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Map of the Various Configuration Attributes from IPv4 to IPv6 Networks for Dual Stack, 6to4 Tunnelling and NAT: Modelling Designs in OPNET Modeller

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Abstract—This paper presents a performance evaluation study of dual stack, 6to4 tunnelling, and Network Address Translation transition schemes on simulative method in IPv4/IPv6 networks. This research aims to find out what IPv4/IPv6 transition scheme performs better in terms of performance parameters packet losses, delays, segment delays, query response times, packet delay variations, packet end-to-end delays, jitters, mean opinion score value, and traffic sent and received for data, voice and video traffic. An equal capacity of network load in terms of probes for the three scenarios is considered and benchmarked to ascertain the impact on the performance parameters on IPv4/IPv6 networks. The scenarios are basically network models configured and simulated using Optimized Network Engineering Tool modeler. The core model designed represents an Internet Service Provider network deployed to form an ideal choice of IP domain corresponded to a realistic network topology running both IPv4 and IPv6 connections. The dual stack, 6to4 tunnelling, and NAT network models are defined which allow the researcher to compare the simulated results. This paper shows that automated 6to4 tunnelling has better performance since it requires only one IPv4 address per tunnel for unlimited number of concurrent sessions though not suitable for voice perhaps because of the encryption overhead.

Keywords— IPv4, IPv6, Dual stack, 6to4 tunnelling, NAT, OPNET

I. INTRODUCTION

The development of IPv6 was to replace and enhance IPv4 power as a key tenet of the current internet platform. Its birth is the preferable alternative to IPv4 since it can support the accelerated growth of the internet enabled applications and devices as well as unlock the security concerns posed by IPv4. Furthermore, the inadequacy and depletion of IPv4 addresses and the growing need for an enhanced next-generation internet protocol that is fundamentally secure, have made IPv6 deployment urgent with a focus on secure, larger address space, and better performance [1].

It is evident IPv6 network platform is maturing, albeit slowly even though IPv6 has been implemented on major networks and host operating systems. Most of the core Internet transit providers have utilized the platforms provided and deployed IPv6. However, the edge networks are lagging in the implementation [2]. Its implementation gave birth to problems such as impending exhaustion of the IPv4 address space, configuration complexities and network optimization concerns at the protocol level that must be considered [3].

A lot of research has been carried out with regard to protocol design, connectivity and routing, and transition of IPv6. Methods have been recommended to evaluate performance and platforms that focus on hardware and compatibility with IPv6. According to [4] once a network begins to provide public services, its performance is always a big issue and for IPv6 it is even more complex. The focal point of this research is about the peculiarities of IPv6 from a transition perspective and its performance differences compared to IPv4. The current state of IPv6 usage, IPv4 to IPv6 transition strategies/mechanisms, routing and optimization/performance perspective of this new protocol is the concern [1].

II. STATE OF THE ART

In the recent past, multiple studies have been conducted on performance comparisons between the three IPv6 transition schemes. Before designing the network simulation models for IPv6 transition in this research, a brief review of these recent studies is presented in Table 1.

TABLE I
DETAILS OF RESEARCH STUDIES, RESEARCH CONTEXT AND METHODOLOGY, AND FINDINGS ON PERFORMANCE COMPARISONS OF IPV6 TRANSITION SCHEMES

Authors	Research Context and Methodology	Findings
[5]	Comparing performances of dual stack, 6to4 tunnelling, and NAT schemes of IPv6 transition by modelling them in Wireshark tool and testing round trip collision delay (latency) using PING and Trace Route processes	Dual stack returned the highest latency compared with tunnelling, and NAT schemes. The latencies of 6to4 tunnelling and NAT were found to be comparable.
[6]	Comparing performance of 6to4 tunnelling scheme of IPv6 transition between Windows 2003 SP2 and Windows 2008 SP1 servers by testing throughput, jitter and average packet network delay for both TCP and UDP traffic types (configured on arbitrary ports).	The TCP jitter through 6to4 tunnels was found as stable and almost identical in both the operating systems for all packet sizes. However, both the operating systems reflected very high jitters through 6to4 tunnels for small packet sizes that reduced sharply for medium packet sizes and then rose gradually for large packet sizes. In UDP the jitters were small and almost stable for small packet sizes. However, UDP jitter values increased gradually in both operating systems for low and medium sized packets and returned slightly lower values in Windows 2003 SP2 as compared with those in Windows 2008 SP1 at larger packet sizes.
[7]	Comparing performance of 6to4 tunnelling scheme of IPv6 transition between Linux Fedora 9.10 and Linux Ubuntu 11.0 servers by testing throughput, jitter and average packet network delay for both TCP and UDP traffic types (configured on arbitrary ports).	The TCP jitter through 6to4 tunnels was found almost identical in both the operating systems for all packet sizes. However, both the operating systems reflected very high jitters through 6to4 tunnels for small packet sizes that reduced sharply for medium packet sizes and then rose gradually for large packet sizes. In UDP, the jitter was found to be very high in Fedora 9.10 for small packet sizes but settled at comparable values with those in Ubuntu 11.0 for larger packet sizes. Both the operating systems returned an increasing trend of UDP jitters through 6to4 tunnels for large packet sizes. The TCP average packet network delay through 6to4 tunnels was found as close to zero at all packet sizes in both the operating systems. The UDP average packet network delay in Fedora 9.10 6to4 tunnel was quite high between 200 and 300 milliseconds for all packet sizes. The TCP average packet network delay through 6to4 tunnel in Ubuntu 11.0 was found as varying between 0 and 50 milliseconds. The TCP and UDP throughputs through 6to4 tunnels were found as exactly identical in both the operating systems The TCP throughput varied from 40 to 70

