Standardisation Support of enhanced IETF IP Encapsulation Techniques

EUROPEAN SPACE AGENCY

CONTRACT REPORT

Contract Number 17477/03/NL/ND

The work described in this report was done under ESA contract. Responsibility for the contents resides in the authors or organisations that prepared it.

Final Report

This investigation has been carried out under a contract awarded by the European Space Agency (ESA), contract number 17477/03/NL/ND. The ESA study manager is Frank Zeppenfeldt.

Authors: Gerhard Geßler
Wolfgang Fritsche
Karl Mayer

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

Telephone:
International: +49 89 6088 2021

Facsimile:
International: +49 89 6088 2845

Alain Ritoux

6WIND
Central Gare, Bat C
1, place Charles de Gaulle
78180 Montigny-le-Bretonneux
France

Telephone:
International: +33 1 3930 9232

Facsimile:
International: +33 1 3930 9211

Issue 1

15.04.2004

Document History

Date	Author	Version	Description
15.04.2004	Gerhard Gessler, Wolfgang Fritsche, Karl Mayer, IABG Alain Ritoux, 6WIND	v1.0	Initial Document

TABLE OF CONTENT

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

AFC	Adaptation Field Control
AH	Authentication Header
AIT	Application Information Table
ARP	Address Resolution Protocol
BARS	BSMS Address Resolution Server
BoF	Birds of a Feather
BRS	BSMS Route Server
BSM	Broadband Satellite Multimedia
BSMS	Broadband Satellite Multimedia System
CIF	Common Interleaved Frame
CLI	Command Line Interface
CRC	Cyclic Redundancy Check
DAB	Digital Audio Broadcast
DECT	Digital Enhanced Cordless Telecommunications
DHCP	Dynamic Host Configuration Protocol
DiffServ	Differentiated Services
DVB	Digital Video Broadcasting
DVB-RCS	Digital Video Broadcasting – Return Channel over Satellite
ESP	Encapsulating Secure Header
ETSI	European Telecommunications Standards Institute
EUA	End User Address
FIB	Fast Information Blocks
FIC	Fast Information Channel
FIDC	Fast Information Data Channel
GSM	Global System for Mobile Communication
IABG	Industrieanlagen Betriebsgesellschaft
IANA	Internet Assigned Numbers Authority
IC	Interaction Channel
IETF	Internet Engineering Task Force
IGMP	Internet Group Management Protocol
IKE	Internet Key Exchange
INSC	Interoperable Networks for Secure Communications
INT	IP/MAC Notification Table

IP	Internet Protocol
IPCP	IP Control Protocol
Ipdvb WG	IP over DVB Working Group
IPsec	IP Security
IPv4	Internet Protocol version 4
IPv6	Internet Protocol version 6
IRD	Integrated Receiver Decoder
ISDN	Integrated Services Digital Network
ISO	International Standards Organisation
ISP	Internet Service Provider
LAN	Local Area Network
LCP	Link Control Protocol
LLC	Logical Link Control
MAC	Medium Access Control
MCI	Multiplex Configuration Information
MHP	Multimedia Home Platform
MLD	Multicast Listener Discovery
MMT	Multicast Mapping Table
MOT	Multimedia Object Transfer Protocol
MPE	Multi-Protocol Encapsulation
MPEG	Moving Pictures Experts Group
MPLS	Multiprotocol Label Switching
MSC	Main Service Channel
MTU	Maximum Transmit Unit
NATO	North Atlantic Treaty Organisation
NCU	Network Control Unit
ND	Neighbor Discovery
PAD	Programme Associated Data
PCR	Program Clock Reference
PDU	Protocol Data Unit
PEP	Protocol Enhancing Proxy (TCP Accelerator)
PES	Packetized Elementary Stream
PID	Packet IDentifier or Program IDentifier
PMT	Program Map Table
PPP	Point-to-Point Protocol
PSI	Program Specific Information

PSSC	Personal Service Session Control Protocol
PSTN	Public Switched Telephone Network
PUSI	Payload Unit Start Indicator
PVC	Permanent Virtual Circuit
QoS	Quality of Service
RFC	Request for Comments
ROHC	RObust Header Compression
RTP	Real-time Transport Protocol
RTT	Real Time Traffic
SC	Service Component
SCPC	Single Channel Per Carrier
SE	Simple Encapsulation
SI	Service Information
SI-SAP	Satellite Independent – Service Access Point
SNDU	Subnetwork Data Unit
ST	Satellite Terminal
TCP	Transmission Control Protocol
TS	Transport Stream
UDP	Unicast Datagram Protocol
ULE	Ultra Lightweight Encapsulation
UT	User Terminal
WAN	Wide Area Network
X-PAD	Extended Programme Associated Data

1 INTRODUCTION

Standards for digital television (DVB) have been extended from their initial definition to also support data communications. The well known Multi Protocol Encapsulation (MPE) method provides today a standardized way to transport Internet Protocol (IP) traffic over satellite links using DVB-S. Such satellite links are more and more used to deliver broad access to today's Internet which is currently based on IPv4 and will in the future incorporate more and more IPv6.

Due to MPE's wide deployment in combination with available and affordable equipment, MPE will be also used in the next time, although there are some limitations related to lack of support of emerging protocols as well as to its limited bandwidth efficiency.

The current MPE standard for IP over DVB encapsulation is not optimized for many emerging protocols such as IPv6, or even for already deployed protocols such as ROHC (Robust Header Compression) or MPLS (Multi Protocol Label Switching). The research community and the Internet Engineering Task Force (IETF) have addressed these issues in a number of personal Internet-Drafts, which proposed improved encapsulation methods like the Simple Encapsulation (SE) or the Ultra Lightweight Encapsulation (ULE). In addition personal Internet-Drafts outlined the requirements relevant for future IP over DVB-S architectures, such as sufficient Quality of Service (QoS) provision, IP address resolution, service discovery, or IP Multicast functionality.

A main objective of this study was to develop a prototype implementation of one of the proposed improved encapsulation methods and to verify the correct functionality of the implementation in interoperability tests and advanced demonstrations. For the interoperability tests, combined efforts have been made with another consortium (Joanneum Research (A), in partnership with GCS (A), University of Salzburg (A), EMS (CAN), and University of Aberdeen (UK)), which was also awarded a contract based on ITT AO/1-4372/03/NL/GS. Both consortia decided in coordination with ESA to implement the personal Internet-Draft draft-fair-ipdvb-ule-02.txt.

Furthermore, this project has contributed to the standardization process within the IETF, i.e. aided to the foundation of the IETF ipdvb working group and participated in its discussions. This working group addresses the development of new protocols allowing a more efficient transport of IP over MPEG-2 networks and therefore a better integration of IP in satellite networks.

In order to create a sufficient level of awareness, the project activities and results have been disseminated to a broad range of fora, task forces, projects, manufacturers, exhibitions, and ISPs.

The project embraced five major work packages, namely:

- Inventory of IP-over-DVB related activities and developments
- Study and prototype implementation of emerging IP-over-DVB encapsulation methods
- Interoperability testing of IP/DVB gateway and IRD unit equipment
- Demonstrations of advanced networking
- Conclusions and Recommendations for further developments

This document describes the work done during the study and also the achieved results. It includes references to external documents which have not been included in this document as they have been prepared as standalone documents. These documents are

“Interoperability test report - v1.4.doc” and “Advanced Networking Demonstration - v1.1.doc” which are available at the eProject site of this study.

During the course of the study, the content and goal of Deliverable 2.3 was modified in coordination with ESA. The initial aim was to collect a representative capture of real Internet traffic for replaying during the interoperability tests. While preparing the interoperability tests, this approach raised some technical issues.

First, capturing of bulk Internet traffic has application issues. Real Internet traffic is a mixture of several very different applications which can not be predicted. The used applications can range from TCP based web serving, file downloading, and file sharing, UDP based VoIP or other streaming services, up to proprietary application protocols over IP/TCP/UDP. Replaying such an Internet traffic capture does not testify that the applications creating this traffic are working over the implemented encapsulation, as they are not available during the interoperability tests. Furthermore, without doing a thorough analysis of the capture of Internet traffic, one can not check the type of the applications used in this capture and therefore can not even make an assumption about the characteristic of the traffic.

Second, commercial IPv6 Internet is not yet really available. The current 6BONE and first small ISPs offering IPv6 service must still be considered as more research oriented activity than real usage. This means that a capture of real world IPv6 traffic is hard to acquire, even for ISPs offering IPv6 services.

Taking all the above discussed points into account, ESA, IABG and 6WIND decided to not use captured Internet traffic but to utilize available traffic generators (e.g. MGEN) to create realistic and reproducible traffic patterns for IPv4 and IPv6 (e.g. VoIP, video streaming) to simulate parts of the traffic currently flowing through the Internet.

This study has been performed by IABG (G) and 6WIND (F). IABG has many years of experience in the areas of IP technologies (IPv4 / IPv6), network protocols and satellite systems. The participation in the IETF standardisation, the implementation of IPv6 networks and services, and the operation of an own Teleport are only some of IABG's key activities. 6WIND has many years of experience in the areas of router manufacturing and software development for IP technologies (IPv4 / IPv6) and network protocols. The implementation of advanced IPv6 and IPv4 functionalities and services within their flagship 6WINDGate is one of 6WIND’s key activities. Furthermore, 6WIND actively participates in the IETF standardisation process.

