# IP Overhead Comparison in a Test-bed for Air Traffic Management Services


Àngels Via, Eriza Hafid Fazli, Sébastien Duflot,
Núria Riera, Markus Werner
TriaGnoSys GmbH
Argelsrieder Feld 22, Wessling, Germany
[Eriza.Fazli, Angels.Via]@triagnosys.com



*Abstract*— **This paper presents the comparison of two IPv6 over IPv4 solutions for a laboratory demonstrator within NEWSKY, a project co-funded by the European Commission within its 6th Research Framework Programme (FP6). NEWSKY aims at developing a concept for a global, heterogeneous communication network for aeronautical communications. It assumes IPv6 hosts, but nowadays satellite networks still run over IPv4 links. Two solutions have been tested and investigated over a real satellite link for this project: L2TP tunneling and NAPT-PT modified. Both are implemented and compared in terms of overhead and complexity. Results show that NAPT-PT modified adds less overhead than tunneling, however, L2TP computation is easier and faster than NAPT-PT modified.**



***Keywords- Aeronautical Communications; Satellite; IPv6; Air Traffic Management; L2TP; NAPT-PT.***


## I. INTRODUCTION

Several European research activities are being undertaken with the goal to develop improved communication technologies for aeronautical communication. These activities comprise ground-based, satellite-based, aircraft-to-aircraft and airport communication for all different application classes, like air-traffic services (ATS), airline operational and administrative communication (AOC, AAC), and aeronautical passenger communication (APC).

NEWSKY [1] is a project co-funded by the European Commission within its 6th Research Framework Programme (FP6). The project aims at developing a concept for a global, heterogeneous communication network for aeronautical communications, based on IPv6 (Internet Protocol version 6) protocol and focusing on developments at network layer.

The networking concepts developed within NEWSKY project are validated by two means: extensive computer simulation, and laboratory demonstration, where future Air Traffic Management (ATM) network is emulated in laboratory environment. The main objective of the laboratory test bed is to show handover (HO) of communication between a satellite and a terrestrial-based communication network. A real air interface is considered for the satellite link, using Broadband Global Area Network (BGAN) service from Inmarsat, and a terrestrial link based on emulated L-band Digital Aeronautical Communication System (LDACS). A second terrestrial link based on 802.16 standard (WiMAX) will be potentially included. As NEWSKY focuses on network layer (Layer 3 in TCP/IP protocol stack), the term HO is understood as network layer handover.

NEWSKY considers IPv6 as the baseline protocol. As currently there is no widely deployed satellite IPv6 network, it becomes necessary to define a mechanism for traversing the IPv4 (Internet Protocol version 4) network segments found when a communication is established over satellite.

For the test-bed implementation two potential solutions have been investigated, namely tunneling and modified Network Address and Port Translation-Protocol Translation (NAPT-PT mod). Both approaches assume the existence of a dual-stack (DS) IPv6/IPv4 router on the ground network which basically performs the function of an access router.

The main objective of this paper is to compare both approaches, which are outlined in the following, in terms of protocol/packet header and signaling overheads, complexity, and processing delay. In order to fairly compare both approaches in the NEWSKY scenario, the comparison shall be done by simulating the continuous IP connectivity during the different phases of a flight, i.e. first establishing a connection between the aircraft and a ground base station over an IPv6-based terrestrial link, afterwards changing to an IPv4-based satellite link and when approaching the destination airport changing again to an IPv4 terrestrial link.

This paper is organized as follows: first the system architecture is explained. Then L2TP is described and after it NAPT-PT modified. Following this, a theoretical comparison and the test-bed results are given including some figures. At the end there are the conclusions.

## II. SYSTEM ARCHITECTURE

The laboratory system architecture is depicted in Fig. 1. In the aircraft there are Mobile Network Nodes (MNN) using HTTP (Hyper Text Transfer Protocol) or FTP (File Transport Protocol) and VoIP (Voice over IP) applications and a Mobile Router (DSMR) which is IPv4 and IPv6 capable (Dual Stack). It can connect to a ground network using either a terrestrial link or a satellite link. In the test-bed the terrestrial link is emulated as LDACS and the satellite connection is done over INMARSAT BGAN terminal. IPv6 is entirely used in the case of L-DACS, whereas in satellite link only IPv4 can be used, so a Dual Stack router (ground DS) is needed to connect to the