		Mbps for small packet sizes and 70 to 90 Mbps for medium to large packet sizes in both the servers. However, for small packet sizes UDP had a higher variation in throughput from 20 to 70 milliseconds in both the servers.
[8]	In a cloud computing virtualisation environment, three types of tunnels were configured using Teredo, ISATAP, and 6to4 and the means of throughputs, means and standard deviations of voice over IP jitters, means of end-to-end packet delay, mean of round trip collision delay (Ping process), mean of tunnelling overhead, mean of tunnel set up times, and mean of DNS query delays were studied.	ISATAP was found to be comparatively better than 6to4 and Teredo in throughput, end-to-end packet delay, round trip collision delay, tunnelling overhead, tunnel set up times, and DNS query delays. However, ISATAP was found comparatively poorer than 6to4 tunnelling and Teredo in VoIP jitters. 6to4 tunnel was found to be better than Teredo in all variables except VoIP jitters in which, Teredo has the best performance. In general, 6to4 tunnelling was found to be having sustained performance in all the performance variables.
[9]	In this research, a scenario was configured in which, the clients on IPv4 needed to connect to servers on IPv4 through a cloud service provider on IPv6 only. Three configurations were studied: dual stack at the client and server ends, 6to4 tunnels crossing the cloud service provider, NAT centralisation and NAT distributions crossing the cloud service provider. The three scenarios were modelled in OPNET Modeller.	This research found highest performance and reliability by NAT centralisation. However, NAT cannot be preferred for high density communications as too many IPv4 addresses will be needed (one each dedicated for a running session). Hence, this research recommended 6to4 tunnelling that appeared as second to NAT centralisation in performance and reliability.
[10]	The research by [10] has similar setup to this research except that the HTTP, E-Mail, DB Query, and VoIP applications were studied for comparing the performances of dual stack, manual 6to4 tunnelling, and automated 6to4 tunnelling.	Dual stack performed best in all the applications and automated 6to4 tunnelling performed second to dual stack. Manual 6to4 tunnelling performed the worst in voice jitters and MOS value.

The comparison in Table 1 reflects that IPv6 transition performance may vary based on many additional factors based on operating systems and their versions. The factors found in the studies compared in Table 1 are based on tunnelling mechanisms, and also based on increase in density of customers. Perhaps, many more factors may be found in the future studies. There should not be any bias towards a particular IPv6 transition mechanism. Instead, there should be more design principles than merely evaluating the performance comparisons between the three IPv6 transition mechanisms.

This research tested automated 6to4 tunnelling with dual stack and NAT and hence it was preferred in the final design. The criteria for this choice is as follows:

1) The IPv4 addresses are limited to about 4.3 billion and may get exhausted in future. Hence, in an ideal design all the equipment, servers, clients, and interfaces should be configured on IPv6 [5]. This is the primary reason an economic IPv6 transition method is needed.
2) Dual stack configuration requires equal number of IPv4 and IPv6 addresses and hence defeats the fundamental purpose for designing an optimal IPv6 transition method. It is not a choice even if it performs the best in most of the cases. Hence, while it may be used for small LANs already having IPv6 addresses, it is not suitable for large networks.
3) NAT may be good for small number of concurrent connections. However, when a large number of client machines are communicating, NAT will require a massive pool of IPv4 addresses and hence may not be suitable. In large networks, a large number of concurrent client connections is expected. Hence, NAT is judged as unsuitable for such networks. Given its lack of viability for long-term usage, it has been rejected in the design of this research.
4) Automated 6to4 tunnelling has been recommended by all the research studies reviewed in Table 1. The primary advantage of this technology is that it requires only one IPv4 address per tunnel for unlimited number of concurrent sessions. However, encryption overheads cause increased voice jitters resulting in low MOS values, as was observed in this research and the research by [8], [10],]6], and [7].

5) However, if voice traffic and video traffic are segregated flowing to different server farms, then the jitters can be reduced improving the MOS value.
6) Voice performance of IP 6to4 tunnelling can also be improved by prioritising voice traffic through Quality of Service (QoS) settings based on Type of Service (ToS)

III. MODEL FOR TRANSITION FROM IPV4 TO IPV6 NETWORKS: SIMULATION RESULTS ANALYSIS

The simulation results of the three model designs (dual stack, IP tunnelling, and network address translation) are presented and analyzed. The simulations have been conducted based on a report configured with performance and traffic statistics of voice, database queries, and video conferencing applications. The outcomes of simulation are presented and discussed.

A. Dual Stack IPv6 Transition

The simulation results of dual stack design of IPv6 transition are used as benchmark for the IP 6to4 tunnelling and NAT transition. The reports are generated for the following parameters (chosen based on the list of statistics in OPNET Modeler): IPv6 packet losses, TCP delays, TCP segment delays, database query response, database traffic sent and received, video conferencing packet delay variation, video conferencing packet end-to-end delay, video conferencing traffic sent and received, voice jitters, voice MoS value, voice packet delay variation, voice packet end-to-end delay, and voice traffic sent and received.

Figure 1 presents the IPv6 and TCP performance statistics. There were some packet losses of IPv6 in the beginning. However, this may have been the period when the network was not stabilized amidst ongoing IP routing updates and broadcasts. Hence, these packet losses may be ignored.

