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A measurement study of network efficiency for TWAREN IPv6 backbone

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The Advanced Research and Education Network (TWAREN) was established by the National Centre for High-Performance Computing. It provides advanced research and education in Taiwan. TWAREN supports the IPv4 and IPv6 protocols. This paper analyses network efficiency under the IPv6 structures. The TWAREN test will focus on the traffic issue for all fixed-size packets. The purpose of this test is to determine packet loss under the maximum packet transfer situation. We measure the network throughput under the maximum speed and the latency associated with each packet. Using that information, we in turn derive the needed data on IPv6 TCP/UDP bandwidth and packet loss under the TWAREN structure.

Introduction

A shortage of IPv4 address space has become apparent with the increasing number of Internet users, particularly in Europe and Asia. The new IPv6 technology was therefore developed and evolved to deal with the traffic issue. TWAREN, as shown in Figure 1, was fully deployed in December 2003. It has established greater than a 20 GB backbone bandwidth within Taiwan, especially for research and education purposes. A TWAREN project was proposed and implemented between two college campuses using Cisco network apparatus. The main purpose of this project is to analyse network efficiency under the IPv6 structures.[1]

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Among the entire network test instruments available, free software, Iperf,[2] was selected for its usage and budget consideration. Iperf is capable of measuring the maximum TCP network bandwidth and finding the network efficiency by setting and tuning the variables involved. Network information, including bandwidth, delay jitter and diagram loss, can be revealed.

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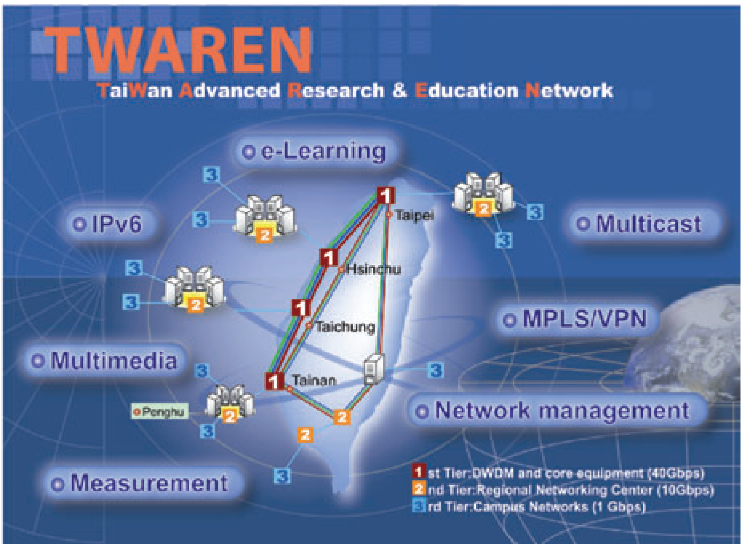

Figure 1. TWAREN topology

We make the following contributions:

- We share our test data on a web site with the National Centre for High-Performance Computing. Readers can reference the URL at http://www.ndhu.edu.tw/~yin/IPv6/.
- We performed bandwidth measurement, delay jitter and diagram loss. We conducted experiments to evaluate, measure and optimize IPv4/IPv6 UDP, TCP and RTT transmission performance using a TWAREN backbone.

The TWAREN test focuses on traffic issues for all fixed-size packets. The test determines packet loss under maximum packet transfer conditions. Network throughput is measured under the maximum speed and latency associated with each packet. Using that information, we will in turn derive the needed data for IPv6 TCP/UDP bandwidth and packet loss under the TWAREN structure.

The rest of this paper is organized as follows. The second section introduces the test instrument and methodology. The third section examines the proposed test data and simulation results. Conclusions are drawn in the fourth Section.

Testing Instrument and Methodology

This section provides a detailed description of our test instrument and methodology. Our test topology consists of a server-testing platform, core router, packet generator and sniffer.

