A Comparative Performance Study of IPv6 Transitioning Mechanisms - NAT-PT vs. TRT vs. DSTM

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Abstract. One of the major challenges faced by the IPv6 community in recent years has been to define the scenarios in which transitioning mechanisms should be used and which ones should be selected given a specific scenario. This paper aims to supplement this by presenting the results of a comparative evaluation carried out on three major IPv6 interoperation mechanisms; NAT-PT, TRT and DSTM. This work attempts not only to determine the outright performance of each mechanism against the other but also against a theoretical evaluation of the specification. Our results show that while DSTM performs well both NAT-PT and TRT place significant overheads on the network.

Keywords: IPv6, Transitioning Mechanisms, NAT-PT, TRT, DSTM

1. Introduction

One of the major challenges faced by the IPv6 community in recent years has been to define the scenarios in which transitioning mechanisms should be used and which ones should be selected given a specific scenario. This is well illustrated by the IETF V6OPS working groups [1] who have led this process by defining and analyzing four broad IPv6 deployment scenarios; Unmanaged [2], Enterprise [3], ISP [4] and 3GPP [5], which each represent a key area for IPv6 deployment. As such, the thorough completion of this process is critical since its outcome may largely determine the future use of all such mechanisms.

Transitioning mechanisms can generally be divided into three groups according to their operation and functionality: Tunnelling, Translation and Dual Stack. We choose however to focus on mechanisms that support the interoperation between IPv4 and IPv6 which includes both translator and dual stack mechanisms. This paper presents the results of a comparative evaluation carried out on three interoperation mechanisms; NAT-PT, TRT and DSTM which each allow IPv4 and IPv6 hosts to communicate. Our aim is to supplement the ongoing analysis work with a comparative evaluation to show how each performs under test conditions. This paper does not attempt to evaluate the implementation of each mechanism but rather concentrates on extracting the mechanism-specific properties to test each *transitioning approach* against the other.

Hereafter this paper is organised as follows, section 2 conducts a theoretical performance analysis in an attempt to extract any inherent qualities. Section 3 presents the testing and section 4 concludes with an analysis of our results.

2. Theoretical Mechanism Evaluation

This section presents a theoretical evaluation of each mechanism to estimate the test performance we can expect in each case. In each case, diagrams outline the tasks that must be performed with the darker shading indicating the more complex operations.

2.1. NAT-PT Performance Evaluation

NAT-PT (Network Address Translation - Protocol Translation) [6] extends NAT to provide a translator that binds IPv6 addresses to IPv4 addresses from a local pool and keeps state on sessions passing through it. One weakness of NAT-PT is its inability to translate upper layer protocols (e.g. DNS) using embedded IP addresses requiring the use of application level gateways (ALGs). While NAT-PT is likely to be deployed to some degree, it is now unpopular with the majority of the IPv6 community due to it over-complex approach and has recently been moved to experimental standard.

Session Initiation - In NAT-PT this will incur significant overheads due to the address allocation and the state that is kept on each session which must be setup during initialisation. Fig 1 shows the steps to initialise a session in NAT-PT with the heavyweight aspects including the address allocation translation of the first packet.

Operation - Once the session is in progress, translation is done on a per-packet basis with lookups needed to retrieve the address bindings. During translation, IP headers are completed first before upper layer (TCP/UDP) protocols. Finally any higher-level protocols (e.g. FTP) must be translated before the packet is forwarded. This process is shown in Fig 2. As such, the overhead introduced will vary according to the packet being translated and depending on the complexity of the packet, these overheads may be quite significant. Overall, we expect NAT-PT to perform quite poorly, session initiation will be significant while bi-directional per-packet translation suggest that operational performance will be poor also.