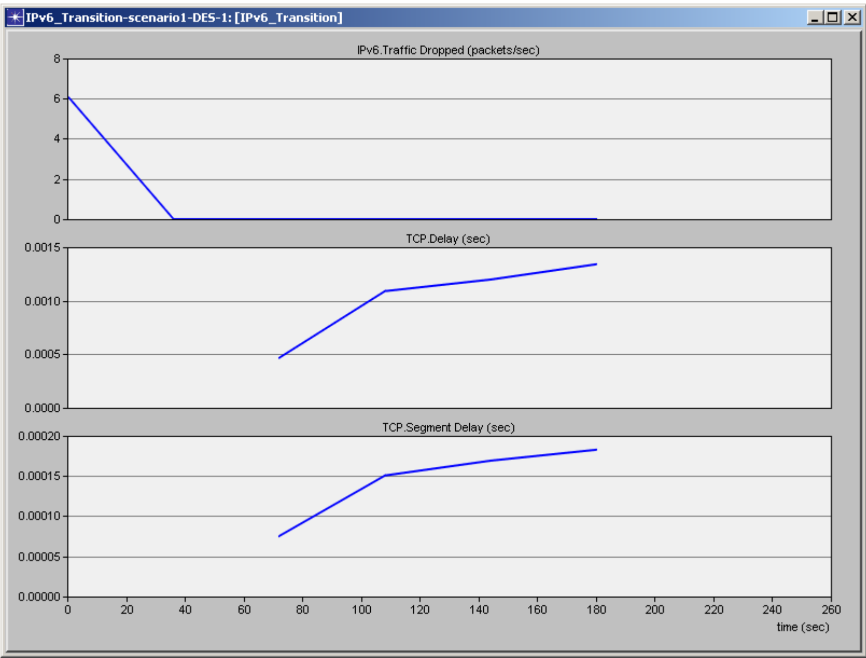

Fig. 1 IPv6 and TCP Performance of Dual Stack Model (Source: Researcher's OPNET simulation results)

There is a finite TCP delay and TCP segment delay on the network. Although the delays are recorded in milliseconds, they can serve as benchmarks when analyzing the simulation results of the other two models in this research.

Figure 2 presents the overall database query response time and traffic on the network. The response time of database querying is excellent and somewhat constant at 349.3 milliseconds. The maximum traffic sent and received at a moment is 243.12889 Kbps.

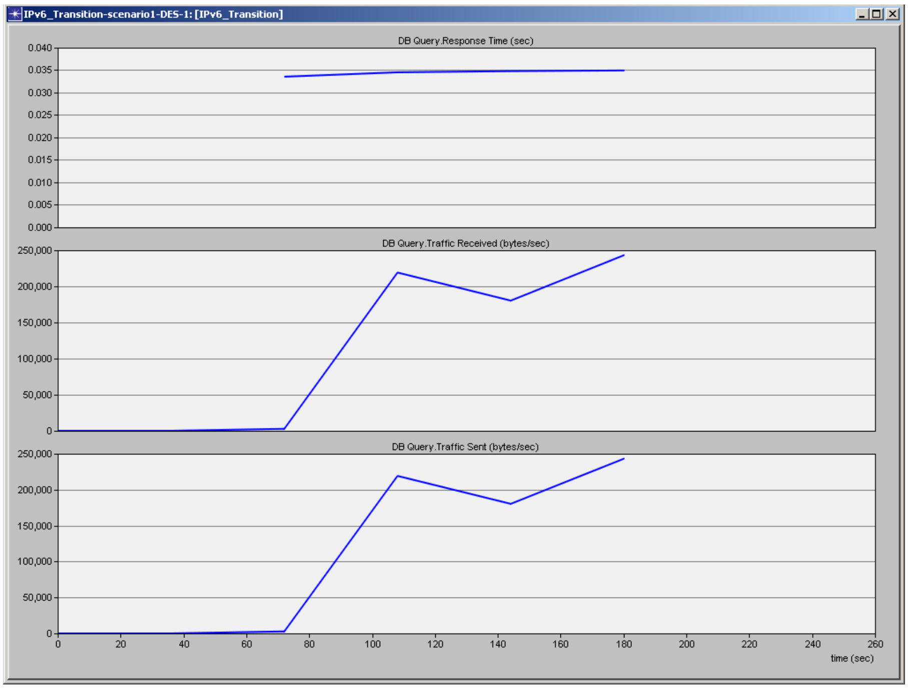

Fig. 2 Database Query Performance and Traffic of Dual Stack (Source: Researcher's OPNET simulation results)

The benchmarks of database querying response time and database traffic are also noted here for comparing with the remaining three models in this study. Figure 3 presents the performance statistics and traffic data of video conferencing application. The packet delay variation and packet end-to-end delay are observed as reducing gradually from initial spikes. Although the delay variation and delay statistics have reported values in milliseconds, they cannot be ignored as they are important statistics for comparing with the remaining two models. The video conferencing traffic sent and received increased gradually and peaked at 78.229443.56 Mbps and 78.226560 Mbps respectively when the simulation was stopped. These have been noted as benchmarks, as well.

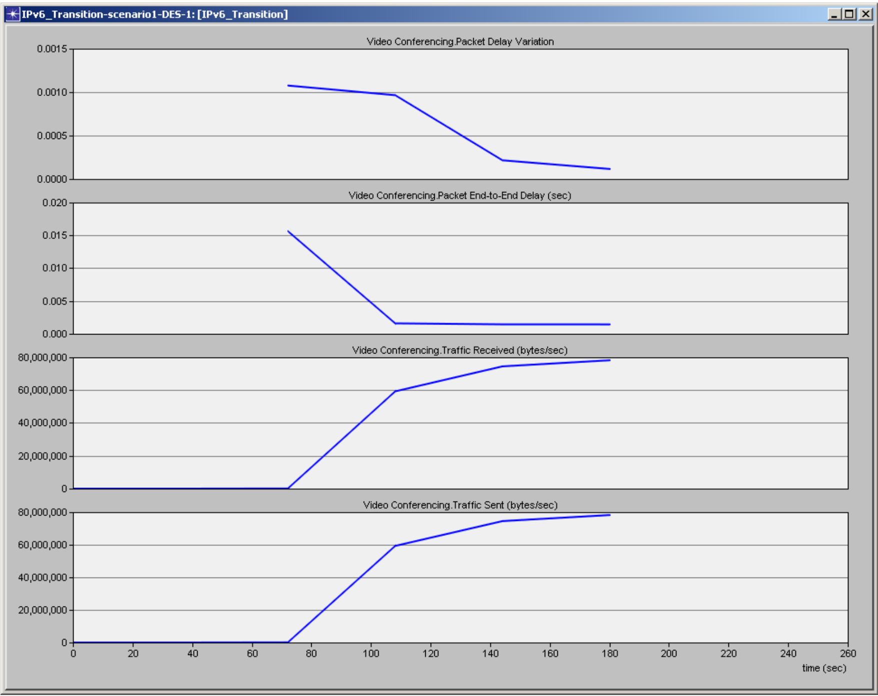

Fig. 3 Video Conferencing Performance and Traffic of Dual Stack Model (Source: Researcher's OPNET simulation results)

Figure 4 presents the voice IP telephony performance and traffic statistics in the dual stack IPv6 transition design. Voice jitter is almost negligible as the values (both positive and negative) are in micro-seconds. MOS (Mean Opinion Score) is a measure of VoIP voice quality. Its value should be less than 5 for acceptable voice quality. MOS measurement is based on ITU P.861 and ITU P.862 standards. A score in the range of 3.0 to 4.2 is acceptable for VoIP voice quality. The score is very slightly above 3 in Figure 4 indicating excellent VoIP performance.

