An Empirical Study on Transmission Performance of IPv6 over WAN Latency

Liu Meijia 1,2, Zhang Qing1,2*
1 Aerospace Information Research Institute, Chinese Academy of sciences, Beijing 100094, China
2 School of Electrical Electronic and Communication Engineering, University of Chinese Academy of Sciences, Beijing, 100094, China
*Corresponding author’s e-mail: zhangqing@radi.ac.cn

Abstract. Compared to IPv4, IPv6 provides more internet protocol (IP) addresses and higher security and has easier routing capability; and these advantages lead to tendency of the IP protocol used by a network to be upgraded from IPv4 to IPv6. With the global transmission requirements of Big Data increasing rapidly, wide area network (WAN) will play a crucial role in data transfer, but majority of previous research studies are limited to local area network (LAN). Therefore, in this study, a WAN experiment is implemented to estimate the transmission control protocol (TCP) throughput of IPv4 and IPv6, which is used as an index to evaluate the efficiency of data transmission. Four latest operating systems were tested to assess performance, and a pair of operating systems was chosen to estimate the transmission efficiency of WAN by time delay. In this experiment, performance degradation in latency was quantified. The results will be a useful reference for followup research in the future.

1. Introduction
Fast network development and rapid increase in internet users cause extreme shortage in IPv4 addresses. The Internet Engineering Task Force prepared to improve IPv4 in 1993 and released the standard document for IPv6 two years later. However, the deployment of IPv6 was dramatically postponed by network address translation (NAT) and dynamic host configuration protocol (DHCP), although they were applied to prevent IPv4 addresses from exhausting quickly, until the Internet Assigned Numbers Authority (IANA) assigned the remaining five IPv4 address blocks to Regional Internet Registries on February 3, 2001, which was the first stage of IPv4 address exhaustion, and IPv6 renewed the focus of the world. The IANA then launched World IPv6 day on June 8, 2011, when more than 1000 internet service providers (ISPs) tried to run IPv6 on platforms such as Google, Facebook, Yahoo!, Akamai, and Limelight Networks for 24 hours; but the real journey of IPv6 began when another activity called World IPv6 Launch day was promoted by the Internet Society on June 6, 2012. This activity accelerated thousands of ISPs to provide continuous IPv6 services.

According to the statistics of APNIC Labs, the IPv6 usage ratio (users by country) was unsatisfactory until April 2019. Belgium, India, USA, Germany, Greece, Switzerland, Uruguay, Luxembourg, UK and Japan were the top 10 countries using IPv6. Except for Belgium and India that achieved 57.87% and 52.15% usage ratio of IPv6, respectively, those of the other countries were all below 50%. China was one of the countries that lacked IPv6 address as it only had 2.06% usage ratio of IPv6.
Rogers’ diffusion model [1] predicted that an IPv6 usage ratio of 50% for the world will be achieved in early March 2021 or in late October 2022. Therefore, China needs to actively develop the construction of IPv6 networks in the next few years to follow the world. The Chinese government [2] and ISPs [3, 4] declared to accelerate the network development of IPv6, so it is necessary to assess the performance of IPv6 for the reason that IPv4 will be replaced by IPv6 in the near future. First, four latest operating systems namely Windows 10, Windows Server 2019, Ubuntu 18, and CentOS 7 are tested, then a couple of operating systems that performed better are selected to test by time delay the impact on WAN.

The rest of this paper is organized as follows. Section II reviews the previous empirical papers and proposes innovation points. Section III builds the experiment environment and illustrates the experiment parameters. Section IV analyses the experiment data. Section V includes the summary and future development of IPv6.

2. Related work

In 2005, Sulaiman Syed Mohamed et al. [5] used TCP throughput and three other indexes of Quality of Service (QoS) to evaluate three operating systems: Windows 2003, Redhat Linux 9.0, and FreeBSD 4.9. In this article two experiments were conducted. In the first experiment, only one computer in network topology was used, and data stream was both generated and received by the computer. The results showed that the TCP throughput of Redhat Linux 9.0 was significantly higher than that of the two other operating systems in the IPv6 network environment. In the second experiment, two computers were connected by a hub to form a local area network (LAN). The result also indicated that Redhat Linux 9.0 performed best.

