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Article

Routing Performance Evaluation of a Multi-Domain Hybrid SDN for its Implementation in Carrier Grade ISP Networks

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Abstract: Legacy IPv4 networks are strenuous to manage and operate. Network operators are in need to minimize the capital and operational expenditure of running network infrastructure. The implementation of Software-defined networking (SDN) addresses those issues by minimizing the expenditures in the long run. Legacy networks need to integrate with the SDN networks for the smooth migration towards the fully functional SDN environment. In this paper, we compare the network performance of the legacy network with the SDN network for IP routing in order to determine the feasibility of the SDN deployment in the Internet Service provider (ISP) network. The simulation of the network is performed in the Mininet test-bed and the network traffic is generated using distributed Internet traffic generator. Open network operating system is used as a controller for the SDN network in which SDN-IP application is used for IP routing. Round trip time, bandwidth, and packet transmission rate from both SDN and legacy networks are first collected and then the comparison is done. We found that SDN-IP performs better in terms of bandwidth and latency as compared to legacy routing. The experimental analysis of interoperability between SDN and legacy networks shows that SDN implementation in production level carrier-grade ISP network is viable and progressive.

Keywords: ISP; SDN; SDN-IP; legacy network; performance comparison

1. Introduction

Networks are organized groups of devices or nodes with communication links among them. Traditional IP networks are termed as legacy networks. In spite of the World-wide use, the traditional network is complex and tedious to manage. Adding a new device or changing the network configuration is complex in traditional networking i.e. it should be done using low-level languages and rigid commands thus taking days and months for large networks. Thus, the expansion of existing legacy network is fairly expensive. The demand for the network based services is increasing rapidly. To meet those growing demands, numbers of running hardware should be increased and changes should be made in software leading to higher cost in system upgrades. Manual configuration, inconsistent policies, and inability to scale are the major problems of the traditional IP networks. Vertical integration has made traditional IP networks more complex in its operation and management. Legacy networking devices have the control plane and data plane integrated into the same physical device. The data plane, also called the forwarding plane, is hardware unit whose job is to collect the network packets and forward them to the destination based on the entries provided in routing table. Network policies are enforced in the control plane. The control plane determines how the packets in the data plane should be handled e.g. drop, reject, forward etc.

In SDN, network devices are controlled by SDN controller and the applications are installed on the top of controller. When the control and data plane functionalities are segregated, network switch becomes simply a data plane forwarding device. The control logic is implemented in a logically centralized controller, which runs network operating system (NOS) that runs on commodity server hardware to provide necessary resources to facilitate the proper control and operation of data plane devices based on a logically centralized, abstract network view [1]. The logical centralization of the control logic makes it simply flexible and error-free policy deployment through high-level programming languages as an application programming interfaces (APIs), compared to low-level device-specific configurations frequently done in legacy networks. The controller provides the global view of the overall network that simplifies the development of more robust network functions, services, and applications. The resulting network is also programmable through software applications running on top of the controller OS that interact with the underlying data plane devices. The APIs at controller can automatically react to spurious changes of the network state and maintain high-level policies intact [1].

Though SDN implementation at datacenter network is popular, its proper implementation with the migration of legacy network at carrier grade ISP (CG-ISP) and telecommunication (Telcos) networks is becoming a central challenge for service providers due to the need of real time migration as well as higher cost of investment [2,3]. Additionally, real time implementation of SDN in production networks is an ongoing research. Hybrid SDN is the only solution for the smooth migration of legacy ISP/Telcos network into SDN [4,5]. In this paper, we consider hybrid SDN implementation and routing performance evaluation by comparing the legacy routing and SDN routing with their interoperability through an experimental analysis using an open network operating system (ONOS)/SDN-IP [6] and evaluate the viability of SDN implementation in ISP/Telcos networks. The major contributions of this paper are as follows.

- A multi-domain hybrid SDN environment is created and implemented the routing between SDN and legacy network domains.
- Routing performance is evaluated between legacy routing and SDN routing using ONOS/SDN-IP. Routing using SDN-IP has better performance than legacy routing.
- This experimental analysis evaluates the viability of SDN implementation in ISPs/Telcos networks and encourages the service providers to migrate their legacy networks into SDN.

The rest of this paper is organized as follows. Section 2 presents the background and related work in the field of SDN and legacy network integration. Section 3 presents the problem description of our research and the proposed method. We present the details about experimental setup, analysis, and evaluations in Section 4. Section 5 provides a discussion and future work, while the paper is concluded in Section 6.

2. Background and Related Work

New technology implementation cost is generally higher in terms of capital and operational expenditure (CapEX and OpEX) investment and the development of technical human resources (HR) to manage and operate those newer technologies for ISPs and Telcos service providers. There are also certain implementation challenges with respect to management, availability of technological standards, and user interface provisioning while providing new technology-based services to customers during and after the network migration [7,8].

Legacy network is less flexible to customized programming and is more vendor specific leading to higher dependency towards support, management, and operation. A better solution would be the implementation of SDN. In SDN, networks are controlled by software applications running on the top of SDN controller. The separation of control and data plane operations in SDN simply transforms the network switches as a simple forwarding devices.

NOS provides the essential resources and abstractions to facilitate the programming of forwarding devices based on a logically centralized, abstract network view. The resulting network is also programmable through software applications running on top of the NOS that interacts with the underlying data plane devices. ONOS [9] is the robust and distributed controller OS, which provides better solution to build next-generation SDN/NFV solutions. The need of ISPs and Telcos service providers can simply be fulfilled by the introduction of ONOS to carrier-grade solutions that leverage the economics of white box merchant silicon hardware while offering the flexibility to create and deploy new dynamic network services with simplified programmatic interfaces [9]. ONOS is developed with set of other several applications that makes it flexible, modular, scalable in terms of both the architecture and the cluster, and distributed SDN controller. SDN-IP is one of the ONOS application developed to implement routing with external legacy networks using standard border gateway protocol (BGP) to enable interoperability with legacy routing. In ONOS/SDN-IP, the SDN can be treated as a single autonomous system (AS) and communicates simply with external AS as a traditional routing. SDN-IP integrated BGP and ONOS enables communication with external AS in the hybrid SDN so that SDN-IP behaves as a regular BGP speaker and uses its services to install and update the appropriate forwarding state in the SDN data plane devices.

Dawadi et al. [3,10–12] presented approaches for legacy network transformation to SDN and IPv6 networking so that service providers can smoothly plan for network transformation with optimised migration cost. Authors implemented IPv4/IPv6 routing in multi-domain SoDIP6 network using ONOS/SDN-IP.

Friyanto [13] presented the use of multiple ONOS controllers in a cluster for high available services using ONOS/SDN-IP reactive routing. Efficient routing implementations in the different aspects of wired and wireless SDN [14–17] are the primary concerns. But their implementations in production level networks have to be evaluated considering the smooth transition from legacy to hybrid SDN to pure SDN.

There are many researches looking after the hybrid SDN implementations. For example, HARMLESS [18], Panopticon [19], RouteFlow [20], Fibbing [21], OSHI [22] are some of the attempts, but most of these researches have not been implemented in production level. Similarly, few researches dealt with the implementation of SDN in CG-ISP networks using ONOS/SDN-IP [6,23–25], while ONOS is the best controller by its features and dedication towards transport SDN over wide area network [26]. Kong et al. (2013) [27] has evaluated the performance of OpenFlow switch in SDN by comparing with legacy networking and found that OpenFLow based communication was not well performed. During that period, SDN was almost in the emerging stage but now, SDN is well matured [28–30] and robust. Research to implement SDN in ISP network is in progress [23,31]. SDN is popularly implemented in data center networks [32,33] and its implementation in ISP network is an ongoing research. Because of being early stage of SDN implementation in service provider networks, we found limited or no research works related to routing performance comparison in terms of BGP implementation in legacy and SDN in the service provider networks. Our approach in this study is not scoped towards migration techniques, but we focused on the production level implementation of routing in hybrid SDN and its performance comparison with legacy network to measure the viability of legacy network transition towards SDN by implementing ONOS/SDN-IP.

