Determining SDN Stability by the Analysis of Variance Technique

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Abstract. Over the past years, many algorithms have been proposed for task scheduling and congestion control in typical Networks, such as Round-Robbin, Greedy, and many others. Whilst these algorithms are very effective in their capacities to address the targeted problems yet to compare their performance concerning the level of stability they offered in respective network systems has been a gap in the research environment that needs to be addressed. Proper scheduling mechanism along with reliable algorithms does not often guarantee a stable network else, this article is proposing a very simple but popular technique known in the statistical world as Analysis of Variance (ANOVA) as a tool for relatively determining the level of stability based on the data that are generated from the network. An OMNET++ simulator was used to conduct the simulation of the network environment and the SDN toolkits called INET framework was installed on top of it to enable the deployment of both Greedy and Round-Robbin scheduling algorithms to run. The simple analysis from the ANOVA was able to determine the level of stability between the two samples of algorithms used in these experiments. The performance evaluation while determining the response time from each experimental setup discovered that assuredly ANOVA analysis is capable of determining network stability level as well as proof that the Greedy scheduling algorithm performs better in terms of stability level than Round Robin (RR).

Keywords: SDN · ANOVA · Greedy · RR · Stability

1 Introduction

The Data Centre environment is either a virtual or physical infrastructure that houses several computers, servers, and other computing resources to meet up with an on-demand request for services. Due to the popularity and importance of the Data centre to the users of services, it becomes imperative that it is enhanced to be able to deliver a guaranteed level of performance to them. To this effect, the issue with high bandwidth, low latency, and high throughput cannot be over-emphasised or dissociated from the performance of Data Centre networks [1]. The Data Centre has numerous masses of servers containing several data and information that need to be frequently routed between the connected network nodes/hosts through the multiple available paths. This has necessitated the deployment of multi-rooted topologies such as the fat-tree and many more to ensure

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even routing of these requests down the various channels appropriately. Other approaches deployed layered architecture with some centralized control devices to ensure the bandwidth is well maximized thereby enhancing high scalability without flow deterioration at the course of routing [2].

Moreover, these approaches are only realizable with the aid of well-designed routing algorithms which are used to route the packets and (or) flows accordingly. Apart from the possibility of bursty flows which could jeopardize the performance of a data centre network, other major challenges that are encountered while designing the routing algorithm among which includes the techniques used for load balancing. Most of these suffer from effective addressing of the reordering processes during routing [1]. The reordering process impacts the throughput of a Transmission Control Protocol (TCP) causing computational overheads within the network. Also, there are contentions for network resource usage from a various number of flows which ranges from long/giant, short to Mice/small flows within the network as well. Several of the giants' flows often tends to persevere with the use of the resources at the expense of the other short and small flows. While the giant flows are quite busy with the resources, the short flows and small flows are subjected to high latency and some level of dissatisfaction to the user. Thus, the situation becomes dicey when there is a need for the latency for short flows to be minimized to the minimum while on the other hand, the throughput for the giant flows must also be maximized.

Unfortunately, the traditional routing gives more preference towards determining the shortest paths to minimize the waiting propagation duration. However, the Data Centre network has edged above the concern and challenge with the propagation delay in the shortest paths most importantly because the distances within the servers have been reduced, but the attention now has been shifted to the contention for the utilization of the bandwidth [3]. This need to balance such contention that is commonly experienced within the network environment is a measure of the level of the stability of the network. Hence, we defined the stability of a network as the measure of how long the network can maintain relatively stable flows over a network in a given period of allocated time [4]. Thus, our work in this write-up fills in the existing research gap by a proven simple analysis called the ANOVA technique to determine the amount or level of stability that is guaranteed from the adopted network flow routing approach. The remainder of this work is structured below as Sect. 2 discussed the related works to our subject of concern in this work. Section 3 detailed the analysis of variance technique termed ANOVA while Sect. 4 dealt with the implementation of the idea described in the last section. The simulation of the implementation is carried out in Sect. 5 with the results discussed alongside. The conclusion of the paper is carried out in Sect. 6.