In 2011, Samad S. Kolahi et al. [6] tested the performance of Windows Vista and Windows XP in a Gigabit Ethernet LAN. Two hosts were directly connected by a Category 6 crossover cable. QoS indexes were used to evaluate a peer-to-peer (P2P) network and a client/server (C/S) network. The results indicated that the P2P network performed better than the C/S network when the IPv6 payload was between 128–640 bytes. However, the conclusion was exactly the opposite when the TCPv6 payload was between 896–1408 bytes. Besides, the TCP over IPv4 (TCPv4) throughput was always higher than that of TCPv6 in a P2P network.

In 2013, Burjiz Soorty and Nurul I Sarkar [7] assessed the transmission efficiency of IPv6 in a P2P Gigabit Ethernet LAN. Two hosts were directly connected by a Category 6 crossover cable. Then, two pairs of operating systems were evaluated using TCP throughput, TCP round trip time, Jitter, and a CPU. One group used Windows 7 with Windows Server 2008. The other group used Ubuntu 10.04 and Red Hat Server 5.5. The results showed Red Hat Server 5.5 performed better than Windows Server 2008, and the TCP throughput of IPv6 was higher than that of IPv4.

In addition, [8, 9] vast research studies were carried out to study the performance of diverse Windows operating systems. In all of the experiments in the articles mentioned above, IP QoS was used to measure the transmission performance of operating systems in a LAN, especially the TCP throughput, which was used in this study. Considering that few researchers have assessed the performance of IPv6 on WAN, this study mainly did a research on the transmission efficiency of WAN delay over IPv6. For the reason that the data being transmitted among continents over WAN have increased with global digitization, IPv4 will be gradually replaced by IPv6. Therefore, we will mainly study the impact of IPv6 with WAN delay, which is the main factor for affecting data transmission. One conclusion that can be drawn from the above literature is data transmission rate is related to operating systems and types of networks. We first evaluated the performance of latest operating systems because there have been no previous empirical studies involved. The four latest operating systems are Windows10, Windows Server 2019, Ubuntu 18, and CentOS 7. Then, a couple of operating systems that performed better will be selected for the experiment on WAN delay. Specific experiment steps are introduced in the next section.
3. Experiment setup and parameter configuration

3.1. Data transmission influenced by operating systems

Fig. 1 shows the network topology that was used to test the performance of different operating systems in a P2P network model. To avoid additional delays caused by intermediate network equipment, two hosts with Gigabit Ethernet (GBE) network interface cards were directly connected by a Category 6 crossover cable. In this figure, the host on the left is called Client, which consists of an Intel(R) Core(TM) i5–3330S CPU and DDR3–6GB–1600MHz RAM. The other host is called Server, which has 16 hard disks configured RAID5 and ECC DDR4–256GB–2400MHz RAM.

Table 1. Experiment parameter for evaluating transmission performance of operating systems.

| Operating System | Testing Tool | IP Version | Payload of TCP (Byte) |
|------------------|--------------|------------|-----------------------|
| Windows OS       | IP Traffic   | IPv4       | 128, 384, 640, 896, 1152, 1408 |
| Windows OS       | IP Traffic   | IPv6       | 128, 384, 640, 896, 1152, 1408 |
| Linux OS         | Iperf        | IPv4       | 128, 384, 640, 896, 1152, 1408 |
| Linux OS         | Iperf        | IPv6       | 128, 384, 640, 896, 1152, 1408 |

3.2. Transmission efficiency impact by WAN delay

Fig. 2 shows the network topology that consisted of four facilities. The center device of the topology was a Gigabit Ethernet switch with a backplane bandwidth of 240 Gbps. Client was on the left side of the switch, Server on the right, and above was a WANem (wide area network emulator) host. The three terminals were connected by three 10/100/1000 Base-T Ethernet ports of the switch with a Category 6 crossover cable. Default configuration was used for the switch, which means that packets were only forwarded. Client and Server had been mentioned in the previous experiment. The WANem
The host had an Intel(R) Core(TM) 2 Duo CPU and 6GB RAM. WANem is simulation software that runs on a computer to simulate WAN in an environment of LAN. Payload length was fixed to a value that corresponded to the highest TCP throughput value to measure the degradation in WAN delay. Two operating systems with better transmission effect were selected for this experiment. The time delay values for WAN were set to 0 ms, 10 ms, 20 ms, 40 ms, 60 ms, 80 ms, 100 ms, 150 ms, and 200 ms.