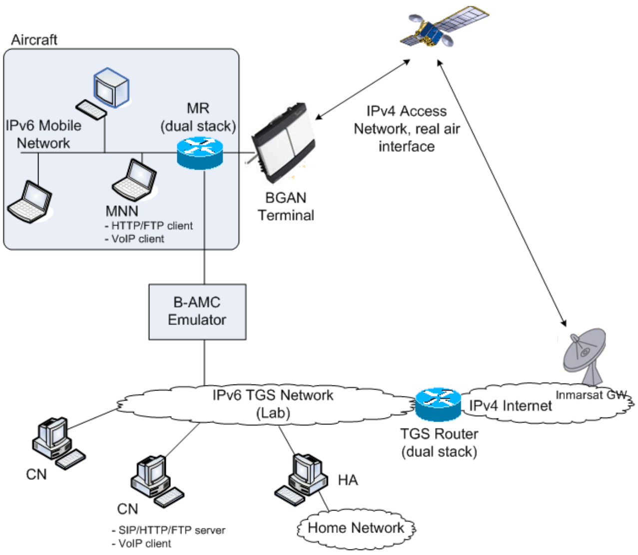


Figure 1. Laboratory Test-bed network architecture

ground IPv6 network, where the Home Agent (HA) and some Correspondent Nodes (CN) are placed.

When the aircraft is outside its Home Network, a mobility protocol is used, namely Network Mobility (NEMO) [6] which is an extension of the Mobile IPv6 (MIPv6) protocol to enable an entire network to move instead of only one node.

NEMO is implemented in the test bed using implementations from Nautilus6 project.

## III. TUNNELING

A tunnel interface is created between the DSMR and the ground DS router. The ground DS router is assigned an IPv6 prefix which it advertises in the tunnel interface. Once the tunnel interface is established, the intermediate IPv4 network will be transparent to the MIPv6 protocol.

There are several possibilities of tunnel types that can be used. The simplest approach would be to use a simple IP-in-IP tunnel, as described in transition mechanisms for IPv6 [2]. However this interface is not supported by the Nautilus6 NEMO implementation. The proposed substitute is Layer 2 Tunneling Protocol (L2TP) [3], which is designed to carry PPP (Point-to-Point Protocol) frames over an IP network. The two endpoints of an L2TP tunnel are the LAC (L2TP Access Concentrator) which is the tunnel initiator and the LNS (L2TP Network Server) which waits for tunnel requests. The necessary setup for tunneling a PPP session with L2TP consists of two steps:

1. The LAC sends a request to the LNS in order to create the tunnel. Then, a Control Connection Establishment signaling is performed to set up the tunnel.
2. Once the tunnel is established, the network traffic between the two peers is bidirectional. In order to carry PPP frames through the tunnel, either the LAC or the LNS has to initiate a session, making a call through the tunnel. The traffic for each session is isolated by L2TP, so that multiple session establishments across a single tunnel are possible.

Because only the IPv4 address of the ground DS router is permanent, the LAC has to be in the DSMR, and the LNS in the ground DS router.

L2TP is actually a layer 5 protocol in OSI (Open Systems Interconnection) protocol stack. It adds additional PPP, L2TP, UDP (User Datagram Protocol), and IPv4 headers to the original IPv6 packet. This is shown in Fig. 2, where an inner IPv6 header appears as a result of the NEMO protocol.

The amount of added header is potentially larger e.g., due to the use of security measures such as IPSec.

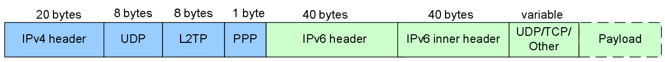


Figure 2. IPv6 packet encapsulation in L2TP tunnel

## IV. NAPT-PT MODIFIED

Network Address and Port Translation-Protocol Translation (NAPT-PT) is a mechanism to allow IPv6 hosts to communicate with IPv4 hosts or vice versa, but not when both ends are IPv6 with an IPv4 network segment in between. Thus, the standard NAPT-PT, defined in RFC2766 [5] can not be used in our scenario.

The following describes a modified mechanism [4] of the standard NAPT-PT especially developed for NEWSKY.

The main difference from the standard is the fact that both ends have IPv6 instead of only one. Thus two translations between IPv6 and IPv4 and vice versa are required, i.e. one on the plane (DSMR) and one on the router on ground (ground DS), cf., Fig. 1.

Like in IPv4 NAT, the router has a table with the relation between the inner addresses (IPv6) and their correspondent external addresses (IPv4).

As all packets entering or exiting the aircraft IPv6-network should be translated to version 4 (in DSMR) and again to version 6 (in ground DS router), both translation routers must have the same translation tables.

