Preparation for IPv6 in Satellite Communications

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Executive Summary

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Authors: Wolfgang Fritsche
Karl Mayer

IABG
Department for Communication Networks
Einsteinstrasse 20
D-85521 Ottobrunn
Germany

Telephone:
National: 089 6088 2897
International: +49 89 6088 2897

Facsimile:
National: 089 6088 2845
International: +49 89 6088 2845

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1 INTRODUCTION

This document is the executive summary report of ESTEC Contract Number 17629/03/NL/ND entitled “Preparation for IPv6 in Satellite Communications”. The objective of the project is to support users, provider and manufacturer in the introduction of IPv6 in satellite networks. Therefore the project identified any IPv6 specific protocol issues with satellite communication and outlined appropriate transition scenarios for the various satellite network architectures. Within two major trials it demonstrated various aspects of IPv6 over satellite and described the lessons learns. Finally it gives a roadmap and recommendations for the next steps required to allow for a smooth integration of IPv6 over satellite.

The project has been performed by a project team of IABG. IABG has many years of experience in the areas of Advanced IP Services like IP over satellite and IPv6. The operation of an own teleport, the participation in many satellite related projects, the active contribution to the IETF standardisation, as well as the membership of the Global IPv6 Forum, the European and German IPv6 Task Force and the IPv6 Cluster are some of the key activities of IABG related to this project.

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2 PROJECT OBJECTIVES

The new Internet Protocol IPv6 has been in the process of standardization within the Internet Engineering Task Force for about 10 years now, and reached a level of maturity, which allows the start of the deployment phase. This deployment is clearly led by the Asian region, due to their severe shortness on global IPv4 addresses, their progressed deployment of the 3rd Generation cellular networks, and their strong commitment to go for IPv6. It will be followed by deployment in the US and in Europe.

As many regions with IPv4 address shortage also have a bad terrestrial network infrastructure, IPv6 over satellite can be an attractive solution for them. However, contrary to the investigation done for terrestrial and 3G cellular networks, the integration of IPv6 in satellite networks has not been analysed in the same detail. Due to their specific characteristics, the frequent use of unidirectional links, or the deployment of proprietary components like Performance Enhancing Proxies, such an analysis is important.

Hence, this project conducted a solid analysis of the link layer, network layer, transport layer and management protocols used in satellite networks, and identify their issues concerning the introduction of IPv6. Knowing these protocol issues it has been possible to assess their impact on various satellite network architectures and to specify appropriate transition scenarios. Finally it has been investigated, in which way IPv6 affects current satellite services or allows for new ones.

Beside the theoretical analysis, a second key objective of the project has been to demonstrate IPv6 over satellite communication in two pilot scenarios, which both used the IPv6-capable DVB-S equipment developed and implemented in two parallel ESA projects.

Finally the project produced a roadmap including recommendations for the future research, development and standardisation activities, as well as for IPv6 over satellite related trials required to support a smooth introduction of IPv6 in satellite networks.

The project embraced six major work packages, namely:

- Identification of satellite specific protocol issues for IPv6,
- Impact of IPv6 on existing and future satellite network architectures and services,
- Definition and Preparation of IPv6 demonstration over satellite,
- Pilot demonstration of IPv6 over satellite,
- Identification of IPv6 roadmap and recommendation, and
- Dissemination of project activities and results.

The work undertaken for the project consisted partly of analysis and research, and partly on practical work related with the pilot demonstration. For the latter part the experience of IABG's Teleport operation as well as the operation of several testbeds for Advanced IP Services provided a valuable input.

3 SATELLITE SPECIFIC PROTOCOL ISSUES FOR IPV6

3.1 Link characteristics

Compared to IPv4, IPv6 modifies the IP header format, e.g. by introducing 128 bit IP addresses, and adds new functionality to the IP layer, such as IPv6 Neighbor Discovery and IPv6 stateless address autoconfiguration.