3. Problem Description and Proposed Method

The overall structure of our experimental evaluation is based on the concept of ONOS/SDN-IP implementation as depicted in Figure 1. All the external networks i.e. external ASes are supposed to be the legacy networks, directly connected with backbone transit AS, which is SDN based.

A use case topology network as shown in Figure 2 is created in Mininet for experimental analysis in this study. For routing purpose, Quagga routing suite [35] is used at

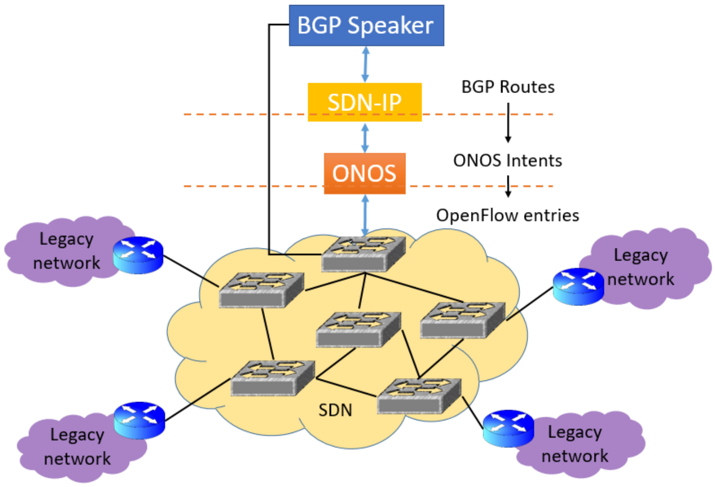

Figure 1. Use case network of SDN integration with legacy networks [34]

which BGP is implemented. For SDN integration with legacy network, ONOS controller is configured to implement BGP and SDN-IP with reactive routing enabled.

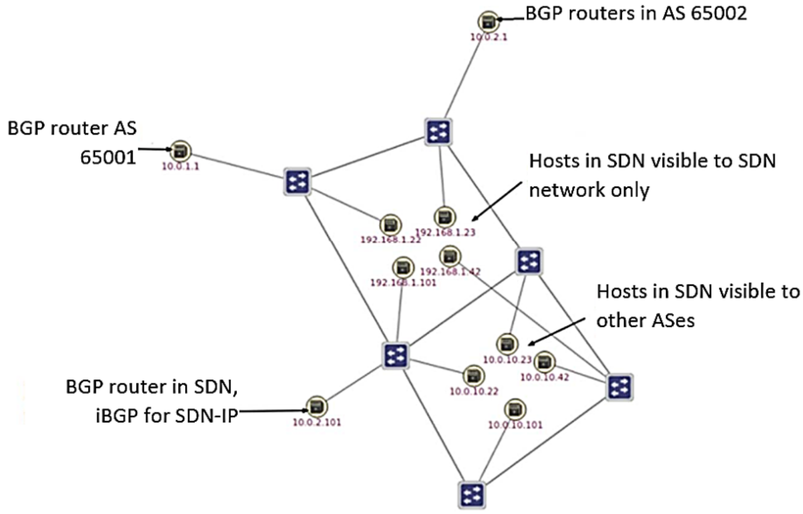

Figure 2. Experimental topology of SDN integrated with Legacy networks

A complete legacy network mimicking Figure 1 is created as shown in Figure 3, where BGP and OSPF are used for routing purpose. Each router is a virtual machine loaded with BGP and OSPF configuration. In the Figure 3, r5 is route reflector router [36] and r4, r3, r6, r7, and r8 are its clients, whereas r4-r2 and r3-r1 are BGP peers.

The SDN integrated legacy network and pure legacy network are chosen in the present study to analyze network performance. For comparison between them (hybrid SDN and legacy network), distributed internet traffic generator (D-ITG) [37], Packet InterNet Groper (*PING*), Iperf, and statistical rules are applied. Varying number and size of packets are created and transmitted from one host to another in each network and corresponding delay, latency, and total packet transmission are observed. *PING* utility is used to check the network connectivity between hosts. In both networks, first, *ping* is used to ensure total communication in the network, then it is used for finding out RTT. We have used *Iperf* to determine the maximum bandwidths offered by the network. The compatibility and performance of SDN integration with the legacy network for multi-domain routing purpose is clearly depicted by statistical values and comparison techniques required for SDN and legacy network. Mininet emulated the hosts as a Linux machine. ONOS running on the same machine is used as an SDN controller.

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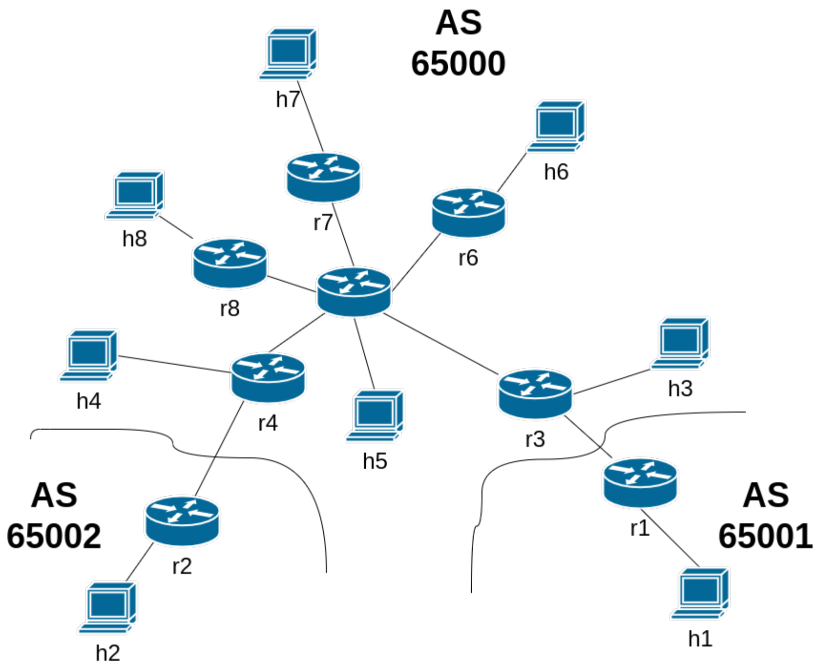

Figure 3. Use-case of legacy routing network

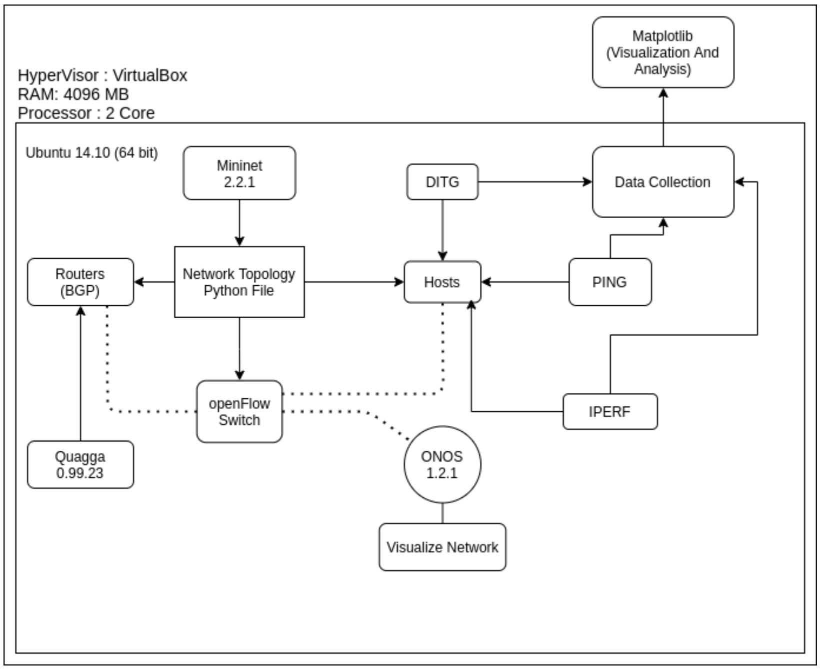

Figure 4. System setup simulation environment

The experimental setup of this study is depicted in the Figure 4. The experiment is executed in a virtual environment for which we used Oracle VirtualBox as the hypervisor. The guest operating system is allocated with 4GB of base memory and 2 processor cores. The experiment was carried out in Ubuntu 14.10 (64 bit) operating system. The network topology file uses Mininet to create routers, hosts and OpenFlow switches. Quagga version 0.99.23 is configured in the routers for BGP routing in SDN, while OSPF and BGP are configured for legacy network. Routers and hosts receive data routed through the OpenFlow switches. ONOS (version 1.2.1 user) interface provides the visualization of the network. DITG, PING and IPERF tools are used for the data collection. The collected data are analyzed and visualized using python Matplotlib module. The brief of the APIs enabled over ONOS are as follows.

