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A Comparative Performance Evaluation of IPv4/IPv6 Using Network Simulation and Virtualization Tools

W.M. Almutlaq[1]; N. Elfadil[2]
[1]Computer Engineering- Fahd Bin Sultan University, KSA
[2]Computer Engineering- Fahd Bin Sultan University, KSA
[1] trhhal@hotmail.com; [2] nfadel@fbsn.edu.sa

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Abstract— Internet users are expected to grow from 4.5 billion in 2020 to 5.3 billion by 2023. In terms of the population, this represents 66% of the global population. However, the growth of connected devices and internet users is going very fast. Not yet as the number of the internet of things (IoT) applications such as video surveillance, smart meters, and tracking and the machine to machine increased as well. The address space of the IPv4 cannot meet these requirements and this growth in the connected devices. According to that another IP address scheme designed to meet the requirements and the needs for the IoT & M2M and the growth of the number of internet users. This is the IPv6 which consist of 128 bit and can provide a huge number of addresses. The limitation of the addressing space was solved by the IPv6 but the problem arises in the migration from IPv4 to IPv6 as the migration cannot happen overnight so transition mechanisms developed to allow the communication between both IPv4 and IPv6 network. This paper aims to study the performance parameters such as the delay, the throughput, and the TCP establishment time which could be affected by the transition mechanism. The methodology that used in this project is using a network simulation tools such as GNS3 and virtual box to simulate the network scenarios and network performance check such as Wireshark and iperf3 tools to analyse the traffic. The results in this project show that if the delay is the main concern, then the tunneling machine will be the best choice, behind that when the TCP flow playing an important role for the network engineer then the tunneling machine will be the best option. However, the dual-stack method is considered the best in terms of throughput.

Keywords— IPv6, transition mechanisms, tunneling, translation, dual stack

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I. INTRODUCTION

In October 1969 the first internet message was sent by ARPANET, for today's networks this design considered the foundation for the networking devices. After fifty years the number of internet users exceeds 4 billion and besides that the number of connected devices became more than double the global population. Globally, as shown in Fig. 1 internet users are expected to grow from 4.5 billion in 2020 to 5.3 billion by 2023 [x]. In terms of the population, this represents 66% of the global population. While the growth in the number of Internet users is a global trend, the fastest growth is projected to occur in the Middle East and Africa. Besides that, globally the connected devices are growing faster than the population and the internet users. Each year the technology market introduces a lot of intelligent devices with various capabilities, this increment on the intelligent device contains an internet of things devices and machine to machine devices as well. According to that the expected number of connected devices will be increased up to 28 billion devices by 2023.

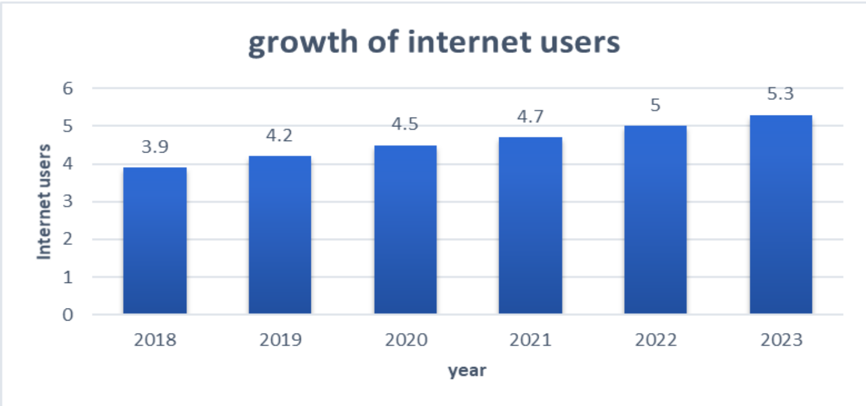

Fig. 1: Growth of Internet Users

The majority of internet devices now work by Internet Protocol Version 4 (IPV4). The total number of the available IPv4 address is 4,294,967,296 [x]. This number generated from the 32 bit that shapes the address. However, there are more than 18 million addresses reserved for the private networks and another 270 million addresses reserved for the multicast. The address space became smaller. Each connected device needs an Internet Protocol (IP) address. The dominant addressing scheme is the IPv4 but this type has reached its limit. According to that another IP addressing scheme was designed. This is the IPv6 which consist of 128 bit and can provide 3.4 exp (38) addresses.