2 Related Works

The Data Centres provide a broad range of services each with various unique delay requirements. Several designs in the modern data centres design tried to mitigate this with the use of various network topologies such as the VL2, fat-tree, DCell thus making provision for a large computational scale for accommodating a huge number of servers [4]. The goal of these topologies is to ensure that multiple paths were used to support intense communication that takes place between servers thereby enabling the ability to tolerate some sort of possible failure in the network. Among the several areas of developments that were implemented on the network topologies, include improved routing algorithms, congestion control mechanisms, resource scheduling algorithms, and many others. Thus, for this section, we shall discuss the related work based on these three areas to address network instability within a data centre network environment.

2.1 Routing Algorithms

Both the load balancing and task scheduling algorithms have been identified as one key factor that needed constant optimization to be able to address the constant increase in the rate of traffic flows in a data centre network. The old hardware-centric and traditional link-state routing algorithms cannot make use of the capabilities of the modern topologies in directing and reordering the flows along the multiple routes [2, 6]. Some of the scholarly works that introduced the idea of redundant links to avoid link failure were the work of authors in [7] on the proposed Equal-Cost Multipath (ECMP). In the proposal, Dijkstra's algorithm determines the shortest path for the network setup before utilizing the module-n hashing method to arrive at the destination path. The result of the proposed work was compared with the static routing approach. The result showed that the use of ECMP gained more throughput to the tune of 60.14 Mbps and a reduction in packet loss to the degree of 15.72% in comparison with static routing. However, one of the aspects that we wish to determine in this work is the level of stability that the better approach could guarantee to the users in the course of the network usage.

Another work in [5] and [8] both proposed an Equal Cost Multipath and Variant that is capable of balancing network load using flow hatching in randomly splitting flows over the accessible paths with equal cost. However, many flows do not have similar size and duration, thus this strategy is not well equipped in ensuring that hots-spot are not experienced in the network. Asides, we cannot ascertain how stable the network would be in the sense that it is more favourable to a large number of small flows and not inclusive for the long flows.

The work in [9] argued that the Weighted Multipath Routing approach to the management of Elephant flows performs better than Single path routing and ECMP. This implied that it might be possible that two long-lasting elephant flow-hashing may be sharing a similar path for a longer duration, therefore, resulting in the reduction of the performance of the network while there is a possibility of using an alternative path within the network. The proposed SDN-based algorithm was enhanced to enable maximization of bandwidth utilization when compared with other available approaches from the literature but yet it is deficient in depicting to us the level of stability that the network can be guaranteed.

The scholars in [10], an SDN-based dynamic load management scheme was proposed. The goals of the work were to first prioritize the traffic flow within the network and then optimize the utilization of the available links. In this proposed scheme, the controller discovered the shortest route between the destination and source host and thereafter calculates the cost of utilizing each discovered link. In the cases of congestion, the controller utilizes its intelligence and discovers the better link based on the calculations that have been carried out earlier on and it uses the least link in terms of cost and minimum flows. However, with this approach, the proposal is still lacking in terms of determining how stable the network could be while deploying the proposed scholarly approach.

The reported work in [11] proposed a server-centric DCN which can provide the applications running on the Data Centre with high bandwidth and the capacity to tolerate network failure. Exchange of control messages are used to secure a better path whenever a flow failure is envisaged to have happened among servers. The approach was seen to attain high performance in terms of ameliorating the occurrence of network failure within the Data Centre network. Furthermore, we are not able to quantify the guaranteed level of stability that such a solution proposal can provide for the network environment.

