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EMPIRICAL ANALYSIS OF IPV4 AND IPV6 PROTOCOLS IN END USER ENVIRONMENT IN CROATIA

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ABSTRACT

IPv6 is a protocol which is in implementation phase for many years now. Implementation progress varies from country to country, but in majority countries it still doesn't surpass IPv4. Croatia is not an exception. This paper gives an analysis and comparison of IPv4 and IPv6 protocol performance in end user environment in Croatia. Testing is conducted with a series of ping tests on IPv4 and IPv6 enabled top 50 visited sites in Croatia as well as traceroute tests for both protocols. Tests targeted web sites with enabled IPv4 and IPv6 (dual stack).

Keywords: *end user IPv6, IPv4 vs. IPv6, IPv4 and IPv6 performance, IPv6 Croatia*

1. INTRODUCTION

Even though IPv6 implementation rate in Croatia is on a low level, with March 1st, 2022, stands on 5,8% according to Google Statistics, we can expect IPv6 taking over majority of internet traffic in years to come. Such trend is already visible in countries like Belgium (55%), France (53%), India (63%), etc. [1]. Currently, in Croatia, there is only one internet service provider (ISP) with IPv6 enabled core network and assigns IPv6 address space to its end users [2]. It is a service provider for landline internet services with market share less than 35% [3].

In 2019 there were approximately 10 billion of internet connected "classic" devices (desktops, laptops, servers, etc.) and 10 billion of Internet of Things (IoT) internet connected devices (sensors, actuators, home appliances, etc.) with predictions of stagnation of the number of "classic" devices and a significant growth on number of IoT devices. By 2025 it is predicted that there will be 30 billion of IoT connected devices [4]. All these newly connected devices will need addresses. Since part of IoT devices, especially the Industrial IoT (IIoT) segment devices are and will be located in open space environment and connected via 5G network, it will be crucial to enable this vast amount of IoT devices with sufficient address space. IPv6 would be the reasonable solution.

IPv6 protocol was designed to ensure not only larger IP address space, but also to enhance the routing efficiency and performance as well as security and quality of service. This is enabled with simpler header format, automatic encryption of traffic, checking packet integrity and fields for "traffic class" and "flow label"[5].

Over last 25 years, since IPv6 protocol is present, there has been a significant number of works published on IPv6 performance testing with majority of the work done in lab or simulation environment with just a few in real life environment.

At this moment, what can end users in Croatia expect to get with IPv6 protocol? Is communication with IPv6 as reliable as with IPv4? Through a series of simple network tests, we will answer these questions.

2. RELATED WORK

Extensive research on IPv6 performance was done in 2011 [6] with authors concluding that IPv6 protocol data plane performance is on par with IPv4 but still with poorer results on IPv6 side as a result of the use of less efficient paths. Authors based their results on monitoring access to web content from multiple vantage points to exclude location based biased results. They used results obtained on sites that were reachable over the same IPv6 and IPv4 AS path (so results would be comparable).

In [7] authors made a study of end user performance when accessing dual stack web sites around the world, measuring connectivity, packet loss, hop count, round-trip time (RTT) and throughput. This is the most recent study of this type, performed in 2021 with results concluding IPv6 has lower packet loss rate, higher RTT and lower throughput. Authors also compare results with previous related studies (2004, 2007, 2014) concluding improvement of IPv6 connectivity by 1-4%, IPv6 RTT greatly reduced but with no improvement for throughput.

A comparative study on the performance of IPv4 and IPv6 on voice and video network traffic flow using performance metrics such as jitter, throughput, and packet loss was done in [8]. The study concluded that IPv6 is very robust and has performed better than IPv4 on both experimental modes (voice and video).

In [9] author measured how the IPv6 protocol performs in comparison to IPv4 protocol in an UMTS mobile network lab environment concluding that signalling and web loading time is less with IPv6 than with IPv4.

Authors in [10] designed and applied an active measurement methodology to compare IPv6 and IPv4 performance from a perspective of an end user. They conclude there is still space left for IPv6 performance improvement, with increasing connectivity and lowering the packet loss rate.

