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BALANCING SERVICE PROVIDER AND END-USER REQUEST INTEREST IN AN SDN-ORIENTED DATA CENTRE NETWORK

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Abstract

The problem of network flow interference within a data centre network has been addressed by several scholars in the literature with a number of solutions provided. However, many of such solutions does not take into cognisance the relative cost effect of the proposals on the service providers and end-users. The solutions are either on the benefit of the service providers at the expense of the end-users and vice versa. We proposed a Multi-Criteria Optimization Crosspoint Queue which was able to address the traffic flow interference that results into both network instability and unbalanced provider-user relationship. The experimental results showed that the proposed approach is able to maintain a stable specified QoS metric as a single-parameter amidst several QoS and likewise balanced the cost effects on either side of the stakeholders. The solution is relevant to the network organization in prioritizing network quality to adapt to changing business requirements and market demands.

***Keywords*: Service Provider; End-User; Stability; DCN.**

1. Introduction

The Data Centre storage has become one of the vital aspects of the Internet components in recent times due to very huge functions that they perform in online storage and retrieval of information [Ullah *et al.* 2020]. Its continual optimization cannot be far-fetched from the need to be able to have access to vital information from anywhere in the world so far there is Internet connection to the user devices. With the increasingly serious situation of network communication among devices on the Internet, the volume of traffic flows increases as well at a rapid rate and sometimes it becomes difficult for the data centre itself to handle such volume of traffic [Al-Tarawneh and Saraereh, 2022]. Such situation often results into network problem within the data centre which becomes unfavourable to both the user and the provider of such services.

Therefore, due to the need of modern data centres to meet the stringent low-latency that is needed for most of the real-time interactive sessions on the Internet, the issue of ensuring that the traffic flow is stable becomes very important [Al-Tarawneh and Saraereh, 2022]. Authors defined the term flow interference to imply that two or more flows impaired one another when they struggle to access a definite resource, while overlapping in time, thus contend for the use of such resources (i.e. link capacity, buffer memory, network bandwidth) [Akinola *et al.* 2022]. Addressing this problem is one aspect that this article would resolved however the solutions from several literature does not answer this in the limelight of ensuring that both the providers and users are not deprived in the long run. The balance of interest between the data centre service providers and end-users still remain a gap in the literature that is yet to be addressed. Most of the solutions that addressed this research area either proposed those solutions at the expense of one of the stakeholders (i.e. service providers and end-user). Among the recent studies, the work of [Zhang *et al.* 2022], were proves/evidences that the solutions to the performance degradation were not well suited for the kind of traffic characteristics that are common to data centre network.

Moreover, a number of OSI layer solutions which were proposed in the literature used a coarse queue management approach that are subject to imprecise rate control situation due to the bursty data centre traffic flow system

[Shvedov *et al.* 2022]. Others used the Cross-point queue with random-drop approach combined with a simple fine-grained queue management scheme but not without the expense of some degree of goodput decrement from the solutions [Shvedov *et al.* 2022]. Our approach addressed this gap by proposing an Adaptive Rendering Technique solution which incorporate the optimization solution through Multi objective Optimization Cross-point Queue based system. The uniqueness of this solution is such that the system can select a specific quality to maximize its cost on both sides of the stakeholders at once. We understand from the literature that in some cases, a particular network quality is prioritized above others and the stakeholders cannot afford to accept its deterioration over the short range of time. Thus, our solution balanced the prioritized stakeholders' interest while addressing the traffic flow interference that results into network instability within the data centre network environment. Our contributions can be summarized as follows:

- We proffer a simple mathematical model that normalizes the flow traffic by giving preferences to a specified network quality.
- We implemented a Multi-Objective Optimization Cross-point Queue scheme that regulates the traffic flows.
- Deriving a technique that ensure a balance is maintained between network stakeholders within a data centre network.

The rest of this paper is organized as follows. We reviewed the related works in Section 2 while Section 3 discussed the background analysis of the problem at hand within data centre network. In Section 4, we illustrate the overview of SDN as an excellent approach to solving the problem in DCN as it related to Service Provider and End-User while Section 5 discussed the proposed Stability Framework and its components. The formulation of the Problem Statement was carried out in Section 6 while the Network Analysis of Stability Request was explained in Section 7. The Experimental design was carried out in Section 8 using OMNeT++ while the performance analysis was discussed in Section 9. Finally, in Section 10, we draw conclusions while discussing the results and looking at the future perspectives.

2. Related Works

Several works have been carried out in the area of data centre network to optimize the performance of the traffic flow within it. Originally, the traditional network setup was insufficient and it is obviously limited by the close nature of its architecture due to lack of programmability. The significance of programmable network cannot be overemphasized due to the need for a control network environment which is needed to eradicate the network flow interference. We categorise all the various approaches used from literature to address the flow interference while prioritising a single quality among the network parameters. These categories are divided into three major subsections as found below:

2.1. *Transport Layer Approaches*

The transport layer happens to be one of the OSI model layers in the network layer system. The solutions from this layer is to address the traffic flow problem via the transport layer control mechanisms. The adaptive rate control scheme was used by the scholars in [Alizadeh *et al.* 2012] to manage the rate of flows which are designated as a giant flow (100kb as short/small flow, above 100kb as large/long flow while 1Mb and above as giant flows). The emptiness of the switch queue size capacity through this control mechanism ensures that the traffic flows are properly managed to prevent the possibility of interference and flow delay.

A similar approach to what was implemented in the work of [Alizadeh *et al.* 2012] was carried out via the Explicit Congestion Notification (ECN) to the IP addresses [Ramakrishnan *et al.* 2001]. Even though the current operation of the ECN to ip congestion avoidance does not rely on the number of packets drop alone, the rise in the number of the deployed applications as well as intolerance in the delay which occurs as a result of the same has made the approach inadequate for the highlighted challenge.

The current research findings proved that the normal congestion notification mechanism is highly insufficient to address the challenge thus resulting in sub-optimal solutions. With the proposition of the distributed controller's mechanism to address network latency and flow set up delays in a scalable data centre [Yeganeh *et al.* 2012] [Tootoonchian and Ganjali, 2010], the stability of network is often still at stake. The proposed layered distributed controller architecture by [Tso *et al.* 2016] with good scalable features is still not without the both the challenges of delayed set up flow and stability due to interference. The work of [Tseng *et al.* 2019] and [Wilson *et al.* 2011] both deployed the use of deadline information from the various incoming packets to set up the control rate for packet-in messages to be attended to in the memory buffer. Thus, the rate of flow of a particular packet is dependent on the ascribed deadline information to the packet in questions.

A scalable ElastiCon was proposed in [Dixit *et al.* 2013] containing elastic distributed controllers which pools a dynamic control to either shrink or grow the network based on the traffic flow conditions, thus enabling the loads to also be dynamically balanced across the control plane. The proposal still has the load adaptation module under implementation with the deployment of concurrent running controllers to perform equal role in attaining optimal performance is both tasking and as well at huge cost. The work in [Chaudhary and Kumar, 2019] addressed switch-controller assignments along with the load-aware operation measure to inculcate a stringent and efficient traffic flow performance within the network. However, important parameters like queue sizes and flow table sizes were not considered in the work which might not make the solution generally acceptable.