This new functionality as well as many other protocols used for routing and IP multicast in the Internet expects certain characteristics from the underlying links. Most protocols require bidirectional links, which means that the IP layer sees the same interface for sending and receiving, some of them additionally require link multicast (each node attached to a link can send packets to each other). For example IPv6 Neighbor Discovery mechanisms like address resolution, neighbor unreachability detection, duplicate address detection (DAD), and router and prefix discovery require bidirectional links. Furthermore, DAD even expects full link multicast of the underlying architecture. Furthermore the stateless autoconfiguration is a new feature of IPv6, allowing the configuration of nodes without an additional DHCP server. As it makes use of prefix discovery and DAD, it also requires bidirectional links with full link multicast support.

However, in many satellite networks only unidirectional links are used, such as in hybrid satellite networks with a terrestrial return link or in DVB-S / RCS architectures. In this case appropriate solutions have to be developed and implemented to cope with this issue.

One solution to address this issue is the UDLR mechanism described in IETF RFC 3077. In satellite network architectures with a unidirectional forward and a bidirectional return link, UDLR emulates a single bidirectional interface with link multicast support. In RFC 3077 it is explicitly stated that UDLR is not designed for architectures deploying unidirectional links in opposite directions. Hence, UDLR can be used for example in architectures based on a DVB-S forward link and a return link via Internet or PSTN, but cannot be used for architectures using a DVB-S forward link and a return link via DVB-S, SCPC or DVB-RCS.

For the latter architectures other solutions have to be taken into account. For example two unidirectional, physical interfaces can be integrated in a single bidirectional, logical interface provided to the IP layer. The logical interface concept still cannot help to provide full link multicast in hub and spokes architectures. Therefore, additional functionality has to be implemented in hubs in order to redistribute multicast packets received from spokes to other spokes.

3.2 Satellite specific link layers

DVB-S link layer

DVB-S links are unidirectional links, and hence, in architectures deploying DVB-S links the issues addressed in 3.1 arise. Currently, mainly the Multiprotocol Encapsulation (MPE) mechanism is used to encapsulate IP packets in MPEG-2 TS frames. In principle, MPE can be used for IPv4 and IPv6 but in the standard it is not specified clearly how to signal the receiver the IP version encapsulated.

For this purpose the IETF ipdvb WG specified a new encapsulation protocol, the Ultra Lightweight Encapsulation (ULE). ULE supports natively the encapsulation of IPv4 and IPv6 in MPEG-2 TSs, and consumes compared to MPE less satellite bandwidth. Several prototype implementations already exist for ULE. Currently, neither for MPE nor for ULE a dynamic address resolution between IPv6 address, MAC address, and PID value is specified.

DVB-RCS link layer

On DVB-RCS links either IP over MPE or IP over AAL5/ATM can be used. IPv6 runs smoothly over AAL5/ATM, however, using IP over MPE the IPv6 issues discussed in the previous section are given. As the DVB-RCS standard does not specify the use of Ethernet bridging, this option cannot be deployed for transporting IPv6 traffic over IPv4-only DVB-RCS devices.

Principally a DVB-S/RCS system is well suited for the provision of bidirectional satellite links. However, depending on the implementation of the DVB-S/RCS functionality the IP layer will recognize DVB-S/RCS as a single bidirectional or two unidirectional interfaces. In the latter case UDLR or logical interfaces are measures to cope with this limitation.

Currently the DVB-RCS connection control protocol, which could be used for the management of a DVB-S/RCS network, is only roughly specified. As the messages only contain 6 byte address fields, nodes cannot be addressed by IPv6 addresses.

Serial line protocols used on SCPC satellite links:

Several serial line protocols can be deployed on SCPC links, e.g. Cisco HDLC, PPP, and Frame Relay (FR). All these serial line protocols are prepared for IPv6, and hence, IPv6 can be transported natively over SCPC satellite links.

3.3 Network layer

Header compression:

The introduction of IPv6 in satellite based networks using header compression could only cause problems if an early version as specified in RFC 1144 is used. This version is anyway not the best choice for satellite networks, as the compression of UDP traffic, RTP/UDP traffic and plain IP traffic are not supported. If header compression as specified in RFC 2507 or ROHC (RFC 3095) is deployed in the satellite network, IPv6 can be expected to work.

IPv6 Multicast:

While in IPv4 networks with IGMPv3 a separate protocol is used for group membership management, IPv6 provides this by the Multicast Listener Discovery (MLD) integrated in ICMPv6. Contrary to IGMPv3 the current MLD version 1 does not support source specific IP multicast, however, this limitation will be removed in version 2 of MLD.