Notable work on the global round-robin algorithm as depicted in [12] with the development of a framework that enables the deployment of flow scheduling routing protocol algorithms. The method proposed here simplified how traffics is routed in fat-tree thus improving the throughput under the network traffic in the network. Furthermore, the work in [13] proposed a per-flow round robin called Digital Reversal Bouncing (DRB) that enhances the interleaving of best flows within the network. The result depicted that DRB could enable smaller bounded queues when there is huge traffic patrolling the network. This is achieved by a small re-sequencing queue to avoid the flows from arriving in a non-orderly manner. Both of these research works above have no clue to determine how stable the network is throughout the time frame of use. Our work in this article explained a simple method of determining the level of stability that a data centre network could be guaranteed.

The work of Dong and others in [14] proposed a greedy task-scheduling scheme called Most Efficient Server First (MESF) which is purposely designed to reduce the rate of energy consumption of the data centre servers. The approach schedules task to the most efficient server among the ones in the data centre thereby ensuring that there is the maximization of the average response time and on the other way round minimizing the rate of energy consumption incurred. The work of both [15] and [16] proposed a power-aware routing algorithm that enhances the reduction of power consumptions in high-density Data centre networks while meeting the overall throughput demands. There is a comparison of routing paths on all flows in the network to remove some switches and subsequent links whose path violates the demands stipulated by the network in terms of throughput. The work achieved over 55% power deduction though not taking into consideration the time between wake-up and sleep in the switches under consideration.

2.2 Congestion Control Mechanisms

The work in [17] proposed an OpenFlow protocol for practical decongestion of flows in the data centre network. The links congestion is detected and monitored centrally by tracking the ports statics of the OpenFlow enabled switches. The available resources were used to decongest the traffic from the congested links through the OpenFlow controller whenever the link is reported to be congested. The further work carried out by [18] deploys a notification mechanism that notifies at the inception of congestion as soon as it is experienced. The mechanism controls the length of the queue to regulate the flows such that the incurred latency is drastically reduced. The challenge with this scheme is the fact that it only decreases flow delays in short flows, therefore specific latency requirements are not guaranteed. Moreover, it does not provide special services that require unique traffic delay requirements.

3 Analysis of Variance Technique (ANOVA)

The analyses of variance (ANOVA) are statistical models used to analyse the difference between group means and their associated procedure, developed by R.A Fisher. In the ANOVA settings, the observed variance of a particular variable is partitioned into components attribute of different sources of variation is partitioned into components attribute of different sources variation. For analysing the statistical characteristics of the network stability, F-test was used in this study to detect whether there is a significant difference among the level of stability offered by various network scenarios and approaches. These differences between network scenarios are calculated by the measure of dispersion between the average values of the intra-group scheduling algorithms in different network scenarios.

The F-test is a statistical method used to identify a batch of groups based on distinction. The mean square is acquired by calculating the two parts by their degree of freedom. The F-value is defined as intra-difference or inter-difference according to a comparative analysis of F inspection. This will help in determining the difference in the instability experienced within any number of network scenarios under consideration. Thus, In Eq. (1) given as the function of F as,

$$F = \frac{MS_b}{MS_w} = F(df_b, df_w) \tag{1}$$

where MS_b represents the differences between groups of network scenarios, while the MS_w expresses the difference within-groups of the network having different parts. Given that N_i is the number of traffic flows through a series of a factor set A_s such as A_1; A_2; $A_3 \ldots A_i$ has k different parts. Let X be a function concerning the response time in terms of $X_{i1}, X_{i2} \ldots X_{in}$ of the set of levels of stabilities at each set. Then, we also consider the expression (2):

$$\begin{aligned} \overline{X} &= \frac{1}{N} \sum_{i=1}^{k} \sum_{j=1}^{n_i} X_{ij}, i = 1, 2, 3, ..., k, \\ N &= \sum_{i=1}^{k} n_i \end{aligned} \tag{2}$$