### A. *Header Translation*

All the fields in IPv6 header must be transmitted to the other end of the link in order to translate the packet to IPv6 again. They suit to the IPv4 fields except the addresses and ports, the Flow Label and the Next Header.

As the table is based on addresses and ports, only UDP (User Datagram Protocol) and TCP (Transport Control Protocol) can use the table. Thus the addresses and ports need to be sent only once per session, as they are stored in the table for further packets. In all other protocols, like ICMPv6 (Internet Control Message Protocol version 6), a UDP header is added just after IPv4 header, so the operation is the same.

An additional UDP header has to be added after the IPv4 header for TCP traffic (see Fig. 3d and e).

The other two remaining fields have 28 bits and are added just after the UDP header. Four bit-flags have been added in order to have this kind of extended header length multiple of 32 bits and to indicate, for example, if the addresses are sent or not in this packet.

Note that in Fig. 3 the IPv6 inner header for the MIPv6 protocol is already counted and the Extension Headers are treated as payload.

### *B. Protocol Operation*

The protocol explained here assumes that most of the packets are generated from inside the mobile network (DSMR egress direction), thus, these packets are translated automatically whereas the packets generated outside need some signalling before.

The basic operation for the DSMR egress packets is explained here:

1. A node generates the first packet of a session, which is destined to the outside IPv6 world and therefore sent to the NAPTPT modified router (DSMR).
2. When the DSMR receives it, it looks for an entry in the translation table but it does not find any, as it is the first of a session. Then, it creates a new entry, assigning an IPv4 address and port pair in this router and also in the router on-ground (ground DS).
3. Afterwards the DSMR translates and sends the packet with the IPv6 addresses and original ports, as shown in Fig. 3b, d and f.
4. After going through the satellite link, the packet arrives at the ground DS router who reads the IPv6 addresses and ports and creates a new entry if necessary.
5. Afterwards, the packet is translated and sent to the IPv6-Internet.

The following packets of the same session are translated using the table and sent to the other end of the satellite link using the format described in Fig. 3c, e and f.

On the other hand, for the packets generated outside, the protocol is the following:

1. A node on ground (i.e., a CN) sends a packet to a node on-board (MNN). The packet is routed to the HA, which will then forward it to the ground DS router.
2. The ground DS router looks up in its address translation table and, as it does not find anything, it sends a signalling packet to the DSMR with the addresses and ports in IPv6 and asking for the IPv4 corresponding addresses.
3. DSMR assigns IPv4 addresses and ports and creates a new entry in the table after receiving the request.
4. DSMR sends them back to the ground DS router.
5. After receiving the information, the ground DS router creates a new entry in the translation table and translates the header. Note that, unlike in the other direction, this first packet does not contain the IPv6 addresses.
6. The ground DS router sends the packet.
7. The DSMR receives the packet and translates it to IPv6.
8. The DSMR sends the packet to the node inside the A/C.

The following packets of the same session are translated using the table and sent to the other end of the satellite link using the format described in Fig. 3c, e and f.

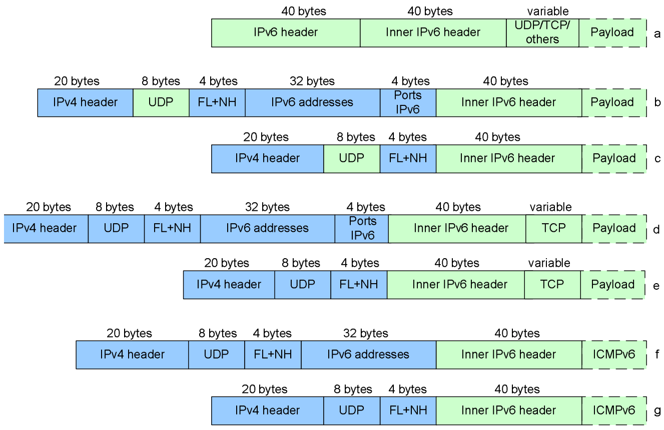


Figure 3. Header structure for IPv6 to IPv4 packet translation in NAPTPT modified. a) Original packet; b) first UDP translated packet; c) following UDP translated packets; d) first TCP translated packet; e) following TCP translated packets; f) ICMPv6 or other protocols first translated packet; g) following ICMPv6 translated packets

## V. THEORETICAL COMPARISON

Table 1 lists the main differences between L2TP and NAPT-PT mod.