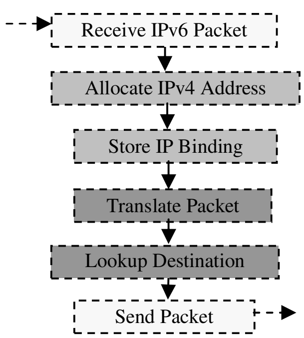

Fig 1. Initiation tasks for NAT-PT

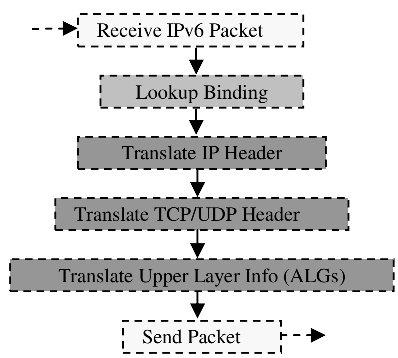

Fig 2. Per-Packet translation for NAT-PT

2.2. TRT Performance Evaluation

TRT (Transport Relay Translator) [7] transparently relays TCP/UDP connections between IPv4 and IPv6 and between the source and destination. As with NAT-PT, it keeps state on sessions and cannot handle embedded IP addresses. As a relay, TRT is reasonably efficient and is now the preferred translation-based solution. We expect therefore that TRT will perform better than NAT-PT but still introduce significant overheads as packets are translated at the transport layer before being forwarded.

Session Initiation - On initiation TRT must setup two TCP/UDP connections, from the IPv6 host to the relay and from the relay to the IPv4 host necessitating a certain amount of state being configured. Fig 3 gives an overview of TRT initialisation which is the simplest and therefore (we expect) the quickest on test.

Operation - Once the initialisation in complete, a limited amount of processing in necessary as flows are relayed between connections as shown in Fig 4. The only real overheads introduced are a lookup to establish the outgoing address and the construction and sending of the packet. Upper layer protocols such as FTP must again be handled via an ALG. The most significant aspect of normal TRT operation will be in the relaying of packets between connections. This necessitates the packet traversing up one IP stack to the transport layer and back down the other, however, we expect TRT to perform better than NAT-PT in most aspects.

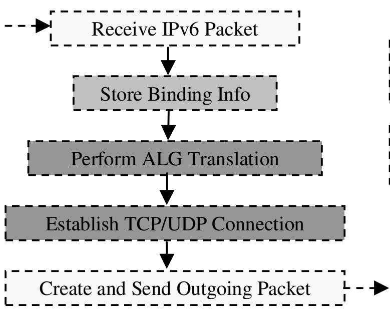

Fig 3. Initiation of TRT

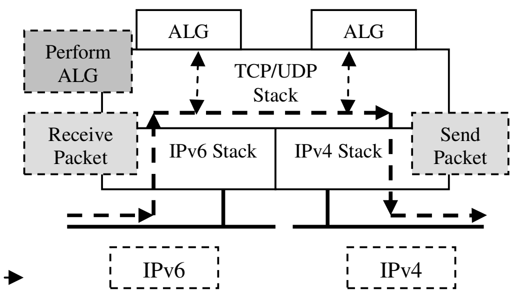

Fig 4. Operation of the TRT mechanism

2.3. DSTM Performance Evaluation

DSTM (Dual Stack Transition Mechanism) [8] uses automatic tunnelling to enable Dual Stack enabled hosts in an IPv6-only network to acquire a temporary IPv4 address and communicate with IPv4 hosts. It is composed of a Server for address allocation, a Tunnel End Point (TEP) and the hosts.

Session Initiation – The DSTM initiation process is complex, involving communication between all three components. On initialisation, a DSTM client in the IPv6 host will contact the Server which replies with both an address allocation and the address of the TEP. The host then encapsulates the first IPv4 packet and sends it to the TEP where the packet is decapsulated, the IPv4<->IPv6 binding is stored and the IPv4 packet is sent. This process is shown in Fig 5 indicating which components are involved in each step. The overheads in this process will be incurred during the communication between the components prior to traffic flow starting. **Operation -** Once the session is in progress, DSTM is far more straight-forward as its operation simply involves an IPv4-over-IPv6 tunnel with the IPv6 host and TEP performing (d)encapsulation on packets sent. The TEP must also do a lookup on each IPv4 packet received to determine the destination IPv6 address. Fig 6 shows this from the perspective of a returning IPv4 packet. Once DSTM is established, its overheads will be minimal as only simple (d)encapsulation and forwarding is necessary. As such, we expect initiation performance to be poor but the operational should be excellent.

