Rate of Network Convergence Determination Using Deterministic Adaptive Rendering Technique

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Abstract. Software-Defined Networking (SDN) has become a popular paradigm for modern day optimal performance of the network system as a result of the separation of the control component from other network elements. This enables the maintenance of the flow table structure on these devices while optimal forwarding of packets is enhanced via the central controller. Being a growing network architecture which is supposed to be able to meet up with increasing traffic demands in the future, it becomes apparently important that the mechanism that takes care of the QoS of the network demands is put in place. Such demands include the smooth running of big data transmission, D2D video exchange, Voice over IP and real-time multimedia applications which needed certain QoS requirements for optimal service delivery. However, fewer research articles have reported on the improvement on the QoS routing especially in connection with the SDN paradigm. We propose a multi-criteria routing algorithm that is based on deterministic Adaptive rendering technique called DART_MCP. Our DART_MCP QoS routing algorithm deployed Dijkstra's algorithm to simplify the topology of the network before using multiple-criteria energy function to address the QoS requirements. We recorded a relatively stable bandwidth and user experience maximization under a low rate of network convergence in comparison with other approaches.

Keywords: SDN · Protocol · Multi-criteria · ART · SDN · DART_MCP

1 Introduction

The Software Defined Networking has recently been a popularly recognised approach in the networking field as a better platform for a fast and easily deplorable networking system that addresses most common challenges encountered in the networking field today [1, 2]. Due to the spurious increase in the number of devices that access the internet especially the mobile devices, the act of ubiquitous computing had been a common practise nowadays. Many real time applications are commonly seen running concurrently which are highly resource consuming applications such as real-time multimedia, device to device video chat and Voice over Internet Protocol applications [3]. Several existing Internet transmission approaches are still deploying Best-Effort single service which is

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not good enough or perhaps practically impossible to enhance the smooth running of the applications aforementioned. In a similar manner, the OpenFlow has evolved as a core technology and a robust enabling approach for realizing a flexible control of network traffic in SDN thus, proven to be a reliable solution for the future Internet technology [1, 4].

The marriage of the novel SDN architecture and OpenFlow have given an optimistic platform for a tailored networking service provisioning that is expected to meet up the need of the future demands in terms of Quality of Service (QoS) requirements. By QoS, we mean the provisioning of several network QoS based on the best network state requirements for optimal performance of each application. Hence, QoS routing entails the consideration of both the network optimal path selection as well as the quality of the network based on the available resources to be able to make an appropriate decision for user demands [5]. This implies that the QoS routing for an SDN based network environment needs to speak to both network extension as well as the efficiency of the network flows in such a manner that the stability of the network is guaranteed over a specified range of time. Moreover, as the future network demands are gradually ascending its peak, the quest‘ for fast deployable and efficient utilization of network resources becomes a challenge [6].

As several applications evolve and many are still yet to be released, it becomes more paramount that the QoS routing algorithm needs to be more equipped to be able to meet up with the needs of network users. Asides, the need to maintain good network qualities, several network traffic flow challenges also forestall the drop in the network qualities which can be check through the routing algorithms. An example includes traffic flow interference which often results in network instability [7–9]. Furthermore, several literature have proposed various QoS routing algorithms which among which include HAS_MCP, H_MCOP and SA_MCP but most of these approaches are confined to a speculative framework with the evaluations restricted only to algorithm evaluation with respect to memory consumption and complexity computation [4, 10]. Moreover, none of these algorithms has featured the concern for network instability that arises from traffic flow interference within the networking environment [10]. It is easier to include several constraints into a routing algorithm however, the daunting task lies on how the bunches of network constraints (such as “k”), is able to relate to network stability.