Equation (2) gives the average of all of the traffic values, being referred to as the number of groups which invariably refers to the number of the total monitoring times. Considering the total sum of squares denoted by SS_b using the expression in Eq. (3) as:

$$SS_b = \sum_{j=1}^{k} n_j \left(\overline{X}_j - \overline{X}\right)^2 \tag{3}$$

where the sum of squares between-group refers to a sum of squares of the deviations about the value between each group means and population means. Furthermore, considering the total sum of squares SS_t which is given by the expression in Eq. (4) below thus:

$$SS_t = \sum_{i=1}^{n}\sum_{j=1}^{k}\left(X_{ij} - \overline{X}\right)^2 \tag{4}$$

where the total sum of squares refers to the value equals the square sum of deviations between every sub-sample in population and population mean. In a similar vein, considering the expression in Eq. (5) below thus:

$$SS_w = \sum_{i=1}^{n}\sum_{j=1}^{k}\left(X_{ij} - \overline{X}\right)^2 \tag{5}$$

In (5), SS_w is the sum of the square for within-group, being equal to a sum of squares of the deviations about the value between every sub-sample value in the group and each group mean. Therefore, we have the expressions in Eq. (6) thus:

$$\begin{aligned} MS_b &= \frac{SS_b}{df_b} \\ &= \frac{n_1(\bar{X}_1-\bar{X})^2+n_2(\bar{X}_2-\bar{X})^2+\cdots n_k(\bar{X}_k-\bar{X})^2}{N-1} \\ &= \frac{\sum_{j=1}^{k} n_j(\bar{X}_j-\bar{X})^2}{N-1}, \\ MS_\omega &= \frac{SS_\omega}{df_\omega} \end{aligned} \tag{6}$$

In (6), the division of SS_b by the degree of freedom returns a numeric result and assigns the result to MS_b which indicates within-group variance. Similarly, MS_w which refers to between-group variance can be obtained according to the result of the expression derived in Eq. (7).

$$\begin{aligned} &= (n_1 - 1)S_1^2 + (n_2 - 1)S_2^2 + \ldots + (n_k - 1)S_k^2 \\ &= \frac{\sum_{i=1}^{n}\sum_{j=1}^{k}\left(X_{ij}-\overline{X}\right)^2}{N-K} \end{aligned} \tag{7}$$

In the F-test method, F-value is obtained. An observed value of F which is greater than the critical value of F determined from tables indicates that there are significant differences among groups. Conversely, a small test value that does not exceed the critical value determined from tables indicates that there is no fundamental distinction among groups.

4 Implementation

The simulation setup is designed to constitute two network scenarios. The first scenario is a Data Center Network with one controller and the second scenario is a Data Center network with two controllers. Each of the controllers has the same capacity and ports for traffic flows. To implement the deployment of ANOVA in determining the level of stability that is guaranteed by a network, we run two major task scheduling algorithms called Greedy and Round-Robin algorithms respectively. These algorithms were used to schedule packet flow in the network. The increasing number of packets were simulated in the two networks and response time for each task was recorded.

A greedy scheduling algorithm is a form of priority scheduling algorithm which executes the processes according to the predetermined priority and in the case of our work we gave priority to the lightest data packets to be attended to first before the heavier packets. On the other hand, the Round Robin (RR) executes the processes based on the time quantum defined i.e. each process is executed for a fixed amount of time. The performance of both algorithms on the network scenario was important due to the method of the ANOVA that uses at least 2 sets of variables to determine the output P-value.

We then analysed the P-value obtained from the analysis of variance calculation using response time from each network scenario when each of the algorithms is employed. This is a value that is randomly obtained when the static test used for analyses of the data set is distributed and used to test the null hypothesis. Under null the hypothesis, the P-value based on a constant test statistic, has a consistent distribution over through 0 to 1, without being affected by the sample size used in the experiment. Mean and percentile of P-value distribution can give an accurate and deep understanding of how the P-value behaves for various parameter values and sample size. The distribution of P-value may be used to evaluate the variability of the evidence as measured by P-value against null hypothesis when the same value of parameters is assumed for each of several studies.

5 Simulation Results

The simulation of the network setups was to determine the performance of the scheduling algorithms as well as use the same to find the level of stability that is made available by a typical network.