A fair end-to-end window-based congestion control was proposed by Kumari and Singh in [Kumari and Singh, 2019]. It derived a protocol that is deployable for packet-switched networks with first come-first served routers. An optimisation problem in terms of network fairness was derived from a generalized proportional fairness definition which addresses the compromise between resource utilization and user fairness. However, the end user cannot decipher precisely the value of the delay experienced hence leading to problems issues in the case of rerouting in packet-switched networks. The gaps in the approach here do not make the proposed protocol suitable in addressing the network flow interference which often makes the DCN unstable.

The work of the group of scholars in [Greenberg *et al.* 2008] addressed the dynamic network resource allocation by enhancing the agility and cost effectiveness of data centre networks. This proposed architecture uses the flat addressing mode to allow instant placement of service request on any server on the network, enables the use of valiant load balancing as a technique in ensuring that loads are spread uniformly across the network channels and lastly eradicated the occurrence of complexity through the deployment of suitable mechanism for network address resolution especially with the large-scale server pools. However, the measure of or reliability in terms of the stability that this architecture offers was not factored into the design hence leaving behind an aspect that needed to be addressed. These and several other works have been proposed in these areas to enhance better network management in terms of performance and effectiveness with efficiency but one of the integral aspects is the area of stability which several approaches were silent about according to [Ashouri and Setavyesh, 2018] and [Hadley *et al.* 2017].

2.2. *Switch Based Approaches*

The network elements are one of the key devices in the network environment whose settings and designs typically influence the control and management of the network traffics. Several approaches were dependent on the management of the traffics queue using various schemes with the aim of providing efficient and guaranteed flow fairness level for network flows. One of such typical work is that of [Shreedhar and Varghese, 1996] which proposed an efficient way of managing the traffic queue through the Deficit Round-Robin (DRR) mechanism. The major goal of this work is to provide a throughput fairness that is implementable for queuing at routers and network gateways. The work was able to achieve near perfect isolation of traffic queue flows through satisfying the Golestani's definition of throughput fairness as provided in [Golestani, 1994]. The definition advocated for the use of a normalized bandwidth allocation on any pile-up flows to be made to have relatively equal intervals which made the outcome of the paper more general and implementable for several network scenarios.

The work was typically tested on datagram network packets and was found to be highly suitable and efficient in terms of its performance. Further testing was carried out using the ATM network packets with fixed cells and was found to be useful as well especially with networks requiring weighted fair queuing system. However, the challenging aspect of the work has to do with the need for the packet processing task to be low thus DRR necessitates devising the size of the quantum packet to be modified into the maximum packet size so as to avoid the problem of delay bounds. Another challenge reflects the need for the test to be performed in a typical data centre network to ascertain its effectiveness in terms of performance. Most of these solutions were really design for the traditional LANs as well as local routers and switches with the major characteristics of the Data Centre Network (DCN) in mind.

The efforts of scholars in [McKenney, 1990] also refers to the management of the network traffic flows through regulating the Transmission Control Protocol (TCP) via a class of probabilistic variants of Shenker's fairness algorithm for queueing. It was found very suitable when there is need for trade-offs in terms of memory, CPU capacity as well as the fairness performance especially with regards to network communications with high-speed movements. The availability of several resources has proven to enable the approach under this work to attain a good output with respect to queueing fairness however the main goal of many of the network challenge is to see how to effectively and efficiently manage the insufficient resources with the deployment of proven methods and algorithms for proper managements.

One of the highly related useful work is the work of [Shpiner *et al.* 2012] which uses the Hashed Credits Fair (HCF) to resolve the network flow interference challenge through providing a proven scheme for the management of switch queueing better than the already discoursed works under this subheading. It performs highly better than the traditional output queue (OQ) flow which has been existing earlier in the sense that a transparent lightweight data centre switch algorithm was designed based on a fair TCP flow with credits which was able to attain an appreciable time complexity of 0(1) under less significant resource consumption. Furthermore, the HCF approach increases the goodput of the small TCP traffic flows which are usually affected by network incast challenge and at the same time alleviated the long TCP starvation challenge. However, one of the effects of using the hash flows is the aspect of uniformity in the use of hash function which sometimes attain a static state thus could invariably lead to incurring more hardware cost on the network setup.

A fine-grained work on the retransmission of TCP during data centre communication was discussed in the work of [Vasudevan *et al.* 2009] which uses practical analysis to eliminate the retransmission of timeout bound which could result into an undesirable congestion backlogs with TCP incast collapse. The realization of this approach was tested both in simulation and real-world experiments with the high-resolution timers being able to eradicate the microsecond granular traffics within the specified timeouts. Though this work is well adopted to address management problem in data centre however the aspect of interference of network flow which result into unstable network was not address. Therefore, our work addresses this weakness in providing a stringent low-delay traffics which is able to enhance higher capacity requirements in the same vein guarantees a degree of stability.

2.3. *Predictive Flow Scheduling*

Predictive flow scheduling happens to be one of the views to combating the network management challenge based on the literature [Chen *et al.* 2015 and Cheng *et al.* 2015]. Several works have utilized various flow scheduling mechanisms by considering certain number of priorities in order to reduce the rate of flow completion time, address flow congestions alongside with flow interferences and typical among such works includes the report from Alizadeh and others in [Alizadeh *et al.* 2013]. The work proposes a transport design called pFabric whose main concept was to ensure that the data centre flow transport must decouple the flow scheduling entirely from the rate control. The work shows that by devising solutions separately for both the rate control as well as the flow scheduling would go a long way towards outstanding performance in data centre network management.

Further investigations from the work affirms that larger buffers and complex rate control does not ultimately determine improved performance but rather implementation of simple mechanisms which really does not follow the improved throughput and bandwidth centric TCP goals. However, due to this outright change of directions in the authors view, it subjects the work to reduced stability in some region of the network as a result of size-based traffic prioritization deployed in the study. Though the authors claimed that the issue of stability has something to do with linear network topologies, it becomes evident that the trade-offs incurred in prioritizing the small flows imbalances that flow which are destined for a longer route. Another open challenge to this work is the issue that is related to Non-deterministic Polynomial time problem (NP-hard problem) which is incurred in computation of the global optimal flow scheduling for the separated goals in the work.

The work in [Hong *et al.* 2012] discourages the use of fair sharing approach in addressing the low latency problem in data centre but proposed a Pre-emptive Distributed Quick (PDQ) flow scheduling protocol for managing the network flows and enhancing the promptness in meeting the flow deadlines. The idea of this approach is to approximate the range through emulating the shortest task first algorithm and enable the small flows to gain upper hand with the aid of certain priority measures. The issue of path diversity was also address with the enhanced multipath version of the proposed PDQ scheduling approach. The result of the work showed a tremendous improvement on the existing work such as [Dukkipati and McKeown 2006] and [Wei *et al.* 2022] in terms of resilient to packet loss and preservation of performance gains. However, the at some point the latency for scheduling for short flows are too longer than desired thus enabling the interference of the small flows on the long flows to occur. Moreover, this approach is an almost clean-slate solution that needs a new end host protocol stack and possibly the deployment of a switch hardware design that is unrealistic on the other end.