—Test Instrument—

Most of the testing software used in our proposal was provided free except for the server. The hardware used was a Pentium 4 IBM PC with an Intel Gigabit Ethernet card for the server-testing platform. The operating system employed Fedora Core 2 Linux with Iperf and Ping6 as the software testing instruments. Iperf was used to collect the traffic traces for offline traffic analysis. Iperf free software was used to generate both IPv6 and IPv4 network packets to produce the transmission data list for TCP and UDP. It can also be used to measure the maximum TCP throughput, UDP bandwidth, UDP delay jitter and UDP packet loss. Ping6, another measuring instrument, can be used to obtain information on IPv6 round-trip time over an ICMPv6 packet.[3]

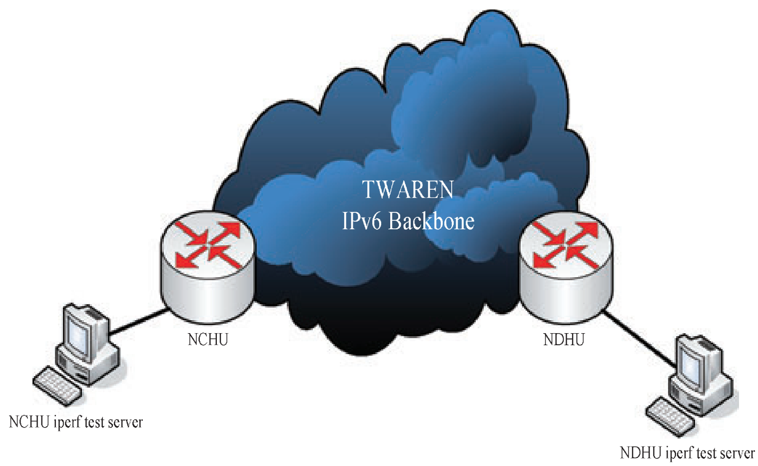

Figure 2. Network testing topology (NCHU: National Chung Hsing University; NDHU: National Dong Hwa University)

—Test Methodology—

This test focused on measuring IPv6 network efficiency over the TWAREN backbone by adopting the RFC 2544 definitions.[4] Under the fixed-size traffic packet situation, it first finds the maximum transmission rate under the presumption of no packet loss. It then derives the greatest throughput for IPv4/IPv6 under the TWAREN backbone. Figure 1 illustrates the test network structure.

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Two servers shown in Figure 2 were located at two separate campuses. Both servers embodied IPv4/IPv6 dual stack architectures and contained IPv4 and IPv6 addresses. The test procedure involved sending different-sized packets at different rates from one campus to another. The purpose was to measure the maximum IPv6 network efficiency by observing packet loss fluctuations between the two sides.[5]

An indirect mechanism was adopted for this test to avoid interference with the existing network at each campus, as shown in Figure 3. The test network was connected to a Cisco 3750 Layer 3 Switch under Giga-POP (point of presence with gigabit capacity).

In addition to the test on network efficiency over the two ends of TWAREN, The TWAREN test also included a server efficiency analysis. The goal was to determine the maximum number of packets transmitted between the two servers. To test the network efficiency, the two servers were directly connected through a Gigabit Ethernet (1000 BASE-T), and point-to-point analysis was conducted on the data packet transmission efficiency.

Testing Data

In this section we examine the IPv4/IPv6 efficiency performance testing by measuring the data on the servers and TWAREN backbone. Experiments were performed to evaluate the effect of the packet size and bandwidth throughput on active transport (UDP, TCP and RTT) traffic flows.

—Analytical Approach—

In our proposed measurement, the TWAREN backbone TCP, UDP and RTT efficiency performance was estimated using Iperf.