Speech quality has no physical definition. Inherently, people just have an opinion about when something sounds good or bad. However, stakeholders need to be able to quantify the quality delivered by a telephone system in order to maximize investment and ensure adequate service is provided to customers. For many years, the only effective manner by which to determine the quality of a telephone network was to perform a subjective test. Subject testing involves asking a panel of users what they think of a recording or connection. The panel typically vote on a five point scale, and the average of the votes is deemed to be the quality of the connection. This number is called the mean opinion score (MOS).

The running of subjective tests is time consuming and costly. During the late 1980s compression technologies were introduced in digital networks to increase capacity while reducing costs. Before their introduction, it was generally possible to determine the performance of a network using simple tone-based measurements. With the introduction of new speech processing technologies, it was found that results from tone-based techniques could contradict users' experiences. A new measurement methodology was required. The increased availability of general purpose computing allowed the development of computer programs capable of modelling the results of subjective tests. In 1996, Recommendation ITU-T P.861 (perceptual speech quality measure (PSQM)) [b-ITU-T P.861] was published. The core concept introduced in this first generation algorithm was that human hearing could be modelled to extract a representation of audible differences between a reference and a degraded pair of signals, and that these differences could be mapped to the scores of subjective tests.

Shortly after [ITU-T P.861] was published, work was started to address practical limitations of the first generation model in terms of its applicability for testing networks. This work led to the publishing of a significantly improved model called perceptual evaluation of speech quality (PESQ), which was published as [ITU-T P.862] in 2001, together with the withdrawal of [ITU-T P.861]. Work continued on [ITU-T P.862] for a number of years, for example, with the introduction of a wideband extension in 2005. However, as more complex signal processing was added to the telephone network, it became clear that a new model was required. In 2006 ITU-T initiated a new activity for the development of the third generation model. The intention was to provide a backward-compatible model that could also assess new speech signal processing technologies as well as the anticipated move to super wideband networks. The result of this work was published as [ITU-T P.863] at the beginning of 2011. It should be noted that the introduction of [ITU-T P.863] does not deprecate [ITU-T P.862].

A subjective test aims to find the average user opinion of a system's speech quality by asking a panel of users a directed question and providing a limited-response choice. For example, to determine listening quality, users are asked to rate 'the quality of the speech' by selecting an opinion against a score: Excellent - 5, Good - 4, Fair - 3, Poor - 2, and Bad – 1. A MOS is calculated for a particular condition by averaging the votes of all subjects. This type of test is described as an absolute category rating (ACR) experiment.

The VoIP packet delay variation is in microseconds again, but is increasing gradually indicating that at some stage as the simulation progresses, the quality may degrade. However, the end-to-end delay of voice packets is constant at 6.027769 milliseconds. The VoIP traffic increased gradually and reached a peak of 57.52278 Kbps when the simulation was stopped. These observations have been noted down as benchmarks for comparing with the IP tunnelling and NAT in this research.

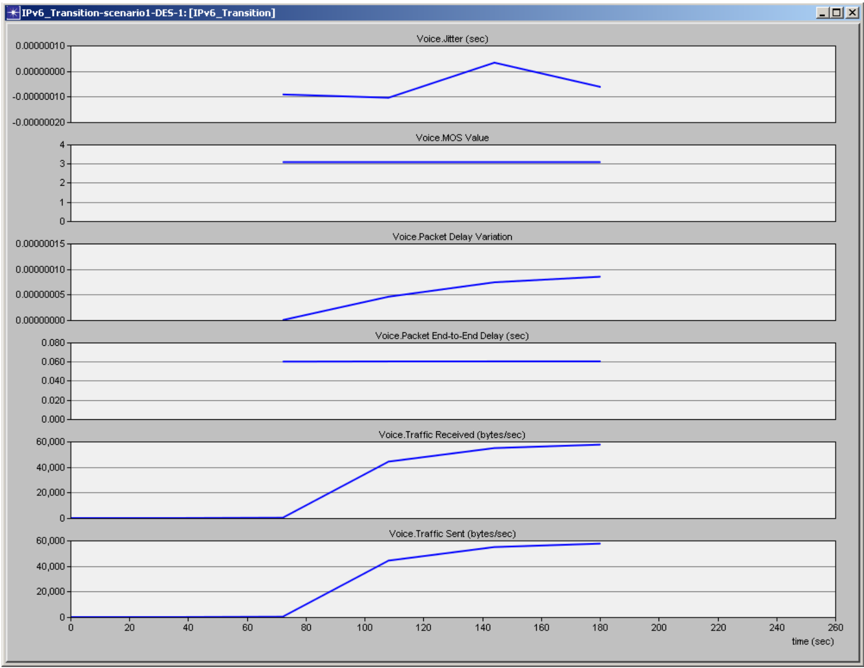

Fig. 4 Voice Application Performance and Traffic of Dual Stack (Source: Researcher's OPNET simulation results)

Overall, dual stack design has returned excellent performance results in the simulations. The simulation results of the IP tunnelling and network address translation designs of IPv6 transition are compared with the results benchmarked in the IP tunnelling scheme.