Furthermore, the authors in [Verloop *et al.* 2005] illustrated the effects of stability concerns in size-based scheduling approach to multi-resourced systems flow control. The approaches such as Shortest Remaining Time First (SRTF) and the Least Attained Service First (LASF) were tested and the varied stability conditions in various limiting regimes were deciphered in the course of the experiments. The reported work revealed that the available resources were inefficiently utilized, resulting into an instability effect especially on the giant network flows dues to performance degradation that is experienced. Hence, this task requires more than just a scheduling approach but also incorporated with a dynamic and an intelligent system that is able to adapt to the present situation of the network at hand.

2.4. *The gaps in the existing research works*

Network stability is a challenge that is typically common as depicted from several reviewed research works [Cheng *et al.* 2015], [Chen *et al.* 2015] and [Akinola *et al.* 2020]. Several of these research works have been reviewed in section 2. Some of the reviewed pieces of research deployed the Transport Layer Approach (i.e., adaptive rate control schemes, Explicit Congestion Notification), Switch Based approach (i.e., Deficit Round Robin, deployment of fairness through queuing routers and network gateways), Predictive flow scheduling and the Ethernet Techniques.

However, this study deduced from literature that none of these types of research evaluated the network stability while optimising the benefits regarding the service providers (the owner of the data centre) and the end-users. Though the literature also provided some reports that either dwell on maximizing the benefits of the service provider only and others on the end-user experience only, none to the best of our knowledge till this article is being written has address ensuring both stakeholder's perspectives are balanced with respect to their interest without one being at the expense of the other.

3. Background Analysis

The existence of network instability within a network such as a data centre network is often reflected by the network metric parameters which fluctuate in such a manner that affect the experiences of users. The assumption we are making in this particular paper is that either of a single network metric such as bandwidth, buffer, cache memory etc. is to be stabilised while the network is experiencing traffic flow interference. Thus, the development of the Multi-Objective Optimisation Crosspoint Queue algorithm in our publication [Akinola *et al.* 2020] is one of the significant achievements that made the proposed solution in this paper achievable towards addressing a balance of stakeholders' interest.

Since the network resources (e.g., bandwidth, Buffer) could warrant prioritising based on the application requirement at any instance of time, the data centre therefore commands the ability to manage its resources efficiently most especially the network bandwidth [Mahimkar *et al.* 2011]. This is because for a DCN setup, several flows could compete for similar resource(s). Furthermore, even while the established algorithm has ensured that the flow stability is in place, the relative effect of the achieved stability on both the provider and the end user should be balanced in the same manner in terms of the cost at both ends.

The goal of this article, therefore, is to ensure that high-quality service is available for various end-users while not jeopardizing the cost on the path of the service provider. This solution is very significant, especially to the business-oriented service providers with cost management in mind to ensure a guaranteed overall cost balance. The solution in this article utilised the Transmission Control Protocol (TCP) to optimise the requirements for the network setup so that user fairness alongside a guaranteed degree of stability is established in an SDN oriented network (Data Centre Network).

4. SDN Overview

Software-defined networking decouples the control plane of a typical network system from the data plane of the networking devices/elements. This was born out of the need to centrally control network traffic flows rather than engaging in the traditional/old model of fused control and data plane. Typically, an SDN controller exist within the network such as POX, RYU, OpenDaylight and others, that enhances a global view of the network operations. The existence of traffic flow interference causes a reduction in performance delivery which impairs the optimal utilization of network resources. The relative impact of the result is the unbalanced satisfaction in terms of benefits which could be one sided, either on the side of the Service provider (Network provider) and the End User (Consumer). The model of approach to be deployed in this article is to program the network controller with our proposed algorithm. As one of the significant goals required for building an efficient and smooth operating data centre is to be able to manage the resources efficiently especially the network bandwidth.

5. Stability Framework

The operation of the proposed system is a typical SDN paradigm, having the control plane separated from the data plane with the application plane placed on top to allow for the deployment of varying applications. See Fig .1 The major modification on the framework was carried out in the control plane section to include features like stability control mechanism, flow statistic evaluator, Available Bandwidth (ABW) Accessor, level surveillance, link detection as well as manipulative modules (Extension and Basic modules) for network control.

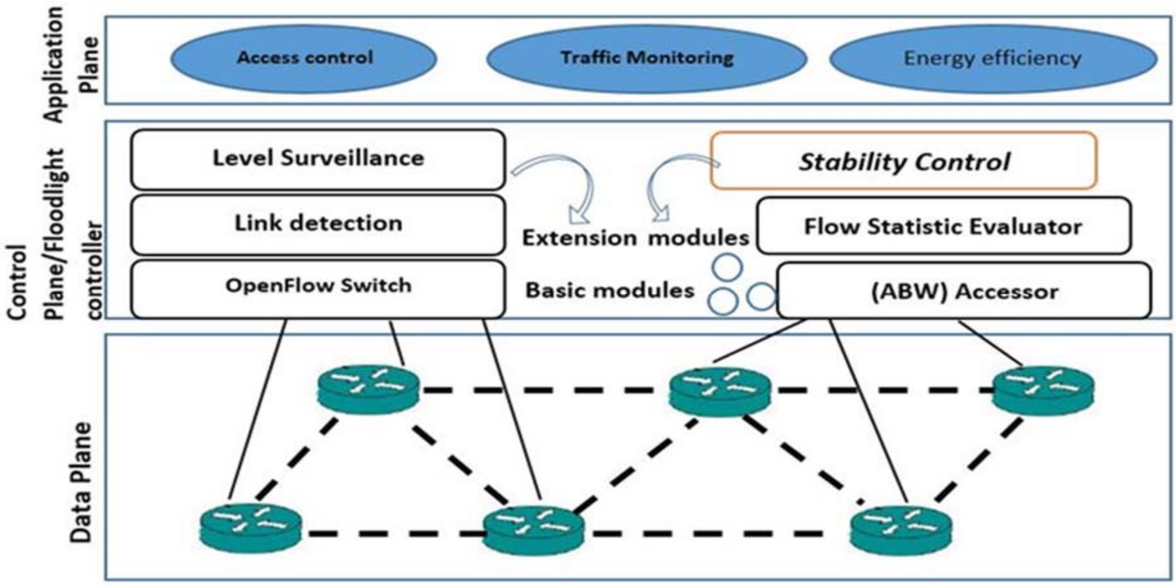

Fig. 1. Framework for Network Stability.

The data plane consists of various network elements such as switches and routers which are meant to forward packets within the network. The application plane also enhances the deployment of new applications in the network, thereby creating an opportunity for network upgrades. The flow statistics of the network were collected by the level surveillance which was processed and fed into the control section for informed decisions. The link detection section compares the various multiple links that are available to determine the ones with less congestion possibility based on bandwidth availability. Some counters determine the number of bytes being transferred on the links so that the flow statistic evaluator takes the timestamps of replies to messages that are generated.
Moreover, the flow statistics data that are generated from level surveillance are fed into the stability control module to enhance network stability through the control plane. Let us consider a typical OpenFlow switch specification that supports both per-port counters and per-flow counters. The per-port counter enables the transfer of flow statistics to the controller (floodlight) when the switch sends a request. This typically describes the level of packet counts that is being transferred, aided by flow statistic evaluator, although this does not yield an accurate result of the network [Jasim, 2018]. The OpenFlow specification cannot detect accurately the timestamp for measuring the response to the messages, thus, before the messages arrive, a new level would have been attained. Hence, the level surveillance determines the link level by finding the difference between the sending rate of the packets and the receiving rate at the destination and quickly re-run the differences to maintain the least possible result that yield the most recent solution.