- **OpenFlow**: It is the southbound protocol in the SDN control plane. It enables communications between data plane and control plane devices so that the control plane deploys flow rules in the OpenFlow table of data plane and provides decision for every packet incoming to data plane devices.
- **Config**: This application is activated for loading network configuration.
- **ProxyARP**: It is the process of resolving the address of a host. It responds to address resolution protocol (ARP) or neighbor discovery protocol requests on behalf of a target host if the target host is known to ONOS (i.e. it is present and active in the host store). ProxyARP considers the network to be a single IP network, therefore if it receives a request for which the target host is not known, it will flood the request out every edge port in the network (apart from the input port) in the hope that the host exists in the network and will reply.
- **SDN-IP**: It is an ONOS application for routing implementation that allows an SDN to connect to external networks on the internet using the standard BGP.

After running those APIs, we can see the routes learned by ONOS, which can be seen using *routes* command on the ONOS console. The routes learnt by BGP speaker in SDN is shown in Figure 19. In the legacy ASes, an eBGP router is connected with a single host. The SDN network in our proposed use case consists of a BGP border router, which acts as iBGP to SDN-IP and eBGP speaker to the external legacy networks. The BGP policies advertised by external network border routers will be received by the ONOS/BGP speakers in the transit SDN and re-advertised to other external legacy networks by SDN-IP as an iBGP peer. SDN-IP translates the best route policies into ONOS application intent request (AIR) and deployed into data plane devices as forwarding rules to route transit traffic into appropriate external domains. Internal BGP speakers were configured to use TCP port at 179 to communicate with other BGP speakers and TCP port at 2000 to send the route information to ONOS/SDN-IP instances and the external BGP speakers are connected to OpenFlow enabled switches.

The BGP routers are emulated using Linux hosts in which Quagga routing suite is running. The BGP daemon of the Quagga routing suite is used for the BGP routers. Figure 2 shows SDN-IP implementation for an ISP network, where BGP speakers 10.0.1.1, 10.0.2.1, and 10.0.2.101 are connected to OpenFlow switches. BGP speaker 10.0.1.101 is connected to ONOS. i.e SDN-IP. It advertises route information to SDN-IP using which the SDN network acts as a transit AS. BGP speakers 10.0.1.1 and 10.0.2.1 are connected to external AS. These speakers advertise routes to the AS to other BGP speakers. iBGP speaker 10.0.1.101 listens to these routes and sends it to SDN-IP. SDN-IP changes the known BGP routes to intents and ONOS turns the intents to OpenFlow entries. The OpenFlow entries are then deployed into the OpenFlow switches using OpenFlow protocol.

Using D-ITG, UDP flows were generated with varying packet size and packet rate for 15 seconds. Two log files were generated for both the sender and receiver side. The log file generated at the receiver side contained values for different performance indicators such as delay, jitter, bit-rate, bytes received, packets dropped, and average loss-burst size. On decoding the log file, we get a stream of data containing these performance indicators. The values of these parameters are taken from the log file on receiver's side. Multiple unidirectional flows were sent for fifteen seconds between pairs of hosts in turns by varying transmission rate and packet size to study the performance of the network under low and high load. The packet size set were 512 and 1024 bytes and the packet transmission rates were varied to 100, 1000, and 3000 packets per second. These flows were sent in the traffic via UDP where each host acted both as a client and a server. Ultimately, the log files of flows generated from 10 hosts (ref. Figure 2) in the

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SDN network were further processed to a CSV file using a python script. The D-ITG data samples generation snapshot is as shown in Figure 5.

```
----------------------------------------------------------
Flow number: 1
From 10.0.0.4:34771
To    10.0.0.3:9501
----------------------------------------------------------
Total time                 =      9.999002 s
Total packets              =         10000
Minimum delay              =      0.000000 s
Maximum delay              =      0.000000 s
Average delay              =      0.000000 s
Average jitter             =      0.000000 s
Delay standard deviation   =      0.000000 s
Bytes received             =       7498028
Average bitrate            =   5999.021102 Kbit/s
Average packet rate        =   1000.099810 pkt/s
Packets dropped            =             0 (0.00 %)
----------------------------------------------------------
****************  TOTAL RESULTS   ******************
Number of flows            =             1
Total time                 =      9.999002 s
Total packets              =         10000
Minimum delay              =      0.000000 s
Maximum delay              =      0.000000 s
Average delay              =      0.000000 s
Average jitter             =      0.000000 s
Delay standard deviation   =      0.000000 s
Bytes received             =       7498028
Average bitrate            =   5999.021102 Kbit/s
Average packet rate        =   1000.099810 pkt/s
Packets dropped            =             0 (0.00 %)
Error lines                =             0
----------------------------------------------------------
```

Figure 5. Snapshot of a D-ITG output

Moreover, 507 data samples were captured during simulation. Figure 6a,b,c,d shows the pattern and distribution interval of the data samples for delay, jitter, bit rate, and the packet rate respectively.

The bi-variate distribution of numerical attributes can be observed in the pair-plot shown in Figure 7. A pair-plot visualizes given data to understand the best set of features to explain a relationship between two variables (attributes) or to form the most separated clusters. The plot is in matrix format where the x-axis is represented by row name and the y-axis is represented by column name. The main-diagonal subplots are the univariate histograms (distributions) for each attribute. For example, the plot in fourth row and fourth column shows the univariate histogram for average_jitter where the minimum and maximum of the parameter can be observed. On the non-diagonal subplots, bi-variate distribution between attributes can be observed. Some plots such as those in the first column and the first row represent separate clusters, which show that no relationship exist between the attributes. Certain scatter plots that follow a clear linear pattern with an increasing or decreasing slope can be seen, which shows that some conclusions can be drawn from the distribution. Plots with a linear relationship between the two attributes make it possible to identify, in which space the classes will be well separated from each other. For example, the plot in second row and fourth column shows a linear relationship between the two variables. Such linear patterns are representation of dependencies among the attributes bringing us to the conclusion that average delay and average jitter are correlated.

The pair-plot is an efficient tool for exploratory data visualization and analysis but doesn't show the strength of correlation between the attributes with dependencies.

(a) Data samples for average delay

(b) Data samples for average jitter

(c) Data samples for average bit rate

(d) Data samples for average packet rate

Figure 6. Distribution range of sample dataset (507 samples)

This can be achieved through a correlation heat-map using the heatmap() function available in Seaborn package. The correlation of all the numerical attributes as a heat-map using Spearman correlation coefficient is shown in Figure 8. The scale of color in the heat-map varies from blue to yellow where blue signifies correlation of +1 and yellow signifies correlation of -1. Spearman correlation coefficient measures the extent to which two variables tend to change together. The coefficient describes both the strength and the direction of the relationship. The Spearman's rank-order correlation is the non-parametric version of the Pearson correlation. Spear-man's correlation coefficient(r_s) measures the strength and direction of association or the monotonic relationship between two ranked variables. It requires two variables that are either ordinal, interval, or ratio. For a sample size of n, the attributes X_i and Y_i are converted to ranks rg_x and rg_y. Spearman correlation coefficient (r_s) is computed by equation 1,

$$r_s = cov(rg_x, rg_y)/\sigma_r g_x.\sigma_r g_y \tag{1}$$

Where, $cov(rg_x, rg_y)$ is the co-variance of the rank variables. $\sigma_r g_x$ and $\sigma_r g_y$ are standard deviations of the rank variables.