The work undertaken for the study consisted of analysis, research, implementation, demonstration and dissemination activities. 6WIND’s manufacturer experience, IABG’s Teleport operation experience and the long-standing experience with IPv6 of both companies provided valuable input for this work.

2 INVENTORY OF IP-OVER-DVB RELATED ACTIVITIES AND DEVELOPMENTS

The intention of this chapter is to give a description of several ongoing activities and developments which are related to the transmission of IP data over satellite networks. The list of groups and areas to be investigated was selected during the unofficial Technical Kick-off Meeting held on 11th August 2003 at IABG in Ottobrunn.

A detailed description will be given for the current work at IETF in the IP-over-DVB working group. For the transmission of IP data over MPEG / DVB-S the current versions of public available documents were examined and are summarized. In the chapter of ETSI SES BSM the ongoing activities based on public available documentation are described. An overview over the handling of IP data in ATSC and DAB is given in the end of this chapter.

As agreed, no special attention is given to e.g. DVB-RCS or DVB IP Datacasting as either no recent public documents are available or the targeted forums are closed groups.

Finally, a short summary is given for possible effects of the standardization of ULE in IETF on the investigated activities, i.e. ETSI SES BSM, DAB, and ATSC.

2.1 IETF

Within the IETF standardization all IP over DVB activities take place in a new WG to be founded, called the IP over DVB (ipdvb) WG. Currently ipdvb is no official WG. It met for a first Bird of a Feather (BoF) session during the 57th IETF meeting held in July 2003 in Vienna, and has requested a slot during the 58th IETF meeting scheduled for November 2003 in Minneapolis. The WG is currently proposed to the IESG and awaits their decision.

Ipdvb so far produced four Internet Drafts,

- a draft summarizing the requirements for transmission of IP datagrams over MPEG-2 networks [7],
- a draft specifying a simple encapsulation mechanism for IP over MPEG-2 [8],
- a draft specifying an ultra lightweight encapsulation mechanism for IP over MPEG-2 [9], and
- a draft outlining first ideas concerning address resolution for IP datagrams over MPEG-2 networks [10].

These four Internet Drafts represent the current IP over DVB activities inside the IETF, and will be discussed in the following.

2.1.1 Encapsulation technique

There are currently two mechanisms proposed for encapsulating IP packets in MPEG-2 transport stream packets, namely Simple Encapsulation (SE) and Ultra Lightweight Encapsulation (ULE).

2.1.1.1 Simple Encapsulation (SE)

Basically the simple encapsulation mechanism specified in [8] generates from any Protocol Data Unit (PDU), such as for example from an IP packet, a Subnetwork Data Unit (SNDU) by adding a SNDU header to the PDU. The resulting SNDU will then be sent inside the payload part of a MPEG-2 transport stream packet. Figure 2-1 illustrates this composition of a SNDU.

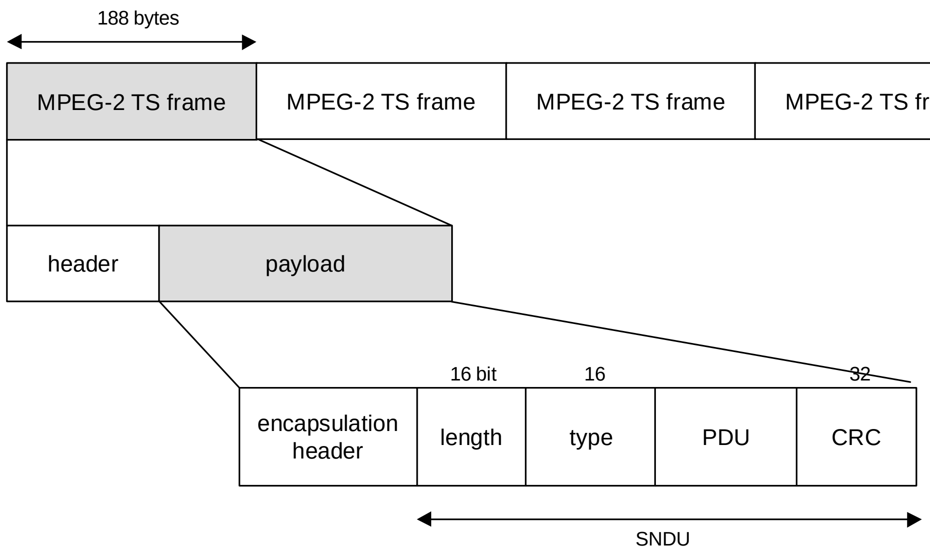

Figure 2-1: Simple encapsulation of SNDUs in transport stream packets

The SNDU itself comprises

- a 16 bit length field, specifying the length of the SNDU in bytes starting after the type field and including the CRC field,
- a 16 bit type field, specifying the type of PDU being encapsulated inside the SNDU,
- the PDU itself, and
- a 32 bit checksum field.

Depending on the way the SNDU is transmitted inside MEPEG-2 transport streams, such as inside private sections or Packetized Elementary Streams (PES), an appropriate encapsulation header is added to the SNDU before being inserted into the payload field.

Currently the SE foresees six different types of PDUs for encapsulation,

- IPv4 packet (type 0x0800),
- IPv6 packet (type 0x86DD),
- MPLS packet (type 0x8847),
- IPv4 packet with Robust Header Compression (ROHC) (type still to be assigned),
- IPv6 packet with ROHC (type still to be assigned), and
- bridged Ethernet packet (type 0x6558).

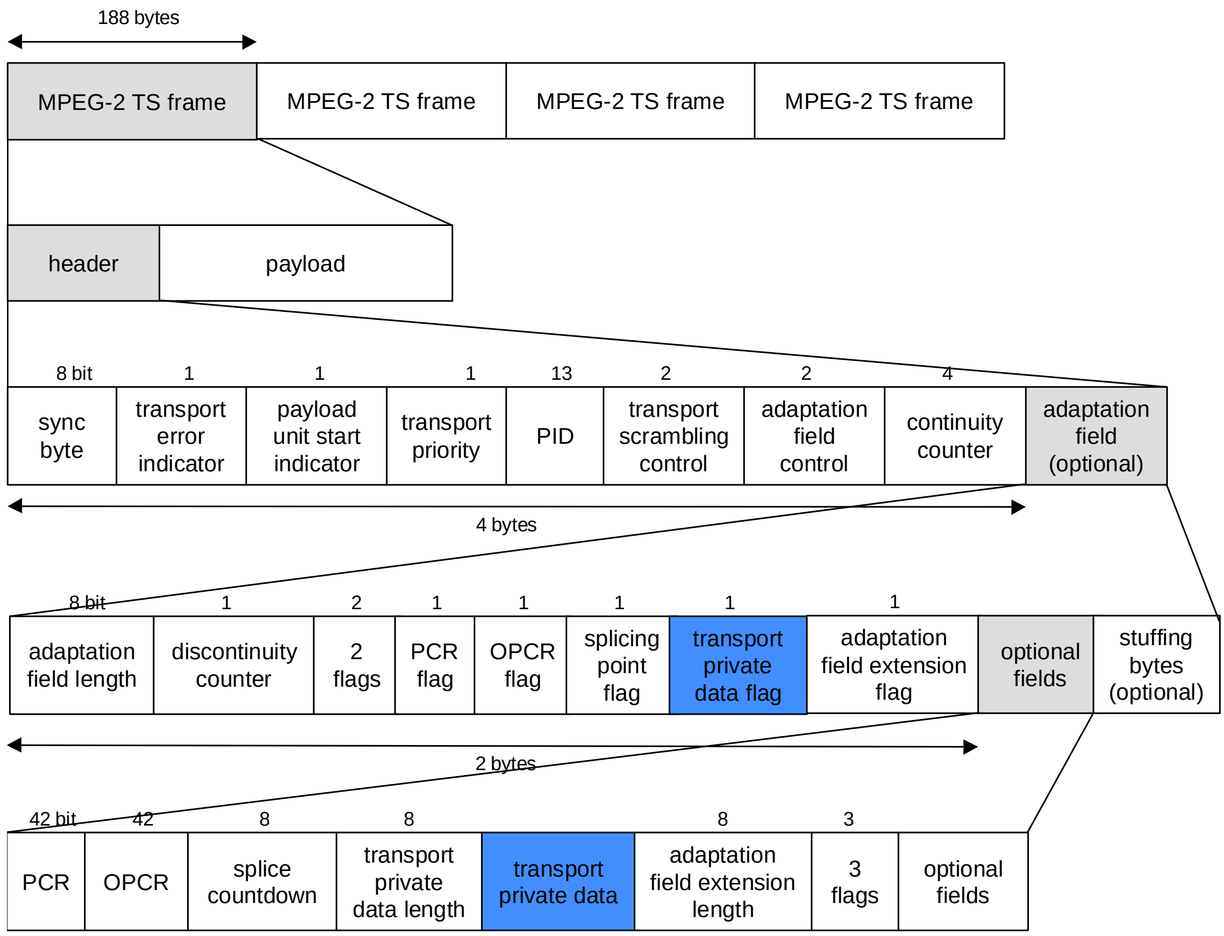

Figure 2-2: Transport stream packet with Adaptation Field present

In the easy case a SNDU would fit exactly in the payload part of a MPEG-2 transport stream packet, however, this will seldom be the case and therefore is not realistic. To still make use of the payload part in an efficient way, and therefore don't waste bandwidth on the MPEG-2 layer, it is necessary to have a flexible scheme, which allows a start and end of a SNDU at nearly every location inside the payload part of a MPEG-2 transport stream packet. This again requires a mechanism allowing a receiver to detect the start of a SNDU inside the payload part. In case the receiver is well synchronized this detection is straightforward, that is by knowing the length of a single SNDU the receiver can easily figure out where a possible succeeding SNDU will start. But this doesn't work in cases like an initial start of the receiver, a loss of synchronization, a lost SNDU due to e.g. a bad checksum value, or a not continuously filled payload part.