Two variants of Protocol Independent Multicast (PIM) are available, PIM-DM (PIM dense mode) and PIM-SM (PIM sparse mode). For PIM-DM an Internet draft is available that is specified for IPv4 and IPv6. RFC 2117 specifying PIM-SM includes many IPv6-related open issues, which are addressed in a revised version. Other multicast protocols like Source Specific Multicast (SSM), DVMRP, MOSPF, BGP-4+, and BGMP support both, IPv4 and IPv6.

In case not all nodes in the satellite networks are multicast capable, multicast relay solutions like the one from OmniCast can be used. These are mostly proprietary and often don’t support IPv6.

IPv6 Multihoming:

Multihoming can allow satellite terminals to associate with different satellite hubs, or with a satellite hub and a terrestrial upstream service provider.

In principal multihoming support already existed for IPv4. However, due to the large availability of globally unique addresses, and more advanced functionality like Mobile IPv6 or HIP multihoming can be done more efficiently with IPv6.

IPv6 mobility support:

The IP mobility area can be divided into host mobility, network mobility and mobile ad hoc networks (MANETs). The currently used protocol to address host mobility is Mobile IP (MIP), and exists for IPv4 (MIPv4) and IPv6 (MIPv6). Contrary to MIPv4, MIPv6 integrates by default already an optimized routing possibility between a mobile host and its communication partner. In order to secure the required control information to establish the optimized routing, a security mechanism called Return Routability (RR) is deployed. For this security mechanism after each movement of the mobile node to a new point of attachment messages have to be exchanged between the mobile host, its communication partner and the home agent. If part of these messages will be sent over satellite links, the handoff delay time of the mobile host will increase.

The IETF nemo WG is currently standardizing a protocol for supporting network mobility, which is basically an extension to MIPv6, but doesn’t make use of optimized routing. Therefore there are no major differences for supporting IPv4 or IPv6 mobile networks in satellite environments.

In MANETs the topology of the network itself is changing, and hence, satellite links do not seem to be good candidates for building MANETs. The MANET routing protocols OLSR and AODV address IPv4 and IPv6.

3.4 Enhanced transport layer protocols

Due to high delay and high loss rate, TCP performs badly on satellite links. Two options exist to work around these issues. The first uses enhanced TCP protocols in end hosts and the second deploys separate gateways, so called Protocol Enhancing Proxies (PEPs) or TCP accelerators, on one side or both sides of the satellite link.

Enhanced TCP: The enhanced TCP protocols TCP Tahoe, TCP Reno, TCP Vegas, TCP NewReno, and TCP Santa Cruz show no difference between operating above IPv4 and IPv6, and can therefore be used for enhancing TCP performance in satellite networks.

PEPs: Some PEP technologies break the end-to-end transparency of the Internet, which could affect IPv6 more severe than IPv4, since IPv6 users expect to get back their end-to-end transparency and deploy services relying on exactly this expectation. Moreover, full IPv6 implementations have mandatory support of IPsec, that is, most probably IPsec will be used more widely with IPv6. However, IPsec works together with PEPs only in certain constellations, and hence, the simultaneous use of IPsec and PEPs could generate more problems in IPv6 networks.

Furthermore PEP devices mostly do not support IPv6, which means they do not implement an IPv6 stack and their management is not IPv6-ready. Hence, TCP traffic based on IPv6 cannot be accelerated.

3.5 Network management and AAA issues

Management Information bases (MIBs) used in satellite networks today are often not IPv6-ready, which means objects cannot contain IPv6 addresses. This includes standardized MIBs like the DVB-RCS MIB as well as proprietary MIBs used by many satellite equipment manufacturers like SkyStream or Harmonic. Furthermore many management applications do not support IPv6 and have to be prepared. This includes the enhancement of input and output fields, the preparation of command line parsers and configuration file parsers, as well as to allow the exchange of IPv6 relevant management information between application and components. SNMP entities like SNMP agents and SNMP managers need to support IPv6. SNMPv1 does not support IPv6, and hence, SNMPv2 or SNMPv3 has to be used in IPv6 satellite networks. All SNMP versions require bidirectional links. The Net-SNMP tool package contains several management applications, SNMP agents, and SNMP managers that support IPv4 and IPv6.