Although the solution for the IPv4 address spaces limitation is the migration from IPv4 to IPv6 but this cannot happen overnight. There are a thousand of networks depends on the IPv4 and they are not ready for the migration. For those a transition method could be used so that they can communicate with both kind of networks IPv4 and IPv6. Besides that, the IPv4 and IPv6 are incompatible which means there is not a direct way for them to communicate.

The transition techniques used in the migration from IPv4 to IPv6 have its impact on the network performance parameters. This problem can affect a lot of sensitive applications that running on the network such as the IoT, M2M & remote surgery. Each transition technique has a different impact on the delay, the throughput, and the TCP establishment time. Addressing this problem will guide the network designers to select the suitable transition technique that meets their network requirements.

II. TRANSITION TECHNIQUES

There is not a seamless migration from IPv4 to IPv6 due to IPv6 being incompatible with IPv4. The needs for the transition mechanism will continue till the completion of the transition to IPv6 is done. As of February 2019, the percentage of IPv6 traffic according to Google statistics is 23 percent which is an increase of 20 percent over the past 5 years. Moreover, it is expected that in the coming 4 to 5 years, the IPv6 traffic will see an increase to between 30 and 40 percent [x]. Therefore, we need to implement the solutions for transitions. The following sections show the transition techniques.

A. Dual Stack

The device can access both IPv4 & IPv6 networks when working as a dual-stack device. Accordingly, the device can connect to both technologies to connect to the destinations and servers in parallel. Fig.2 shows dual stack network.

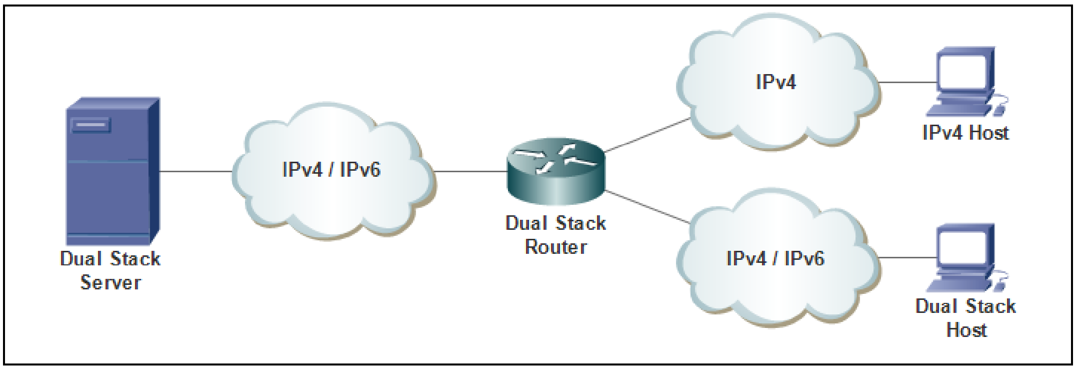

Fig. 2: Dual Stack Network

B. Tunneling

Tunneling transition mechanisms uses encapsulation for the transit of IPv6 datagrams in IPv4 packets. Tunneling is used to connect IPv6 network islands across the IPv4 network. While the tunneling process, itself is the same for all tunneling transition mechanisms, tunnel setup can be automated or manual. Tunnels created manually can be between routers or end-points, depending on the configuration. IPv6 tunnel broker can be used to help in tunnel creation in combination with TSP (Tunnel Setup Protocol) or TIC (Tunnel Information Protocol). Fig. 3 shows tunneling transition technique.

C. Translation

Translation transition mechanisms function similarly to NAT in IPv4 – dual-stack routers translate between IPv4 and IPv6 addresses at network boundaries. However, instead of changing just the address fields, the whole headers are changed to IPv6 or IPv4. This approach enables communication of hosts in IPv6 networks with hosts in IPv4 networks. Fig. 4 shows the translation technique.