To cope also with these kinds of scenarios, SE makes use of the Payload Unit Start Indicator (PUSI) placed inside the MPEG-2 transport stream header together with a pointer field carried inside the transport private data of the MPEG-2 transport stream adaptation field. Figure 2-2 generally illustrates the composition of a MPEG-2 transport stream header with an appended adaptation field, which is specified in detail in [11].

The first relevant part here is the PUSI flag contained in the MPEG-2 transport stream header. SE specifies that this flag has to be set to

- 0, in case a MPEG-2 transport stream packet does not contain the start of a SNDU, and to
- 1, in case a MPEG-2 transport stream packet does contain the start of a SNDU.

The second relevant part here is the adaptation field for carrying the pointer to the start of a SNDU. Here first the adaptation control field as part of the MPEG-2 transport stream header specifies if an adaptation field is present. SE here only allows the following values for the adaptation control field (ACF):

- 01, meaning only SNDU data, but no adaptation field is present, and
- 11, meaning both, SNDU data and adaptation field are present.

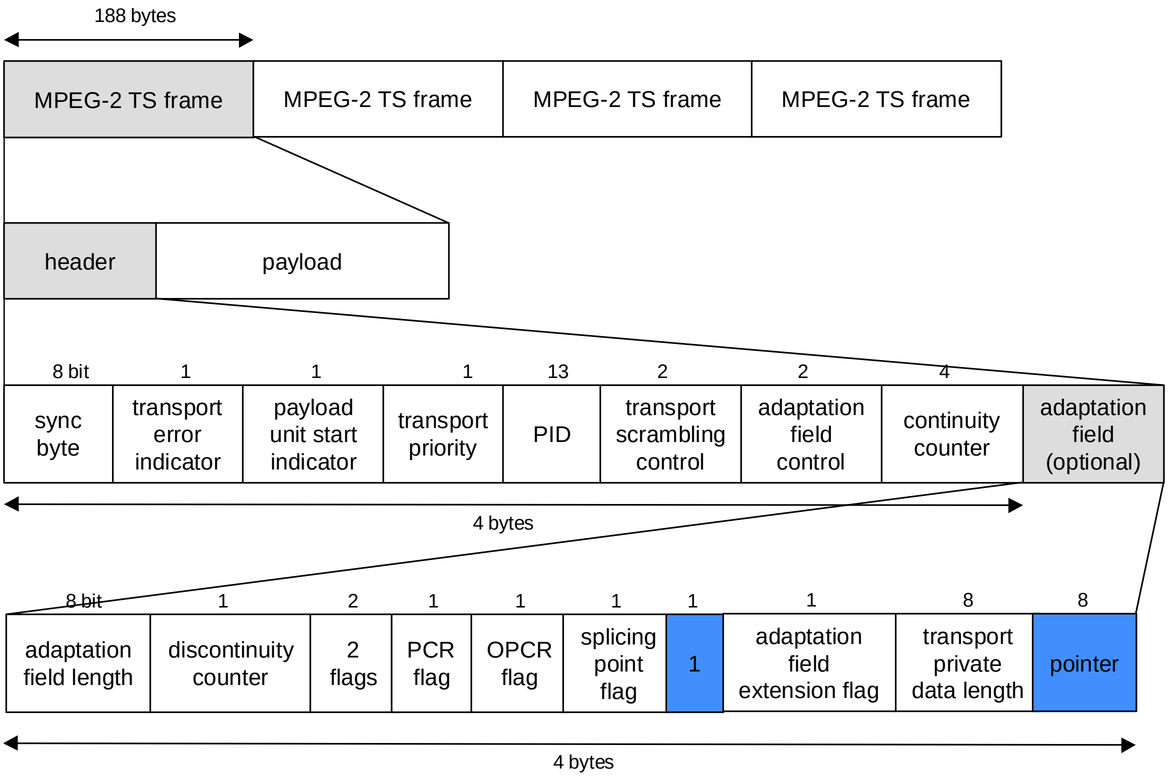

Figure 2-3: Transport stream packet as used within the simple encapsulation

In case the adaptation field is present, there is the possibility to set the "transport private data flag", indicating thereby that a "transport private data" field will follow as part of the adaptation header. SE makes exactly use of this "transport private data" field to carry a one byte long pointer, which is able to point to the starting location of a new SNDU inside the payload part of a MPEG-2 transport stream packet. Figure 2-3 highlights in blue the way SE includes an adaptation field, which in turn contains a one byte long pointer. It also illustrates, that the solution of making use of the adaptation field for carrying a pointer will add another 4 bytes of overhead to the already existing generic 4 bytes overhead caused by the header of the MPEG-2 transport stream packet.

Based on the means of the PUSI flag and the pointer SE defines now the following possibilities as shown in

PUSI	AFC	Meaning
1	01	The PUSI indicates the start of a new SNDU, but there is no adaptation field present and consequently no pointer to the start of the SNDU - this setting can be used if the SNDU starts directly at the first byte of the payload part of the MPEG-2 transport stream.
0	01	The PUSI indicates that no new SNDU is started, and there is also no pointer present - this setting can be used if the complete payload part of the MPEG-2 transport stream is filled by the continuation of a SNDU started in a previous MPEG-2 transport stream packet.
0	11	The PUSI indicates that no new SNDU is started, but there is a pointer present - this setting can be used to signal the end of a SNDU, that is the pointer points to the first byte after the completed SNDU.
1	11	The PUSI indicates the start of a new SNDU, and a pointer is present - in this case the pointer points to the first byte of the new SNDU.

It finally should be noted, that all MPEG-2 transport stream packets containing parts of the same SNDU will set an identical value for the Packet Identifier (PID) contained in the generic header of the MPEG-2 transport stream packets.

2.1.1.2 Ultra Lightweight Encapsulation (ULE)

Also the Ultra Lightweight Encapsulation (ULE) specified in [9] generates from any Protocol Data Unit (PDU), such as for example from an IP packet, a Subnetwork Data Unit (SNDU) by adding a SNDU header to the PDU. The resulting SNDU will then be sent also inside the payload part of a MPEG-2 transport stream packet. Figure 2-1 illustrates this composition of a SNDU for ULE.

However, there are some differences to be outlined if compared with SE. The first one is that ULE limits the possibilities to carry the SNDU inside the payload part of a MPEG-2 transport stream packet to the use of private streams, that is the SNDU will be directly inserted into the payload part without encapsulating it into an additional header required e.g. if the SNDU would be sent inside a private section. Also ULE supports a different set of SNDU types:

- test SNDU packet (type 0x000 proposed, to be confirmed by IANA),
- bridged Ethernet packet (type 0x0001 proposed, to be confirmed by IANA),
- LLC header follows in SNDU (type 0x0002 proposed, to be confirmed by IANA),
- IPv4 packet (type 0x0800), and
- IPv6 packet (type 0x86DD).

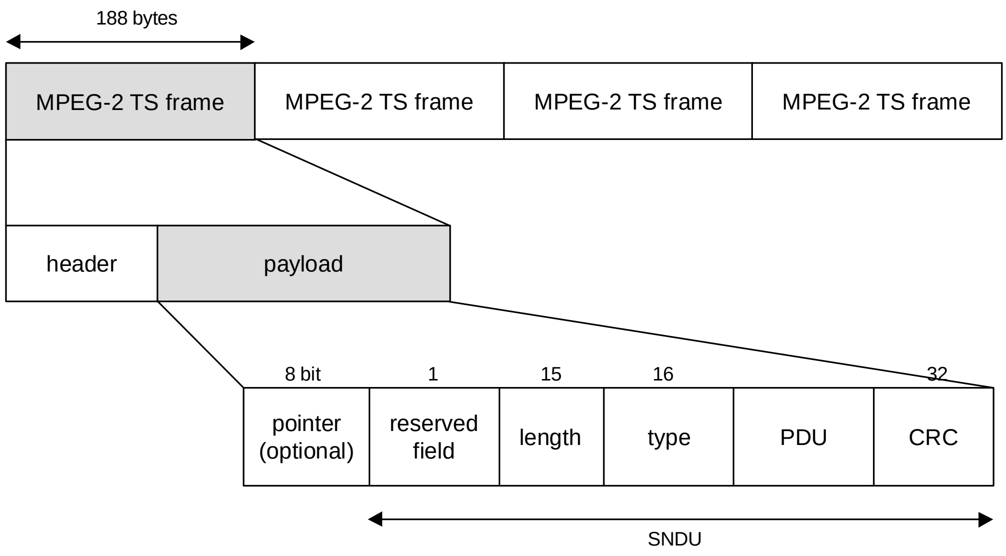

Figure 2-4: Ultra lightweight encapsulation of SNDUs in transport stream packets

Furthermore ULE assigns a special meaning to the most significant bit of the length field, named as reserved field in Figure 2-4. This bit will be set to 0 for all transmitted SNDUs. However, it will be set to one if a so called end indicator is transmitted inside the SNDU. ULE introduced this end indicator in order to signal that the current MPEG-2 transport stream packet does not contain any further SNDU data. This is achieved by setting the first two bytes, which is the reserved field together with the length field, to 0xFFFF. This value will be interpreted by the receiver as stuffing and therefore triggers to skip the remaining payload.