When used in IPv6 networks, all components of an AAA (Authentication, Authorization, and Accounting) framework have to support IPv6, including the protocol entities of nodes, the messages transporting AAA information, and the databases storing IPv6 parameters. The protocols COPS, Diameter, and RADIUS are currently foreseen from the IETF for this purpose and can be regarded as IPv6 compliant.

4 IMPACT OF IPV6 ON SATELLITE NETWORK ARCHITECTURES AND SERVICES

Due to DVB-S encapsulation mechanisms and management functionality without IPv6 support, but often also due to lack of IPv6 capable protocol stacks in general, the majority of the currently available DVB-S and DVB-RCS equipment is not IPv6 ready. Using DVB-S equipment in Ethernet bridging mode is at least an option to conceal IPv6 packets from the devices, however, even this alternative is not possible on the DVB-RCS return link. This lack of IPv6 functionality requires transition methods for introducing IPv6 in satellite networks until IPv6-ready equipment is available.

Three main classes of transition mechanisms are available, the dual stack mechanisms, which deploy IPv4 and IPv6 on a node simultaneously, the tunnelling mechanisms, which encapsulate IPv6 within IPv4, and the translation mechanisms, which provide in specific gateways a translation functionality from one IP version to the other.

4.1 Investigation of various satellite architectures

The project has investigated transition methods for various satellite architectures, such as using SCPC duplex links or deploying DVB-S on the forward link and SCPC, DVB-S, DVB-RCS, the Internet, or the PSTN on the return link. Moreover, the ETSI BSM architecture has been considered concerning IPv6 transition. For all these architectures, trunking scenarios, star architectures and meshed architectures have been taken into account.

For example architectures with SCPC duplex links can be used straightforward to transport IPv6 natively since the serial line protocols used on SCPC links already support IPv6.

When interconnecting IPv6 networks by DVB-S links, an IPv6 over IPv4 tunnel could be configured from the DVB hub station to each branch station. On SCPC and PSTN return links native IPv6 transport is possible. On DVB-RCS and DVB-S return links from the branch stations to the hub station an IPv6 over IPv4 tunnel has to be configured as well. Provided branch station and hub station are connected by an IPv6 Internet, the return link automatically will be native IPv6, otherwise also a tunnel is required. Some tunnelling mechanisms like 6over4 require the underlying support of IPv4 Multicast, which is not always given in satellite networks.

When connecting IPv6 and IPv4 networks via satellite links, translation devices, e.g. NAT-PT boxes or proxies, have to be inserted at the boundary of both networks.

The ETSI BSM architecture supports by definition the transport of IPv4 and IPv6 between its boundaries, however, it does not specify in detail how this support of IPv6 looks like. In case first BSM networks are based on IPv4, transition methods are applied inside the architecture to make the BSM network visible to the outside as IPv4 and IPv6 network.

4.2 Investigation of modified service offerings

IPv6 stateless address autoconfiguration (SAS):

With IPv6 SAS each IPv6 node automatically configures a link-local IPv6 address on each IPv6 interface after startup without the need for a configuration server. Moreover, when IPv6 hosts receive Router Advertisements they get information about default router and prefixes on-link, and hence, they can assign site-local and global addresses to their interfaces. All these features allow a plug and play mechanism of IPv6 nodes (e.g. satellite terminals) without the need for manual configuration.

End-to-end IP addressing:

Due to the huge address space in IPv6 every IPv6 node can be addressed by one or more global IPv6 addresses, and hence, there is no need for deploying NAT devices and Application Level Gateways (ALGs). This brings back the end-to-end transparency to the Internet, which means that IP nodes can be connected end-to-end without intermediate gateways modifying parts of the IP packets. As applications and protocols like IPsec, SIP, and H.323 have difficulties in architectures with broken end-to-end transparency, introducing IPv6 in satellite networks supports a large scale deployment of IPsec and Voice over IP applications.