The bandwidth was calculated as follows:

$$\text{Bandwidth} = \frac{S(N-1)}{t_N - t_i} \tag{1}$$

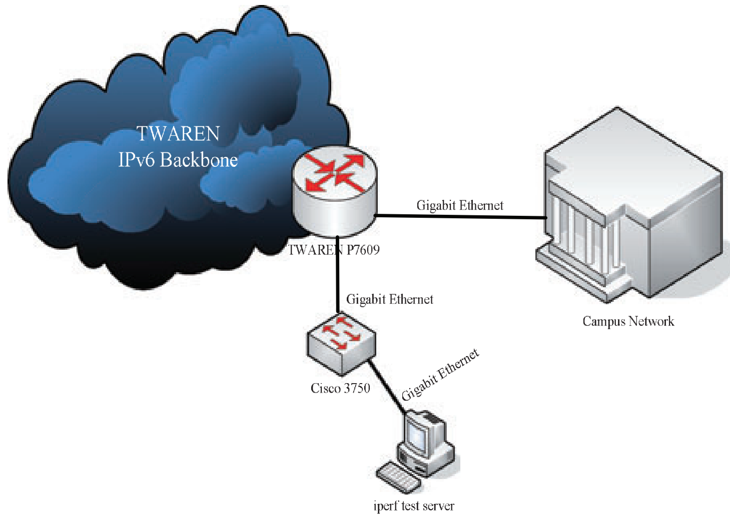

Figure 3. Cisco 3750 Layer 3 Switch partitioned part of the existing network

where S = packet size, N = total number of packets received and t_i = time required to receive the ith packet.

We adopt the Weibull distribution to represent, in terms of theory value, where α is the shape parameter. Shape parameters allow a distribution to take on a variety of shapes, depending on the value of the shape parameter, where β is the location parameter:

$$x = \frac{c \cdot \mathrm{MSS}}{\mathrm{RTT} \cdot \sqrt{\mathrm{Loss}}} \tag{2}$$

$$\mathrm{TCP}_{\mathrm{throughput}} = \mathrm{BW} \cdot \left(1 - e^{-\left(\frac{x}{\beta}\right)^{\alpha}}\right) \tag{3}$$

where c is a random variable, BW = measuring bandwidth, MSS = maximum TCP segment length, RTT = round trip time and throughput = 800 Mbps.

TCP calculates RTT upon every received ACK and estimates the retransmission timeout (RTO):[6]

$$\mathrm{SRTT}(\kappa) = (1-g) \times \mathrm{SRTT}(\kappa - 1) + g \times \mathrm{RTT}(\kappa) \tag{4}$$
$$\mathrm{SERR}(\kappa) = \mathrm{RTT}(\kappa) + \mathrm{SRTT}(\kappa - 1)$$
$$\mathrm{SDEV}(\kappa) = (1-h) \times \mathrm{SDEV}(\kappa - 1) + h \times |\mathrm{SERR}(\kappa)|$$
$$\mathrm{RTO}(\kappa) = \mathrm{SRTT}(\kappa) + f \times \mathrm{SDEV}(\kappa)$$

SRTT, SERR and SDEV are the exponentially smoothed RTT, error term and deviation estimates, respectively; g, h and f are the tunable parameters.

From Equation 3 we can calculate the throughput ratio with packet size as shown in Table 1.

Order	Packet size (bytes)	Throughput ratio
1	64	0.7619
2	128	0.8421
3	256	0.9142
4	384	0.9411
5	512	0.9552
6	640	0.9638
7	768	0.9696
9	896	0.9739
10	1024	0.9770
11	1152	0.9795
12	1280	0.9815
13	1408	0.9832

Table 1. Throughput ratio with packet size

Figure 4 Shows that the packet throughput reaches a maximum (800 Mbps) when the packet size is 768 bytes.