Of course also ULE has to provide a mean for the detection of the start of a SNDU in case of lost synchronization. For this purpose on the one hand side it makes use of the PUSI flag in the same way like SE. But contrary to SE it doesn't use at all the adaptation field, that is ULE always sets the adaptation field control to 01, indicating that there is no adaptation field present. In the absence of the adaptation field ULE defined an optional pointer to be inserted immediately after the generic header of a MPEG-2 transport stream packet. If a new SNDU starts inside the payload part, the PUSI flag will be set to 1, and the optional pointer will be inserted, pointing towards the start location of the new SNDU inside the payload part of the MPEG-2 transport stream packet. If no new SNDU starts inside the payload, the PUSI flag will be set to 0, and no pointer will be inserted.

2.1.1.3 Comparison of SE and ULE

Along with the work done for SE and ULE the requirements concerning an encapsulation mechanism for IP packets in MPEG-2 transport streams have been already investigated in detail along with the proposal of two alternative solutions. Even if parts of these solutions are quite similar, like the format of the SNDUs, there are still many differences between them. Some of the major ones are:

- While ULE clearly states to be limited to private streams, SE claims to support the encapsulation of SNDUs within private streams and private sections. However, SE does not address how e.g. an encapsulation of a SNDU within a private section will be done.

- Contrary to ULE SE still supports MPLS and ROHC. Instead ULE supports a test packet and an explicit end indicator.
- While ULE doesn't use at all the adaptation field, SE supports this. This will allow SE to make use of the full functionality of the adaptation field, such as time synchronization based on Program Reference Clock (PCR).
- While SE includes the required pointer inside the transport private data field of the adaptation field, ULE inserts a separate pointer straight after the generic header of MPEG-2 transport streams. The result is that SE requires 4 bytes to carry pointer information of one byte compared to one byte required for ULE. On the other hand SE will sustain the 4 byte alignment this way.
- The ULE Internet Draft is written in a more precise way, leaves less room for interpretation, and will therefore easier allow interoperable implementations. To pick just few examples, ULE describes the algorithm for calculating the checksum, addresses the handling of the pointer at the receiver side, and specifies the encapsulation into the last bits.

2.1.2 Address resolution mechanisms

Transmitting IP packets over MPEG-2 networks will require appropriate address resolution mechanisms. For example the derivation of the PID to be used on the MPEG layer from the destination address of the encapsulated IP packet has to be specified. In today's deployed MPE scenarios and IP destination address to PID mapping is often configured statically, which of course restricts flexibility and scalability. Also in case of sending bridged Ethernet packets inside MPEG-2 transport stream packets on needs to find out the destination Ethernet address of the receiving system.

[10] discusses briefly these requirements and highlights some possibilities to address them.

One option would be the use of a static configuration. This would mean that the mapping of IP addresses to PID values has to be agreed outside the means of MPEG-2, that is using some kind of outband signaling.

Another solution could be to use already existing MPEG-2 mechanisms for address resolution purposes. Such a mechanism could be for example using table-based information of MPEG-2 for carrying additional address information. Possible approaches would here be using the IP/MAC Notification Table (INT), using the Application Information Table (AIT) of the Multimedia Home Platform (MHP), or the Multicast Mapping Table (MMT).

Finally a real IP address resolution protocol, like the Address Resolution Protocol (ARP) or the Neighbor Discovery (ND) Protocol could be adapted to MPEG-2 network. Even if this would greatly alleviate address resolution by becoming MPEG-2 table and hardware independent, it still implies a lot of complexity, as these types of protocols usually run over bi-directional links, what most satellite systems, including DVB-S/RCS, do not provide.

Even if the subtle field of address resolution has been touched by the ipdvb WG, it is not more than a generic discussion of the problem scope, and still needs huge investigation to come closer to any kind of solution.

2.1.3 Quality of Service (QoS)

QoS is not explicitly discussed within the ipdvb WG. However, QoS provision included in the MPEG-2 generic header of the transport stream packet will be implicitly available also to SE and ULE packets, like setting the transport priority flag to prioritize certain packets.

Furthermore, as SE also supports the syntax of the adaptation field, QoS provision included there will be implicitly available to SE packets, like using the time synchronization provided by the Program Clock Reference (PCR).

2.1.4 Service discovery/advertisement

Service discovery/advertisement is not explicitly discussed within the ipdvb WG. However, generic service discovery/advertisement provided for MPEG-2 transport streams will be also available, like the Program Specific Information (PSI) contained in the Program Map Table (PMT) or the Transport Stream Description Table.

2.1.5 IP Multicast

Also the field of IP Multicast over satellite networks has been touched only on the surface by the ipdvb WG. Even if both investigated encapsulation mechanisms, SE and ULE, would also cope with IP Multicast packets quite efficiently, other issues like running IP Multicast routing protocols over satellite networks, or IP Multicast address resolution are far away from being solved. [10] briefly discusses some IP Multicast related problems in satellite networks, such as

- determination of group membership, which would require an adaptation of the Internet Group Management Protocol (IGMP) and Multicast Listener Discovery (MLD) protocol,
- mapping of IP Multicast groups to MPEG-2 PIDs, or
- provision of a mean for efficient filtering mechanism for duplicate or wrongly received IP Multicast packets,

but does not propose any solution for them.

2.2 MPEG/DVB-S

The Digital Video Broadcasting Project (DVB) is an industry-led consortium of over 300 broadcasters, manufacturers, network operators, software developers, regulatory bodies and others in over 35 countries committed to designing global standards for the global delivery of digital television and data services.

DVB technology has become an integral part of global broadcasting, setting the global standard for satellite, cable and terrestrial transmissions and equipment. DVB standards and specification are available from ETSI.

Initially designed for Audio and Video transmission, MPEG is a set of norms defining every transmission details from the system part, to video compression details. More and more, however, DVB is used to build Internet-compatible networks. In order to do this an MPEG-2 Transport Stream cell is used as a “container” for the IP packets with an added encapsulation header to allow the information to be adequately processed. Over the years a number of encapsulation methods have been explored to transmit data over broadcast media. The current standard for DVB is the Multi-Protocol Encapsulation (MPE). While this may be used to send Internet Packets, there are further issues that arise when used to build an Internet Service.

2.2.1 MPEG-2 Overview

2.2.1.1 Introduction

MPEG system coding exists in two forms: The Transport Stream and the Program Stream, each being optimized for a certain type of application. Both kinds of streams are logically constructed from a flow of PES packets; they differ mainly in their timing and error requirements.

This definition stand for video and audio transmission, but we'll see that pure data transmission has not been left apart.

2.2.1.2 The MPEG / DVB Stack

A simple overview of the 'packet' stacks if given in Figure 2-5.

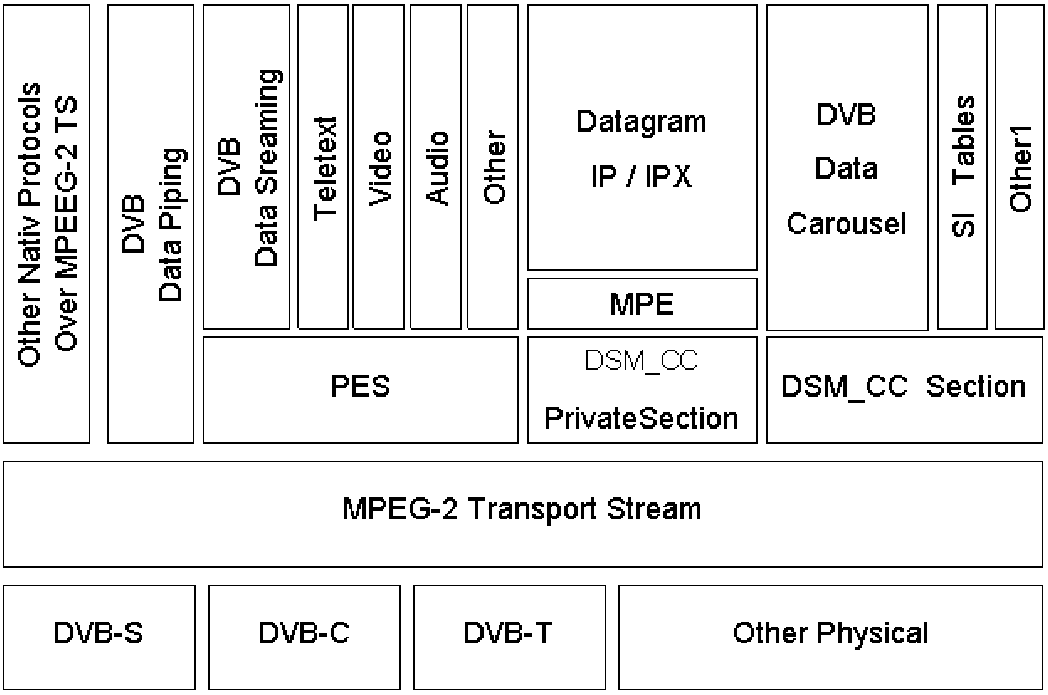

Figure 2-5: DVB protocol architecture

We will have a closer look only on the elementary blocks used in data transmission, and more precisely, where IP datagrams transmission is standardized.