6. Problem Formulation

Mathematically, considering a network whose parameters were as follows: Mathematically, considering a network whose parameters were as follows: Let DY_i denotes the number of headers packet size currently flowing for the ith data flows. EY_i represents the number of header size of the ith data flow yet unsent while the P_i denotes the payload size. Also, if h is the number of total data flow in and out of the network and j represents the number of unsent data flow. Thus, representing the bandwidth available (BA) in the network as the summation of the total from the used bandwidth as stated in equation 1 thus

$$BA = \frac{\sum_{i}^{h}(DY_i - EY_i)}{\sum_{i=1}^{j}(DY_i + Pa_i)}. \quad (1)$$

For similar data flows running using the same payload size and network protocols on other links, re-expressing the function in equation 2 as:

$$\frac{\sum_{i=1}^{h}(DY - EY)}{\sum_{i=1}^{j}(DY + Pa)} = \frac{h(DY - EY)}{j(DY + Pa)} \quad (2)$$

Therefore, the ratio that is derived from h to j has a significant influence on the available bandwidth of the system each time. When the number of data flowing is more voluminous than the unsent data, there is a high probability that the number of bandwidth available is very meagre and vice versa. Utilizing the correlation coefficient expression to determine a relative expression for fast bandwidth availability derivation. This approach considers both the sending and the receiving rates of packets and linearly calculates a faster projection based on the Meta-data from the improved calibrated Pathload Algorithm (PA) [Jasim, 2018]. Hence, this study determines the transition of correlation coefficient Cor(k) between the sending rate and packet loss rate for the network. Thus, taking the packet loss rate for Cli_1 through to Cli_2 to be measured for sending node N_s and the receiving node N_r as shown in equation (3)

$$Cor(k) = \frac{\sum_{i=k}^{n}(N_s - \bar{N})\left(Cli_{\_1} - \overline{Cli}\right)}{\sqrt{\sum_{i=k}^{n}(N_s - \bar{N})^2}\ \sqrt{\sum_{i=k}^{n}\left(Cli_{\_1} - \overline{Cli}\right)^2}} \tag{3}$$

The mean of the sending rate is given by $\bar{N}$ when packets were sent from N_s to N_r, while $\overline{Cli}$ referred to the mean of the packet loss experienced between Cli_1 to Cli_2. A strong value of the **Cor(k)** results in a value that is very close to unity or the negative unity value which signifies that the stability of the network is high. Any value that is close to 0 depicts a weak correlation hence a low stability network system. In a situation where the network path/link is considered, the usual trade-off for ABW measurements is dependent on achieving a more accurate ABW value at the expense of the timestamp needed to complete the process. Using a typical 1000MB full duplex capacity, the bandwidth utilization is calculated as (TxLoad + RxLoad)/510 where Tx is the rate on sending the packets and Rx is that at the receiving end. Assuming there is communication from an end-to-end path along which there are *i* numbers of sequential links, the maximum capacity of the path is always the minimum capacity of all the available links. Hence, we describe the minimum path for the links with equation 4 as

$$P_{link} = min(p_1, p_2, p_3, \dots p_i) \tag{4}$$

Where p_1 represents the available bandwidth of link 1 and the P_{link} refers to the end-to-end aggregate bandwidth of a given path. Since the pathload induces a fleet of probe trains that flood the network, the use of iterations to enhance the accuracy of this solution is needed. However, the calibrated PA stipulates the use of only one train of probe samples and the bit rate for each of the subsequent iterations were shown in equation 5 as

$$Q_n = \bar{Q} + \frac{|\bar{R} - \bar{Q}|}{2} \tag{5}$$

where Q represent the mean of the inter-packet interval from the sender of the recent packet on the iteration; R refers to the mean of inter-packet interval on the reception of the packet while Q_n represents the inter-packet on the sender node for the subsequent iteration. The relationship between these values is significant in that the mechanism compares and find the average inter-packet interval time differences between the destination node and the sending node. Our hybrid concept (improved calibrated pathload and correlation coefficient approach) comes in here by using the method of correlation coefficient to provide a faster solution in comparison to the network specified threshold. Based on the existing approach, the measurement of the traffic is faster when the cross-traffic measurement is in a static state. However, as soon as the situation becomes unstable, the accuracy of the approach usually downgrades, or else there is a need for the deployment of the faster correlation coefficient.

The correlation coefficient approach stipulates that when measuring the ABW in a network that is affected by the network channel and flow path interferences, the deployment of an approach that quickly considers the packet losses within the path/link is imperative. For example, given that the available bandwidth in a network is greater than the packet sending rate, there are still some arbitrary packets that are lost although could be very infinitesimal. Conversely, the rate of packet sending could be greater than the available bandwidth that the network provides, yet the relationship is that there is a linear increase in the rate of packet losses as the rate of packet sending increases. Therefore, with the use of the hybrid approach here, the study determined the amount of ABW present within a network at every instance of timeframe for the optimization of the traffic flows, considering the impact of this optimization on both the service provider and end-users in a DCN. This is also contained in the flow statistics which forms part of the module information to be injected into the floodlight controller.

7. Network Analysis for Stability Request

This research considered a service provider with C numbers of a set of controllers to be used for a DCN which are C = {$a_1, a_2, \dots, a_c$}. Each of the controllers was an element of the total number $a_j \in C$ is assigned with a fixed bandwidth capacity of B_j. If the number of users within the network is denoted by U = {$s_1, s_2, \dots, s_u$} and the variable N represents the set of application instances currently offered by the service providers on the network being $\{p_1, p_2, \ldots, p_n\}$. Let the variable b_i be the value of the bandwidth that will be required to address a service request $p_1 \in N$. Varying the setup of the service providers applications in the data centre are usually considered to provide several samples of each application such that when an application is not available, it can be fetched elsewhere within the network. Hence, each copy of these applications that was hosted by a_j is defined by $q_j = (q_{1j}, q_{2j}, \ldots, q_{Nj})$, in which $q_{i,j}$ represents the binary pair variable that indicates if p_i is found on a_j. Then, having the expression in equation 6 thus:

$$q_{i,j} = \begin{cases} 1 & if\ p_i\ is\ found\ on\ a_j \\ 0 & \text{otherwise.} \end{cases} \tag{6}$$

Having all $p_1 \in N$, assuming that $s_u \in U$ can make a single request at one particular time. Therefore, the end user's request can be represented in a kind of matrix form by $t_N = [t_{k,i}]_{K\times N}$, the value $t_{k,i}$ representing the s_u which represents the end-user requesting the service p_1. The expression for the analysis is given in equation 7 as:

$$t_{k,i} = \begin{cases} 1 & if\ s_u\ is\ found\ on\ p_i \\ 0 & \text{otherwise.} \end{cases} \tag{7}$$

If $r_{i,j}^k$ denote that aj receives the request that s_u made to p_i. Thus, representing this with the expression in equation 8 as:

$$r_{i,j}^k = \begin{cases} 1 & if\ t_{k,i}q_{i,j} \neq 0\ and\ s_u\ receives \\ & the\ request\ from\ s_u\ to\ p_i, \\ 0 & \text{otherwise.} \end{cases} \tag{8}$$

If the available bandwidth that is derived from the previous section is denoted by ABW, then $r_{i,j}^k$ which happens to be the main task of this analysis should be enabled to achieve a successful and optimal traffic flow through the controller in such a manner that both the end-user and the provider of the service have their interests guaranteed. This research deployed the use of the Kalai-Smorodinsky (KS) solution for *N* numbers of players in a win-win solution to a utility-demanding network scenario such that the benefits are maximized at both ends of the provider and users [Kalai, 1985] and [Zehavi and Leshem, 2009]. Solving the derived optimization would result in achieving a higher level of satisfaction as well as utility and service fairness for both players.