B. IP Tunnelling Design of Ipv6 Transition

Figure 5 presents the IPv6 packets dropped and TCP performance metrics. After a brief initial period, when the network is establishing through routing protocols, there are some IPv6 packet losses. Thereafter, no packet losses have been reported. TCP delay peaks at 1.203 milliseconds and TCP segment delay peaks at about 0.165 milliseconds. Comparing with Figure 1 of the dual stack model, the performance appears to be slightly improved as the same indicators are reported at 1.341 milliseconds and 0.183 milliseconds in the dual stack model.

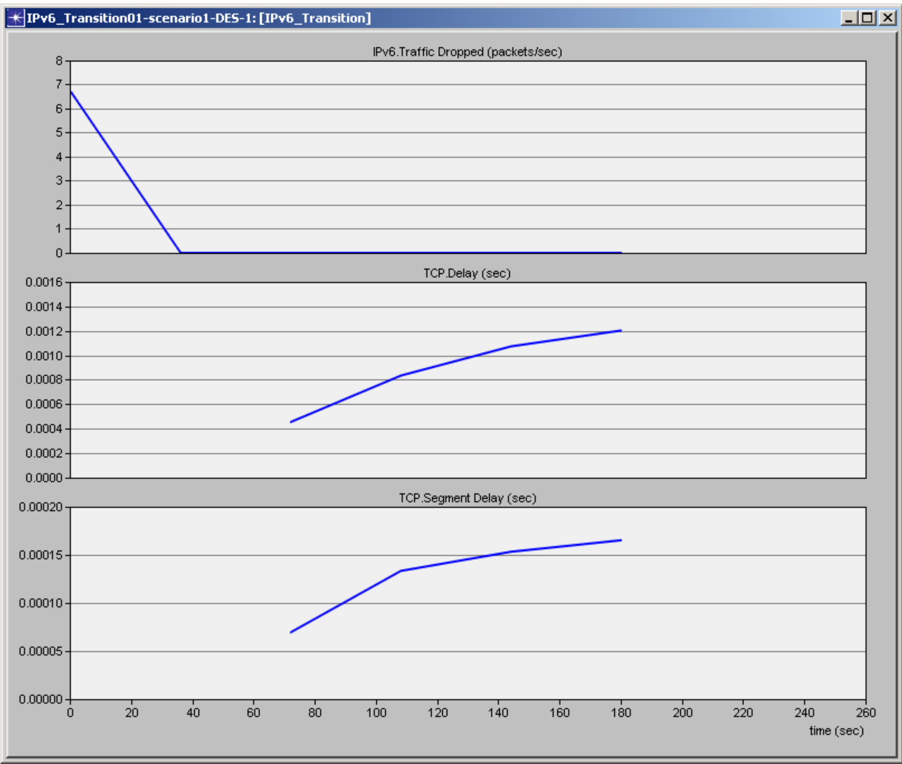

Fig. 5 IPv6 and TCP performance of IP Tunnelling model (Source: Researcher's OPNET simulation results)

As reported in Figure 6, the DB query response time is at 347.11 milliseconds for a traffic volume reaching 258.858666667 Kbps in both sent and received traffic. Comparing with Figure 2, this performance is reported as identical to that of dual stack design with the database query response time at 349.3 milliseconds for a traffic volume reaching 243.12889 kilobytes per second in both sent and received traffic.

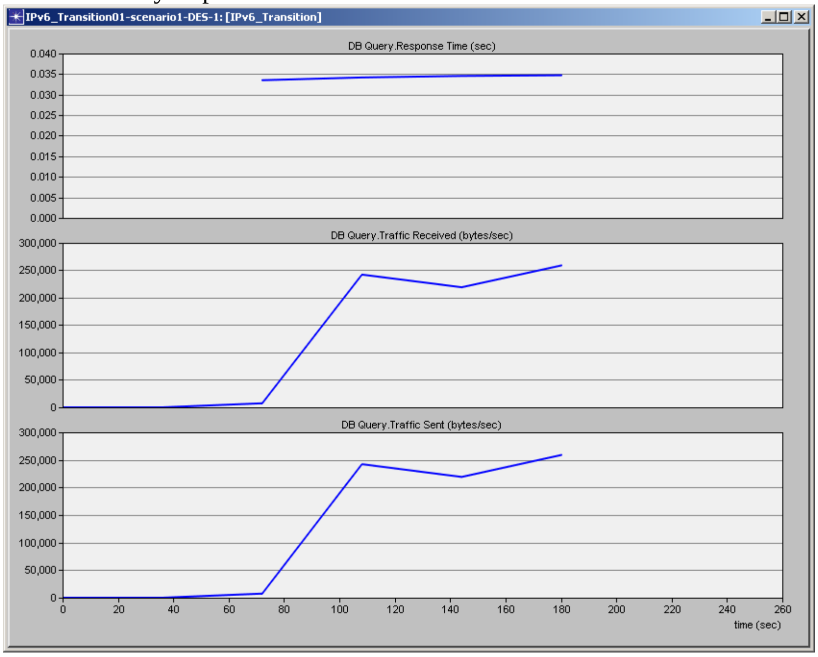

Fig. 6 Database Query Performance and Traffic of IP Tunnelling Model (Source: Researcher's OPNET simulation results)

However, video traffic seems to have improved significantly in IP tunnelling design. The video packet delay variation increased gradually to 0.96 milliseconds and then dropped gradually to a mere 0.042 milliseconds. In comparison, as evident in Figure 3, the video packet delay variation remained between 1.076 milliseconds and 0.965 milliseconds for quite some time in dual stack design and finally reduced to 0.215 milliseconds and later to 0.116 milliseconds. While the network finally stabilized to 0.1 milliseconds in both the designs, the video delay remained at a much higher value in dual stack design for a while. The end-to-end packet delay started from 6.27 milliseconds and later stabilized at 1.913 milliseconds in the IP tunnelling design. In comparison, the end-to-end packet delay in dual stack design started from 15.633 milliseconds and finally settled at 1.435 milliseconds after reducing gradually. If this is a cyclic trend, then video performance may cyclically degrade and then improve in dual stack design while IP tunnelling design may provide more stable performance. The traffic volume peaked at 77.241610666667 Mbps and 78.22944356 Mbps in both dual stack and IP tunnelling designs and hence this is a fair comparison of performances.