The challenge of flow interference is divided into two types which are intra or inter traffic interferences [11]. Intra occurs within switches in the same slots while Inter is experienced in different slots on the network. These interferences are caused by the sharing of the same network channels and or control flow paths. Thus, the QoS routing algorithm needs to be robust to be able to prevent the occurrence of network interferences thereby ensuring that the users’ network optimal performance are guaranteed. This paper thus creatively introduces the adaptive rendering technique (ART)-enabled algorithm which is typically a computer graphics rendering approach coupled with deterministic multi-criteria energy function to enhance optimal QoS routing performance. This approach was typically deployed to be able to address the interference in network flow which impedes the network stability. Thus, this serves as one major contribution that our proposed QoS routing algorithm is unravelling to the body of knowledge in Software Defined Networking field.

The remainder of this article is organized as follows. Section 2 gives some brief explanation of the related works on the previous routing algorithms attempts while Sect. 3 provides the proposed algorithm model. Section 4 discusses a short preliminary result of the experimentation while Sect. 5 concludes the paper alongside with its future works.

2 Related Works

SDN is one of the latest approaches for an optimal network performance most especially with increasing demands in network performance to meet up with the users' device requirements. Several attempts have been carried out by the scholars to bring about the improvement in network users' experience. The work of Hilmi Enes Egilmez produces the LARAC algorithm [12]. The algorithm introduced a multiplier that represented two major concerned parameters being cost and delay to video streaming service. The algorithm was able to use the iterative method similar to Lagrange relaxation to select the optimal path for the network packets. It is one of the effective algorithms that address the constrained shortest path problem. In [13], the authors propose an algorithm that uses Multi-constrained approach to find the shortest path for routing in a network. However, the work does not discuss any optimization techniques to improve the proposed algorithm. The work presents three path computation algorithms and further opened up future works such as integrating the algorithm to address admission control and resource setup. The convergence speed after failure is also proposed to verify the degree of stability of the proposed algorithms.

The work of Chen and others in [14] proposes Interference azimuth spectrum (IAS) and geometry based stochastic models (GBSMs) as an important mechanism of an analytic framework which measures the network interference performances. Several numerical examples were depicted to demonstrate the usefulness of the mechanism though the work proposes that other effects of interferences can result from specific multiple access and adaptive transmission schemes. The survey article in [15] provides various routing algorithms varying from approximate to exact solutions. These algorithms derived their solutions using Multi-constrained optimal path problem (MCOP) that includes several metrics such as packet delay, available bandwidth, packet loss and buffer overflow. Most of the review algorithms in the survey are restricted to a speculative framework and take little or no cognisance to the memory requirement or computational complexity of the proposed algorithms. Among such works include the work of Lee and others in [16] that propose a Fallback algorithm of one main constrain. This algorithm serially considers other constrains if it meets the requirement else it continues the search. The major issue with this approach is that it does not guarantee the optimal routing path and also, it cannot be used for an autonomous network environment where attaining an optimal solution becomes non-negotiable.

Moreover, a novel QoS provisioning architecture called PRICER was developed to enhance QoS routing update (ROSE) as well as promoting effective pricing incentive for routing algorithm (PIRA) [17]. This proper incentive was carried out through integrating efficient pricing function into the QoS routing algorithm. Extensive simulations as well as the conducted theoretical analysis proved the better performance of the proposed architecture over the existing state of the art approaches with an added contribution in terms of evaluating the staleness of the network link-state information.

Gang Liu and K. Ramakrishnan propose a heuristic algorithm called Heuristic Multi-constrained optimal path problem (H_MCOP) [18]. This algorithm provided a cost function that helps to prune up the paths that violate the candidate path list thus achieving an optimal path solution. The algorithm also uses the Dijkstra's shortest path approach to predict the pruning and ordering process thus making the algorithm somehow intelligent towards arriving at a precise solution. The enhancement of the prune algorithm with any of the established ϵ-approximate algorithm to achieve BA*Prune, therefore made this approach to be a comparable solution to some of the best know polynomial-time ϵ-approximate algorithms. However, the proposed algorithm is regarded as being classical and needed more improvements to achieve an optimal performance.