It can be observed from the Figure 8 that average delay and average jitter are highly correlated with a Spearman coefficient of 0.92. Similarly, bytes received, average bit rate, and average packet rate are highly correlated as well. Parameters, e.g. average delay

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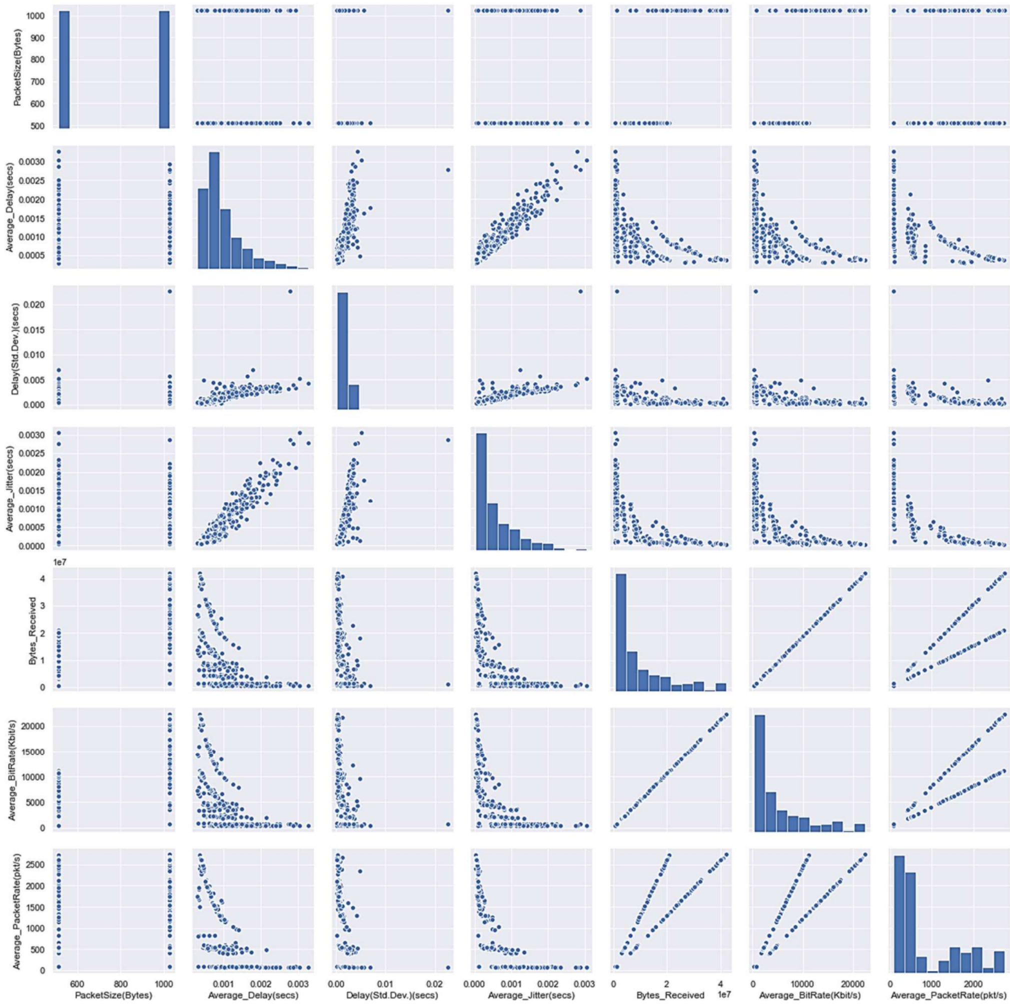

Figure 7. Pair-plot of Data set

and average packet rate can be observed to be negatively correlated with Spear-man coefficient of -0.75.

4. Analysis and Evaluations

This section aims to highlight the differences between the integrated SDN network and the legacy network by comparing them in terms of various performance indicators. Additionally, the performance of the integrated SDN network was further observed by taking note of the network quality of service (QOS) parameters defined.

4.1. Comparison between SDN and legacy network

In this section, we provide a comparative analysis of the use case network proposed as hybrid SDN and legacy network in terms of QoS parameters defined. The comparison is done by analysing the performance of both networks (legacy and SDN) on the basis of bandwidth capacity, packet transmission rate, and time required to transmit packet from source node to the destination node.

4.1.1. Bandwidth

The results of bandwidth capacity in both the SDN and legacy network is obtained by using '*Iperf*' tool in Mininet. Here, we show the maximum bandwidth between hosts in neighbouring AS and within the same AS for both the SDN and the legacy network. In addition to that, maximum bandwidth when the hosts that use AS65000 or SDN as a transit network to connect is also shown. As shown in the Figure 9, the maximum

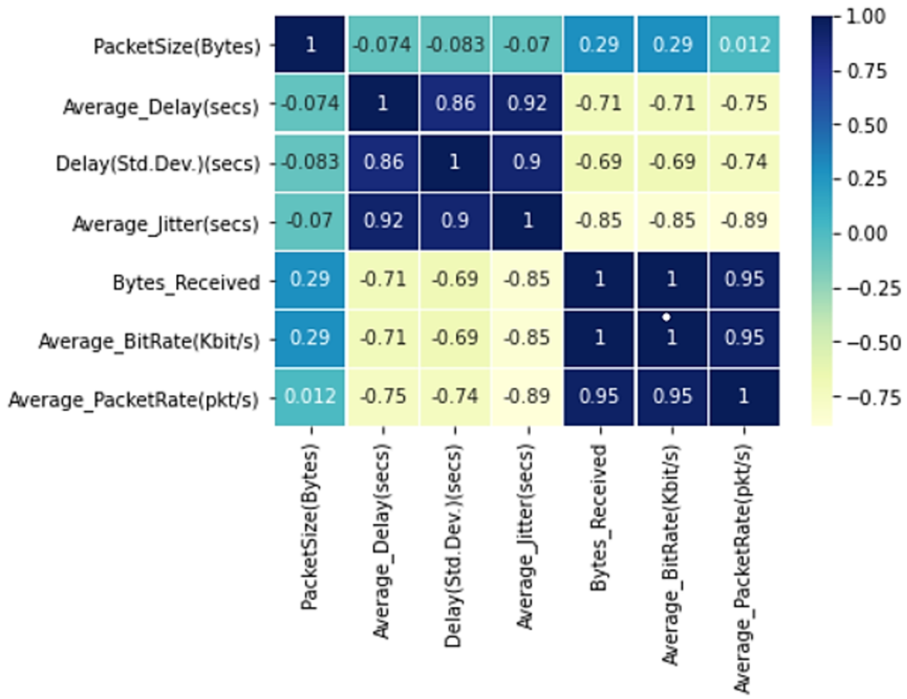

Figure 8. Spear-man correlation heat-map

bandwidth seems to be higher in the case of SDN network, which can highlights the ability of SDN to transfer more data per second compared to their legacy counterparts.

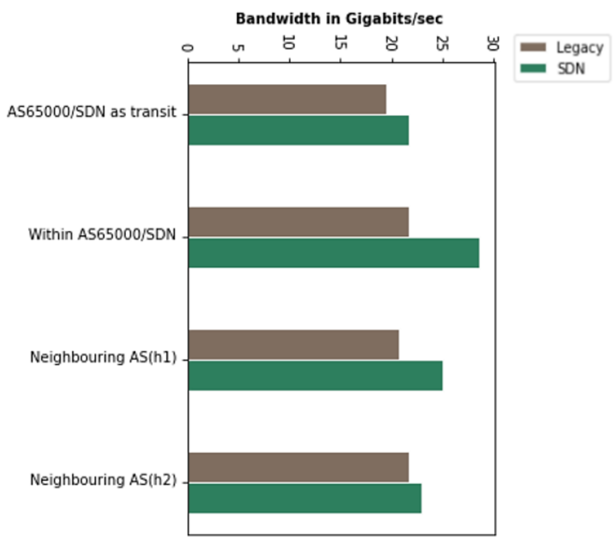

Figure 9. Bandwidth capacity for SDN and legacy network

It can also be seen that the maximum bandwidth is higher for nodes within AS65000 or within the SDN compared to neighbouring AS or when AS65000 and SDN are used as a transit network.