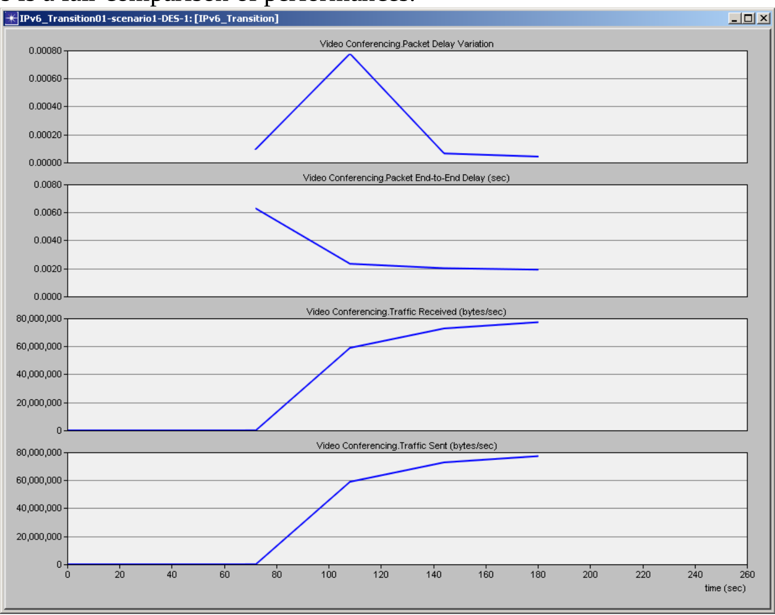

Fig. 7 Video conferencing Performance and Traffic of IP Tunnelling Model (Source: Researcher's OPNET simulation results)

The voice performance in IP tunnelling design is, however, inferior to the dual stack design. The jitter and packet delay variation patterns reported in Figure 8 reveal that they are higher than the report in Figure 4 for dual stack model. Further, end-to-end packet delay in IP tunnelling is 100.19892 milliseconds and the MOS value reported in IP tunnelling is 2.517918703 (Figure 8). However, dual stack design reported end-to-end packet delay at 60.27769 milliseconds and MOS value at 3.080868722 (Figure 4). MOS value of 2.5 is anyways less than the acceptable range of 3.0 to 4.2 thus making IP tunnelling design not suitable for voice. Perhaps, the encryption overhead causes the harm.

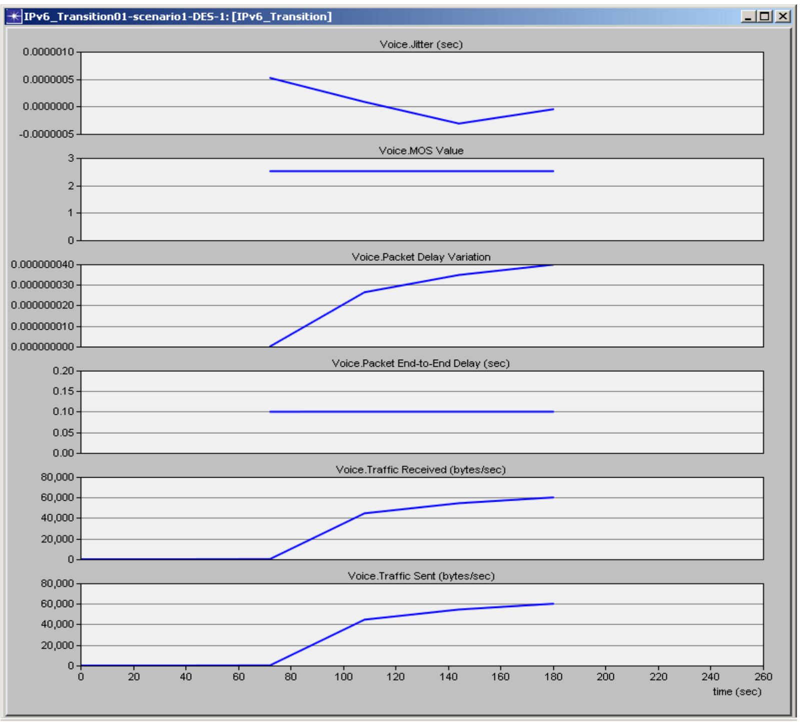

Fig. 8 Voice Application Performance and Traffic of IP Tunnelling Model (Source: Researcher's OPNET simulation results)

C. Network Address Translation IPv6 Transition

This sub-section presents the simulation results of NAT design and their comparison with the results of dual stack design. The IPv6 traffic drops and TCP performance of the NAT design are almost identical with those of the dual stack design (Figure 9 compared with Figure 1).

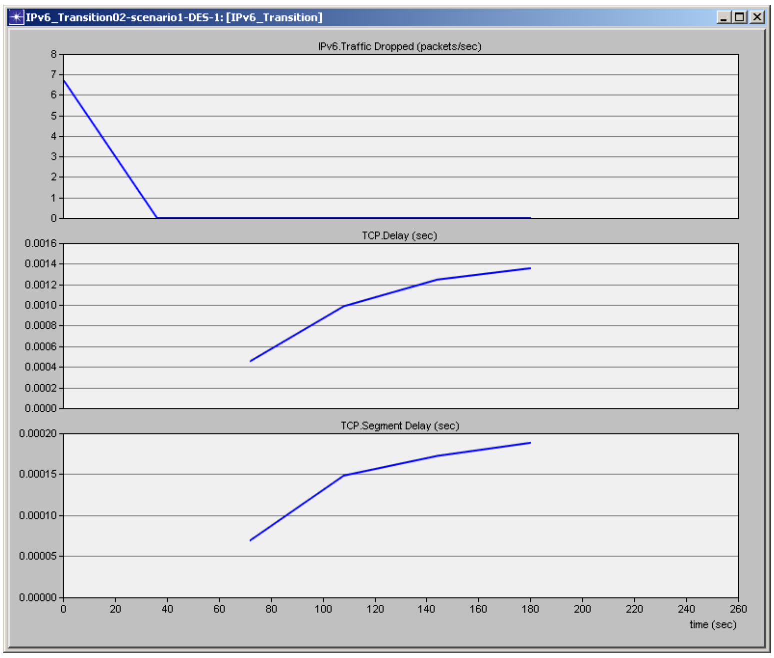

Fig. 9 IPv6 and TCP Performance of IP-NAT Model (Source: Researcher's OPNET simulation results)

Further, the DB query performance reports of NAT design (Figure 10) are almost identical with those of dual stack (Figure 2) and IP tunnelling (Figure 6). The differences are evident in video and voice performances.