—Measuring Data on the Servers—

According to the connection scheme shown in Figure 3, the UDP packet efficiency performance can be found through tuning the packet generation rate. When the rate was set at 100–700 Mbps, the UDP network efficiency for both IPv4 and IPv6 was about the same with respect to different-sized packets and reached the wire speed. When the rate was brought up to 800–1000 Mbps (as shown in Figure 5), the IPv6 UDP efficiency reached a ceiling, while on the IPv4 side efficiency continued

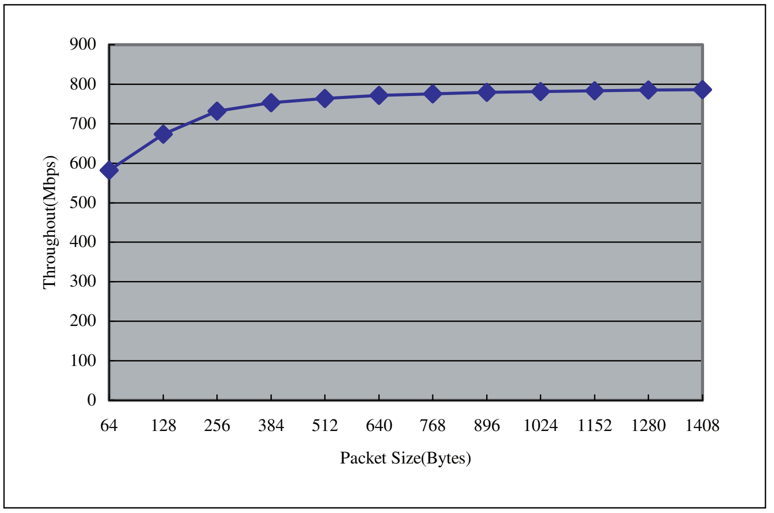

Figure 4. Packet generation rate (800Mbps)

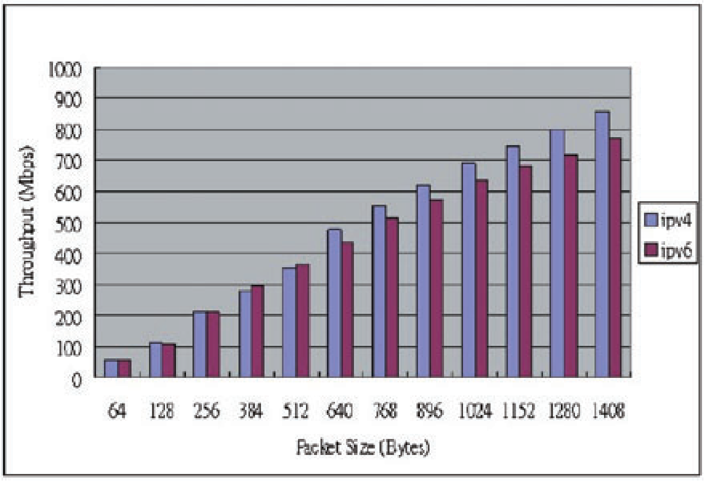

Figure 5. The efficiency performance of IPv4/IPv6 UDP from measuring the server data (800 Mbps)

to rise and reached steady state at 800 Mbps. From the server perspective, the UDP packet throughput for IPv4 reached a maximum at 800 Mbps, compared with 700 Mbps for IPv6. Thus, IPv6 UDP efficiency is roughly 87.5% of the IPv4 efficiency.

Figure 6 demonstrates the efficiency analysis targets for IPv4/IPv6 TCP packets. The preset window size limit for Fedora Core 2 Linux was 256 kbytes. When the packet size was set to over 640 kbytes, IPv4 TCP packet efficiency was higher than its IPv6 counterpart by about 10%.