Mobile IPv6 Route Optimization:

Contrary to MIPv4 MIPv6 already has an optimized routing functionality between the mobile host and the communication partner integrated in the basic protocol. Therefore using MIPv6 the routing to and from mobile nodes will happen in an efficient way and consume less of the costly satellite bandwidth.

Mandatory IPsec:

Full IPv6 implementations have to support IPsec, that is with IPv6 it is more likely that a communication partner will support IPsec. Furthermore due to the removal of NAT boxes in IPv6 networks IPsec be easily deployed in a larger scale. This will make IPsec an attractive candidate to secure information sent over vulnerable wireless links, such as satellite networks.

Cryptographically Generated Addresses (CGAs):

The use of CGAs provides a mechanism to include information about the public key of a sender into its IP address. This is mainly done by hashing the public key and using 64 bits of this hash within the identifier part of the sender’s IPv6 address, that is, the generation of CGAs is only possible for IPv6. By having a combination of IPv6 address and public keying information integrated in the CGA, it can serve as a kind of certificate, proving that a certain public key belongs to a certain IPv6 address. Consequently a public key infrastructure is no longer required. Once the communication partner receives the public key of a sender in a certified way, the sender could authenticate its messages with its private key.

For example satellite terminals communicating with the hub could authenticate their messages using CGAs.

4.3 Detailed transition plans

Transition plan for a DVB-S/SCPC Teleport:

A detailed transition plan for a DVB-S/SCPC scenario a teleport has been examined, which required first to investigate the current status of the network including the IPv6 deficiencies of devices, applications and protocols. Understanding these deficiencies, in a first approach to integrate IPv6 quickly the use of IPv6 over IPv4 tunnels have been proposed on DVB-S links interconnecting IPv6 networks. For the connection of IPv6 and IPv4 networks translation devices at the boundaries of the IPv6 networks are recommended.

For the long term vision of a native IPv6 scenario, devices and applications without IPv6 support need to be upgraded or replaced by IPv6-capable ones. In the example this included upgrading the IOS of Cisco routers, replacing Harmonic DVB equipment by IPv6-capable DVB equipment, and upgrading operating systems and applications of management PCs.

Transition effort and costs are mainly due to the costs of new IPv6 capable DVB-S devices and the costs of the IPv6 training required for the teleport personnel.

Transition plan for a DVB-S/RCS Teleport:

The detailed transition plan for the DVB-S/RCS teleport is similar to the transition plan for the DVB-S/SCPC teleport. Also here in a first step tunnelling and translation are used as short term solution and upgrading or replacing devices and applications is used for a long term solution. In the example the DVB equipment of SkyStream and the Nera Satlink 1900 DVB-S/RCS terminals have to be upgraded or replaced by IPv6-capable ones. Furthermore, an upgrade of the IOS of Cisco routers is needed, and a replacement or upgrade of the HP disk cluster, the Oracle database system, and the operating system of management PCs is required.

Transition effort and costs are mainly due to the costs of new DVB-S and DVB-RCS devices and the costs for IPv6 training of the network personnel.

5 IPV6 DEMONSTRATION OVER SATELLITE

5.1 Demonstration scenario 1: IABG

The first pilot demonstration of IPv6 over satellite deployment has been established and performed at IABG's Teleport.

The architecture outlined in Figure 5-1 includes a DVB-S based forward link and a terrestrial return link. The DVB-S forward satellite link is realized by an IPv6-capable ULE enabled 6WIND DVB gateway (6W) at the hub station and PCs at the branch stations (RX-PC1 and RX-PC2), which are equipped with Pent@Value DVB receiver cards supporting ULE. For the return links simply Ethernet links have been used.

This demonstration especially has been selected to illustrate proper functionality of advanced IPv6 features and applications over an DVB-S architecture, such as the usage of IPsec to encrypt one satellite link between Hub station and Branch station 1, or Mobile IPv6 to enable a mobile node (MN) to roam between a WLAN at Branch station 1 and a WLAN at Branch station 2. As applications audio and video conferencing sessions between a correspondent node (CN) at the Hub station and the MN have been demonstrated.