Several other similar QoS routing solutions have left out the information of the link state in the process of deriving an optimal network path by assuming the state is accurate and readily available. Examples of these algorithms include the general simulated annealing multi constrained path problem (SA_MCP) which happens to be an expansion of local search algorithm [10] as well as the upgraded version of it called Heuristic simulated annealing multi constrained path problem (HSA_MCP). The upgraded version was able to enhance better optimization process to be executed faster than the former but however not tailored to enhance a stable network [10]. The work of Apostolopoulos and others in [19] incorporate different update policies to check the link state such as equal class, threshold and exponential class policies. It was derived that with a given threshold value (τ), the update link signal is triggered under the threshold policy used such that when $|l_c - l_o|/l_o > \tau$, with the l_o being the least advertised value among the available latency and l_c appears to be the current latency of the link.

However, among all the highlighted literature, none of them had address the impact of network interference within a network hence there is a need to establish stability in a network that is designed to meet up the varying users' network requirement. Considering various approaches that try to optimize the network requirements that are needed by users, we extended the knowledge body along network routing through integrating the network stability measures into the routing technique that we propose to optimise the QoS routing algorithm. In order to achieve this, we deploy the Dijkstra's algorithm to simplify the network topology for easy analysis and then make use of the multi-criteria energy function to deploy the network requirement constraints while the stability evaluation in relation to interference was implemented into the Adaptive Rendering Technique approach to optimise the users' need.

3 Proposed Algorithm Model

There are three SDN network flows that were considered within the network environment which are transferred between the data plane elements and the network controllers. These are majorly symmetric messages, asynchronous messages and controller-to-switch messages [20]. The symmetric messages are typically the echo and hello messages which do not need any solicitation from a controller. The Asynchronous messages are typical messages that are sent to the controller in response to the reception of packets by the switches such as flow_removed and packet_in messages. The last and commonest type of message is the controller-to-switch messages which are responsible for delivering messages to the switches without any necessary acknowledgement.

The development of deterministic Adaptive Rendering Technique (DART_MCP) algorithm contains the Monte-Carlo (ZZ) buffer which supposedly assists in establishing the stability of the network performance in relation to the effect of network interferences. The buffer approaches the versatility of distributed networks as it can render wide influx of transferred packets while maintaining the QoS of varying network users.

One major goal of proposing the DART_MCP algorithm among the various available ones in the networking environment is its ability to enhance an optimal performance in terms of rate of network stability when tailored user requirements are to be harnessed. In this section, we deploy a mechanism similar to the ticket based probing TBP used in [21] however we deploy network interference alleviation scheme to enhance network stability while meeting up with user requirement. This network interference alleviation was modelled into the rendering equation to input network stability. Since the rendering equation is already established as proven by the published works in [23] and [24]. The modelled equation is written in Eq. 1 thus:

$$L_o(x, w_o, \lambda, t) = L_e(X, w_o, \lambda, t) + \int_{\Omega}^{1} f_r\big(x, w_{i,} w_{o,} \lambda, t\big) L_i\big(x, w_{i,} \lambda, t\big)(w_i.n)dw_i \quad (1)$$

Where $\boldsymbol{L_o(x, w_o, \lambda, t)}$ equals to the total outgoing packets from various network hosts with bandwidth **"$\boldsymbol{\lambda}$"** directed in a poisson distribution manner of "w_o" through time **"*t*"** on a path distance of **"*x*"** away.

$\boldsymbol{\lambda}$ represents the bandwidth.

$\boldsymbol{w_o}$ represents the poisson distribution value.

t represents the time for packet delivery.

$\boldsymbol{L_e(X, w_o, \lambda, t)}$ represents outward packet distribution.

$\boldsymbol{\Omega}$ represents units of packets transmitted through mean network n containing all possible values of w_o.

$\int_{\Omega}^{1} \ldots .dw_o$ is an integral value over Ω.

$\boldsymbol{f_r\big(x, w_{i,} w_{o,} \lambda, t\big)}$ is the bidirectional poisson distribution of packets whose proportion varied from w_i to w_o over distance.

x, time t and bandwidth λ.

$\boldsymbol{w_i}$ is the inverse packet flow from controllers to hosts.

n is the mean controller equidistance apart.