—Measuring Data between the Two TWAREN Campuses—

Figure 7 illustrates the throughput versus packet size relationship for TWAREN between National Dong-Hwa University and National Chung-Hsing University campuses for IPv4/IPv6 UDP efficiency. The test between the two campuses focused on throughput, UDP packets loss rate, TCP throughput and round-trip time. When the packet generation rate was set to 100–300 Mbps, UDP

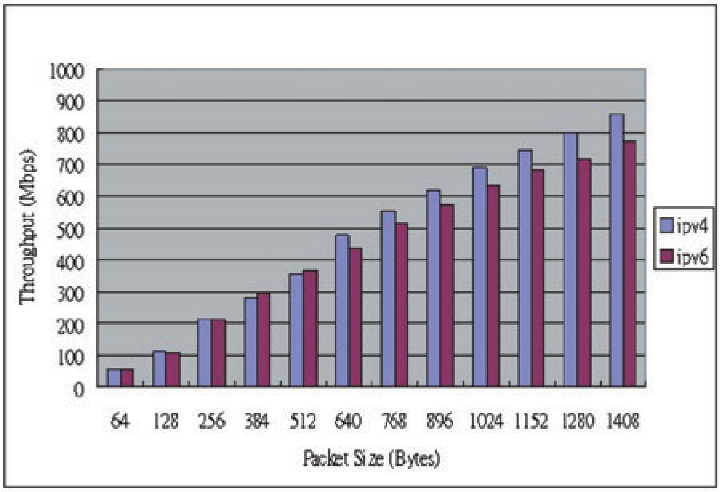

Figure 6. IPv4/IPv6 TCP efficiency performance measuring the server data

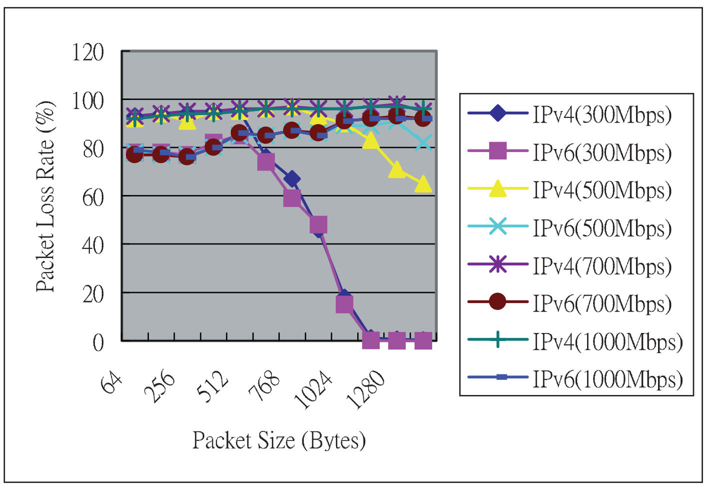

Figure 7. The efficiency performance of IPv4/IPv6 UDP with TWAREN backbone (300, 500, 700 and 1000 Mbps)

IPv4 and IPv6 efficiency was about the same for different packet sizes. They all reached wire speed.

When the generation rate was set to 500 Mbps, it can clearly be observed that the packet loss rate for IPv6 started to lead the IPv4 case when the packet size fell into the 1204–1280 byte region. The IPv4 UDP throughput was about twice that for the IPv6 case.

The generation rate was set to 700 Mbps. It can be seen that the packet loss rate for IPv4 was higher than that for IPv6 and reached over 95%. The UDP efficiency for IPv6 was better than that for IPv4.

When the generation rate was set to 1000 Mbps, again the packet loss rate for IPv4 was higher than that for IPv6 and reached over 97%. The UDP efficiency for IPv6 was better than that for IPv4.

The best UDP efficiency versus packet size performance under the no packet loss condition (RFC 2544) is shown in Figure 8. The IPv4 UDP packets reached 360 Mbps at most, while IPv6 UDP packets reached 340 Mbps.