Prior to performing advanced demonstrations the performance of the IPv6 over DVB-S link is evaluated. Latency measurement between Hub station and Branch station 1 resulted in an average latency of about 380ms. Measuring packet interarrival time (PIT) at Branch station 1 resulted in 92% of packets with a PIT of 1ms, 5% with a PIT of 55ms, and the rest with a PIT arbitrarily distributed between 1ms and 100ms. These results are mainly related to the buffer management and the MPEG-2 TS packing functionality of the DVB-S devices. TCP throughput measurement between hub station and Branch station 1 resulted in an average throughput rate of about 1.35Mbps. The limiting factor was the bandwidth delay product due to a default TCP window size of 64kByte.

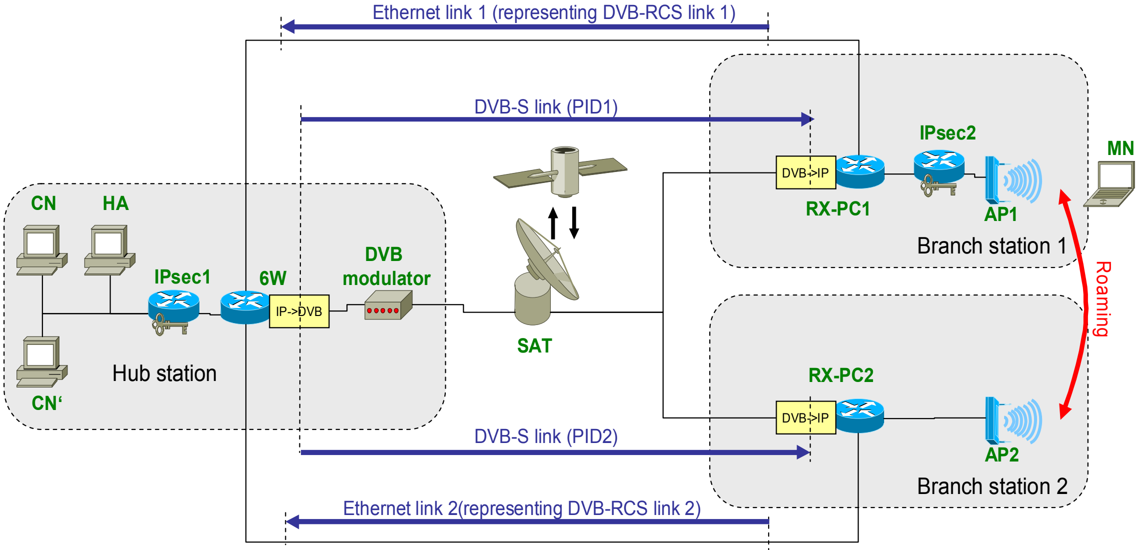

Figure 5-1: Demonstration setup at IABG Teleport

Performing advanced demonstrations showed that IPsec, Mobile IPv6, and audio and video conferencing operated smoothly together in an architecture with IPv6 over DVB-S links. However, using the MIPv6 route optimization functionality over satellite links caused handoff delays in the order of 5s.

5.2 Demonstration scenario 2: SILK

Within the second IPv6 over satellite pilot demonstration IPv6 has been integrated into the SILK network.

The SILK project has been founded in order to allow an Internet based communication of academic and educational institutions residing in the Central Asian and Caucasian region with the rest of the world. For this purpose the national research networks (NRENs) in the 8 SILK countries Armenia, Azerbaijan, Georgia, Kazakhstan, Kyrgyz Republic, Tajikistan, Turkmenistan, and Uzbekistan, have been connected via satellite to the European research network GEANT. Technically the SILK satellite network architecture represents a DVB-S/SCPC hub and spoke architecture, with a hub located at the Deutsches Elektronen-Synchrotron (DESY) institute in Hamburg.

The SILK user community has a high interest in getting also IPv6 connectivity to GEANT. In order to send IPv6 over satellite natively via the existing SILK architecture, a separate DVB-S carrier transporting IPv6 traffic has been set up and the hub station has been enhanced by an ULE enabled, IPv6 capable Open DVB-S gateway (ODG) from GCS. Each remote station has been enhanced with an additional Linux PC equipped with an ULE enabled, IPv6 capable DVB-S receiver card from Pent@Value.

As this pilot demonstration has been set up for several months, and a large community of real users participated in the trial, the SILK demonstration has the character of a pre-commercial deployment of native IPv6 over satellite.