3. METHODOLOGY

Tools ping and traceroute were used for testing purposes. These tools provide a basic method for testing reachability (connectivity), packet loss, RTT and route of a packet to its destination. Reachability calculation is based on the number of ICMP echo replies received for each domain. RTT value is presented in ping and traceroute results and represents a time measured from a moment sender sent a packet to its destination till a moment sender receives a reply packet. Hop count of a packet is based on a number of hops an ICMP packet must traverse to reach its destination.

Testing environment is a home internet connection, fibre optic metropolitan infrastructure with coaxial connection to the home, as seen in Figure 1. Access speed varies from 140 Mb/s to 200 Mb/s. Tools were deployed in a Windows 11 PowerShell environment with prepared scripts copying the output to log files. Each domain had a separate script for IPv4 and IPv6 ping and traceroute tests. Ping tests were run in a 24-hour period from June 30th, 2022, 10.00 AM till July 1st, 2022, 09:59 AM. Traceroute test was run on June 30th, 2022, 10.00 AM. Log files were automatically stored in dedicated files. Collected data from log files were copied to Excel files, separately for IPv4 and IPv6 ping and traceroute tests. The data was processed and analysed in Excel.

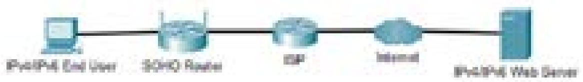

Figure 1 *Network testing environment*

Based on online resources, 50 top visited sites from Croatia were selected [11]. To determine whether the sites are IPv4 only or dual stacked, nslookup was done on all 50 sites for which an online tool was used [12]. The results are downloadable in .csv format and ready for further processing in Excel, example of nslookup results is shown in Table 1. The DNS lookup resulted in 26 out of 50 top visited sites as dual stacked sites, which means they are IPv4 and IPv6 enabled. Ping test over 24-hour period was done on 26 dual stacked web sites, simultaneously and separately on IPv4 and on IPv6 addresses. Some sites have more than one IPv6 address, only one IPv6 address was tested.

A. Ping test

To test reachability and delay, a series of ICMP packets were deployed via ping script. Example of ping test script is shown in Figure 2.

IPv4 ping

```
ping.exe -t -4 domain_name | ForEach-Object
{"{0} - {1}" -f (Get-Date),$_} | Tee-Object
C:\Users\Korisnik\Desktop\ping_domain_name_
v4.log -Append
```

Table 1 *Example of DNS lookup results*

Domain Name	A name (IPv4 address)	AAA name (IPv6 address)
germaniasport.hr	104.22.12.183	2606:4700:10::6816:cb7 2606:4700:10::6816:db7 2606:4700:10::ac43:7af
linker.hr	172.67.70.217	2606:4700:20::681a:1d 2606:4700:20::681a:11d 2606:4700:20::ac43:46d9
story.hr	104.26.7.202	2606:4700:20::681a:7ca 2606:4700:20::ac43:46d8 2606:4700:20::681a:6ca
novilist.hr	172.67.69.46	2606:4700:20::ac43:452e 2606:4700:20::681a:8f2 2606:4700:20::681a:9f2
dnevno.hr	104.21.28.208	2606:4700:3030::ac43:9395 2606:4700:3031::6815:1dc0

IPv6 ping

ping.exe -t -6 domain_name | ForEach-Object {"{0} - {1}" -f (Get-Date),$_} | Tee-Object C:\Users\Korisnik\Desktop\ping_domain_name_v6.log -Append

B. Traceroute test

To establish a route to a domain, a series of ICMP packets were deployed via traceroute script. Example of traceroute test script is shown in Figure 3.

IPv4 traceroute

tracert.exe -4 domain_name | ForEach-Object {"{0} - {1}" -f (Get-Date),$_} | Tee-Object C:\Users\Korisnik\Desktop\tracert_domain_name_v4.log -Append

IPv6 traceroute

tracert.exe -6 domain_name | ForEach-Object {"{0} - {1}" -f (Get-Date),$_} | Tee-Object C:\Users\Korisnik\Desktop\tracert_domain_name_v6.log -Append

4. RESULTS

The results on reachability, packet loss, RTT, and a route of a packet to its destination are presented in this section. Domain netflix.com does not support ICMP traffic, resulting in no responses from the domain hence the results were not included in further calculations since they do not reflect real situation (domain is online and reachable but cannot be reached via ICMP). Netflix.com domain was one out of 26 dual stacked domains, hence results on 25 domains were used in this research.