2.2.1.3 MPEG-TS

The lowest level, common to all form of DVB transmission (satellite, cable, and terrestrial), and possibly to other physical links, is the Transport Stream Packet Layer. It is fully described in [12].

What is of the most importance for us is that it is constructed with elementary cells with the following properties:

- fixed length (188 bytes)
    - fragmentation/reassembly is left for upper layers
- fixed header (4 bytes) including :
    - multiplexing thanks to the PID
        - some values are reserved for system control
        - the range of available values is quite large for a good multiplexing scheme (13 bits), but not enough to allow to use it as a level 2 discriminator (MAC)
    - payload start indicator and adaptation field indicator, for upper layer framing

More over, the cells transmission also respects

- some level of priority management (two levels managed within each PID)
- Cell Ordering
- Some loss detection, (only 'some" because the associated counter is only four bits long)

2.2.1.4 PES packets

PES stands for Packetized Elementary Streams.

It provides an additional level of multiplexing thanks to the stream_id field. If necessary, it can also include elements of time synchronisation within Transport Streams.

2.2.1.5 DSM_CC Sections

DSM_CC stands for Digital Storage and Medium Command and Control. It is defined in [13].It provides a powerful, but heavy, sections mechanism that allow various types for objects to be transported, and among them the MPE.

The DSM_CC section syntax is compatible with the private section syntax as defined in [12].

2.2.2 Encapsulations technique

The DVB standards define some ways of data delivery over MPEG-2 TS packets. Those techniques are defined in [14], [15] ; these are mainly:

- Data Piping
- Asynchronous or Synchronous Data Streaming
- Multi Protocol Encapsulation (aka MPE)
- Data Carousel

The first two of them are here for remembrance, but as not really used/deployed for carrying IP packets, they won't be studied in the following sections about address resolution etc.

The last one is more meant for cyclic broadcast of pieces of information, and is hence of definitely not adapted for IP transport

2.2.2.1 Data Piping

This is a very crude encapsulation technique: it is an asynchronous transport mechanism, and the data is to be carried directly as MPEG-2 payload. No fragmentation/reassembly mechanism is provided, it is left for upper levels.

Any form of data can be transmitted this way, but specific usages such as transport of IP packets, even if technically possible, are not specified.

2.2.2.2 Data Streaming

Both synchronous and asynchronous Data Streaming techniques make use of standard PES packets, with specific value reserved for the stream_id (see [15]).

Possible Synchronisation is done with optional fields in the PES packet header.

It suffers from the impossibility for two chunks of different PES packets to be present in the same MPEG-2-TS cell.

Any form of data can be transmitted this way, but specific usages such as transport of IP packets, even if technically possible, are not specified.

2.2.2.3 MPE

MPE (for Multi Protocol Encapsulation) is especially meant for transporting data network protocols over the MPEG-2 TS in the DVB world. It relies on the private sections mechanism, and has been somehow optimized for the transport of IPv4 packets: in this case the IPv4 packet is stored as the section payload. Details are found in [15]. What has to be kept in mind is that:

- About fragmentation
  - Section maximum length is 4080, so with an adapted MTU, there is no need for fragmentation at IPv4 level over the sections.
  - Section themselves provide fragmentation / Reassembly over the MPEG2-TS cells
- About the link capacity
  - Support for multi-protocol: An indicator within the section header show the presence of a LLC/SNAP encapsulation, hence allowing any protocol to be carried.
  - Link reliability: a strong checksum is available (CRC32 for a 4 Kbytes payload)

More over, it provides a layer two function, with an explicit MAC address usage for destination. However it must be noted that the allocation of those MAC addresses to the receivers is not defined.

2.2.3 Address resolution mechanisms

Static address resolution is of course always possible, but a more flexible is defined, through the use of INT (IP/MAC Notification Tables). As address resolution for MPE has been accepted only after MPE itself, it is, although recommended, optional.

This is done thanks to INT (IP/MAC Notification Tables) that are periodically broadcast. Those tables are a flexible way to describe associations between IP addresses and MAC addresses, but goes beyond a classical ARP result for it allows:

- Network association i.e. full prefix can't be associated to a MAC address.
  This helps avoiding the usual two stages IP to MAC paradigm involving the gateway IP address in case of non final receiver IRD (destination IP address → gateway IP address → gateway MAC address)
- Covers both IPv4 and IPv6.

- Source address for packets may be used as selectors (with possible full prefixes as in destination addresses), which goes far beyond the IP routing paradigm, and must be used with great care.

The way the tables are constructed is not standardized.

2.2.4 Quality of Service (QoS)

Quality of Services don't seem to be really taken into account at MPEG level, this is mainly because:

- MPEG header only provides one bit for priority indication, which doesn't provide a great flexibility, and for example makes the DSCP mapping quite useless.
- As specified in [12]: "This filed may be changed by channel specific encoders or decoders"
- The way MPEG-2-TS cells are 'numbered' with the continuity counter, and the need for ordering within a single PID, doesn't seem compatible with queuing mechanisms and priority management at MPEG level.

2.2.5 Service discovery/advertisement

Even if multicast MAC address can be automatically derived, its announcement through the IP/MAC Notification Tables, allows a receiver to be aware of which IPv4 / IPv6 multicast streams are available in the multiplexes.

2.2.6 IP Multicast

IP and IPv6 multicast are taken into account for MPE, thanks to MAC address filtering. The MAC address used in MPE for multicast can be the one automatically derived from IP multicast groups, as defined in [24] and [25].

This of course needs to be efficient that hardware can manage multiple MAC address, as many Ethernet cards do.

2.3 ETSI SES BSM

Interesting for IP-over-DVB is a standardisation approach for Broadband Satellite Multimedia (BSM) of the Satellite Earth Stations and Systems (SES) group of ETSI. One aim of the BSM working group is to provide IP-based services in a BSM network. This part is of special interest for IP-over-DVB and will be considered in the following.

Five Technical Reports (TRs) of BSM with respect to IP over Satellite are currently available ([1], [2], [3], [4], and [5]). A BSM network is expected to transport all IP structured signals transparently preserving the addressing and all other properties of the IP signal. The BSM bearer service is aimed to be capable of transporting IPv4 as well as IPv6 packets. Although this leads to the assumption of a dual stack implementation, statements are given that BSM networks are either IPv4 or IPv6 based. Quality of Service (QoS), IP Multicasting, security, and TCP acceleration are also considered in the approach.

Satellite Terminals (STs) are the edge devices of a BSM System (BSMS), for instance, a satellite feeder or a satellite receiver. The protocol stack of STs differentiates between satellite dependent and satellite independent functionalities. Network layer protocols access the satellite dependent functionalities via a Satellite Independent Service Access Point (SI-SAP) as illustrated in Figure 2-6.

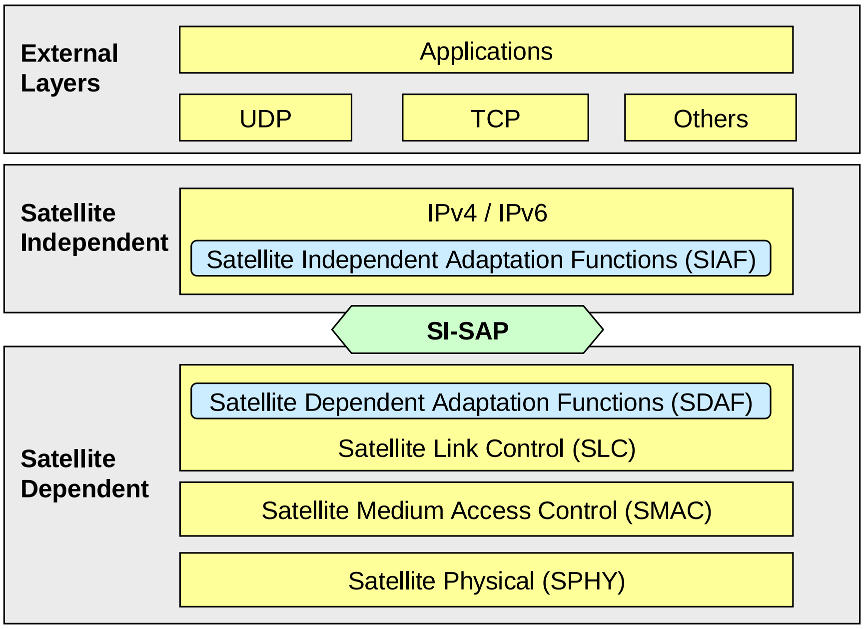

Figure 2-6: Generic protocol architecture of BSM

An ST may implement the BSM protocol stack to a certain extent. The functionalities of STs ranges from link layer relay over IP interworking to higher layer interworking.