$\boldsymbol{w_i.n}$ is the weakening interference factor of packets as it transverse the network.

Hence, Eq. 1 expresses the solution to the DART_MCP algorithm model whose analysis enhances network stability through elimination of network interference. Our idea is that once the solution to a single interference is determined, it is sufficient enough to address similar multi-objective optimization problem efficiently, then the summation of such singular solution gives the aggregate of the larger network interference problem, hence, the stability of such network can be guaranteed based on the aggregate solution.

We formulate the users' requests as a poisson distribution requesting for network resources and we considered this as an optimization problem that needed to find a balance between the network resources and user requirement. We look at a poisson cluster process which is motion-invariant requests, thus from a single user point process. For practical illustration, assuming a request is sent from the source to the sink, however the best route at any point in time is required which meet the user requirements. The throughput, latency and bandwidth of the routes were specified on the routes connecting one node to the other thus depicting the state of network routes at timeslot *t*.

4 Result and Discussions

4.1 Performance Tests

We first deployed an OMNeT++ network simulator aided by a real word traces to a certain the performance of adaptive rendering algorithm. Recall the proposed rendering equation that was proposed in Sect. 3 to address the flow interference that brings about instability in networks performance. We simulated a network provider which enables the operation of four data center with each having 50 controllers each. Four different instances of application were hosted on each data centre and the Wikipedia request traces [25] which happen to be a real word traces was used to represent the network traffic arising from the requests. We first test the rate of congestions for the traffic flows through the request for the running applications. This was ranged for an interval of 50 h which is approximately two days' duration. We divided the whole traffic flow among the users to attain normal distribution state (even).

We set the controllers to have a fixed bandwidth capacity with the running applications instances consuming relatively same amount of bandwidth. We briefly access the level of bandwidth consumption and the nature of user experience in the course of affirming the level of stability of the network performance. We intend to find out the average bandwidth utilization over a duration of 50 h as discussed earlier when the capacity of each controllers were set to 1000 units. The first inference we are interested in was the rate of consumption of the bandwidth on arrival of several requests as shown in Fig. 1. One important deduction from the experiment is the maximization of the bandwidth cost. We inferred from the experiment that the rate of average bandwidth consumption barely exceeds 1.80, thus providing a benefits to the service provider in terms of bandwidth maximization.

The service providers do not unnecessarily incur more expenses and cost on extending insufficient bandwidth. The experiment in this section is therefore very useful in maintaining a fairly stable network provisioning, considering the limited size of bandwidth at hand.

Furthermore, the Fig. 2 showed us more information about the optimization of the bandwidth for network stability on the part of user experience. The Fig. 2 depicted a relatively stable experience over a range of 0.50 irrespective of the fluctuations in the average requests that was incurred. The red line which showed the fluctuating requests with the least at around 2200 and highest of 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 h. A tilt was experienced which could be attributed to the accumulated network flows which was 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.