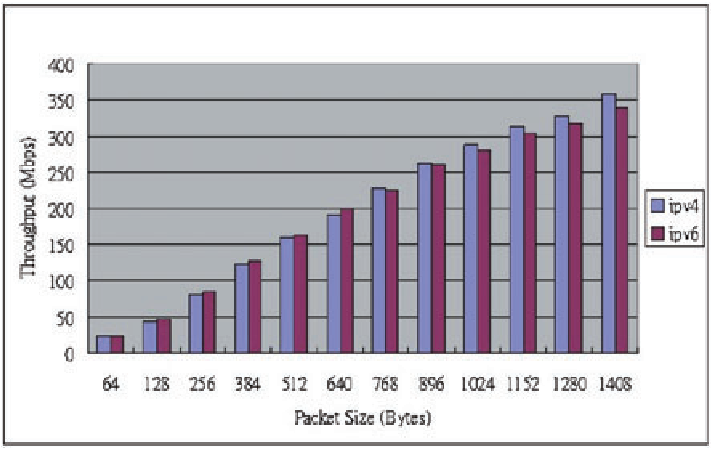

Figure 8. The best efficiency performance of IPv4/IPv6 UDP with TWAREN backbone

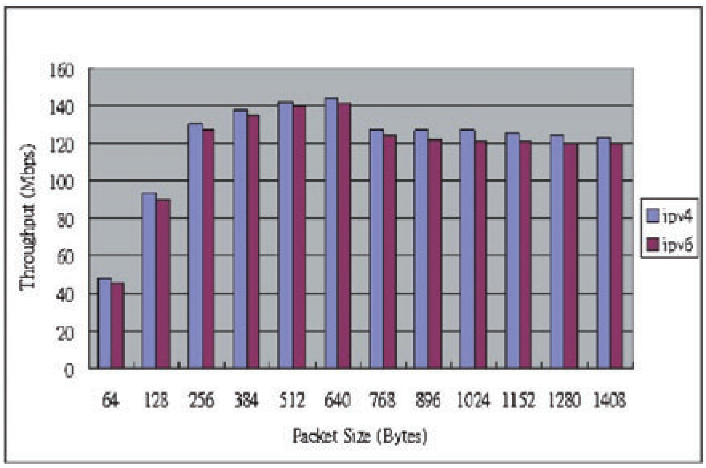

Figure 9. The best efficiency performance of IPv4/IPv6 TCP with TWAREN backbone

The best scenario for IPv4/IPv6 TCP efficiency analysis (window size to be 256 kbytes) is shown in Figure 9. When the packet size equalled 640 bytes, the IPv4 TCP packets reached the maximum efficiency of 144 Mbps, while the IPv6 TCP packets reached 141Mbps.

Figure 10 demonstrates the ICMPv4/ICMPv6 round-trip time (RTT) data analysis for the TWAREN backbone. It is clear that for all packet sizes the IPv4 data transmission was faster than that for IPv6 by about 0.4 ms. The RTT for the ICMPv4 1408 byte packet is slower than that of ICMPv4 64 bytes by 0.2 ms. The RTT for the ICMPv6 1408 byte packet is slower than that of ICMPv6 64 bytes by 0.3 ms.

This paper reveals the efficiency test of the IPv4/IPv6 experiments over the TWAREN backbone. From this collected data it is quite clear that the efficiency of transmitting IPv4 packets surpasses that for IPv6 packets. The reasons can be summarized as follows:

- Owing to cost and market considerations, commercial router would use hardware to process IPv4 packets while some IPv6 operations might be handled through software. Therefore, the efficiency will be influenced.
- IPv6 actually introduces three times more address bits than IPv4, resulting in more time to process the header. A header compression