4.1.2. Packet transmission rate (PTR)

We compared both networks based on the PTR obtained by executing '*PING*' tool in Mininet. PTR for both topologies is shown in Figure 10 for source and destination hosts that use AS65000 or SDN network as transit network for varying number of packets.

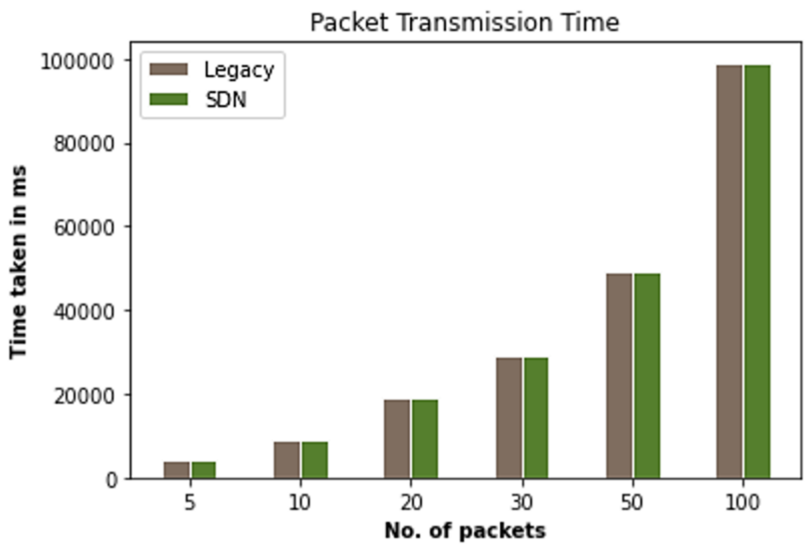

Figure 10. PTR for AS65000/SDN as transit network

The results for PTR obtained indicate that the total time taken by both networks for a given number of packets is almost equal. It is noted that both networks are active for same amount of time interval to execute the command.

4.1.3. Round trip time (RTT)

Next we compare the delay between nodes in each network. *'PING'* command was executed to obtain the RTT between the source and the destination nodes. The networks are compared on the basis of the variance of RTT, and minimum and maximum values of RTT.

RTT variance:Here the standard deviation of values of RTT for both the networks are plotted in a graph. This is done for source and destination nodes within an AS, in neighbouring AS, and when AS65000 and SDN network are used as transit networks.

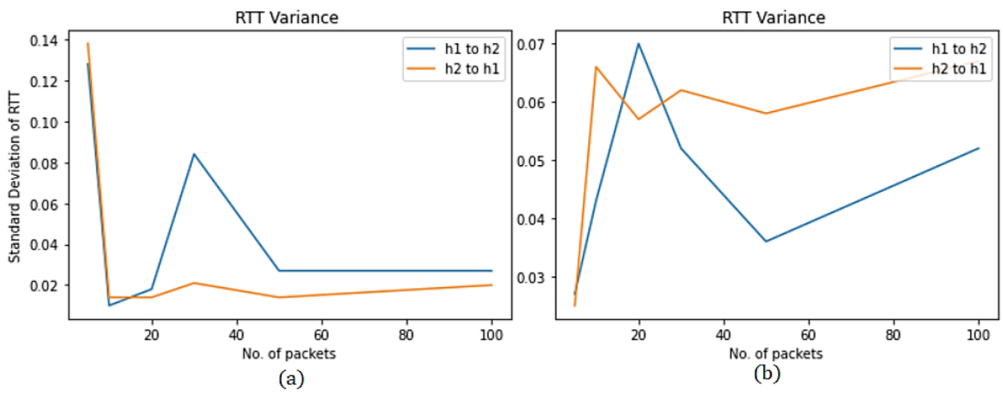

Figure 11. RTT Variance, (a) AS65000/SDN as Transit in SDN, and (b) in Legacy

Since, standard deviation is simply the average of how far each RTT value is from the mean RTT. This shows how the round trip time varies with time. Higher the value of variation in RTT value results in a more unstable network. As shown in the plots of Figures 11a,b, 12a,b,13a,b,c,d, and 14a,b,c,d, the standard deviation values with varying number of packets for SDN is lesser than legacy network. This signifies that SDN can be more reliable and stable than their legacy counterparts.

The values used in the plots are used as point estimates to provide a rough estimate of the population parameter (i.e. mean RTT variance of the population) within a confidence interval. Two different samples for the legacy (ref. Figures 11b,12a, and 13a,b,c,d) and SDN network (ref. Figures 11a,12b, and 14a,b,c,d) were taken respectively.

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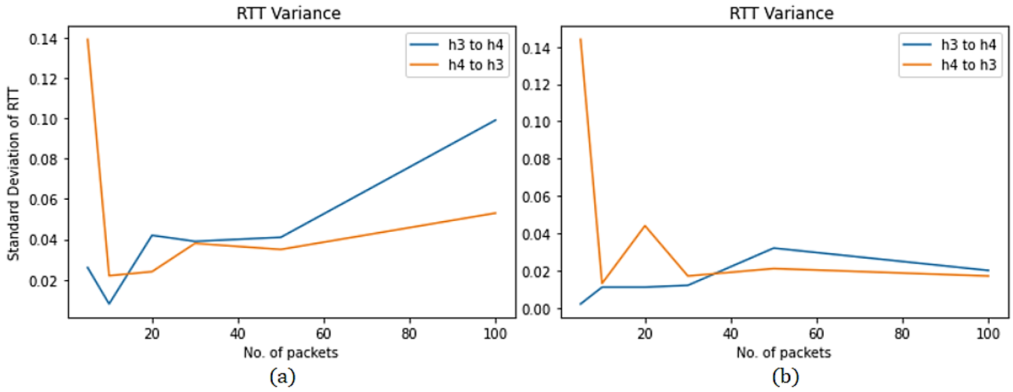

Figure 12. RTT Variance, (a) Within AS65000/SDN in Legacy, and (b) SDN

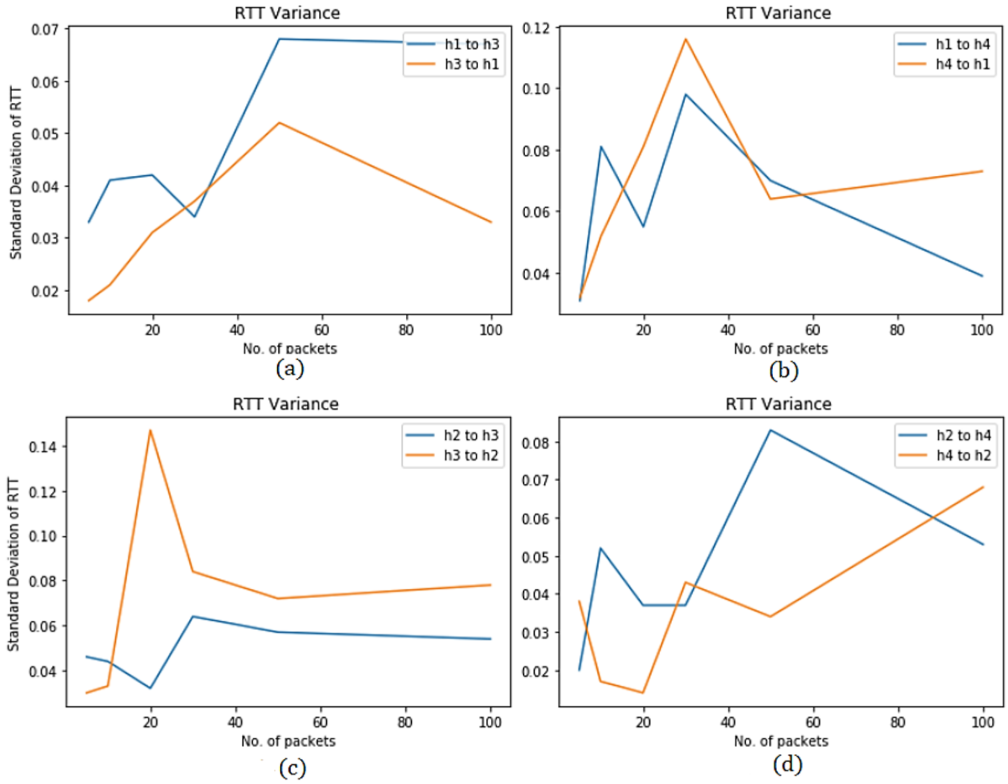

Figure 13. RTT Variance for Neighbouring AS of Legacy Network, (a) h1<->h3, (b) h1<->h4, (c) h2<->h3, and (d) h2<->h4

T-distribution of the samples are determined at the confidence level of 95% as the standard deviation of the population is unknown to us. For legacy network, a confidence interval of (0.02495, 0.06938) is obtained with sample mean equal to 0.0472 and t-critical value equal to 2.200985. Similarly, for SDN network, a confidence interval of (0.0304, 0.0551) is obtained with a sample mean equal to 0.042767 and t-critical value equal to 2.000995.