Internally, the BSM network does not support all functionalities of IPv4 and IPv6. Instead, new functions for e.g. address resolution and multicast/broadcast are specified, that are tailored for satellite networks.

In Figure 2-7 an example of an IP communication between two end systems over a BSM network is illustrated, in which the satellite terminals have got IP Interworking functionality implemented, and the satellite has got an on-board processor with layer 2 switching functionality. To the external networks, the BSM network provides usual IP network functionalities, but internally satellite network specific protocols are used.

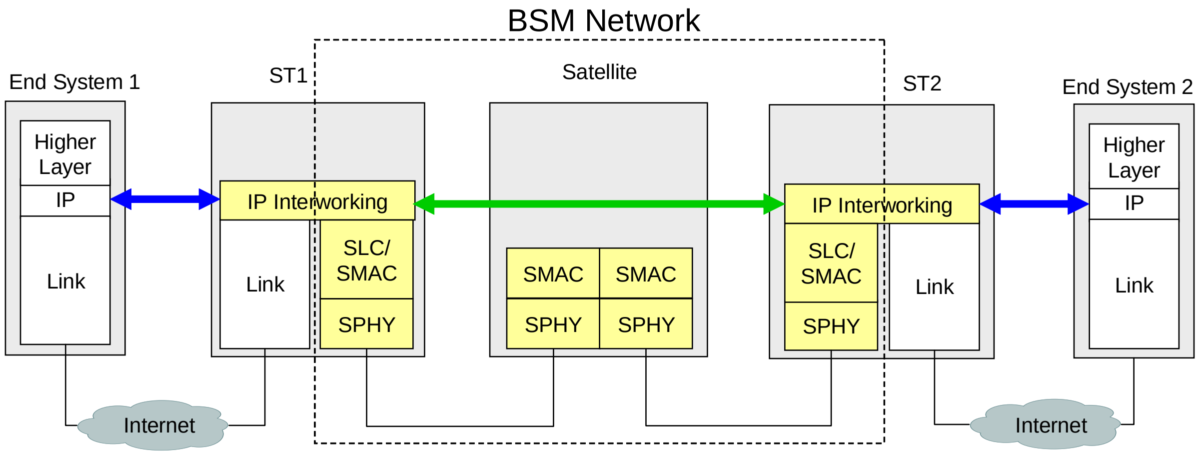

Figure 2-7: Example for IP interworking

The SES technical body of ETSI has created a Specialist Task Force (STF) 237 [6], a group of experts, to produce one Technical Report, which is already public available, and five Technical Specifications for enabling Internet services over Broadband Satellite Multimedia Systems.

The Technical Specifications will be based on Internet Protocols, and will range from the transmission layer to the application layer. Table 2-1 lists the deliverables of STF 237. Where relevant to address resolution, QoS, encapsulation, and multicasting, the scope of the deliverables will be given in the following sections.

Deliverable name	Title	Publication
DTR/SES-00083	IP inter-working over Satellite: Performance, Availability and Quality of Service	2003-07
DTS/SES-00087	Broadband Satellite Multimedia Services and Architectures; Functional Architecture for IP interworking with BSM networks	2004-03
DTS/SES-00088	Broadband Satellite Multimedia Services and Architectures; interworking of IP multicast services with BSM networks	2004-03
DTS/SES-00094	Broadband Satellite Multimedia Services and Architectures; mapping, satellite IP multicast group management	2004-07
DTS/SES-00095	Broadband Satellite Multimedia Services and Architectures; IP interworking satellite, multicast	2004-07

	functional architecture	
DTS/SES-00096	Broadband Satellite Multimedia Services and Architectures; interworking over satellite, BSM traffic classes	2004-07

Table 2-1: Deliverables of STF 237

2.3.1 Address resolution mechanisms and routing

In the BSM approach, for address allocation and address resolution a centralized BSMS Address Resolution Server (BARS) is foreseen. A BARS can be located at the Network Control Centre (NCC) or in the satellite in case of a satellite with On Board Processor (OBP).

When a new ST is connected to the BSMS it has to go through an authentication procedure, and afterwards, obtains an IP address for the satellite interface form a BARS. After receiving an IP packet at the interface connected to the Internet, the ST has to determine the link layer address of the next hop. Therefore, each ST stores IP address link layer address relations in an Address Resolution (AR) cache. If a relation can not be found in the AR cache, the ST queries the BARS by an ARP command. The ARP message is translated at the Satellite Dependent Adaptation Functions (SDAF) of the ST in a satellite specific ARP command (S-ARP). ST and BARS communicate via S-ARP to obtain network layer address/link layer address resolution.

For better scalability and capacity saving reasons, determining routes and updating routes in BSMSs is proposed to be performed by a central BSMS Route Server (BRS), co-located e.g. with the BARS at the NCC. The BRS advertises routes across the BSMS and is also used as “designated router” for OSPF protocols. Each routing protocol packet that is received on the Internet interface of the STs is forwarded to the BRS, which afterwards performs any routing protocol or algorithm.

Currently, the recommendations for address resolution and routing support of BSMSs focus on IPv4. A Technical Specification of the STF 237 denoted as DTS/SES-00087 is created to provide a definition of functions, functional architecture and interfaces to be included at the IP layer of BSM terminals at the user and network sides to provide addressing and routing functionality. The document will be based on the relevant material from the IST-SATIP6 project (Satellite Broadband Multimedia System for IPv6).

2.3.2 Encapsulations technique

In [3] a new label-based solution as link layer architecture is proposed. This solution can be a kind of shim layer between IP layer and link layer of the underlying satellite technology (e.g. DVB-S/RCS or ATM). Labels are assigned to logical broadcast paths. A path is considered as being a connection between several STs.

After reception, two selection methods are used:

- first, only packets with the right label are selected, and

- second, the ST compares the network prefix of its Internet interface with the IP destination address of the packets.

Currently, BSM does not specify this label-based solution as mandatory and the report [3] states, that some standardisation is necessary:

- Link layer labeling concept and label structure
- Operations for Router STs and for Bridge STs
- Mapping of labels to standardized satellite access layer identifiers (PID, VPI/VCI)
- Satellite ARP for dynamic resolution
- Segmentation and reassembly functions
- QoS support

2.3.3 Quality of Service (QoS)

Quality of Service (QoS) is the ability of a network to differentiate between traffic types and flows to treat a specific traffic type or flow different form the others.

When defining Quality of Service (QoS), BSM bases QoS functionality on already specified protocols and technologies where appropriate, and defines new methods where existing ones are not suitable ([1], [2], and [5]). BSM QoS focuses on the BSM bearer service and does not consider end-to-end QoS, but ETSI plans to give specifications to ensure end-to-end QoS.

The BSM documents state that BSM QoS should be able to support the IETF QoS models Integrated Service (IntServ) and Differentiated Service (DiffServ) beside a service based on best effort. Both IP based QoS models should be mapped on the edge of the BSM network to BSM QoS. The mapping process is not defined yet. In BSM networks only operating at link level (bridging), layer 2 QoS mechanisms are applied.

A BSM protocol manager (BPM) has already been specified in [5] that inherits a lot of QoS management functionality of UMTS, like control functions, translation of protocol primitives, admission control, and enforce policy. BPM is part of the ST's protocol stack

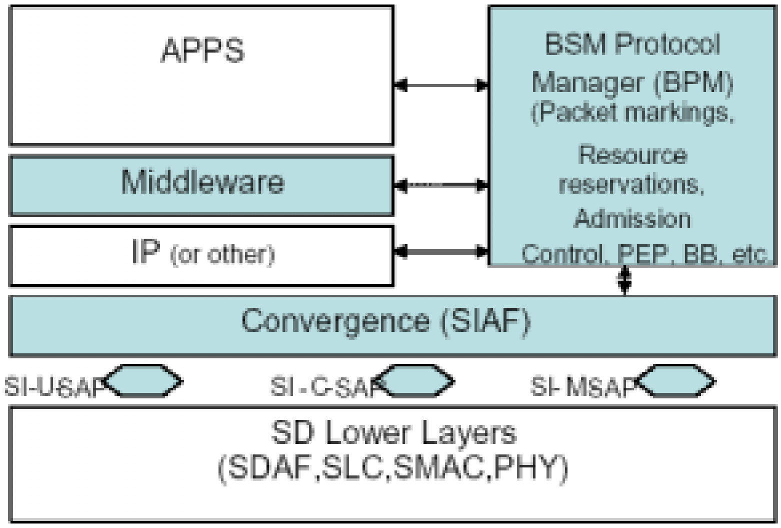

Figure 2-8: System architecture for providing QoS

The BPM interacts with middleware to establish transport level and application level Policy Enforcement Points (PEPs), communicate with bandwidth brokers and potentially with service discovery and security/authentication functions like COPS (Common Open Policy Service) (see Figure 2-8). At the convergence layer, the BMP sets queuing policies. In this model the BMP does not interact directly with the satellite dependent part of the BSM stack. All satellite dependent functions are controlled and negotiated by satellite independent proxies and indirectly via the BMP.