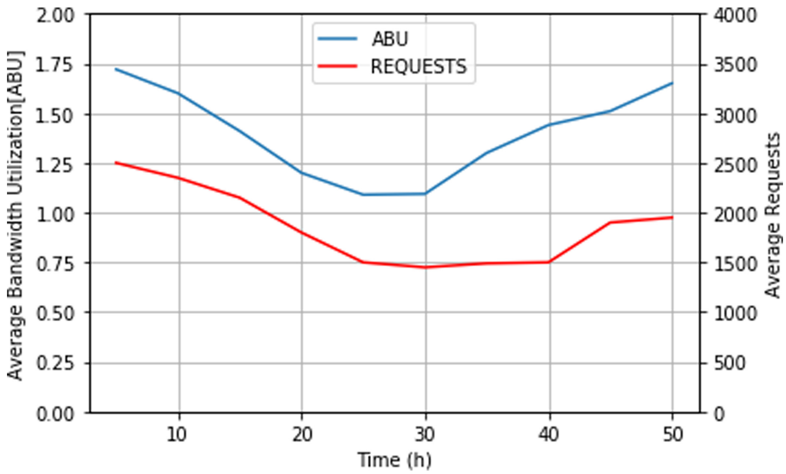

Fig. 1. Network average bandwidth utilization

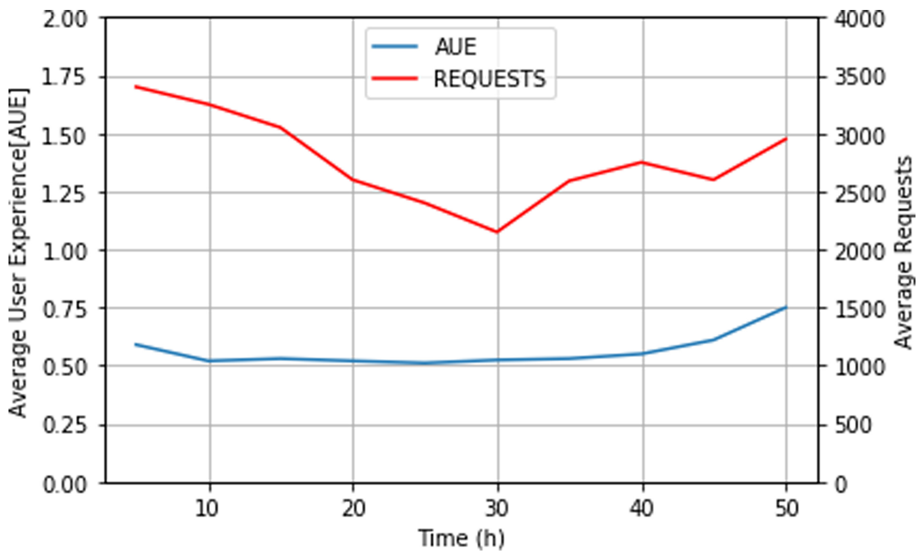

Fig. 2. Network average user experience.

4.2 Convergence Rate

The need to deploy this work on a new platform to test the rate of it convergence is buttress on the fact that we used a separate script to aid the determination of the rate of convergence. We deployed the gt-itm application that was used in [22] so as to produce the required network topology. The performance was tested using the number of success rate achieved and the duration of time at which the algorithm performs the simulation (running time). We considered the performance of the DART_MCP with one competitive algorithm from the earlier mentioned algorithms which is HAS_MCP.

We also evaluate the performances of the algorithm when there is an increasing number of packet transfer and the packet size was kept constant as well as when the packet size was varied with constant packet transfer rate within the network. The diagram in Fig. 1 and 2 compare the performance of both HAS_MCP and DART_MCP algorithms especially in terms of the duration of delays before a stable state is reached by the algorithms. We selected only these two among others for this test because only HSA_MCP can be seen to perform at least in a comparable manner to our proposed algorithm. A total of 10 controllers and 1500 switches were used to investigate the impact of network interference on the stability that was attained in the course of packet routing. The delays were measured in milliseconds while the progressive results were derived in the course of sending packets. The three dimensional representation was depicted in Fig. 3 and Fig. 4 for HSA_MCP and DART_MCP respectively.

Table 1. The analysis representations. Comparison of network stability delays.

SDN resources		Algorithm delays			
Switches	*Controllers*	*H_MCOP*	*SA_MCP*	*HSA_MCP*	*DART_MCP*
300	2	128	88	47	26
600	4	255	176	96	55
900	6	388	267	145	83
1200	8	518	356	194	111
1500	10	650	450	245	140

The figures clearly showed that for network nodes of 1500 running with 10 controllers, it took HAS_MCP approximately 245 ms to attain network stability while on the other hand, DART_MCP in Fig. 4 only used 140 ms instead. The differences between these two values occurred as a result of network interferences as earlier highlighted. Under this experimental design, there are some cases in which an appropriate number of controllers would have enabled total avoidance of network interferences however, this was designed to see how much of the effects could be reduced by the deployed algorithms.