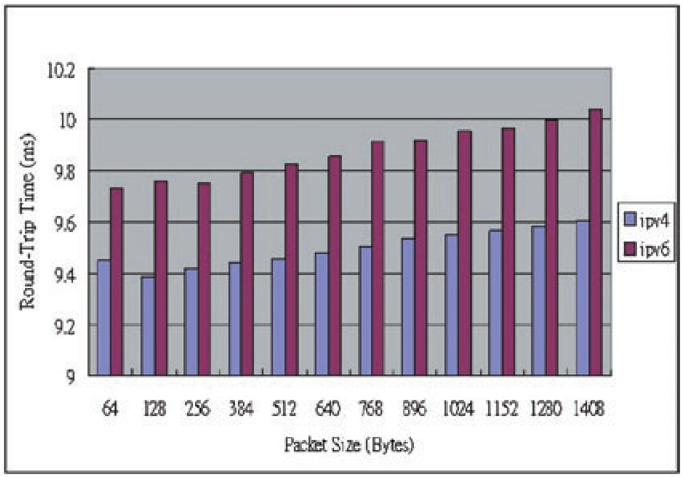

Figure 10. The efficiency performance of IPv4/IPv6 RTT with TWAREN backbone

mechanism[7,8] has been proposed to cope with this problem but has not yet been widely accepted.

Conclusion

The measurement results from the first test (the efficiency test on the servers) showed that the highest throughput for IPv4 UDP packets reached 811 Mbps under the no packet loss condition. The throughput for the IPv6 side was about 715 Mbps, which is roughly 88% that of the IPv4 case. The TCP packet test result reached the highest throughput at 859 Mbps for IPv4 TCP when the window size was set to 256 kbytes. The throughput on the IPv6 side was about 770 Mbps, roughly 89% that of the IPv4 case. The packet generation rate (packets/s) indicated no apparent relationship for different packet size or various throughput values. Regardless of packet size, the IPv6 generation rate was on average 90% that of the IPv4 rate. The server test result without any network apparatus connected verified the 90% relationship between IPv6 and IPv4 cases. This was independent of UDP packets, TCP packets or packet generation rate variables.

The second test focused on a point-to-point connection between the two campuses—National Dong-Hwa and National Chung-Hsing universities—over the TWAREN backbone. The packet loss was excluded and the highest IPv4 UDP packet throughput was about 303 Mbps. This was no different from the 304 Mbps in the IPv6 case. Since the server test showed the packet generation rate for IPv4 was about 10% faster than the IPv6 case, the IPv4 packet loss rate was relatively higher than that for the IPv6 case. The IPv6 UDP packet efficiency was quite compatible with that for the IPv4 case without the packet loss consideration. We used the RFC 2544 measurement to derive the UDP packet efficiency over TWAREN under the no packet loss presumption. We found the highest throughput for IPv4 UDP packets was 359 Mbps and 339 Mbps for IPv6 UDP packets. Comparatively, a figure of 94% reflects how the two packet versions behaved in the TWAREN backbone. The server efficiency measurement efficiency for the IPv4 packets was adjusted to 44% after passage through TWAREN. The IPv6 packet value was 47% using the same adjustment. If the same scenario was applied to TCP packets, the highest throughput for IPv4 TCP packets would be 144 Mbps, making the window size 256 kbytes. The throughput for IPv6 packets would be 141 Mbps. The percentage is 98% for TCP packets in conjunction with the TWAREN backbone. The efficiency measurement adjustment after TWAREN passage reduced to 17% on IPv4 TCP packets and 18% for IPv6 TCP packet.

The following are the TWAREN network efficiencies between National Dong-Hwa University and National Chung-Hsing University. The highest throughput for IPv4 UDP packets was 359 Mbps—44% of the value when tested on the server. The highest throughput for IPv6 UDP packets was 339 Mbps—47% of the value when tested on the server. The highest throughput for IPv4 TCP packets was 144 Mbps—17% of the value when tested on the server. The highest throughput for IPv6 TCP packets was 141 Mbps—18 % of the value when tested on the server. The round-trip time analysis on ICMP/ICMPv6 reflects that the IPv4 value was faster than the IPv6 value by about 0.4 ms with respect to all packet sizes. The RTT on the ICMPv4 1048 byte packet was roughly 0.2 ms slower than that for the ICMPv4 64 byte packets. The RTT on ICMPv6 1048 byte packets was roughly 0.3 ms slower than that for ICMPv6 64 byte packets.

Acknowledgement

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