In [5], recommendations for five Technical Specifications (TSs) to be produced by ETSI are given to ensure that BSM systems can support QoS under measurable and consistent performance:

- TS1: Architecture for QoS and performance protocol manager (functional and software specifications). The QoS manager is already specified in [5] chapter 9.
- TS2: BSM Traffic Classes. The deployment of TS2 has already started in the STF 237 by creating deliverable DTS/SES-00096: “Satellite Earth Stations and Systems (SES); Broadband Satellite Multimedia; IP interworking over satellite, BSM Traffic Classes”. The BSM traffic classes are based on well known work from TIPHON and 3GPP but include specifics that are derived from the BSM inherent architecture.
- TS3: Performance Goals
- TS4: BSM specific functions for QoS management in Intserv and Diffserv models.
- TS5: Performance

2.3.4 Service discovery/advertisement

Service discovery and service advertisement is not considered in the BSM approach. The BSM system defines no link layer technology, and hence, if DVB-S/RCS is used, the service discovery mechanism of DVB could be applied in BSM networks.

2.3.5 IP Multicast

Due to its broadcast nature over a large scale, satellite networks have advantages in multicasting to widespread groups. Therefore, a Technical Report is created by the BSM working group [4] which focuses especially on multicast support in BSM networks. Its scope is:

- identifying relevant multicast issues and service architectures for satellite multicasting,
- identifying satellite specific issues and technical requirements for satellite multicasting,
- identifying relevant standardization work in other standards bodies,
- and concluding what actions ETSI should be taking to prepare Technical Specifications.

The BSM satellite multicast architecture considers all kind of satellite architectures, star architectures with or without multiple spot beams, with a single or with several hubs, as well as meshed networks.

The BSM will be visible to external networks as usual multicast network, because BSM multicasting is expected to interact externally with commonly used multicast protocols like IGMP (Internet Group Management Protocol) and PIM-SM (Protocol Independent Multicast-Sparse Mode). Internally, satellite specific protocols and functions may be applied, e.g. a layer 2 multicast distribution tree between gateways, satellites, and satellite terminals is built to deliver multicast traffic from the multicast source ST to all multicast destination STs.

The recommendations in [4] focus on a BSM Multicast Proxy (BSM-MP) approach. The BSM-MP functionality is split over different BSMS components, like Network Control Center (NCC), gateways, and STs. External multicast sources consider the BSM-MP as a multicast enabled router (PIM-SM router) and forward multicast content to it. Furthermore, the BSM-MP is responsible that the multicast content is forwarded to the STs that have joined.

The Multicast Entry Point (MEP), the logical satellite entry point of the multicast traffic (e.g. the NCC), acts as Rendezvous Point of the PIM-SM concept.

In Figure 2-9, an illustration of the BSM multicast functionality is given. Externally, BSM is visible as a usual multicast network, featuring PIM-SM and IGMP. Internally, the BSM-MP functionality is responsible for managing multicast sessions.

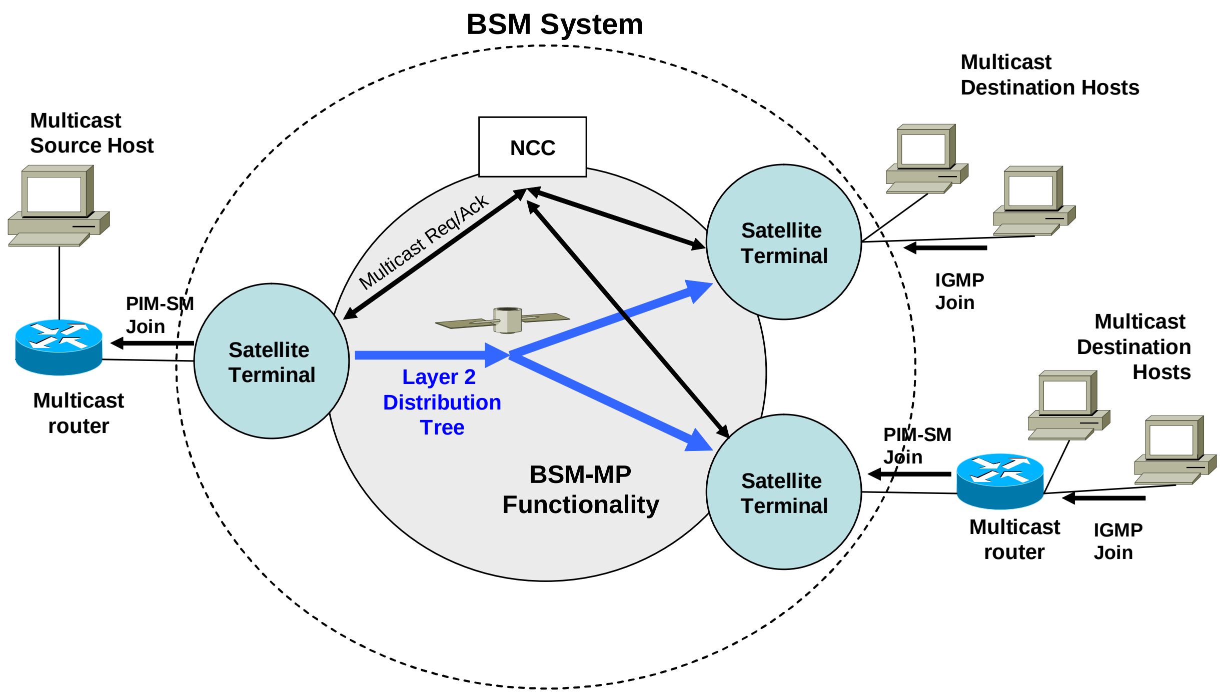

Figure 2-9: Illustration of the BSM multicast architecture

Currently, no documents with specifications for BSM multicasting are publicly available yet. The STF 237 specifies currently multicast support of BSM networks in the deliverables DTS/SES-00088, DTS/SES-00094, and DTS/SES-00095.

DTS/SES-00088 will define adaptations required by the Internet Group Management Protocol version 2 (IGMPv2), in order to optimise its use in satellite networks. Furthermore, the document will describe the requirements for other required functions, such as an IGMP proxy.

DTS/SES-00094 will define the specific mapping required by the satellite IP multicast and group management between the satellite independent and the satellite dependent layers (SI-SAP), with specific focus on IGMP and the BSM family TSS-A.

In DTS/SES-00095, architectures that BSM networks will use for delivering IP multicast traffic will be specified. These architectures will include non-routed as well as routed solutions. While not specifying any routing protocol, it is assumed that the architectures will use at least IGMP- and PIM-based solutions as specified in other BSM Technical Specifications. The architectures will also refer to work already performed in the IETF in the multicast working groups as well as in the unidirectional link routing group.

2.4 ATSC

The Advanced Television Systems Committee, Inc., is an international, non-profit organization developing voluntary standards for digital television. The ATSC member organizations represent the broadcast, broadcast equipment, motion picture, consumer electronics, computer, cable, satellite, and semiconductor industries.

Specifically, ATSC is working to coordinate television standards among different communications media focusing on digital television, interactive systems, and broadband multimedia communications. ATSC is also developing digital television implementation strategies and presenting educational seminars on the ATSC standards.

ATSC Digital TV Standards include not only standards related to television, but has also focused on data broadcasting.

2.4.1 ATSC Overview

2.4.1.1 Introduction

ATSC is (at least for data transmission) very close to DVB:

- It is built on top of MPEG-2 Transport Streams as described in §2.2.1.3.
- It makes use of PES packet as described in §2.2.1.4.

All details are found

2.4.1.2 The MPEG / ATSC Stack

A simple overview of the 'packet' stacks is given in Figure 2-10.