Most of the observations presented in the graph have spikes at the beginning because of the fact that in both the topologies, the pinging host first needs to discover the target to be communicated with which takes additional time. Spikes other than in the starting phase is due to performance of the computer on which tests were performed. The experiments were carried out in virtual machines and the resources might not be equally allocated by the computer during the testing period. The values might vary if performed on different computer but the results would be similar and SDN would generally provide better performance.

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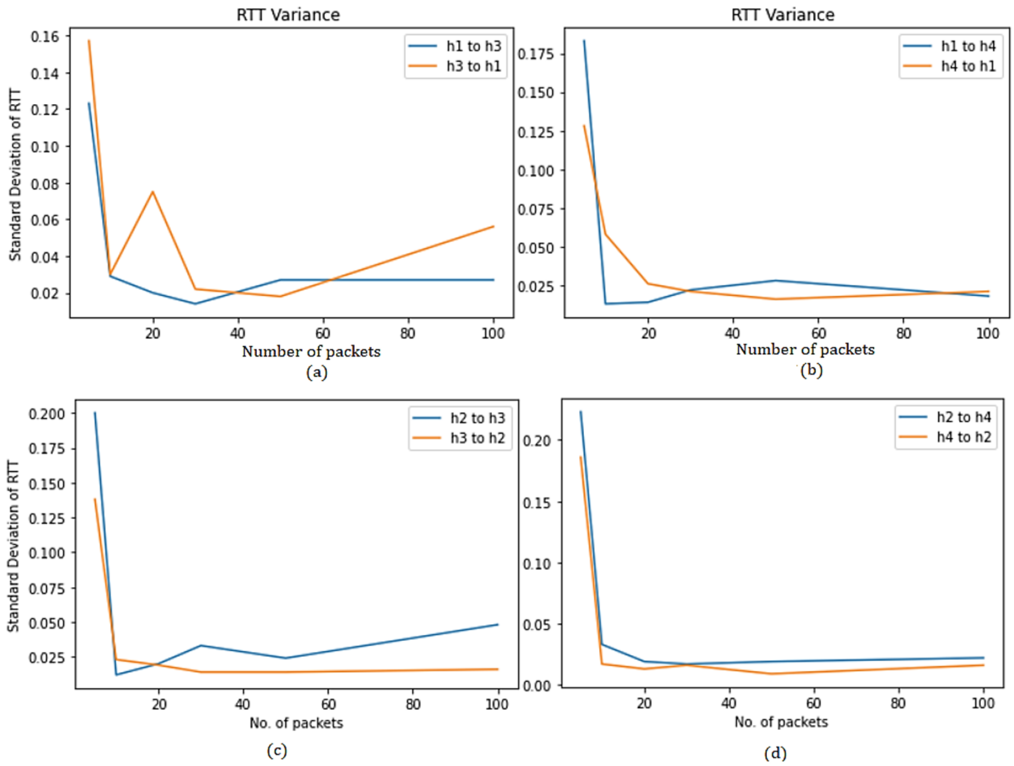

Figure 14. RTT variance for neighbouring AS of SDN, (a) h1<->h3, (b) h1<->h4, (c) h2<->h3, and (d) h2<->h4

Maximum and minimum RTT: The minimum and maximum values of RTT for both networks are plotted in a graph of Figures 15a,b,c,d, 16a,b,c,d, and 17a,b,c,d. This is done for source and destination nodes within an AS, in neighbouring AS, and when AS65000 and SDN network are used as transit networks.The traffic were captured at multiple rounds and more than one plots are provided in the Figures 15, 16, and 17 respectively.

From the plots of Figures 15a,b,c,d, 16a,b,c,d, 17a,b,c,d, and 18a,b,c,d, it can be observed that for varying number of packets, the minimum and maximum values of RTT are lesser in SDN compared to that of legacy network. Higher RTT value signifies more time taken for transmission of packets that can affect the speed and reliability of the network. Thus, it can be concluded that routing in SDN using ONOS/SDN-IP performs much better than legacy network in terms of speed and reliability.

4.1.4. Learning time

Figure 19 and Figure 20 shows the routes learnt by ONOS controller in SDN and our BGP router in legacy topology respectively. It is noted that the controller took about ten to fifteen seconds to learn the complete routes, whereas the BGP routers in legacy network took around one minute. This shows that the learning rate of SDN is faster than that of legacy network. In legacy network, every router needs to learn about the changes in the topology whereas in SDN, only controller needs to know about the changes and it will install corresponding flow entries in the forwarding devices if required. This improves network performance as no routing advertisement messages are advertised in the network.

5. Discussion and Future Work

Virtualization capability of SDN enables to have powerful APIs, which can be used to control many network functionalities with intelligence. The lack of backward compatibility of SDN with the legacy network enforces research communities to develop

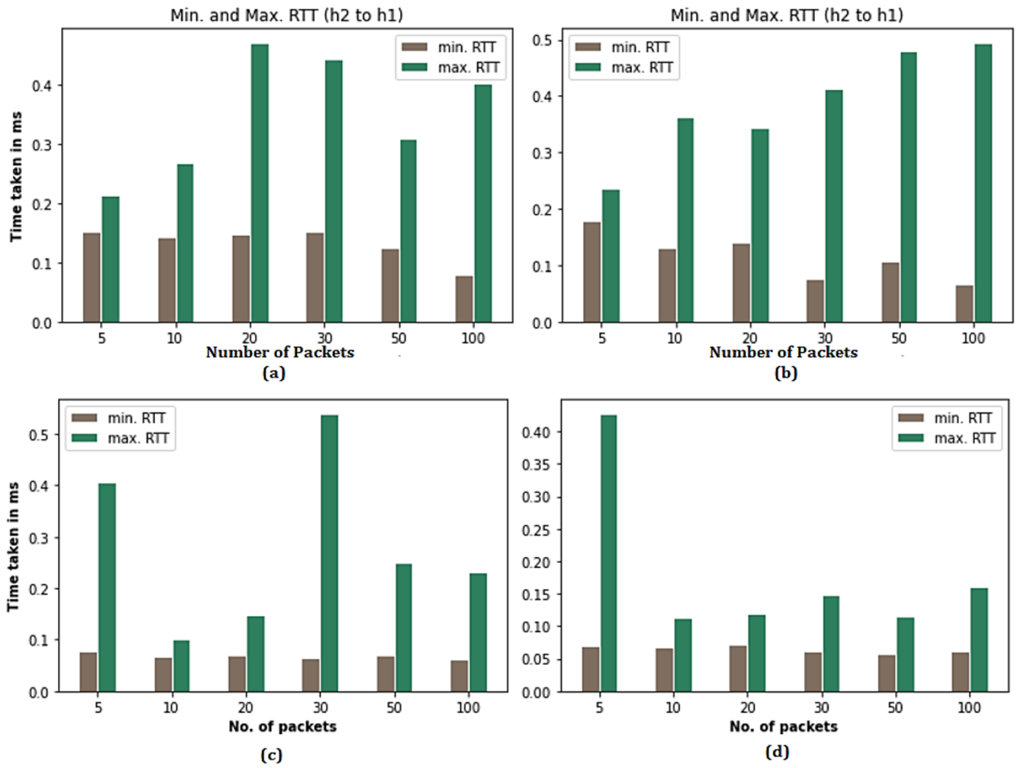

Figure 15. RTT variance between h2 and h1, (a)/(b) AS65000/SDN as transit in legacy, (c)/(d) RTT variance between h2 and h1 in SDN