8. Experimental Design

This study deployed an Objective Modular Network Testbed in C++ (OMNeT++) network simulator aided by real word traces to ascertain the performance of the ART algorithm. This section simulated a provider which enabled the operation of four data centres with each having 50 controllers. Four different instances of application were hosted on each data centre and the Wikipedia request traces which happened to be a real word trace was used to represent the network traffic arising from the requests [Gebrehiwot *et al.* 2017].

This research first tested the rate of congestions for the traffic flows through the request for the running applications. This was ranged for 50 hours which approximately ran for two days. Although the data sets have no end-user details, dividing the whole traffic flow among the users such that a kind of normal distribution is attained. This research set the controllers to have a fixed bandwidth capacity with the running applications instances consuming relatively the same amount of bandwidth. This research first determined the benefit of the end-users and service providers in a situation where both are set to be equal. The initial parameters for this experiment included four controllers with just four users while keeping all other parameters at default state. The cost can be varied in practical response to the changing demands of the end-users [Unizulu Repository]. The predictions of the requests for over 50 hours (~2 days) are depicted in Figure 2.

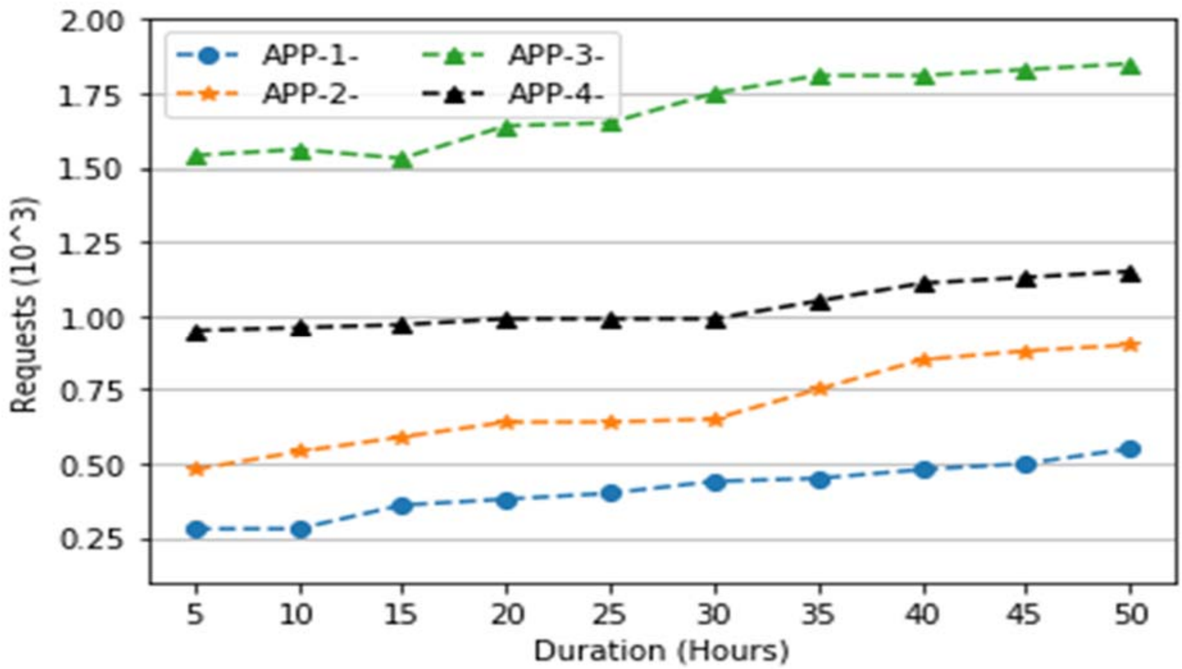

Fig. 2. Request traces for the applications on the Wiki platform.

The requests that were made on the Wikipedia platform vary from application to application and a simple check-up showed that the platform was working efficiently enough to test the performance of the adaptive rendering algorithm that was proposed earlier. Fig. 2. depicted that the requests were evenly responded to, except in some locations along the line where they dropped a little. The droppings at these locations can be accounted for by several issues which could range from congestion as a result of flow interference, bad network supply, unavailability of the applications itself, or even fewer demands for the respective users. Whatever the case, this research needs to run some experiments that will give us appropriate explanations of Fig. 8 as well as tell us more of the effect in terms of benefits to the service provider and the end users.

9. Performance Analysis

The metrics in the following subsections were used to test the performance of the proposed algorithm.

9.1. *Transport Layer Approaches*

Testing the performance of our proposed MOCQ algorithm. The performance test intends to find out the average bandwidth utilization over 50 hours when the capacity of each controller was set to 1000 units (meaning that the set B_j to be equal to 1000 for all the controller j's). Assuming the interface has a capacity of 100MB full duplex, the bandwidth utilization is calculated as (TxLoad + RxLoad)/510. And for this experiment, with 1000MB, similar calculation was made to determine the utilization of the bandwidth utilization. The first inference was to determine the rate of consumption of the bandwidth on the arrival of several requests. The diagram in Fig. 3. depicted the performance of the algorithm in addressing the traffic flows in the network. Some similarities exist in the behaviour of the average requests sent out which has been earlier plotted and the bandwidth utilization behaviour. One important deduction from the experiment is the maximization of the bandwidth cost. This inference from the experiment is that the rate of average bandwidth consumption barely exceeds 1.80, thus proving beneficial to the service provider in terms of bandwidth maximization. The service providers do not unnecessarily incur more expenses and costs on extending insufficient bandwidth. The experiment in this section is therefore very useful for the service provider in identifying the maximum technical know-how of maintaining a fairly stable network provisioning, considering the limited size of bandwidth at hand.

In the same vein, the second experiment gives more information regarding the corresponding behaviour of the end user with the current provision of the service provider. It must be noted, however, that before the service provider's relative stability is achieved, the end-user demands have already been considered for optimal satisfaction of their requirements. Furthermore, Fig. 3. showed us more information about the optimization of the bandwidth for network stability on the part of user experience.