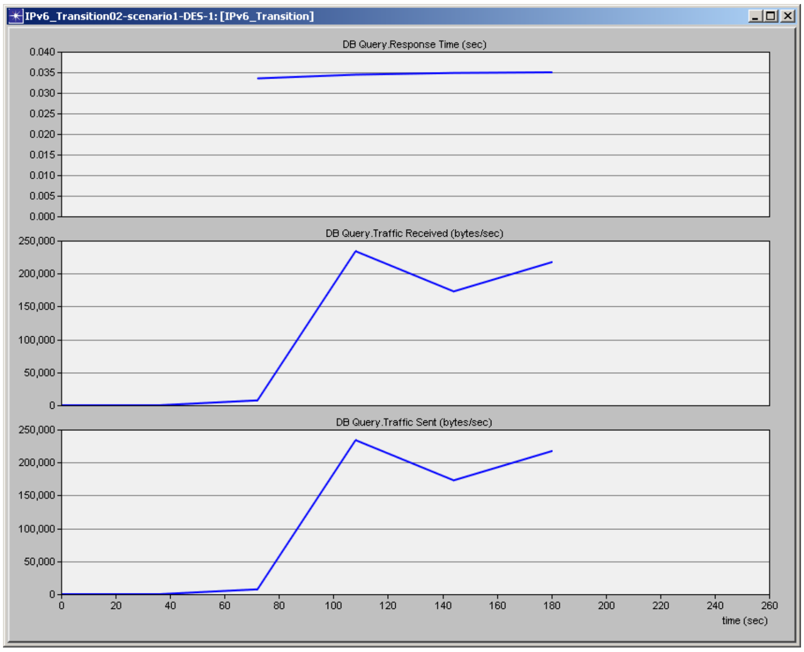

Fig. 10 Database Query Performance and Traffic of IP NAT Model (Source: Researcher's OPNET simulation results)

The video conferencing packet delay variation increased gradually from 0.875 milliseconds to 0.989 milliseconds, then decreased gradually to 0.072 milliseconds and finally settled at 0.037 milliseconds (Figure 11). This performance is superior to that of dual stack design (Figure 3) but is inferior to IP tunnelling design (Figure 7). The packet end-to-end delay started from a peak of 18.22 milliseconds, dropped to 1.542 milliseconds then 1.399 milliseconds and stabilized at 1.366 milliseconds (Figure 3). The performance stabilizing at 1.366 milliseconds is almost similar to that of the IP tunnelling design at 1.913 milliseconds (Figure 7), but the initial peak of 18.22 milliseconds makes the video performance of NAT design inferior to IP tunnelling design (Figure 11). The video performance of NAT design is slightly inferior to dual stack design, as the latter had an initial peak of 15.633 milliseconds (Figure 3).

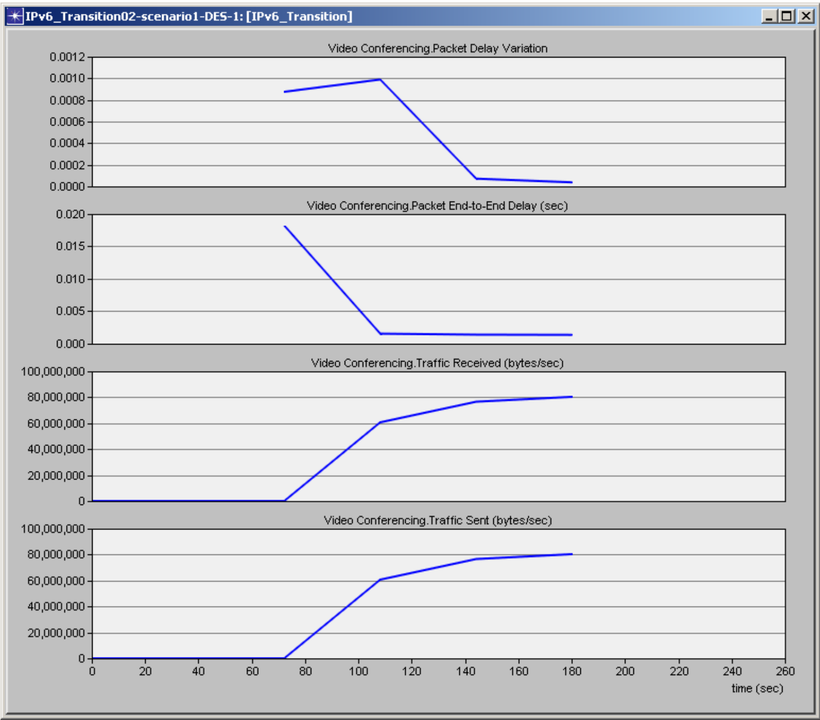

Fig. 11 Video Conferencing Performance and Traffic of IP-NAT Model (Source: Researcher's OPNET simulation results)

Again, the video traffic was 80.34624711 Mbps for sent and 80.34624711 Mbps for received traffic, which is slightly identical to dual stack (at 78.22944356 Mbps and 78.226560 Mbps) and IP tunnelling designs (at 77.241610666667 Mbps and 77.238720 Mbps). Hence, it is a fair comparison. The voice performance of NAT design is clearly superior to that of IP tunnelling design as the MOS is reported at 3.080872556 in NAT design (Figure 12) as against 2.517918703 of IP tunnelling design (Figure 8). However, the voice performance of NAT design (Figure 12) is almost similar to that of dual stack design (Figure 12 compared with Figure 4) with slightly inferior in terms of jitter and packet delay variation, but with identical MOS value and end-to-end packet delay variation. It can be safely concluded that the voice performance of NAT design is equivalent to that of dual stack design. These performance observations are used as the fundamental observations from the simulation results that provide direction for the design of an original application for IPv6 transition. The overall analysis of the simulation results, some evidences from literature, and design details of the models are all presented in the conclusion.