A. Reachability

Reachability for each domain is determined based on the results of the ping test. Ping test in this research had two different types of results: ICMP Echo Reply and Request timed out (there are other types of ping results, not relevant nor included in this research results). Regular ICMP echo reply means a domain is reachable. 25 out of 25 domains are reachable via ICMP request, giving a 100% of reachability for IPv4 and IPv6 protocol.

B. Packet Loss

Packet Loss is calculated with the results of the ping test. It is calculated as share of ICMP echo reply packets that have not been received

Figure 2 *Example of ping test script*

Figure 3 *Example of traceroute test script*

(Request timed out.) of all sent ICMP requests. Summary results are shown in Table 2. and individual results per domain are shown in Figure 4. To be comparable, all results are presented as share of lost packets since the number of sent packets is not the same for all domains and per protocol.

***Table 2** Packet Loss results*

	IPv4	IPv6
Average	0,00348%	0,00334%
Min	0%	0%
Max	0,01763%	0,02351%

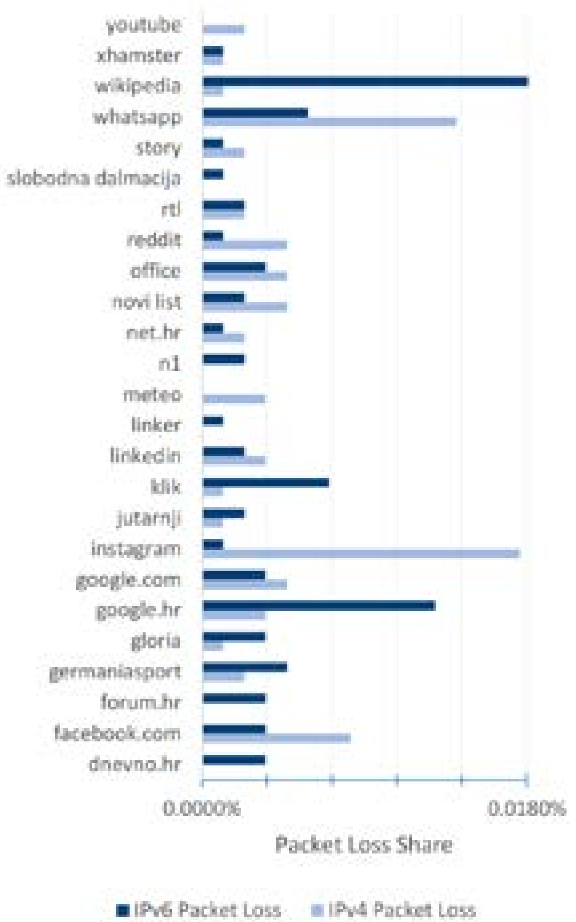

***Figure 4** Comparison of IPv4 and IPv6 ping test packet loss results*

C. Round Trip Time

Each ICMP reply packet contains information on RTT value. It is a value of time measured from the time a packet is sent till the time the packet is received at the sender computer. RTT time is measured in milliseconds (ms) by default.

Summary results are presented in Table 3. Individual domain results comparison for IPv4 and IPv6 protocols RTT values is shown in Figure 5. Individual domain results comparison for IPv4 and IPv6 protocols RTT values obtained via ping and traceroute tests is shown in Figure 6.

***Table 3** RTT ping results*

	IPv4	IPv6
Average	12,92 ms	13,65 ms
Min	2 ms	2 ms
Max	224 ms	195 ms

***Figure 5** Comparison of results on RTT values for IPv4 and IPv6 domains ping tests*

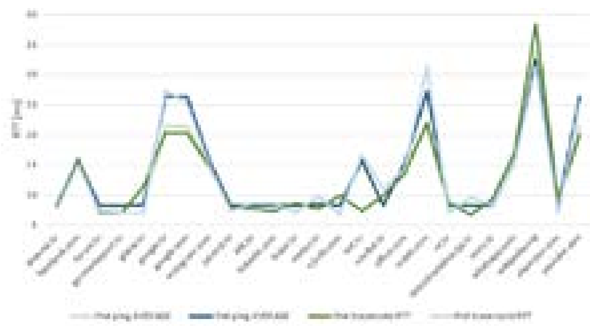

***Figure 6** Comparison of results of RTT values for IPv4 and IPv6 domains traceroute and ping tests*

D. Hop Count

With traceroute results we can determine the number of hops a packet makes on its way to its destination, in our case domain with IPv4 and IPv6 support. More hops a packet makes usually means a higher RTT or latency.