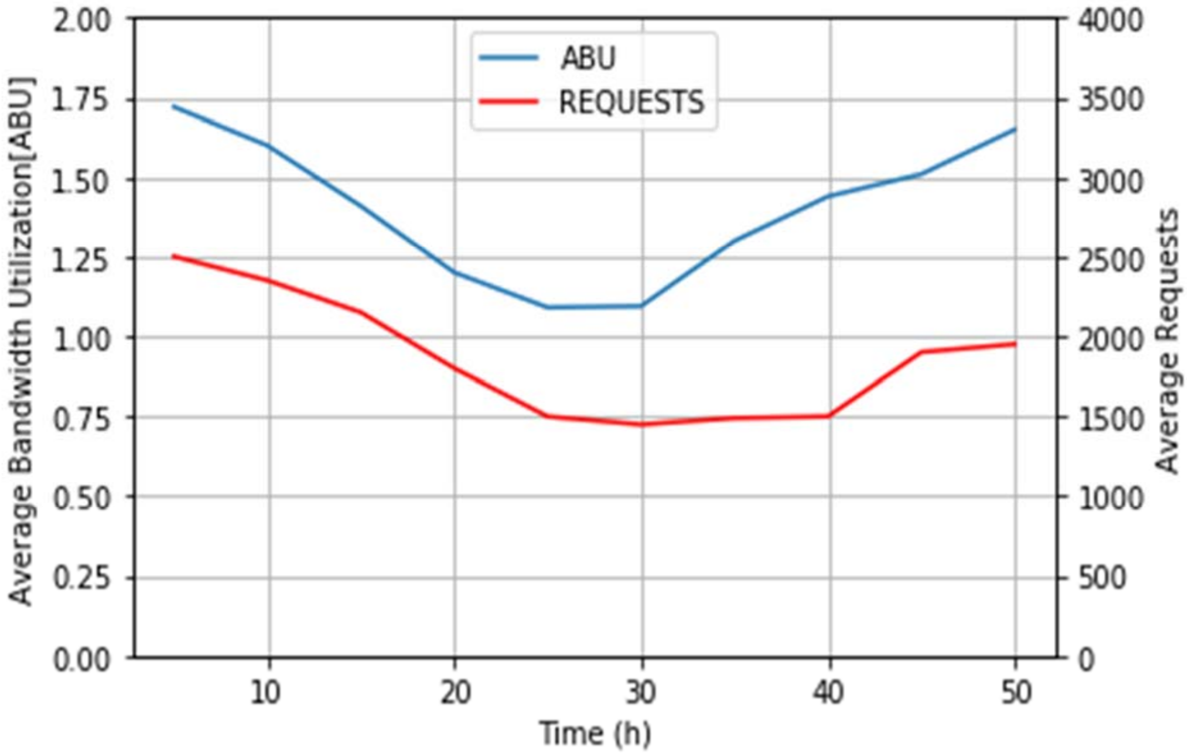

Fig. 3. Network Average bandwidth Utilization.

9.2. *Average User Experience (AUE)*

Fig. 4. depicted a relatively stable experience over a range of 0.50 irrespective of the fluctuations in the average requests that were incurred. This is expressed as the time on the task request that the user experienced. Time on task indicates how long it takes a particular user to complete the specific task from start to finish. Thus, expressing user experience as (user*1* + user*2* + user*N* time ….) /total number of users. The red line which showed the least fluctuating requests at around 2200 and the highest at almost 3500 requests was optimized to maintain a stable average user experience of 0.50. The figure also depicted the impact of time function on the network when it was almost tending toward 50 hours. A tilt was experienced and this could be attributed to the accumulated network flows which were probably meant to initiate the attainment of a new stability level for the network user experience. Thus, the AUE is maintained under a stable rate below 0.75 stability level.

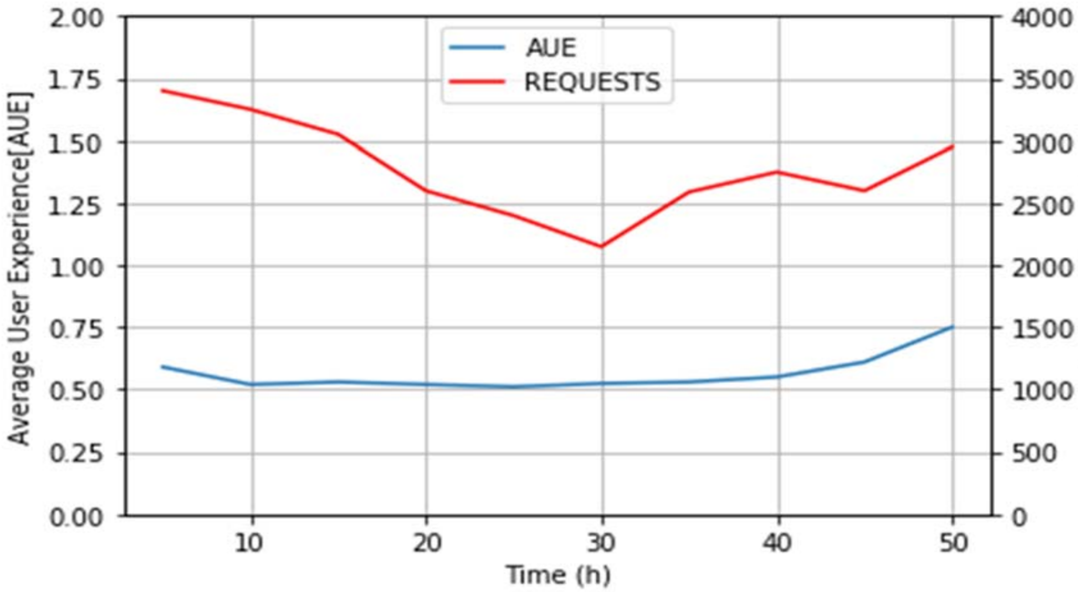

Fig. 4. Network Average User Experience.

9.3. *Cumulative Distribution Function (CDF)*

This research desired to derive the scatter plot cumulative distribution function per number of request responses granted to go through the network and the result is shown in Fig. 5. The OMNeT++ has an in-built function that determines the *CDF* of a parameter over a variable being processed as get *CDF(x)* where in the case of this experiment, the x is the response time. The function returns the cumulative distribution function for the one-parameter distribution function. The processing capacity of the controllers was maintained at B_j = 1000 and this research examined the rate of response time that was derived in the course of the experiment. This experiment critically analyse that the rate of request responses was approximately 98% below 1000 *ms* in performance, depicting that just a little around 2% took more than 1000 *ms* to have feedback. The extracts from Figure 5 showed that the bulk of the traffic flows was responded to at an average of 600 *ms* in terms of response time. One of the goals of our proposed work is to optimised the network systems in such a manner that a guaranteed level of stability is attained in the network which favours both the service provider as well as the end user. Therefore, for industrial use, the network stability that is attained on average for this particular network setup is maintained at 600 *ms* when fixed at a controller bandwidth capacity of 1000 unit setting.