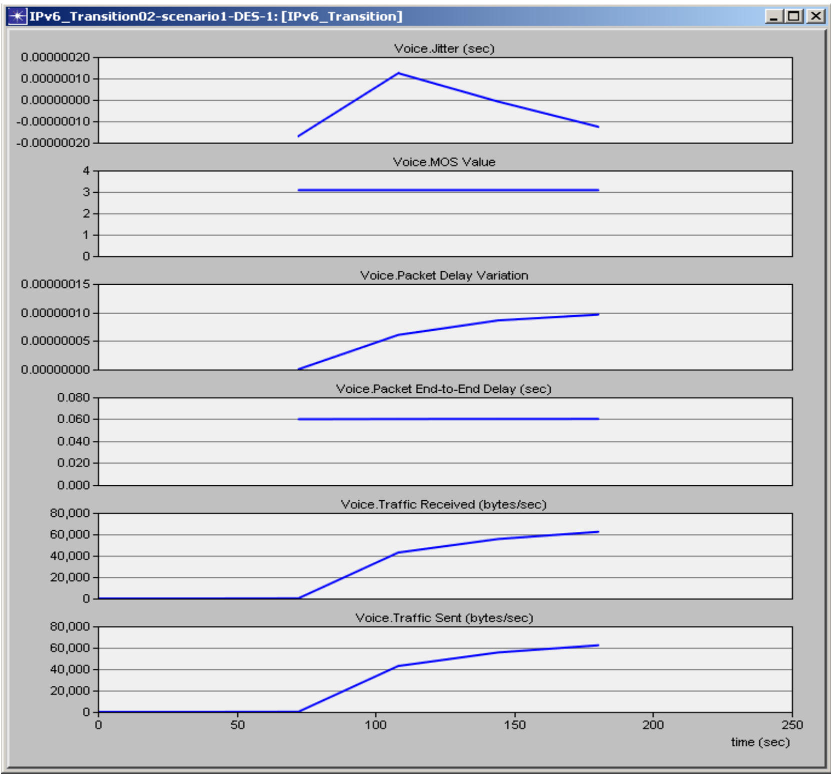

Fig. 12 Voice Application Performance and Traffic of IP NAT Model (Source: Researcher's OPNET simulation results)

The summary of performance parameters for dual stack, 6to4 IP tunnelling, and Network Address Translation transition schemes is presented in Table II for easier comparison.

TABLE III
THE PERFORMANCE PARAMETERS COMPARISON SUMMARY FOR DUAL STACK, 6TO4 TUNNELLING, AND NETWORK ADDRESS TRANSLATION TRANSITION SCHEMES AFTER THE END OF 180 SECONDS SIMULATION TIME

IPv6 and TCP Performance			**DB Query Performance & Traffic**			**Video Conferencing Performance & Traffic**				**Voice Application Performance & Traffic**					
Traffic Dropped (packets/sec)	TCP Delay (sec)	TCP Segment Delay (sec)	Traffic Response Time (sec)	Traffic Received (bytes/sec)	Traffic Sent (bytes/sec)	Packet Delay Variation	End-to-end Delay	Traffic Received (bytes/sec)	Traffic Sent (bytes/sec)	Jitter (sec)	MOS Value	Packet Delay Variation	End-to-end Delay (sec)	Traffic Received (bytes/sec)	Traffic Sent (bytes/sec)

Dual Stack Model															
0	0.001341	0.000183	0.03493	243,128.89	243,128.89	0.000116	0.001435	78,226,560	78,229,443.56	-0.000000619	3.080868722	0.000000085	0.06027769	57,522.78	57,522.78
Tunneling Model															
0	0.001203	0.000165	00.034711	258,858.666667	258,858.666667	0.000042	0.001913	77,238,720	77,241,610.666667	-0.000000050	2.517918703	0.000000040	0.100198920	60,070	60,069.166666667
Network Address Translation Model															
0	00.001357	0.000188	0.034991	217,244.44	217,244.44	0.000037	0.001366	80,347,200	80,346,247.11	-0.0000001258	3.080872556	0.0000000961	0.060282445	62,270.56	62,270.56

IV. CONCLUSIONS

The detailed modelling and analysis of schemes for translating IPv6 to IPv4 in a cloud computing environment were carried out. The schemes modelled were dual-stack, IP tunneling, and network address translation. The purpose of such detailed modelling and efforts and analysis was to explore the performances of data access (measured through response times of database queries), video conferencing (measured through video packet delay variations and end-to-end packet delays), and IP telephony voice communications (measured through jitters, mean opinion score, packet delay variations, and end-to-end packet delays). Special care was taken to ensure that the amount of traffic and network loads remain identical in the three scenarios. Further, it was found that network throughput remained comparable in the three scenarios, perhaps because the network is a cloud environment with high end servers and links of high capacities. From the simulation results, the following observations were made:

1) Dual Stack and NAT having comparable performances for Voice, but IP tunneling returned higher jitters, and more significantly, an unacceptable MOS value (at 2.5 while the acceptable range is between 3 and 4.2).
2) IP tunneling returned a stable performance of video with packet delay variation settling after a small initial variation. However, both dual stack and NAT resulted in high initial variation before settling at almost the same value of video packets delay as that of IP tunneling.
3) The database query performances of dual stack, IP tunneling, and NAT are comparable.

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