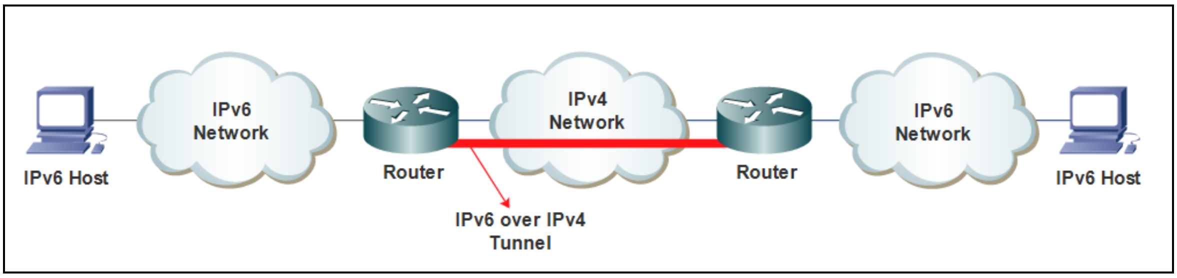

Fig. 3: Tunneling Technique

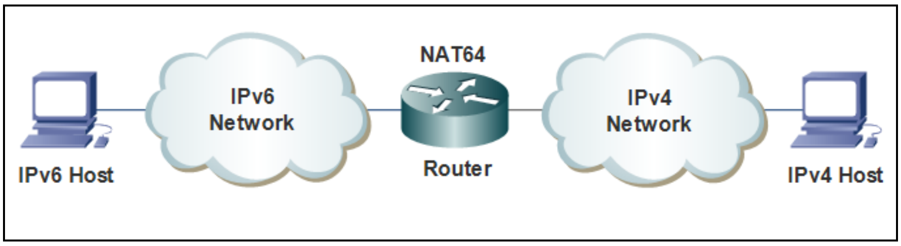

Fig. 4: Translation Technique

III. LITERATURE REVIEW

The researcher in [2] performed an investigation of performance evaluation of IPv4-in-IPv6 tunneling techniques. The transition techniques that are assessed are: 4 over 6, 4rd: NAT, DS-lite, 4rd: NAT Distribution. Two problems are checked: performance, and reliability, in both communication types: Inter-communication and Intra-communication. The authors found that 4rd:NAT Centralization has higher performance and higher reliability. In addition to that, the authors in [6] proposed a model to simulate the transition techniques. In this model the traffic recognized and prioritized to achieve the best and high quality of service by using the transition techniques. However, the authors of [7] also simulate the techniques by using the OPNET and they evaluate the performance of the delay, jitter and packet loss. Furthermore, the researcher in [8] measured the processing time by using the atomic and kernel-space method to evaluate the performance of the transition techniques. However, the author in [9] studied the performance of the QoS in the transition techniques and the researchers in [10] focuses on the performance of the transition mechanism on the VoIP & SIP protocols.

The researchers in [11] performed an analysis for the latency and the packet loss on the transition mechanisms. The analysis performed here transfers an ICMP packet with different sizes and duration. The data collected from the simulation to analyze throughput, it is found that the tunneling mechanism provides the best throughput when compared to the other transition techniques and that's due to the time consumed in the translation of the header. However, in paper [12] the researchers focused on the migration from IPv4 to IPv6 in a large-scale network. They mentioned that the overhead increases the packet loss and latency in the migration process from IPv4 to IPv6. The performance metrics such as round-trip time, time sequence and TCP throughputs used to measure the performance on the IPv4 networks, IPv6 networks and the transition techniques. The IPv6 network does as well as the IPv4 network in terms of end-to-end performance. In dual-stack network round trip time on IPv6 and IPv4 connection do not show a significant difference. In a real large dual stack network situation, the throughput of the IPv6 expanded rapidly. The researchers estimated that the dual stack network is adept to provide stable network connectivity for IPv4 and IPv6. Besides that, the authors in [13] discuss IPV4 and IPV6 and use manual transition strategies and automatic of IPV6 and also compare their performances to show how these transition strategies affect network behavior. The authors of the paper in [14] have investigated the applying of dual-stack and the tunneling transition mechanisms simultaneously in the enterprise's networks. They conclude that the dual-stack speed is efficient and fast as the dual-stack router does not encapsulate or decapsulate the packets.

IV. THE PROPOSED METHODOLOGY

In this paper the performance of the transition methods between IPv4 and IPv6 will be measured by using a virtual lab build on a simulation environment.

A. *Performance Measurement Parameters*

In this paper to get the needed measurement three key performance measurement parameters was selected.
These parameters are the delay, the throughput and the TCP follow.

Network delay: Network delay is a performance characteristic of a telecommunication network. It measures the latency for the data that travel between two endpoints in the network. The delay or the latency is measured by a fraction of milliseconds or multiple milliseconds. A factor affecting the network performance in terms of delay, these factors like the locations of the pair endpoints, the processing delay per each node, and the transmission delay.