4. Results and analysis

4.1. TCP throughput on Client

Fig. 3 shows the TCP throughput increased with the increase in the payload length of both Ub and Win 10 when the TCP packets were not fragmented; Ub is short for Ubuntu 18, and Win 10 stands for Windows 10. The values that are shown in Table 2 correspond to the data points in Fig. 3 that shows the accurate results.

| Payload of TCP (Byte) | Ub-IPv4 (Mbps) | Ub-IPv6 (Mbps) | Win10-IPv4 (Mbps) | Win 10-IPv6 (Mbps) |
|----------------------|----------------|----------------|-------------------|-------------------|
| 128                  | 177            | 176            | 167               | 177               |
| 384                  | 487            | 474            | 521               | 533               |
| 640                  | 706            | 696            | 646               | 642               |
| 896                  | 829            | 830            | 805               | 799               |
| 1152                 | 915            | 907            | 841               | 826               |
| 1408                 | 936            | 923            | 902               | 888               |

Three conclusions are summarized by analyzing the experiment data. First, IPv4 performed better than IPv6 on Ub, except for when the TCP payload length was 896 bytes that the IPv4 throughput was 0.09% lower than that of IPv6. Second, in Win 10, the IPv4 throughput was higher than that of IPv6 when the payload length was longer by about 500 bytes. Third, Ub was always better than Win 10 when the TCP throughput was used for measurement. Furthermore, the theoretical values of the TCP throughput were calculated in the next subsection for the reason that the performance of the operating systems on both Client and Server were analyzed using the same method.

4.2. TCP throughput on Server

Fig. 4 shows that the TCP throughput increased with the increase in the payload length of CentOS 7 and WinSer, and the chart is shown in Table 3. Three conclusions were summarized. First, The TCPv4 throughput was always higher than that of TCPv6 on CentOS 7. The TCPv4 throughput was 8.78%
higher than that of TCPv6 when the payload length was 128 bytes; but when the payload length was 1408 bytes, the value was 1.04%. Then, the TCPv4 throughput was higher than that of TCPv6 on WinSer OS except for when the payload length was 384 bytes. Third, CentOS always performed better than WinSer OS especially when the payload length was 128 or 384 bytes, the CentOS throughput was 3.57 times higher than that of WinSer and IPv4, and 3.84 times higher than that of IPv6.

Theoretical formulas for the TCP throughput are given in [10]. We find that when the TCP payload length was 128 bytes, the difference between the theoretical value and the actual value of the TCP throughput is low on CentOS, while WinSer extraordinarily disappointed us when we compared the actual value with the theoretical one. By checking the system parameters, we found that the RAM of Server was 128 G, which CentOS can fully use, while for the utilization of RAM on WinSer it was only 64G. Therefore, a conclusion that CentOS is more efficient from a utilization of resources aspect can be drawn.

| Payload of TCP (Byte) | Cent-IPv4 (Mbps) | Cent-IPv6 (Mbps) | Winser-IPv4 (Mbps) | Winser-IPv6 (Mbps) |
|-----------------------|------------------|------------------|-------------------|-------------------|
| 128                   | 562              | 513              | 157               | 133               |
| 384                   | 807              | 773              | 473               | 503               |
| 640                   | 877              | 853              | 852               | 847               |
| 896                   | 909              | 891              | 876               | 859               |
| 1152                  | 928              | 913              | 892               | 878               |
| 1408                  | 941              | 928              | 902               | 891               |

4.3. Client transmission rate effect by WAN delay

In this experiment, the TCP payload length was fixed to 1408 bytes, for the above experiments proved that the TCP throughput performed best when the payload is at this length. Table 4 show the comparison of different operating systems when the TCP payload length is 1408 bytes. It can be concluded that UbOS performed better than Win10, and CentOS was better compared with WinSer. Therefore, in this experiment, UbOS was installed on Client, and CentOS was installed on Server.

Figure 5. Graph of degeneration in TCP throughput with increase in WAN delay
Table 4. Performance comparison between Client and Server with payload length of 1408 bytes

| OS   | Throughput       | IPv4 better |
|------|-----------------|-------------|
| Ub   | 936 923         | 1.39%       |
| Win10| 902 888         | 1.55%       |
| Ub better | 3.63% 3.79% |             |

Table 5. Performance comparison between Client and Server with payload length of 1408 bytes

| OS   | Throughput       | IPv4 better |
|------|-----------------|-------------|
| Cent | 936 923         | 1.38%       |
| WinSer| 902 888      | 1.29%       |
| Cent better | 4.13% 4.04% |             |

Fig. 5 shows that the TCP throughput decreased with the increase in WAN delay roughly in a negative exponential tendency. IPv6 always performed better than IPv4, and the black curve at the bottom, which represents the throughput of UbOS on IPv4, was the worst. Additionally, the transmission performance of CentOS was always better than that of UbOS when the WAN delay time was greater than 20 ms (actual latency of WAN was often greater than 20 ms).