Summary results on hop counts is show in Table 4. Individual domain results comparison for IPv4 and IPv6 protocols hop counts is shown in Figure 7.

Table 4 *Hop Count traceroute results*

	IPv4	IPv6
Average	10,32	8,28
Min	7	5
Max	16	15

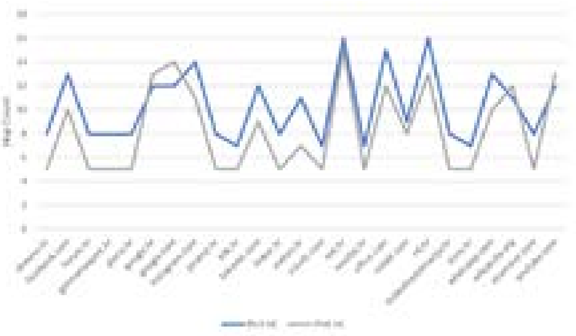

Figure 7 Comparison of results on Hop Count values for IPv4 and IPv6 domains traceroute tests

5. DISCUSSION

When we look at the geo location information of IPv6 enabled domains from top 50 visited web sites in Croatia, we can see that there is only one IPv6 enabled domain hosted in Croatia (meteo.hr), which basically reflects current IPv6 implementation status in Croatia.

Reachability for all tested domains is 100%, both for IPv4 and for IPv6 protocol. Since tested domains are most visited sites in Croatia, 100% availability was expected.

Average packet loss results for IPv4 and IPv6 protocols differ in 0,014% in favour of IPv6, meaning there is no significant difference in average packet loss results between the two protocols. Lowest packet loss rate measured is 0% and maximum 0,02351% for IPv4 protocol with an average of 0,00348% and 0% minimum, 0,01763% maximum and average of 0,00334% for IPv6. If we compare these results with other research, these are very good results. In [7] authors measured lowest packet loss rate at 0% and maximum at 5,56%, the study was conducted in 2021. In [8] authors deter-mined the IPv6 and the IPv4 connections have an average packet loss rate of 3.09% and 0.76% respectively.

Round-trip time average for IPv4 protocol is 12,92 ms and for IPv6 is 13,65 ms, which gives a difference of 0,73 ms in favour of IPv4. Minimum RTT values are the same for both protocols, 2ms. Maximum RTT value is higher for IPv4 than for IPv6, 224 mms and 195 ms respectively. Besides minor deviations, results for both protocols are in line with each other and show no significant leverage for either protocol version. When we compare results on RTT values obtained from ping and traceroute tests, we can conclude there is no significant difference between them.

IPv6 protocol traceroute test results show lower average number of hops a packet makes to its destination, 8,28 for IPv6 and 10,23 for IPv4. In theory, smaller hop count would mean a lower RTT (if all paths would have same parameters). When we compare hop counts and RTT values, IPv6 has lower average number of hop counts but has higher average RTT value. Lower number of hop counts for IPv6 packets can be attributed to simpler topologies for IPv6 protocol and tunnel usage. IPv4 protocol topologies, due to years of usage and greater representation of the protocol are more complex, hence resulting in higher number of hop counts.

6. CONCLUSION

Latest research established that IPv6 protocol in real-life environment provides lower packet loss rate and similar average hop count in comparison to IPv4 [7].

Our results show that 52% of top visited sites from Croatia are IPv6 enabled. IPv6 protocol does not show significant lag behind IPv4 protocol performance regarding the RTT and packet loss values. IPv6 showed 100% reachability, low packet loss rates, comparable RTT values with IPv4 and lower number of hop counts in comparison to IPv4.

Future research will include larger number of tested connections, throughput, and latency measurements as well as quality research on IPv6 paths which will help in creating clear image on end user environment IPv6 performance in Croatia.

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