6 DISSEMINATION OF PROJECT ACTIVITIES AND RESULTS

In order to push IPv6 deployment in satellite networks, it is important to increase the awareness on this subject. Involving the critical mass and the key player is a requirement to help increasing and disseminating experience in this area, to rise funding for performing the outstanding tasks, to get equipment manufacturer integrating required and helpful IPv6 functionality, and to initiate user to ask for the advantageous IPv6 services over satellite networks. Hence, the various dissemination activities performed during the project covers the whole area of IPv6 and satellite communication. To name a few of them, dissemination has been done within fora and task forces, such as the Global IPv6 Forum and the European IPv6 Task Force, within conferences, such as the 6NET Spring Workshop 2004, the German IPv6 Summit 2004 or the Asia-Pacific Advanced Network Conference 2004, within other projects, such as 6NET, SEINIT, SATIP6 or SILK, or within standardisation bodies, such as the IETF ipdvb WG.

7 KEY RESULTS AND RECOMMENDATIONS

In summary one can say that many protocols used in satellite networks are already prepared for IPv6, however some key deficiencies are the lack of IPv6 support in DVB-S devices using MPE, the lack of IPv6 support in management functionalities, the lack of IPv6 support in PEPs, as well as the lack of IPv6 neighbour discovery on unidirectional satellite links and links without support of link multicast. While some of these deficiencies can be solved on short term by appropriate transition mechanisms, others need new functionality to be specified and implemented.

In the following the main recommendations for the next steps in the various areas required for a smooth integration of IPv6 in satellite networks are listed.

7.1 Protocol level viewpoint

- The MPE standard has to be prepared to support IPv4 and IPv6, which requires e.g. a specification of how a DVB receiver distinguishes between both IP versions.
- Satellite specific MIB definitions, management applications, and SNMP entities have to be enhanced to support IPv6. Moreover, SNMPv2 or SNMPv3 have to be used in networks since SNMPv1 is not IPv6 ready.
- DVB equipment manufacturers have to enhance their products with IPv6-ready MPE or/and ULE functionality, with IPv6-ready network management, an IPv6 stack, and IPv6-capable interfaces.
- Protocol Enhancing Proxies (PEP) have to be enhanced for IPv6 support, which includes the implementation of an IPv6 stack, IPv6 capable management applications and MIBs, and IPv6-ready proprietary protocols used over the satellite link. Furthermore the use of PEP could be more problematic in IPv6 networks as one can expect a broader deployment of IPsec.
- Using MIPv6 with satellite networks could increase the handoff times of mobile nodes.

7.2 Address resolution and configuration

- In current satellite networks, address resolution is configured statically by the satellite network administrator at the DVB-S sender side for resolution between IP addresses and link layer identifiers and PID values. This functionality also has to be provided for IPv6.

- Furthermore tables are used in order to dynamically advertise the mapping of IPv4 addresses to link layer addresses and PIDs. This table based mechanisms also needs to be implemented for IPv6.
- Finally it has to be investigated, in which satellite network architectures IPv6 stateless address autoconfiguration could be integrated.

7.3 System and architectural viewpoint

- In order to be able to support more broadly advanced IPv6 features such as the stateless address autoconfiguration, more detailed investigations about the applicability and usability of UDLR or the logical interface concept for the various satellite architectures need to be done.
- In this context it may be helpful to allow the use of UDLR in some architecture also for unidirectional return links.

7.4 Recommendable standardisation, dissemination and deployment activities

- Dissemination activities on IPv6 over satellite need to continue in order to raise the awareness of users, provider and manufacturer on this subject, train them on the various aspects of IPv6, and collect their requirements.
- The standardisation on IPv6 over satellite needs to continue. For example the IETF ipdvb WG needs to investigate address resolution mechanisms, ETSI needs to investigate in more detail the integration of IPv6 in ETSI BSM as well as to specify the IPv6 support in MPE.
- New IPv6 functionality, such as IPv6 capable PEPs, DVB-S/RCS, or management systems need to be prototyped and tested.
- Beyond deployment of IPv6 over satellite in the research community, real users have to test IPv6 over satellite in pre-commercial environment.