Theoretically, the transmission efficiency of IPv6 is always lower than that of IPv4 when the IPv6 header is 40 bytes, which is twice the length of the IPv4 header. However, the results proved that IPv6 performed better. There were many factors in a network that can influence transmission rate; for example, packet efficiency handled by a network intermediary device, complexity of routing protocols, and limitation by ACL. One of the most reasonable arguments was that the theoretical values are only considered as effective information load rate.

We focus on the packet transmission efficiency of other factors that were not mentioned in this study. The IPv6 address field was 128 bits (16 bytes) that was ruled in [11]. It occupied 4/5 of the IPv6 header, while the remaining 8 bytes were only divided into seven control fields [12]. Compared to IPv6, IPv4 owned an address field of 32 bits (4 bytes), but the remaining 12 bytes were divided into 11 control fields. Therefore, the structure of the IPv4 packet header was more complex than that of the IPv6 packet header, and the transmission efficiency of IPv6 packets is higher than that of the IPv4 packets in WAN, for the IPv6 packets took shorter processing time. For this reason, the results were correct and meaningful.

5. Conclusion
In this study, we did two experiments. First, we evaluated four latest operating systems namely Windows10, Windows Server 2019, Ubuntu 18, and CentOS 7. It is concluded that Ubuntu 18 performed better than Windows10, and CentOS 7 performed better than Windows Server 2019. Therefore, Ubuntu 18 installed on Client, and CentOS 7 installed on Server was the configuration of the second experiment. Unexpected but landmark results show that IPv6 performed better than IPv4 in WAN, for less controlled fields cause high forwarding efficiency. However, this experiment was conducted in an ideal network environment; so to promote the construction of IPv6 networks, further research needs to be done to verify the efficiency of IPv6. Furthermore, high latency caused inefficient usage of bandwidth, so relevant transmission protocols should be improved to effectively use the WAN bandwidth.
References

[1] J. Pickard, M. Angolia, and T. S. Chou. IPv6 Diffusion on the Internet Reaches a Critical Point. Journal of Technology, Management & Applied Engineering, 2018, vol. 34(1).

[2] J. Yang. IPv6 development: To win the development opportunity in the next generation Internet. China Education Network, 2018 (In Chinese).

[3] J. Zhang and T. Zhang. IPv6 full-scale deployment, Open a new generation of the Internet of Thing. Cable Television Technology, 2018, vol.340(04), pp. 8-11 (In Chinese).

[4] Huang Haifeng. IPv6 deployment and reacceleration of China Telecom, manager to promote and focus on business transformation [J].Telecom World, 2018, vol. 778(20), pp. 18 (In Chinese).

[5] S. S. Mohamed, A. Y. M Abusin, and D. Chieng. Evaluation of IPv6 and comparative study with different operating systems[C]/Third International Conference on Information Technology and Applications (ICITA’05). IEEE, 2005, vol. 2, pp. 665-670.

[6] S. S. Kolahi, and B. K. Soorty. Evaluation of gigabit ethernet local area networks in windows vista-server 2008 environment. 2011 IEEE Workshops of International Conference on Advanced Information Networking and Applications. IEEE, 2011, pp. 308-312.

[7] N. I. Sarkar and B. K. Soorty B K. Evaluating IPv6 in Peer-to-Peer Gigabit Ethernet for TCP using Modern Windows and Linux Systems: An Empirical Study. International Journal of Business Data Communications and Networking (IJBDCN), 2013, vol. 9(1), pp. 50-63.

[8] S. Narayan, and Y. Shi. TCP/UDP network performance analysis of windows operating systems with IPv4 and IPv6. 2010 2nd International Conference on Signal Processing Systems. IEEE, 2010, vol. 2, pp. V2-219-V2-222.

[9] S. Narayan, S. S. Kolahi, and Y. Sunarto, et al. Performance comparison of IPv4 and IPv6 on various windows operating systems. 2008 11th International Conference on Computer and Information Technology. IEEE, 2008, pp. 663-668.

[10] E. Gamez, and R. Surós. An upper bound model for TCP and UDP throughput on IPv4 and IPv6. Journal of Network and Computer Applications, 2008, vol. 31(4), pp. 585-602.

[11] J. McCann, S. Deering, J. Mogul, et al. Path MTU Discovery for IP version 6. 2017.

[12] S. W. Richard. TCP/IP illustrated. Vol. 1: The protocols. 1993, pp. 181-182.