Throughput: The definition of throughput is that it is the number of packets that are delivered successfully to the receiver end through a telecommunication channel. The bits per seconds (bps) is the unit that is used to measure the throughput.

TCP Flow: Currently, the main protocols on the internet are the TCP (Transmission Control Protocol) & the IP (Internet Protocol) both together build what known as (TCP/IP). The TCP protocol is used to provide reliable and error-free communication between the connected applications that works between hosts that communicated through the IP network. Most of the running applications like email, remote access, and file transfer that work on the internet depend on the TCP.

B. *Performance Measurement Methodology*

To measure the mentioned key performance parameters there are specific tools that could be used in this context. The following sections describes these tools.

ICMP Messages: The ICMP (Internet Control Management Protocol) messages could be used to measure the delay between two end-points. Although there are various uses for the ICMP messages the ping considered the popular ICMP message. Ping message is used to find out the round-trip time (RTT) for the messages that are sent from a network device to a specific destination and the destination sent back the message to the source. Ping works by generating an ICMP echo request to the destination host and then wait for the echo reply. Ping works to get the average, the minimum, and the maximum values of the round trip and also to detect the packet loss. The round-trip time is the amount of time that is needed for a packet to travel from the source to the destination plus the needed time to back again to the source. This time delay includes the propagation delay between the two endpoints.

Throughput measurement: To measure the throughput that could be performed between the source and the destination there are a lot of tools could be used here. In this research (iperf) tool selected to perform this function. iPerf3 is considered one of the most networking tools used to read the performance parameters on the networks. iPerf3 supports a group of different parameters linked to buffers, timing, and protocols such as (SCTP, UDP & TCP). iPerf3 during the test can generate bandwidth report, packet loss report.

TCP Flow Performance measurement: The performance of the TCP protocol and the establishment of the transmission could be affected by the transition techniques in this project we rely on the (Wireshark) to capture the traffic and then to analyze the flow of the TCP messages. Wireshark is the leading software in the analysis of network protocols. It allows checking the details of your network traffic. It is considered the de facto standard for many enterprises, government agencies, and educational institutions.

C. Simulation Environment

The simulation environment is built based on two platforms, the first one is GNS3 (graphical Network Simulator) and the second is VM Virtual Box. GNS3 is used to emulate the network while the Virtual Box is used to virtualize the clients and the server.

D. The Proposed Simulation Topology

The proposed topology in Fig. 5 is used in the simulation environment. This network topology consists of two layers. The first layer is the core network which is consists of the server and the core routers. On the other hand, the second layer responsible for providing users access to the network, this layer consists of the access router and switches and the user's devices. To compare the performance differences between the transitions techniques the topology will not be changed so we will keep it fixed. The change will be performed on the routers and the terminal configuration. In the simulation, the PCs and the server works through VM Virtual Box while the routers will be emulated based on a real Cisco IOS image.

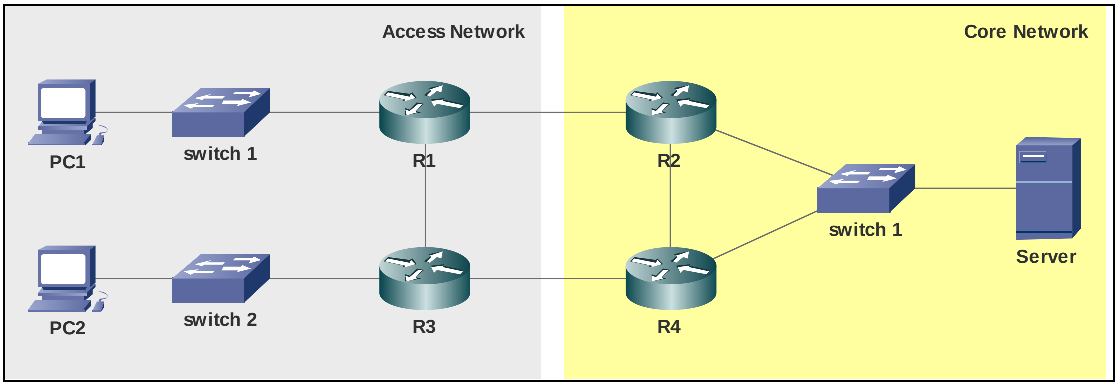

Fig. 5: The Proposed Topology

V. SIMULATION & RESULTS DISCUSSION

In this section, the simulation and the results per transition technique will be discussed. The results will be discussed in terms of the key performance factors such as the delay, the throughput, and the TCP flow. However, a comparison between the transition techniques that related to the key performance factor will be performed.

