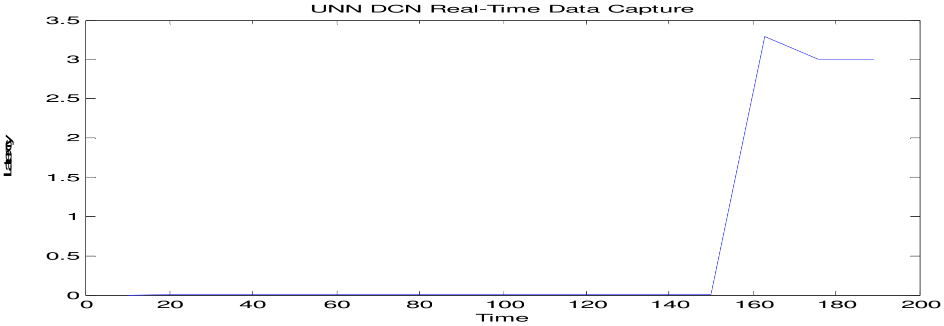


Figure 3.7: Latency Response of Frame Data Capture (UNN DCN)

From the foregoing, we can therefore conclude the results of the traditional DCN analysis (using UNN DCN as a case study) under the following points:

- Three tier DCN model will be highly inflexible and unsuitable for handling complex web applications as shown in figure 3.7. This implies high service instability and high utilization of resources. The problems with this type of model will lead to the significant incremental and heterogeneous expansion, while enabling high capacity, short paths, and resilience to failures and wirings.
- Our study on the predictability of a large number of packet traces of different traffic classes collected on DCN LAN that cover all service metrics, shows that generalizations about the predictability of the traditional DCN traffic are very difficult to make. Network behavior can change considerably over time and space. Prediction should ideally be adaptive and it must present confidence information to the user.
- Aggregation appears to improve predictability; hence, WAN traffic could be more predictable than LAN traffic.
- Enterprise web application services, cloud services, etc cannot scale well in traditional DCNs.
- Fluctuations and irregularities on Quality of Service (QoS) parameters such as throughput and latency will result in poor web application integration in enterprise organizations.

3.5 Limitations of Traditional Data Center Network.

From the traditional DCN topology and analysis in section 3.2 and 3.3, we can summarise the limitations of traditional DCN as follows:

i. Scalability

The rapid growth of online/web services and applications that runs on data center networks makes scalability a key design factor for all modern DCNs. A scalable DCN has the capacity for incremental expansion by adding more servers into the already operational structure without affecting the performance of the already existing running servers. Most traditional DCNs are not scalable, hence, when the number of web application or online users of such network increases, the network will either be congested or break down entirely.

ii. Network convergence and downtime

Traditional DCNs have problems of network convergence and downtime thereby disrupting business operations in the enterprise market segments like ISPs, financial and educational Institutions, oil and gas sector. IT operations are a crucial aspect of most organizational operations. One of the main concerns is business continuity; companies rely on their information systems to run their operations. If a system becomes unavailable due to downtime, company operations may be impaired or stopped completely. It is necessary to provide a reliable infrastructure for IT operations, in order to minimize any chance of disruption.

iii. **Latency**

This is the amount of time that it takes for a packet to be transmitted from one point in a network to another point in the network. In relation to the traditional DCN, the overall architecture generates over 30 percent network latency in switching and traffic delay thereby negatively affecting responsiveness to business demands and services. This is because some of them were not based on technologies such as virtualization which drastically reduces the number of network devices.

iv. Throughput

Throughput is a term used to describe the capacity of a system to transfer data. Since the demand for data exchange in DCNs is extremely large compared with other networks, the first design goals is to maximize the throughput. Actually, here the throughput should be goodput, ie, retransmissions are harmful for DCNs. If there are no retransmissions, generally, maximization of the throughput is equivalent to maximizing the link utilization. The amount of bandwidth allocated to different types of packets affect throughput. Due to the bulky architecture of the traditional data center networks which results to about 30 percent network latency in switching, the overall throughput is negatively affected.

v. High infrastructure Economy

The cost of deployment as well as maintaining the IT infrastructure in data center networks is very immense and hence calls for a better approach to cost reduction as well as service availability. Internet and business applications are increasingly being moved to large data centers that hold massive server and storage clusters. Current data centers can contain tens of thousands of servers, and plans are already being made for data centers holding over a million servers. The massive amounts of computational power required to drive these systems results in many challenging and interesting distributed systems, as well as IT cost resource management problems. The TCO is very high when using a three-tier architectural model.

vi. Network Congestion

Data centres can deploy a variety of middle boxes (e.g., Firewalls, load balancers and SSL off loaders, web caches and intrusion prevention boxes) to protect, manage and improve the performance of applications and services they run. Since existing (traditional) data centre networks provide limited support for middle boxes, administrators typically overload path selection mechanisms to coerce traffic through the desired sequences of middle boxes placed on the network path. These ad-hoc practices result in a datacenter network that is hard to configure and maintain, and which creates unnecessary bottlenecks and congestion.

4. MATHEMATICAL INDUCTION MODELLING

In this paper by mathematical induction, we show that by introducing network enhancement variables in a given network, such network will be optimized for enhanced performance.