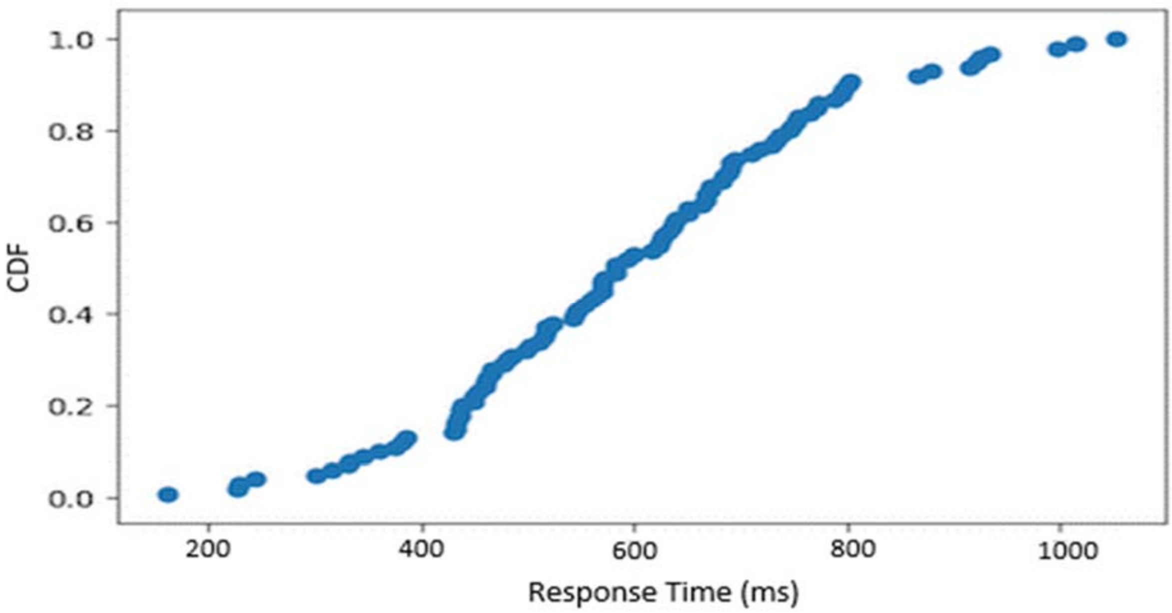

Fig. 5. The Cumulative Distribution Function at B_j equals 1000 units.

9.4. *Reduced Controller Bandwidth Capacity Comparison.*

This study intended to see the effect of the reduction of the bandwidth capacity B_j to 800 while comparing it with the performance of the initial 1000 units capacity which was used in the previous sections. The initial intention was to see the impact of the reduction of the bandwidth capacity on the amount of bandwidth utilization and thereafter try to determine if there was the likelihood of having a fluctuation or probable changes in the level of stability that the end-user experienced. While keeping the capacity at 800, the recorded performance was achieved as shown in Fig. 6. for the Average Bandwidth Utilization *(ABU)*. This study discovered that the consumption was increased a bit above the earlier experiment even though the pattern of the utilization that was recorded was similar to earlier ones. These results prove to be correct in that when there is a reduction in bandwidth size, the utilization might need to shoot up for the number of flows that have been deprived of the network resources. This confirms the stability of the network more and can be used to make several probabilities regarding any specific SDN based network setup environment.

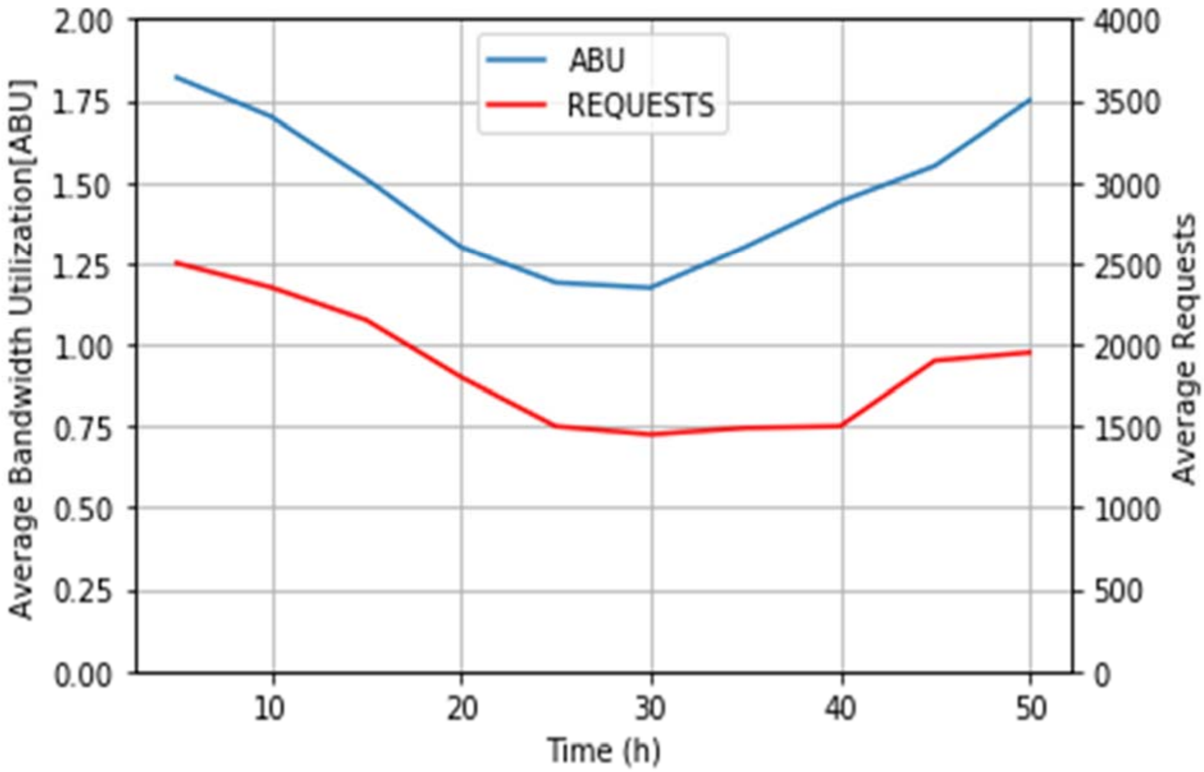

Fig. 6. Network Average Bandwidth Utilization for B_j equals 800.

In the same vein, this research was interested in the performance, in terms of the experience of the end user in the course of maximizing the available bandwidth consumption from the service provider. The result proved that there was relative stability in the end-user experience despite the fluctuating average request accrued. This implied that the service provisioning was not affected in any way by the reduction in the bandwidth that is made available to the traffic flow requests which were sent. This further proved the stability of the network provisioning system that is optimized using the MOCQ approach. The implications and the significance of the result at this point is that the service provider could earn some more profits by not incurring more expenses in acquiring more bandwidth on each of the controllers. This is depicted in the diagram in Fig. 7. The maximization of the bandwidth that was set on the controllers enhances profit realization with relatively no negative effect on the output end-user experience.