A. *Simulated Network*

In GNS3 the network in Fig.6 is configured to provide the reachability between the server on the core network and the PCs on the access network.

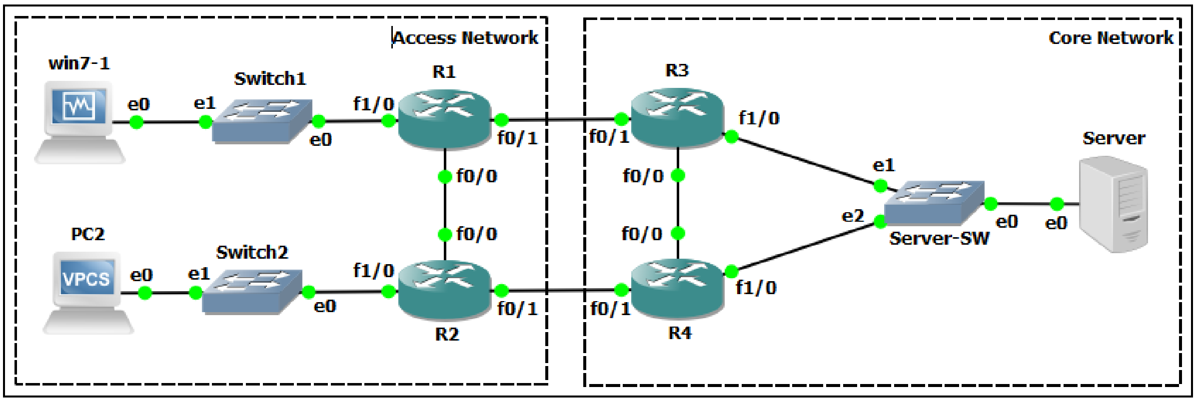

Fig. 6: Simulated Network in GNS3

B. *Dual Stack Performance*

All devices in the network in figure 28 are configured with both IP addresses (IPv4 & IPv6), then a static route on the routers is added to offer the reachability for the non-directly connected networks.

Dual Stack – Delay Measurement: The delay on the dual-stack network is measured by using the ping ICMP messages between the access network and the server. The test was performed twice to get the RTT. The first test was performed based on IPv4 and the second test was performed based on IPv6. The test performed on various sizes of the packets and for each size. The delay in the dual-stack IPv4 is almost double the delay in IPv6. As show in Fig.7 the average of IPv4 delays results is 61.4 ms and the average of IPv6 delay results is 33.2 ms.

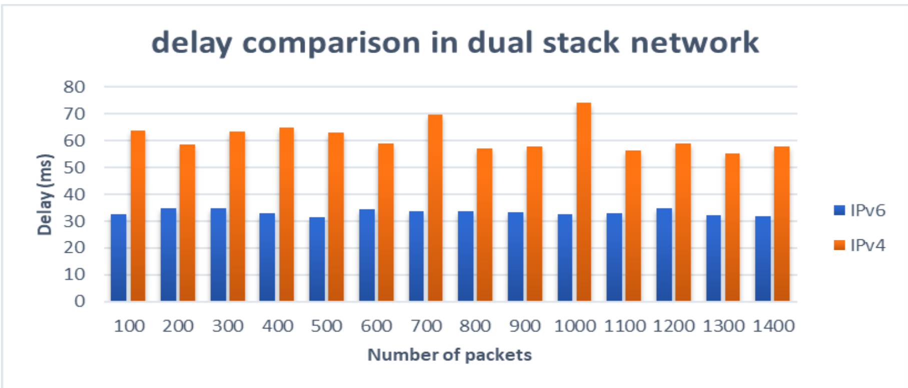

Fig. 7: The Delay in Dual Stack Network

1- Dual Stack – throughput: The test of the throughput in the dual-stack network was performed by using iperf tool. The achieved throughput in the IPv4 test was 1.14 Mbps while the achieved throughput in the IPv6 network was 1.15 Mbps. Although the IPv6 throughput in the dual-stack a little bit better than the IPv4 throughput but the difference does not advance the IPv6 in this case.