5.1 Performance from a Single Controller

The performance of the scheduling algorithms deployed was tested under this section with a single controller network setup. The goal here is to determine if we could derive the level of stability of the network which we know would be relatively affected by the scheduling algorithm deployed. The use of a separate controller wherein the control of the whole network flow is coordinated satisfied the SDN condition. The performance of the response time against the increasing network flow was shown in Fig. 1. The greedy algorithm yields a locally optimal solution which resulted in an approximate network global solution within a reasonable response time allocation. Though not seen to be uniquely better off in the diagram in Fig. 1 because only one single controller was used. The impact would be seen in the second experiment under Fig. 2.

The data are shown in Table 1 depicted the results that were determined in the analysis of variance that was performed under a single controller setup. With the analysis of variance relationship with the level of stability as earlier explained in Sect. 4 of this article, the result of the P-value data for the single controller network setup rose to 0.9 from the table after running the statistical data. The deduction from this value of P-value is interpreted to mean that based on the literature, any value greater than 0.05 depicts that the network is tending towards instability while the value lesser guarantees that the network is stable. Thus, the result of the single controller performance showed that it is unstable especially with the increasing rate of network flow. This does not mean to say that a single controller could not enhance a stable network provisioning but the number of flow that was subjected to it was actually over above what it can handle and of course, instability is expected to occur as depicted by the P-value generated.

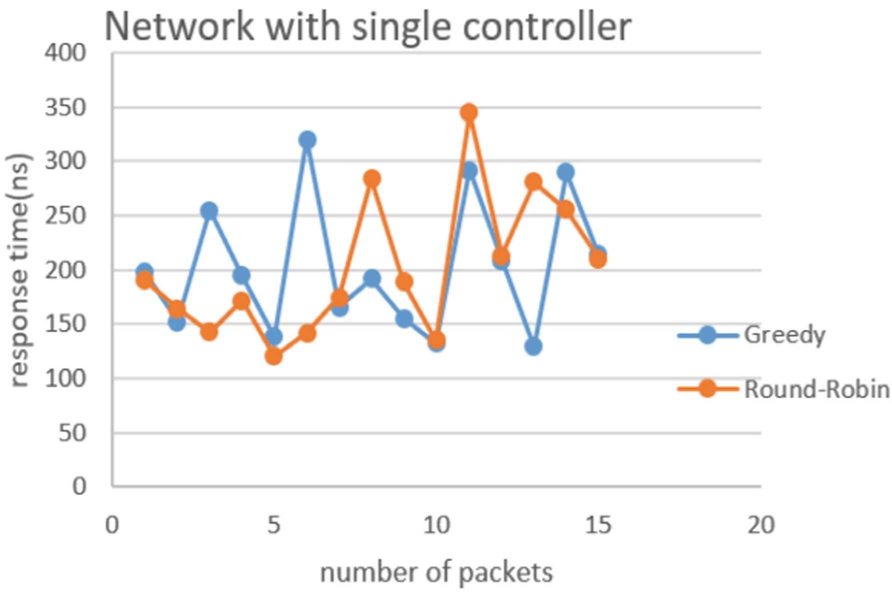

Fig. 1. Response time performance for a single controller.

Table 1. Anova results for one controller.

SUMMARY						
Groups	*Count*	*Sum*	*Average*	*Variance*		
Greedy Values	15	3037	202.4667	3804.41		
Round-robin Values	15	3019	201.2667	4156.21		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	10.8	1	10.8	0.002713	0.958827	4.195972
Within Groups	111448.7	28	3980.31			
Total	111459.5	29				

5.2 Performance of a Double Controller

On the other hand, the simulation performed under a double controller generated the flow values that were depicted in Fig. 2 whose response time is clearly shown. The setup on this simulation gives room for the optimal control of the network environment by the controllers such that the traffic flow can be tolerated by the capacity of the controller however the measure of its stability cannot be determined by mere inspection or assumption unless the kind of evaluation is carried out such as the use of analysis of variance.