Algorithm:

Given the network variable *n* (virtualization and consolidation)

I. Step 1: Verify the result for $n = 1$

II. Step 2: Assume the result to be true for $n = T$

III. Step 3: Prove that $n = T + 1$ is true for all positive integer n.

Let $N_u = \begin{bmatrix} \cos\beta & \sin\beta \\ -\sin\beta & \cos\beta \end{bmatrix}$ where $N_u =$

Traditional network in unoptimized state with its server network component variables $n\,\beta$.

By introducing *n*, we prove that $N_{T_p} =$

$$N_{T_p}^{n} = \begin{bmatrix} \cos n\beta & \sin n\beta \\ -\sin n\beta & \cos n\beta \end{bmatrix}$$ where $n > 0$ i.e. positive integer

Now, If $n = 1$

$$N_{T_p}^{1} = \begin{bmatrix} \cos 1\beta & \sin 1\beta \\ -\sin 1\beta & \cos 1\beta \end{bmatrix} = \begin{bmatrix} \cos\beta & \sin\beta \\ -\sin\beta & \cos\beta \end{bmatrix} \text{----------------------------------- (1)}$$

Eqn. (1) is true for any positive integer T.

$$N_{T_p}^{T} = \begin{bmatrix} \cos T\beta & \sin T\beta \\ -\sin T\beta & \cos T\beta \end{bmatrix} \text{-------------(2)}$$

Now, $N_{T_p}^{T+1} = N_{T_p}^{T} . N_{T_p}^{1} == \begin{bmatrix} \cos T\beta & \sin T\beta \\ -\sin T\beta & \cos T\beta \end{bmatrix} \cdot \begin{bmatrix} \cos n\beta & \sin n\beta \\ -\sin n\beta & \cos n\beta \end{bmatrix}$ ----(3)

$$N_{T_p}^{T+1} = \begin{bmatrix} \cos T\beta\cos\beta - \sin T\beta\sin\beta & \cos T\beta\sin\beta - \sin T\beta\cos\beta \\ -\sin T\beta\cos\beta - \cos T\beta\sin\beta & -\sin T\beta\sin\beta - \cos T\beta\cos\beta \end{bmatrix} \text{---------(4)}$$

$$N_{T_p}^{T+1} = \begin{bmatrix} \cos(T\beta + \beta) & \sin(T\beta + \beta) \\ -\sin(T\beta + \beta) & \cos(T\beta + \beta) \end{bmatrix} \text{---(5)}$$

$$N_{T_p}^{T+1} = \begin{bmatrix} \cos(T + 1)\beta & \sin(T + 1)\beta \\ -\sin(T + 1)\beta & \cos(T + 1)\beta \end{bmatrix} \text{---(6)}$$

From Eqn.6; the result is true for $n = T+1$

Consequently, by mathematical induction, the result is true for all positive integer *n*. this implies that by introducing enhancers on the traditional DCNs, performance will improve by a factor of *1*.

5. DISCUSSIONS/ RESEARCH IMPLICATIONS

Theorem 1: There could be $T + 1$ enhancement integration in any server data centric model in a future DCNs. We show the correctness of Theorem 1 by constructing such $T + 1$ optimal additives in future DCNs. We show that network edge-disjoint complete graphs with $T + 1$ component can be efficiently constructed in a DCN. These complete graphs can speed up data replications in distributed DCNs. In future research work, we shall build a Smart-Cloud testbed using 16 Dell precision, 490servers and 8-8-port DLink DGS-1008D Gigabit Ethernet mini-switches and Cisco MLS switches.

In this regard, each server will have one Intel 2.0GHz dualcore CPU, 4GB DRAM, and 500GB disk, and installs one Intel Pro/1000 PT quad-port Ethernet NIC with Mini-Pop access points. The OS to be used is Linux Ubuntu server 10.12. Virtualization, consolidation, and redundancy with MLS switches with no disk access will be relevant in our experiments. This is to decouple the network performance from that of disk I/O. Next, we shall study the CPU utilization overhead when using CPU for packet forwarding while comparing the overall performance with legacy DCNs. The role of smart DCNs for supporting future cloud computing services will improve service delivery of enterprise organizations with optimal cost expenditure.

6. CONCLUSION AND FUTURE WORKS

In this research work, we have presented an evaluation on traditional three-tier DCNs for enterprise organisations. In the work, we also carried out a field study on a typical enterprise traditional DCN (Swift Network DCN and UNN DCN) while depicting clearly the limitations of the traditional DCN with respect to throughput, and latency. A mathematical theorem justifying as to effects of three-tier to two-tier DCN enhancement was validated. In our future work, the functionality of virtualization and consolidation on a two tier network infrastructure will be implemented alongside with the above specifications. The Mathematical model for scalability, logical isolation of Smart-Cloud architecture, Optimization algorithms, analytical model for traffic control issues, and its security algorithm, will be presented as the key design attributes of our reengineered DCN. As a step future, a comparison will be made with other exiting architectures.

Finally, this work recommends network enhancing schemes for enterprise organisations. This will produce greater efficiency in their data center network. Consequently, this will account for efficiency, scalability, cost effectiveness, rapid service delivery owing to efficient QoS as well as providing tighter alignment with business goals. We shall appreciate technology driven organizations in Nigeria to help in realizing a robust testbed for various performance studies.

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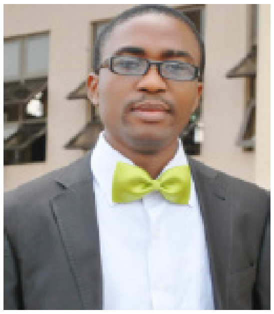

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