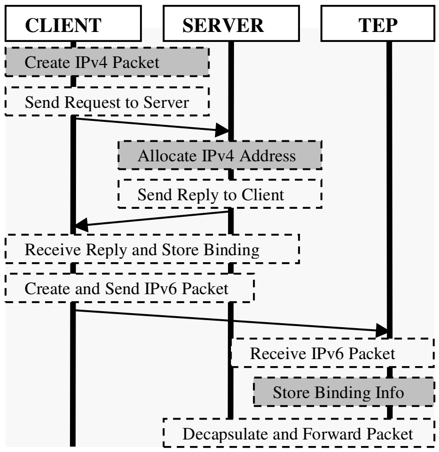

Fig 5. Initiation of the DSTM mechanism

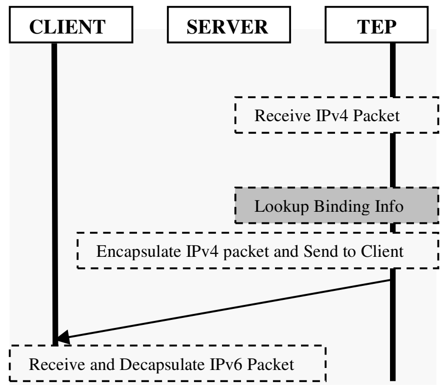

Fig 6. Reverse traversal of DSTM

3. Results

The aim of our evaluation was to test the mechanisms over a common 100 Mbps test network to give a better indication of the relative performance of each approach. The test network comprised of a small IPv6-only subnet behind a Dual Stack gateway with hosts on either side to locate the testing tools. For our tests, the ETRI implementation of NAT-PT [9], pTRTd from Litech Systems [10] and ENST DSTM [11] over Linux Red Hat 9.0 were used with each result representing the average performance from a number of tests. The testing was done using IPERF [12] to benchmark mechanism performance and MGEN [13] to generate network traffic flows.

The testing comprised of three stages with the initial testing establishing the optimum performance of each mechanism to provide a direct comparison of each including initiation performance (from receipt of the first packet to it being sent on the external interface). The next phase tested performance under increasing levels of simplex (IPv6 to IPv4) traffic with the final phase testing duplex traffic performance to represent realistic network conditions. To establish the loading increments for each testing phase, IPv4-only testing was done first and a reasonable scale selected.

3.1. Initial Benchmarking Results

The results of the initial performance testing are shown in Fig 7 with the initiation testing results shown in Table 1. These show to good effect the relative performance of each mechanism in comparison to IPv4. DSTM is the best-performing mechanism, averaging at about 90 Mbps with TRT showing 40 Mbps and NAT-PT only slightly worse at 32 Mbps. This is what we would expect to see in a direct comparison and shows the performance advantage DSTM has over translators giving results only slightly inferior to IPv4-only. The initiation tests again reinforce what we expected to see with TRT clearly the best averaging around 0.26 milliseconds followed by NAT-PT at 0.81 milliseconds with DSTM the slowest at over 1.35 milliseconds on average.