2- Dual stack – TCP flow: The TCP messages generated by using Packet Sender tool, those packets captured by Wireshark to perform the needed analysis. A message consists of 34 bytes sent from the client to the server, one time sent to check the flow of TCP in the IPv4 network and another time to check the flow in the IPv6 network. we noted that the needed time to establish the TCP connection in the IPv4 is similar to the needed time in the IPv6. Behind that, there is no difference in the message time as well. The chart in Fig.8 shows the similarity in the establishment of the TCP connection in both protocols.

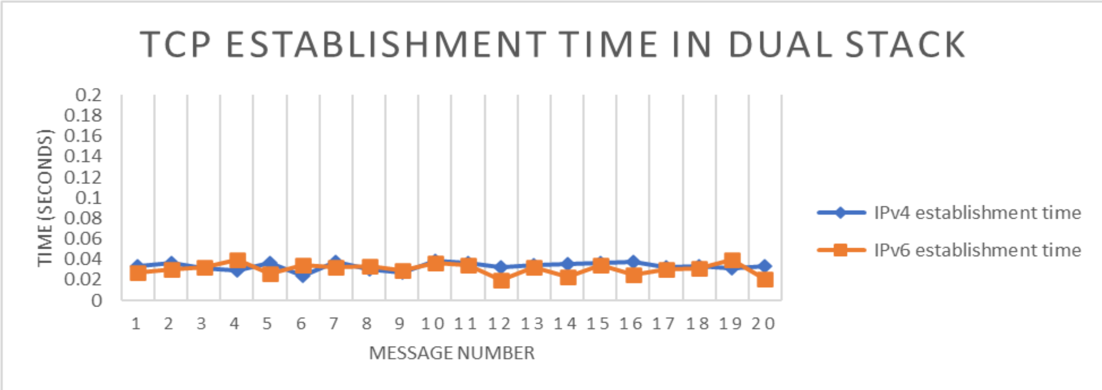

Fig. 8: TCP establishment time on the dual stack

C. *Tunneling Performance*

In the simulation lab, a tunnel between R1 and R3 was performed to carry the traffic that related to IPv6 over the IPv4 network. The measurement methods used in the dual-stack will be used here as well.

1. Tunneling - Delay Measurement: Ping tool used here as well to measure the delay between the client and the server. Most of the results exist around 31 ms, when this result is compared to the IPv6 delay in the dual-stack we can note that the delay, in this case, is better.

2. Tunneling – throughput measurement: The throughput in these techniques not so good when compared to the dual stack. In the simulation iperf used to measure the throughput and the average was 1.08 Mbps.

3. Tunneling – TCP flow performance: The TCP traffic generated by Packet Sender tool and the traffic captured and analyzed by Wireshark. Fig. 9 shows the establishment time in the tunneling.

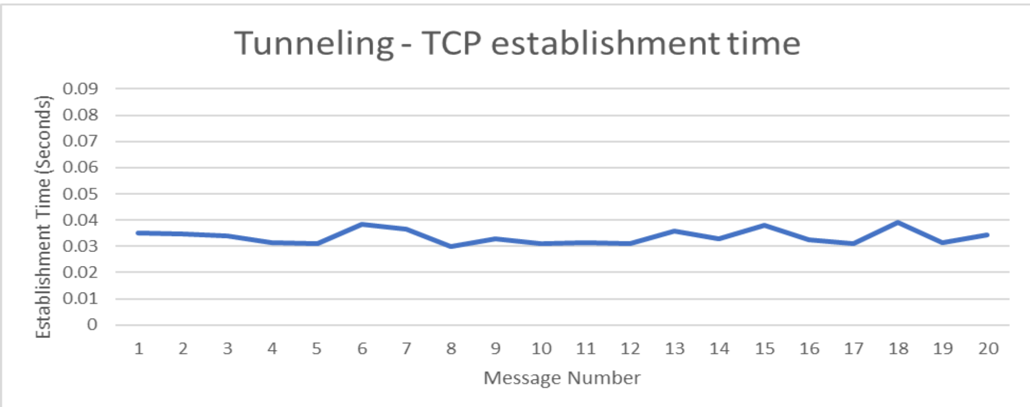

Fig. 9: TCP establishment time in the tunneling mechanism

D. *Translation-Performance*

To check the performance of the translation technique NAT-PT configuration used on R1. The access network works with IPv4 while the core network with IPv6. The NAT-PT router act as a translator between the two networks.