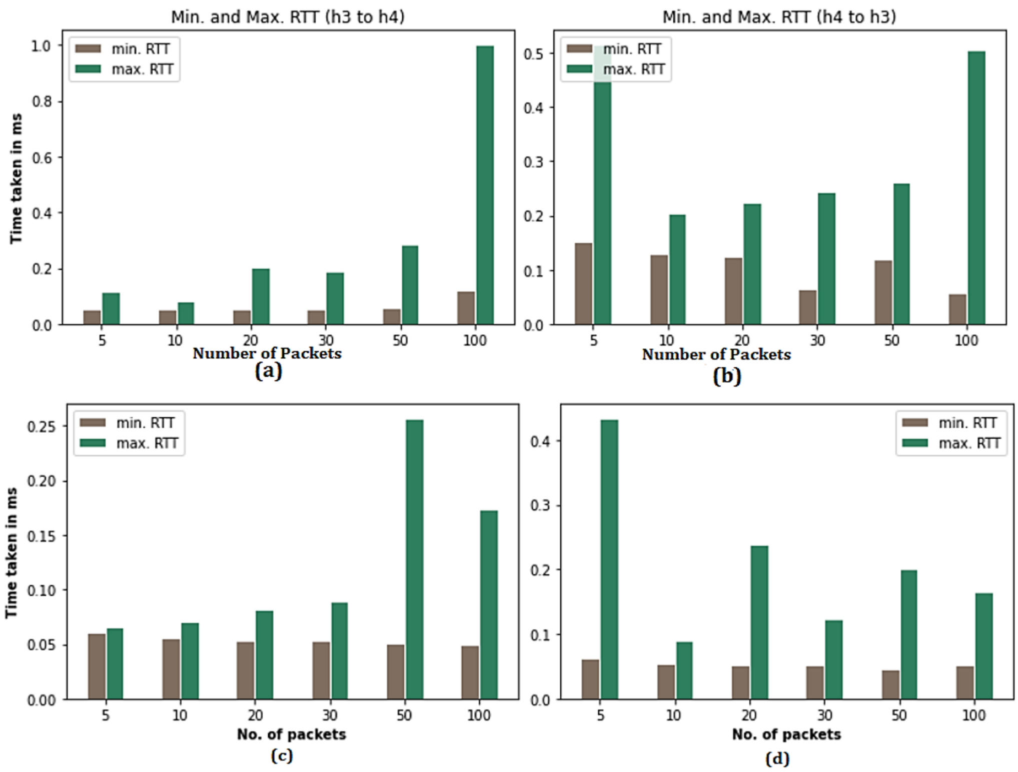

Figure 16. RTT variance, (a)/(b) Within AS65000/SDN in Legacy, and (c)/(d) in SDN

robust system for interoperability between SDN and legacy networks for smooth and low cost migration approaches. Hybrid SDN is the only solution to have smooth transition to pure SDN for service providers so that customers can get uninterruptible services

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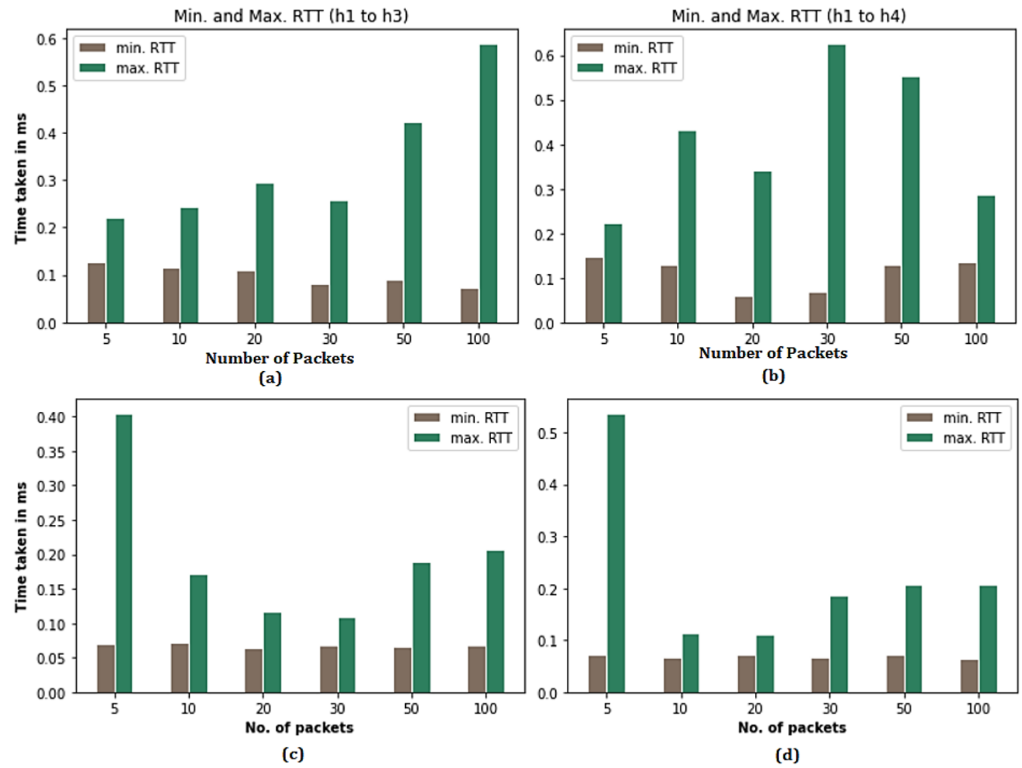

Figure 17. RTT variance for neighbouring AS for Host h1, (a)/(b) in Legacy, and (c)/(d) in SDN

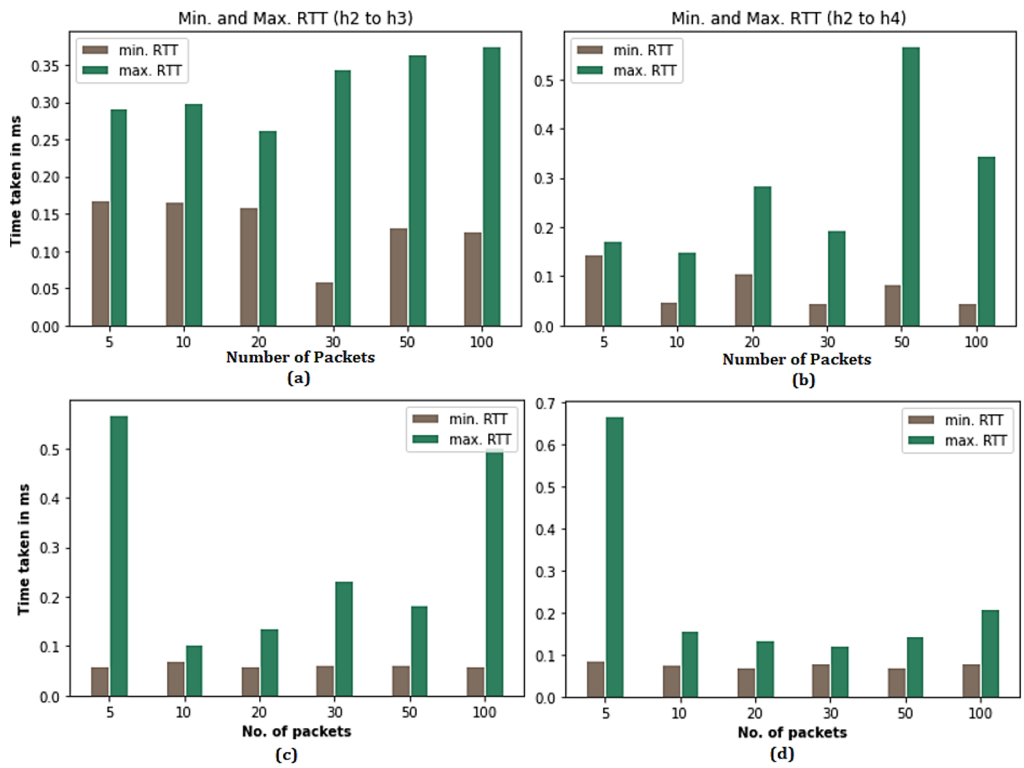

Figure 18. RTT variance for neighbouring AS for host h2, (a)/(b) for Host h1 in legacy, and (c)/(d) in SDN

during the migration period. SDN-IP is an ONOS application that is used to peer SDN networks with external networks on the Internet using the standard BGP so that service providers can run hybrid SDN in their existing network during the transition