TABLE I. MAIN DIFFERENCES BETWEEN SOLUTIONS

| NAPT-PT mod | Tunnel (L2TP) |
|---|---|
| Small overhead | Large overhead |
| Extra processing in user space | Stable implementation |
| New function in user program for every upper layer protocol | Independent of upper layer protocol |
| Needs additional signalling for each session initialized on ground | Signaling only at the beginning of the tunnel setup |

The main advantage of NAPT-PT-modified compared to L2TP is the overhead. For L2TP, the overhead is the same for all the packets of a session and for all the protocols, whereas, as explained before, NAPT-PT modified sends more bytes for the first packet, but less for the next.

This is shown by a simple theoretical calculation of the overhead in Table 2, which shows the bytes added in each case. A mean value has been calculated per session for two different applications: first, a 3 minutes of RTP (Real-time Transport Protocol) packets for VoIP applications (20 ms between each packet makes 9000 packets in each direction, which results with negligible additional header bytes for the first packet), and second, a 1600 KB-file download (about 1900 packets in both directions).

For ICMPv6 is difficult to estimate the number of packets of a session: some are sent only once and some others, like Router Advertisements or Binding Updates (BU), are sent periodically during all the flight. In the calculation it is assumed a mean packet number big enough to consider negligible the additional header bytes for the first packet, like in voice calls.

For the rate Overhead / Payload, the following payload lengths have been taken: ICMPv6 has a mean length of 80 bytes; VoIP applications send 172 bytes of voice using GSM codec; and FTP file transfer uses the Maximum Transmission Unit (MTU), which is 1500 bytes. The overhead also counts IPv6 and transport headers.

The results of this theoretical calculation shown in Table 2 confirm that NAPT-PT mod have less overhead than L2TP.

## VI. TESTS RESULTS

The most important tests results and measured parameters from the test-bed are presented in the following subsections. The aim of the tests is to compare the delay and the throughput performance of the two IPv4/IPv6 solutions over the real satellite link.

All the tests are made using an emulated link with 27 ms of propagation delay and 512 kbps available bandwidth for the terrestrial link, and a BGAN terminal to connect to ground networks through a real satellite link.

A VoIP call and an FTP file transfer session are created on the emulated terrestrial link. Then the link is switched to satellite and switched back to terrestrial before the session ends.

TABLE II. OVERHEAD COMPARISON

| | **Protocol** | **Bytes*** | **Original IPv6 hdr included?** | **Total (bytes)** | **Overhead / Payload** |
|---|---|---|---|---|---|
| **L2TP** | ICMPv6** | 37 | Yes | 77 | 1.46 |
| | TCP | | | | 0.1 |
| | UDP | | | | 0.76 |
| **NAPTPT mod.** | ICMPv6** | 32 | No | 32 | 1.15 |
| | TCP | 32,01 | | 32,01 | 0.06 |
| | UDP | 24 | | 24 | 0.41 |

* Before IPv6 original header

** ICMPv6 and other protocols used for MIPv6

### A. *Delay*

Fig. 4 and 5 show the delay in both directions using L2TP and NAPT-PT in a voice call. This delay has been calculated with each packet sequence number (Seq).

Comparing Fig. 4 and 5 it can be observed that BGAN one-way delay is asymmetric due to different access mechanisms. Notice the difference of the y-axis scales between the two figures.

In both Fig. 4 and 5, it can be observed a lightly higher delay using NAPT-PT mod, due to the processing needed. The variations in delay are due to BGAN characteristics.

For FTP, the delay characteristics are similar in both solutions, so it is only shown for L2TP in Fig. 6. During HO many packets are lost and due to the congestions mechanisms of TCP the observed HO time is bigger than in UDP (see peak in Fig. 6).

### B. *Throughput*

The big difference between L2TP and NAPT-PT can be observed from the resulting data throughput (see Fig. 7). NAPT-PT modified behaves better in this aspect, which is really important when talking about satellites, mainly for the costs, but also for the delay related to the additional bytes.

For FTP applications the difference is also big, though the difference computing the relation Overhead (including all headers) / Payload is less.

## VII. CONCLUSIONS

It is foreseen that future aeronautical networks will use a number of heterogeneous links and base communications on IPv6 protocol. As nowadays there is no widely deployed satellite IPv6 network, it becomes necessary to define a mechanism for traversing the IPv4 network segments found when a communication is established over satellite.

In order to evaluate an assess which is the best solution in terms of overhead, processing complexity and delay for this purpose, a tunneling and a translation methods have been described and implemented in a test bed for NEWSKY.