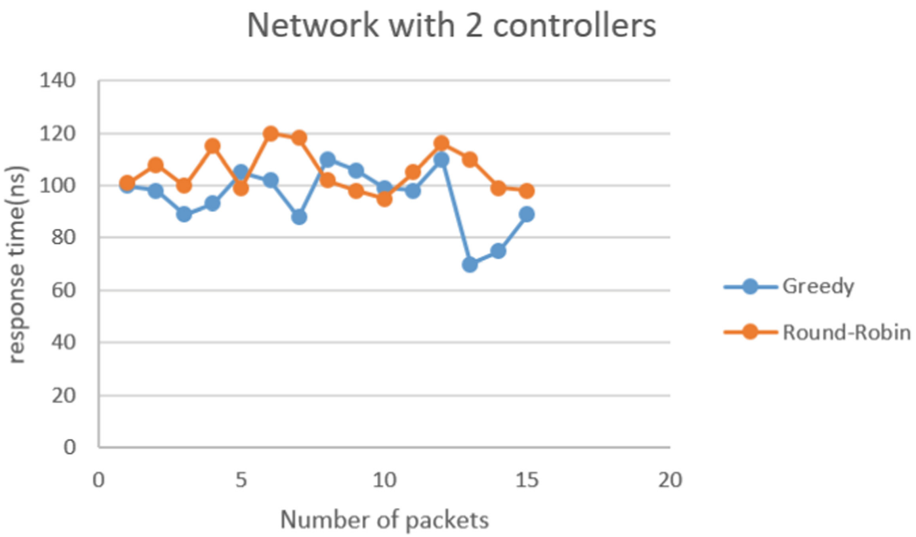

Fig. 2. Response time performance for a double controller.

The response time from the simulation first depicted a very small difference between both scheduling algorithms with the Round-Robin taking more time in completing the required tasks. As the flow proceeds, the greedy algorithms adjusted with time and were able to effectively use its heuristic features to objectively optimize the flow in the network in comparison with the round-robin algorithms. However, the major goal here is to determine how well the network setup could guarantee stability over the range of or series of network flow. This report depicted only the preliminary results of this research study as more investigation would be carried out in subsequent publication after this write-up. We would like to investigate further in determining to what extent several controllers could guarantee stability. The simulation analysis of variance for the double controller software define network showed that the P-Value of the network is 0.01, which is lesser than 0.05 thus confirming that the level of stability at this instance of the packet flow is relatively stable. Furthermore, we could notice the disparity in value in terms of the variance between both algorithms which were extremely high in Table 1 but under the double controller, simulations have drastically reduced with round-robin having the least dispersion. This was as a result of round-robin maintaining the almost same value of response time irrespective of the level of flow either low or high. However, the greedy was able to later manoeuvre to a lower response time over the period thus coming out with a wider dispersion than round-robin (Table 2).

Table 2. Anova results for two controllers simulation.

SUMMARY						
Groups	*Count*	*Sum*	*Average*	*Variance*		
Greedy Va	15	1432	95.4666667	137.5524		
RR Values	15	1584	105.6	68.82857		
ANOVA						
Source of Varia	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between (	770.1333333	1	770.133333	7.463221	0.010779	4.195972
Within Gr(	2889.333333	28	103.190476			
Total	3659.466667	29				

6 Conclusion and Future Works

The simulations in this article have depicted the preliminary result from the deployment of analysis of variance in determining the level of stability that a particular software define network environment could guarantee. Earlier than now, network operators have been relying on the metrics that are described on the network elements to determine its performance and this test could be used by the operator to confirm such attributes. In addition, network operators might need to confirm from their end if the particular network device could be used to its optimal value rather than under-utilizing the device. As we have mentioned earlier, the future work from here is to determine the use of the ANOVA technique in calculating the level of stability that could be offered in a larger scale software defined network environment. We hope to publish the work soonest as works have started in setting up such experiments as we hope to validate the use of the renowned technique in the area of programmable controlled networks.

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