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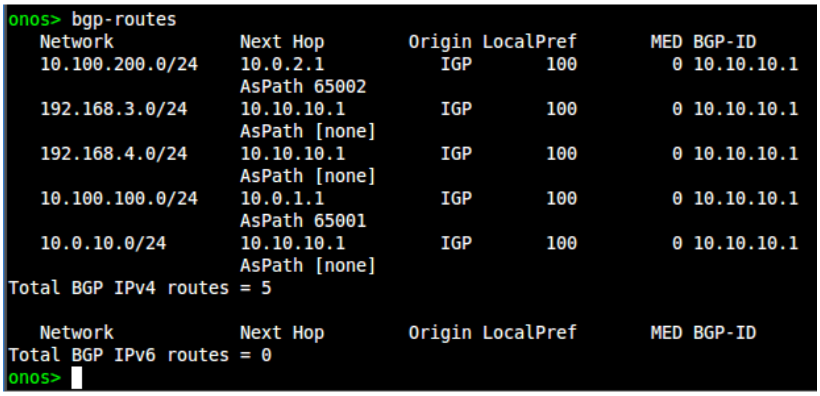

Figure 19. Routes Learnt by ONOS

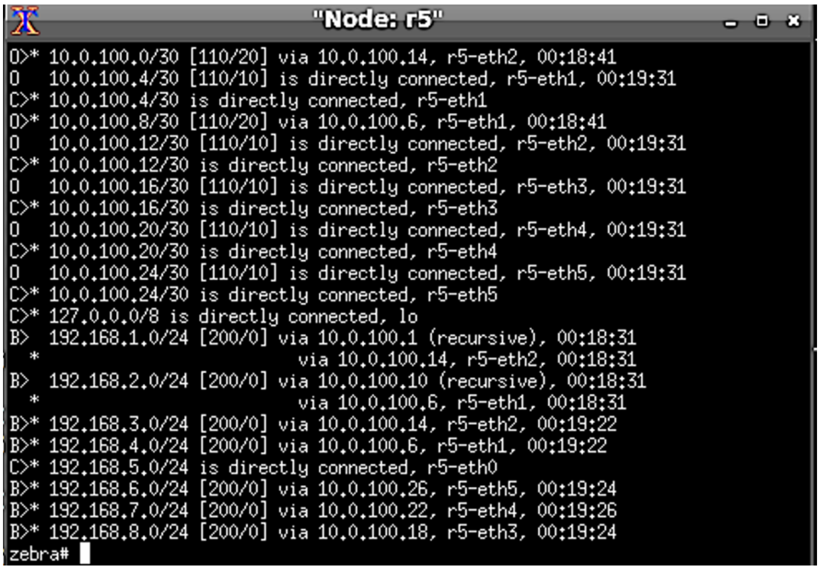

Figure 20. Routes learnt by reflector router, r5 in the legacy network

period of their network migration. SDN-IP controlled network acts as a transit AS that interconnects different legacy IP networks considering each external network as a different AS domains and interfaces with the SDN network through its BGP-speaking border routers.

In this study, an SDN integrated network was created with Mininet and experimental tests were carried out to ensure successful communication of the hosts in different ASes. The output of the tests show smooth transmission of data between hosts thus, providing testament to the possibilities of interoperability between two different networking paradigms. A similar legacy network was also created and observed to note the difference in characteristics of an integrated SDN and legacy network.

To give statistical significance to this experiment, correlation coefficients of the QoS parameters were determined. These values can be further utilized with artificial intelligence technologies or develop machine learning models or rules about the network. These insights can be useful in wide areas of applications such as traffic classification, routing optimization, quality of service and quality of experience prediction, resource management, security enhancement, and many other purposes.

The comparison between legacy and SDN integrated network aimed at verifying the speculations of SDN performing better than legacy networks. By studying both the networks based on key performance indicators such as bandwidth, packet transmission rate, and round trip time, it is observed that the performance of SDN network is much better than its legacy counterpart. Similarly, the exploratory data analysis of the values of QoS parameters collected from the network provided us with insights about the network.

The next generation wireless networking viz. 5G/6G network is considered to be fully SDN based [38,39]. The paradigm shifts in mobile communications by the conceptualization and implementation of 5G/6G added strong requirement of SDN in the modern network environment. The wired/wireless network and server virtualization, high speed communications at highly dense smart devices with ultra low latency for real time mission critical applications, energy efficient smart network deployment with efficient radio access network (RAN) design, smart spectrum management and implementation are the part of 5G and beyond networks that directly concern people's modern living standards. Hence, from core network to end-access network service provisioning, cloud computing to fog computing to edge computing mostly related with the availability of 5G, and SDN. 4G to 5G migration and the performance evaluation of SDN based 5G network as compared with 4G network are considered to be the future works. Though the network congestion optimization is not in the scope of this study, queue length analysis of the network device provides the trade-off between cost and performance of the network to understand the impact of congestion in SDN. Queue length analysis is also considered as future works.

The scope of this experimental analysis was limited to IPv4 addressing network only. routing performance analysis with the networks enabled with IPv6 addresses could further help to establish the significance and prospects of SDN implementation with future networking technologies. Additionally, this study was limited to compare the performance of hybrid SDN and legacy network to determine the feasibility of migration of the legacy networks into SDN. Routing implementations over hybrid SDN with multiple controllers and their placement, large and varying number of data plane devices etc. could be the future works to reflect the situations of CG-ISP networks when implemented into reality. A single instance of ONOS controller is used in the present study. Multiple instances can be run at the same time for high available services. Multiple instances help in load balancing of the whole network and adds reliability to the network. Additionally, other available network controllers can be used to replicate the results for comparison in addition with ONOS.

6. Conclusions

Implementation of SDN is regarded as the best solution to meet the modern age communication requirements and to avoid the issues in legacy networks. The data plane devices that support the SDN network generally use OpenFlow protocol to establish communication with controller. But the legacy devices generally already in operation these days do not support OpenFlow protocol. The replacement of the existing networking devices at once by the OpenFlow supporting devices is not feasible and hence, a phase-wise migration is the only tangible solution. The features of SDN are compelling enough to encourage the migration of larger networks of ISPs from Legacy to SDN. This study has demonstrated the successful integration of SDN networks with legacy networks to show the possibilities of smooth migration and interoperability with legacy networks during migration. The experimental analysis presented are contributory to verify the seamless interoperability of legacy and SDN networks so that service providers can be confident towards the SDN implementation in their ISP and Telcos networks. The experimental analysis is also a testament to SDN-integrated networks performing better than traditional legacy networks based on QOS parameters viz. bandwidth, PTR, and RTT.

Supplementary Materials: The program code in python and dataset of this research work is available at this GitHub page: https://github.com/Abhishekthapa/MajorProject

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Investigation, B.R.D., S.R.J.; Resources, B.R.D., S.R.J.; Data Curation, B.R.D, A.T., R.G., D.L., and S.P.U.; Writing—Original Draft Preparation, B.R.D., A.T., R.G., D.L., and S.P.U.; Writing—Review and Editing, B.R.D; Visualization, A.T., R.G., D.L., and S.P.U.; Supervision, B.R.D., and S.R.J.; Project Administration, B.R.D. and S.R.J.; Funding Acquisition, B.R.D. All authors have read and agreed to the published version of the manuscript.

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