NAPT-PT mod shows better results in terms of overhead, but L2TP processing delay is slightly faster in both directions. Though the implementation effort in NAPT-PT is much higher than in L2TP, the benefit achieved by NAPT-PT in terms of throughput (thanks to the reduced overhead) makes this option the best candidate for the NEWSKY system.

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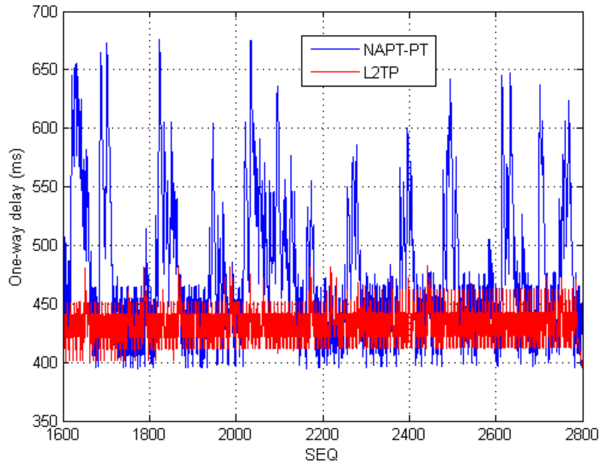


Figure 4. One-way Delay for VoIP RTP packets from CN to MNN

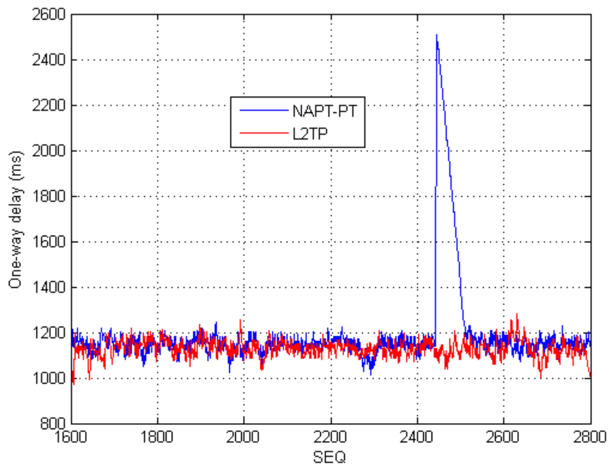


Figure 5. One-way Delay for VoIP RTP packets from MNN to CNN

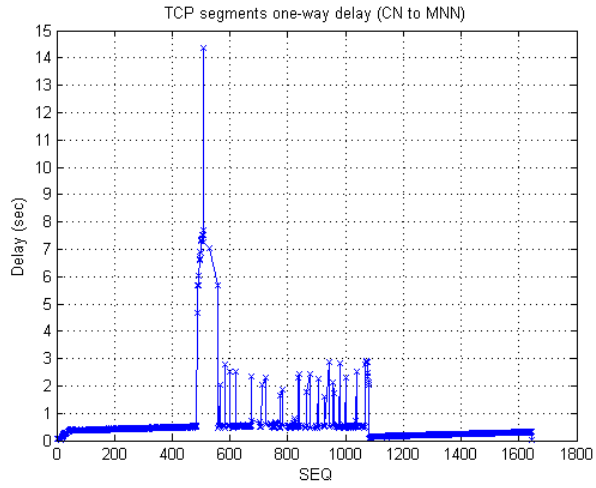


Figure 6. One-way Delay for TCP packets in a FTP file transmission using L2TP

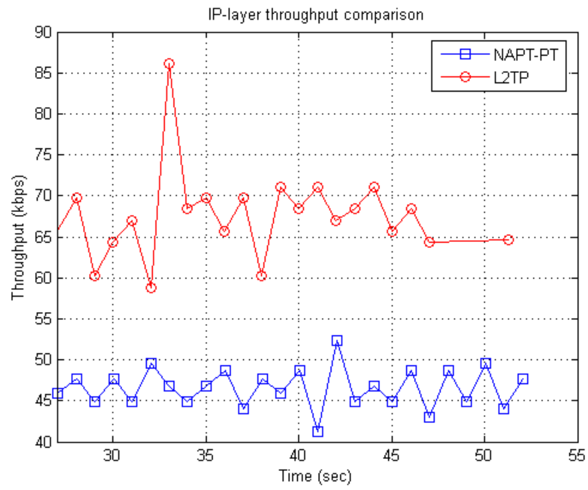


Figure 7. Throughput comparison between both solutions in a voice call