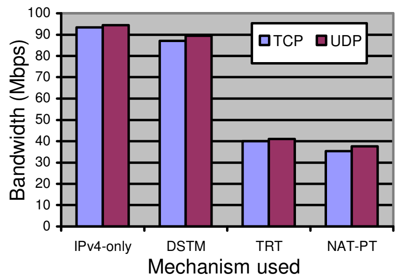

Fig 7. Optimum mechanism testing results

Table 1. Mechanism Initialisation Results

Device	**Min. (ms)**	**Max. (ms)**	**Av. (ms)**
TRT	0.261	0.269	0.264
NAT-PT	0.751	0.899	0.816
DSTM	1.317	1.422	1.353

3.2. Simplex Testing Results

The simplex test results are shown in Fig 8 and highlight the performance against a gradually increasing IPv6 -> IPv4 traffic flow. The **IPv4-only** test showed that the performance decreases roughly in increments of 10Mbps per 1000 packets per second (pps) of loading introduced. One interesting result we noticed was that once the loading increases past a certain point, (around 5000pps) the bandwidth curve tended to level out with no further performance degradation experienced. The **NAT-PT** results were poor in comparison to both the IPv4-only results and the other mechanisms tested. The performance results show it performed consistently in the range on 30Mbps but that the traffic load had a much less pronounced affect on mechanism performance. The **TRT** results again show it to be quite resilient to network load with performance consistently in the 30–40Mbps range and a slight decline in performance as the load increases. It was consistently worse than IPv4 but in all cases performance was superior to NAT-PT. The **DSTM** results clearly show it to be the best performing mechanism tested. In an unloaded network it performed similar to IPv4, around the 90Mbps mark, also falling in a similar way under load.

3.3. Duplex Testing Results

The duplex testing results as shown in Fig 9 show how mechanism performance was affected by both IPv6 -> IPv4 and IPv4 -> IPv6 traffic. The **IPv4-only** results show that performance suffers heavily in this scenario. The bandwidth rapidly falls until a rate of 50 pps where it levels out and falls gradually reaching 9Mbps at 100 flows per host. **NAT-PT** also performed badly in the duplex tests managing results only up to 30 flows per host. Our results show that performance fell sharply from 34 to 18Mbps in the first test and thereafter slowly degraded until it failed testing 40 flows per host. Unfortunately, no accurate test results could be gathered for **TRT** because the approach dictates that it be IPv6-initiated without the use of a DNS-ALG meaning IPv4 initiated traffic is not possible in this case. The **DSTM** results again show it to be the best-performing mechanism tested. It again performs in a similar manner to IPv4-only, initially dropping rapidly before levelling off. As with NAT-PT, DSTM failed to register a complete set of results and failed while testing the 70 pps scenario.

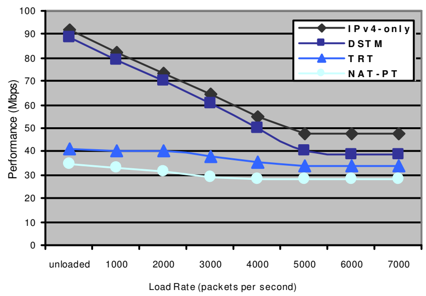

Fig 8. Combined simplex performance

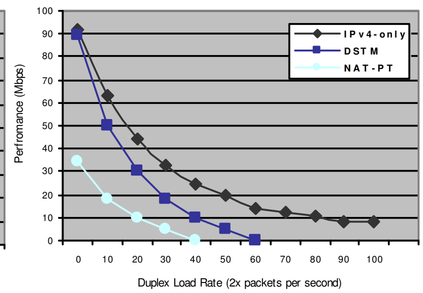

Fig 9. Combined duplex performance

4. Conclusions

The results of the testing both reinforced what we expected to see and produced some interesting results that highlight the behaviour of these mechanisms. The results generally give the order IPv4-only, DSTM, TRT and NAT-PT which is essentially what we predicted. NAT-PT performance was quite poor, TRT outperformed NAT-PT and DSTM was very impressive in its proximity to IPv4 performance. Based on these results there is little to recommend about NAT-PT, also given its move to 'experimental' it is the least preferable solution considered here. TRT fared better and while it is not on a par with DSTM it represents the best translator device. DSTM however is the 'fastest' mechanism evaluated but is the most complex to deploy and IPv4 address resources must be committed to make it scalable. Further work will include simulations to test mechanism scalability in larger networks and testing of other implementations (possibly *BSD) to negate any implementation-specific anomalies.

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