1. **Translation Technique Delay:** ***By using the ICMP (ping) messages the delay of the translation technique was measured and recorded. The delay time in this technique considered very hugely when compared to the other transition techniques. The below figure shows the delay in the translation technique. As shown in Fig.10 the maximum delay in the translation (NAT-PT) reached up to 57 ms while the minimum is 36 ms.***

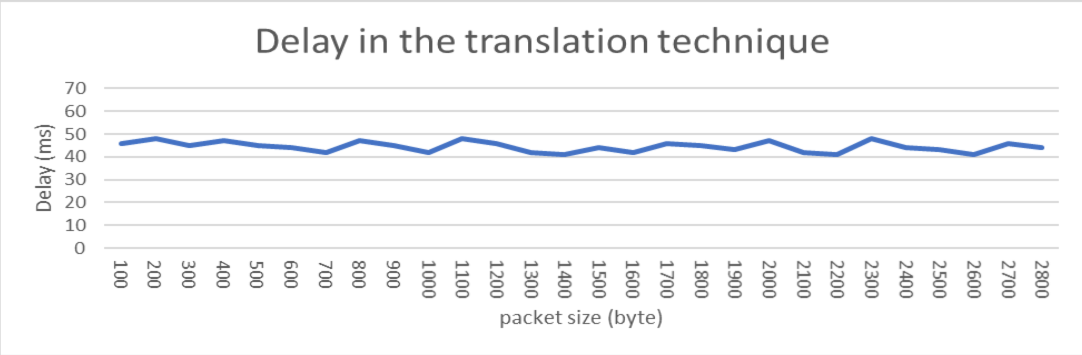

Fig. 10: Delay in Translation Technique

2. **Translation-throughput measurement:** ***Like the previous method, the iperf was used to measure the throughput in this technique. As illustrated in the below figure the measured throughput is 1.12 Mbps. The translation shows a good throughput when compared to the tunneling mechanism.***
3. **Translation – TCP flow:** ***Here again, the packet sender and Wireshark used to measure the TCP flow in the translation technique. The recorded data that related to the establishment of the TCP plotted in Fig.11 shows that the needed time to establish the TCP is around 0.05 seconds.***

E. *Results Summary*

The overall results show that the tunneling mechanism is considered the best technique when the delay plays a vital role in the network applications while the translation technique is considered the worst. Fig.12 shows the delay comparison between the three types. On the other hand, as illustrated in Fig.13 the TCP flow in the tunneling technique looks better than other techniques although the results are too close to the dual-stack. Finally, as shown in Fig.14 we noted that the throughput in the dual-stack techniques considered the best accordingly for those network applications that need high throughput the dual-stack will be the best solution.