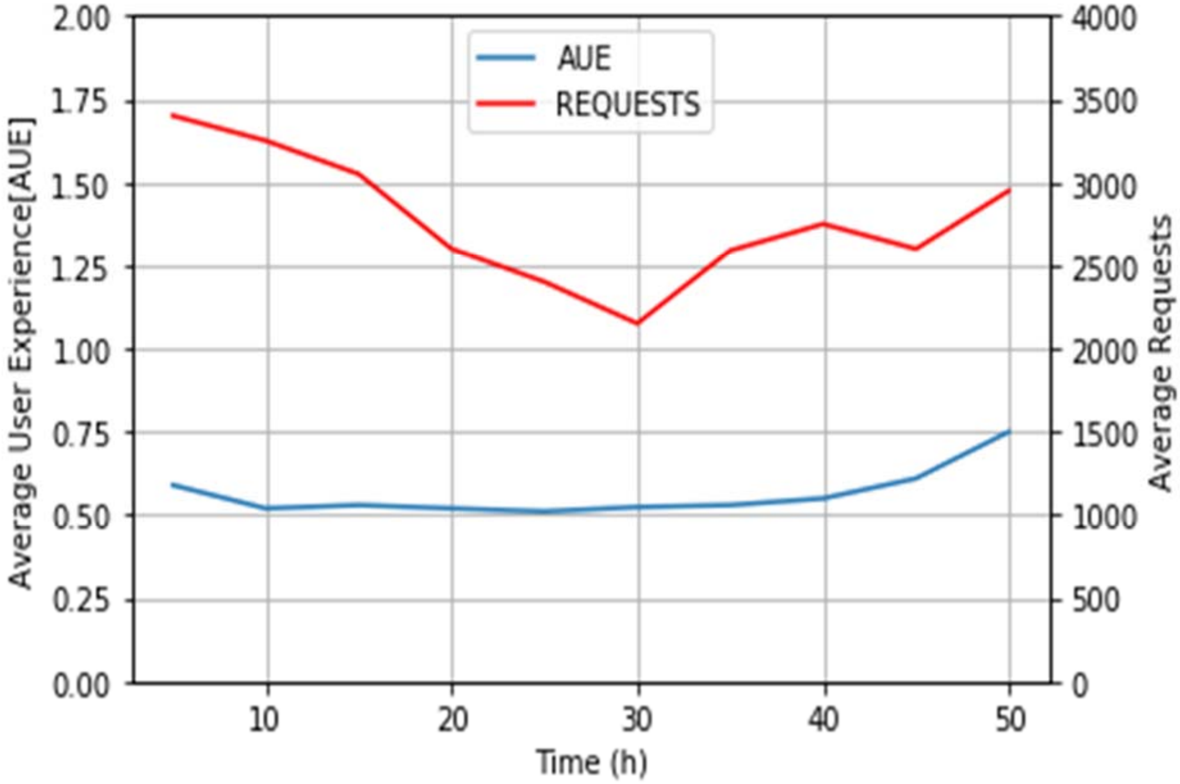

Fig. 7. Network Average User Experience for B_j equals 800.

9.5. *Varying Controller Capacities: The CDF Performance.*

The processing capacity of the controllers was dropped from the initial value of 1000 to 800 and subsequently to 600 to evaluate the effect of constant traffic flows on the average response time taken for the flow setup completion. The Scatter Plot Cumulative Distribution Function *(CDF)* usually depicts the level of distribution of the results especially in places with the highest frequency and in our case, the number of responses was seen to intersect and disperse along an almost similar axis though not the same. Three different validations were determined from this simple experiment. These are:

Firstly, the average overall response time (ms) for traffic flow in the system is determined at around 600 ms, thus the service provider and the end user could derive an optimal benefit.

Secondly, Fig. 8 showed the possibility of the service provider to vary his cost of rendering the services without a drastic effect on the output on the end user part thereby maximizing the providers' cost.

Thirdly, both parties benefit from the service being rendered with the major interest protected.

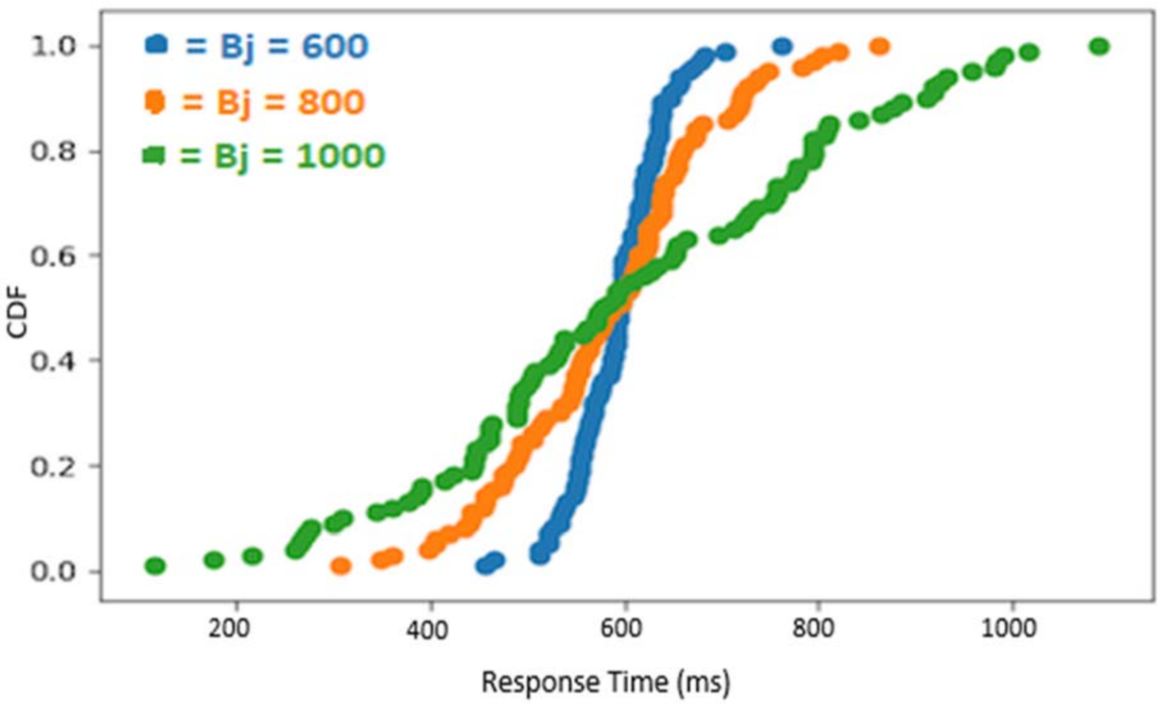

Fig. 8. The Cumulative Distribution Function at various B_{js}' units.

10. Discussion of Results and Future Works.

The specified quality approach in this chapter addressed the network bandwidth as one of the vital network resources that must be maximized on any network platform (data centre networks). The goal is that the flows from the three highlighted categories (giant, long and small flows) must be optimized in such a way that one of the flows is not incurring deterrent delay for the other within the network. Issues of increasing latency in the course of managing the traffic flow in critical flows were addressed via optimisation technique that deployed the MOCQ approach (a model for network management based on ART system). Available Bandwidth Utilization, Average User Experience, and Cumulative Distributive Function were used to determine the level of satisfaction of both the provider and end-user, thus attaining a stability point for both ends. The usefulness of this approach found its relevance mostly in a typical network provider environment (e.g., network virtualization) where the need for a particular network quality happens to be paramount and must be sliced at that level of importance to the end-users.

This solution to manage the bandwidth discussed in this chapter is relevant to the network organisations to use the agility of prioritizing bandwidth to help adapt to the other changing business requirements and new markets for prioritized quality. This usefulness is similar to one of the objectives of Network Function Virtualization *(NFV)* where time-to-market period is shortened because the infrastructure can be changed to adequately support the organisation's new products. The cumulative distribution frequency depicted that the network can adjust quickly and easily to changes in resource demands as appropriate such that the traffic coming to the data centre is regulated either as it increases or decreases. The adaptive rendering mathematical model that was deployed in prioritizing network bandwidth is one of the contributions of this thesis to the body of knowledge in the field. The contribution is significant with the additional advantage of SDN software which provided the controlled program capability feature to scale up or down the network demand(s).

Conflicts of Interest

The authors have no conflicts of interest to declare.

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