Thus, a vast difference of 105 ms existed in the performance of the two algorithms when compared. It is noteworthy to understand that at each interval, the amount of delays could be calculated to determine the corresponding values under similar conditions. However, to avoid unnecessary replication of graphs, we just selected the same number of network setup but running on different algorithms to compare the performances. The remaining results were depicted in Table 1. Hence, in a case where we are short of network resources especially controllers and at the same time we are trying to accommodate more network hosts, a high stability routing protocol will be of importance which can help to reduce if not totally alleviating the effect of network interferences. Based on these four tested algorithms, DART_MCP provides us with the best network stability,

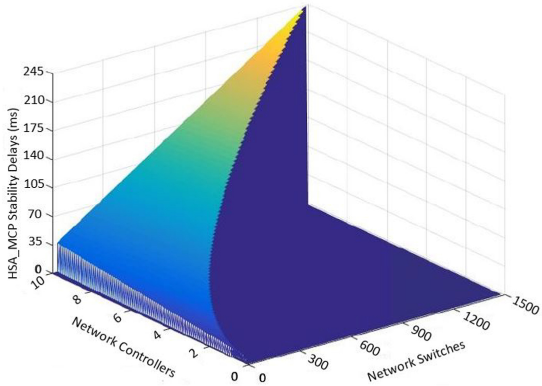

Fig. 3. HAS_MCP Delay before attaining network stability

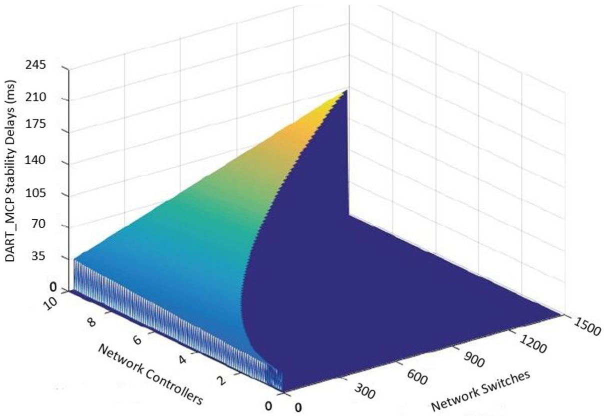

Fig. 4. DART_MCP's Delay before attaining network stability

causing a reduction in the network delays with the percentage of 42.9 as depicted by our experiments.

5 Conclusion and Future Works

This work was motivated by the need for an improved routing network in SDN that focus on a stable network performance when larger network nodes were associated. We identified basically the impact of network interference on affecting the combination of user requirements which invariably reduces the success rate and the running time of the network. The success rate and running time directly speaks to the throughput and the latency experienced in the course of the network operations therefore necessitating the need for their optimisation. We address these basic challenges through deploying a deterministic adaptive rendering technique (algorithm) called DART_MCP. The tests on the efficiency of our proposed approach was first carried out to determine the stability in rate of bandwidth consumption as well as the stability in the user experience that is deciphered. The DART_MCP algorithm contains the Monte-Carlo (ZZ) buffer which supposedly assists in establishing the stability of the network performance in relation to the effect of network interferences. The buffer approaches the versatility of distributed networks as it can render wide influx of transferred packets while maintaining the QoS of varying network users.

Hence, the proposed algorithm was able to optimize the network metrics requirements to a level that is optimal on the basics of this work in the domain of SDN. The evaluation of the algorithm against others showed that our proposed algorithm was able to maintain lower network running time and higher success ratio to provoke low latency and higher throughput respectively. Further experiments also showed a faster convergence (with a reduction of 42.9% in network delays) in attaining the network stability state for DART_MCP than the existing algorithms even though for the kind of design, interference could not be totally eradicated meaning that our proposed algorithms could assist in managing the network resources especially in a situation where the number of controllers available is fewer than what is required. We were also able to reduce the key inhibitors to network stability which is predominantly the control flow path issues and the co-channel interferences. The future work that we envisaged in this work is to introduce the deployment of machine learning algorithms or some AI mechanisms thereby introducing some level of intelligence to enhance the performance of the SDN system in terms of stability.

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