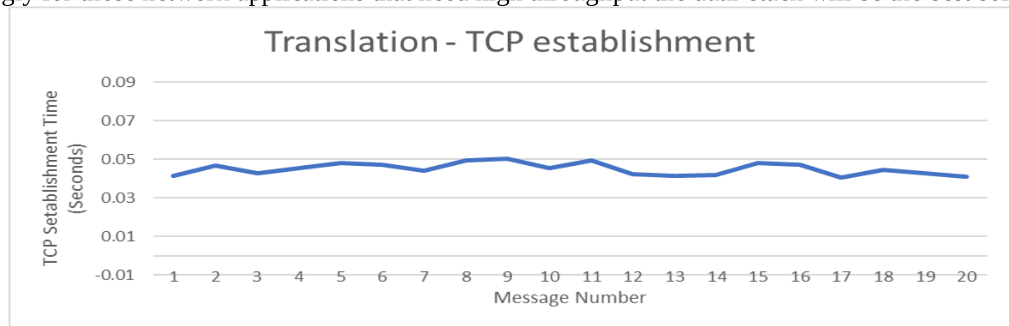

Fig. 11: TCP establishment time in the translation technique

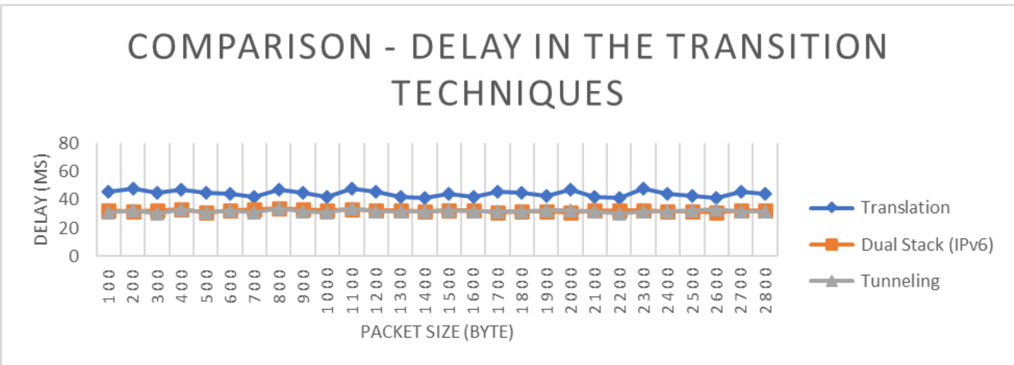

Fig. 12: Comparison Delay

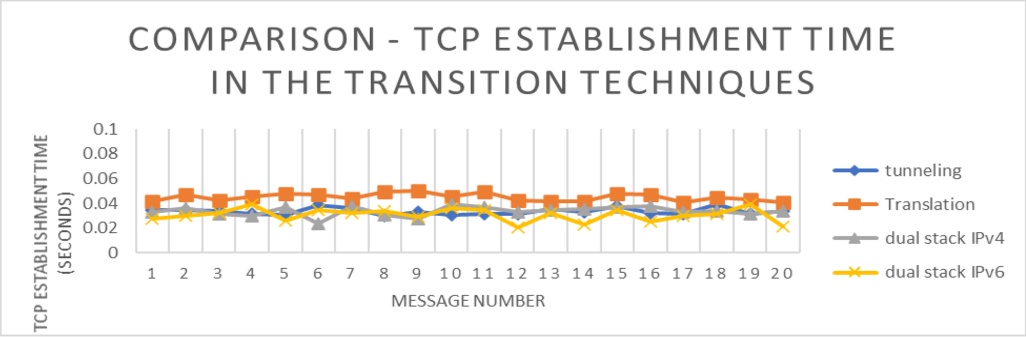

Fig. 13: TCP establishment comparison

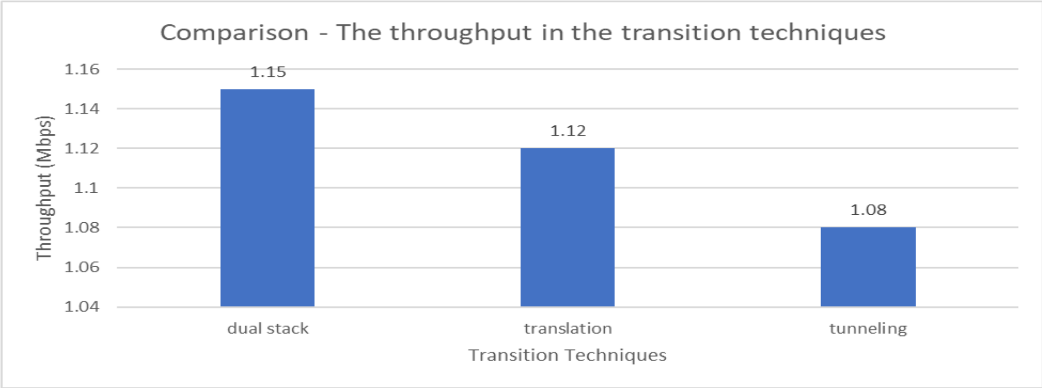

Fig. 14: Throughput Comparison

VI. CONCLUSION

In this paper, the performance of IPv4 to IPv6 transition techniques is measured. The purpose of this work is to find out which transition technique will be suitable for the current applications and networks. The transition techniques considered herein are Dual-Stack, Tunneling, and Translation (NAT-PT). The needed tests were performed on a simulation environment built based on the network simulator GNS3, virtual box to run virtual client and server, packet sender to generate TCP traffic, and iperf to measure the throughput. The results show that the dual-stack considered as the best when the network application needs high throughput. On the other hand, the tunneling technique shows the lowest delay so it will be suitable for applications that need low latency. For the TCP flow, the tunneling and the dual-stack show the same performance.

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