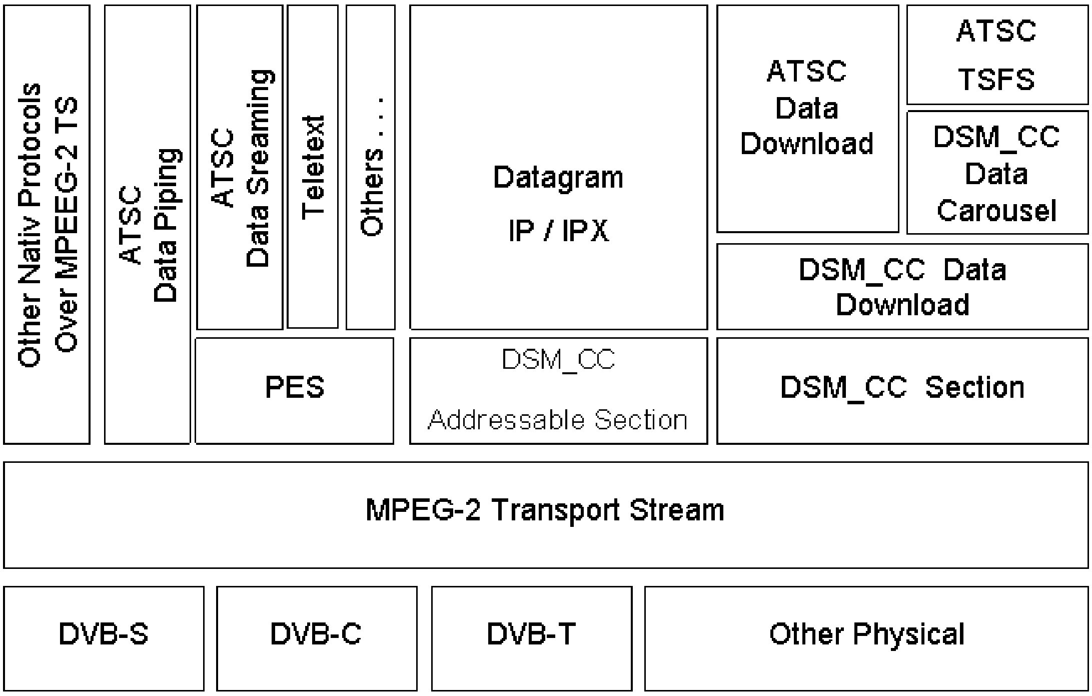

Figure 2-10: ATSC protocol architecture

For simplicity we didn't give the same detail level as in Figure 2-5, but we can see a huge similarity between ATSC and DVB for the data transmission part.

The main difference will be in the DSM_CC section usage: where private sections where used, we find here a new type of section DSM_CC Addressable section (described in [17]).

2.4.2 Encapsulation Techniques

The ATSC standards define several ways of delivering data over MPEG-2-TS packets. Those techniques defined in [17] and [18] are:

- Data piping
- Asynchronous or Synchronous Data streaming
- DMS_CC addressable Encapsulation
- ATSC data download

It is quite similar to the DVB approach, and we'll focus more on the DMS_CC addressable part, which is the DVB-MPE counterpart.

What is interesting in the data download part is the will to specify data distribution at a level which higher than the network's level, hence for example defining standard for delivery of hierarchical name-spaces, directories and files such as in [20].

2.4.2.1 Data Piping / Streaming

ATSC Data piping is more or less equivalent to the DVB data-piping and DVB data-streaming described in §2.2.2.1

ATSC data piping is more or less equivalent to the DVB data-streaming described in §2.2.2.2

The slight difference is that transport of IP packets (and more generally of any packets) is described and normalized.

It makes use of LLC/SNAP encapsulation except for IP, where this encapsulation is not needed (IP being hence the "default" type of packets). For IP, this encapsulation has even been formally deprecated.

2.4.2.2 DMS_CC addressable Encapsulation

We could name it directly ATSC-MPE, because it is really like DVB-MPE as described in §2.2.2.3, offering the same properties (MTU, fragmentation, level 2 addressing, etc.).

Here again, the usage of LLC/SNAP encapsulation for IP is formally deprecated.

2.4.3 Address resolution mechanisms

Program and System Information, specified in [21], is a hierarchical table structure for program announcements. Is has been extended in [19], to provide pieces of information about services.

It allows definition of:

- Type of data (synchronized or not, multi-protocol, ...)
- Element for Multi-protocol Encapsulation
  - Alignment indications
  - Parameters for fragmentation.
  - LLC/SNAP usage or not.
  - IP to MAC address mapping
  - PID lists

2.4.4 Quality of Service (QoS)

No special Quality Of Service seems to be available at ATSC level, hence giving way to the (quite minimal) MPEG QoS management described in §2.2.4.

2.4.5 Service discovery/advertisement

The extension listed in §2.4.3 can also include tables associated to network elements: “Network Resources Tables”. Such tables can include resources descriptor:

- They exist for both IPv4 and IPv6
- They define a complete service :
  - Source and Destination addresses
  - Source and Destination Port
  - Protocol (UDP or TCP)

2.4.6 IP Multicast

ATSC covers IP multicasting in [19]. It is supposed that such multicasting make use of session management normalized by SDP ([22]) and SAP ([23]).

Encapsulation of multicast datagrams is done with the multi-protocol using LLC/SNAP encapsulation. The destination MAC address is derived from the IP multicast group as defined in [24] and [25].

Announcement of ATSC multicast sessions can use the mechanisms described in §2.4.5.

2.5 DAB

In 1987 the Eureka Project 147 was established with funding of the European Commission to develop a system for the broadcasting of audio and data to fixed, mobile or portable receivers. The resulting work was published in the European Standard ETS 300 401 for DAB (Digital Audio Broadcast) which has currently the V1.3.3 (2001-05) [33]. DAB is designed for delivery of high-quality digital audio programme and data services for mobile, portable and fixed reception from terrestrial or satellite transmitters in the VHF / UHF frequency bands as well as for distribution through cable networks. The DAB system is also suitable for hybrid/mixed terrestrial/satellite broadcasting. The basic DAB system in a conceptual block diagram is shown in Figure 2-11.

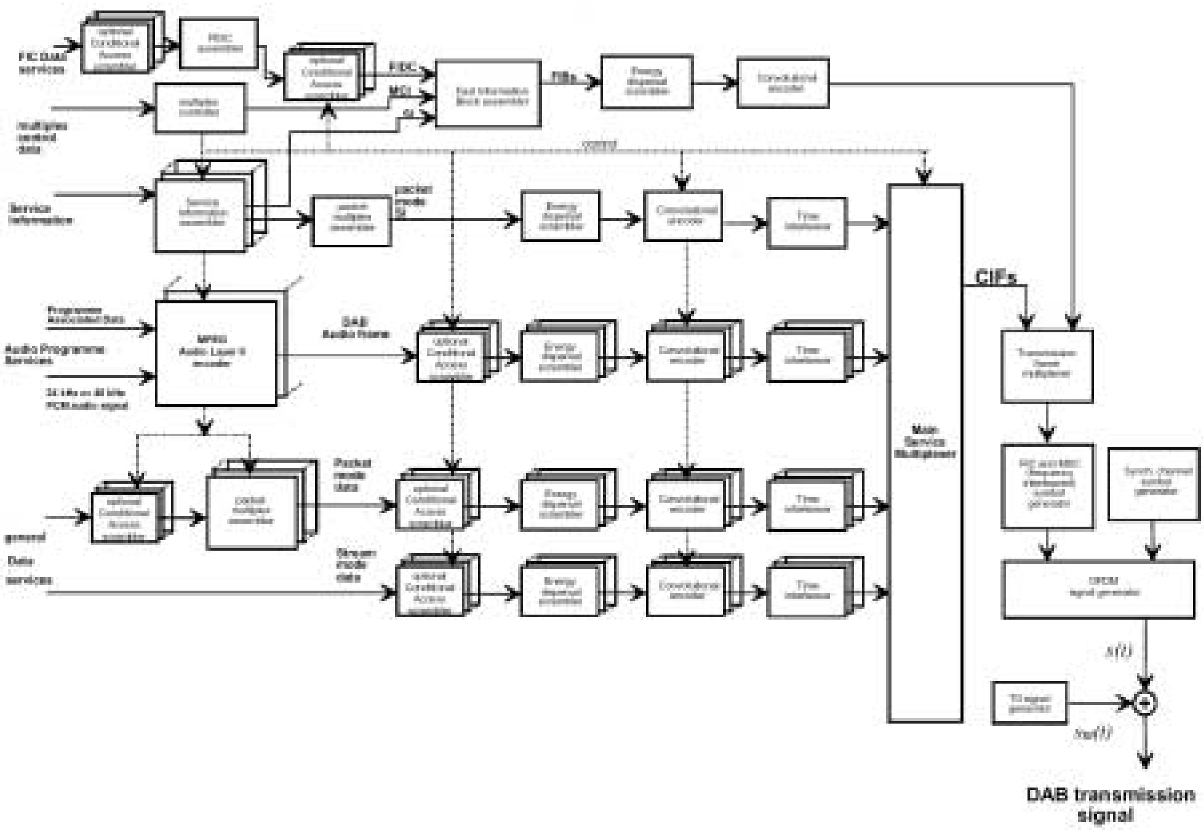

Figure 2-11: Conceptual DAB emission block diagram

The DAB system is designed to carry several digital audio signals together with data signals. Audio and data signals are considered to be service components which can be grouped together to form services. The DAB transmission system combines three channels:

- Main Service Channel (MSC):
  Used to carry audio and data service components. The MSC is a time interleaved data channel divided into a number of sub-channels which are error protected. Each sub-channel may carry one or more service components. The organization of the sub-channels and service components is called the multiplex configuration.

- Fast Information Channel (FIC):
  Used for rapid access of information by a receiver. In particular it is used to send the Multiplex Configuration Information (MCI) and optionally Service Information and data services.
- Synchronization channel:
  Used internally within the transmission system for basic demodulator functions, such as transmission frame synchronization, automatic frequency control, channel state estimation, and transmitter identification.

Each channel supplies data from different sources and the data is then used to build a transmission frame. Figure 2-12 shows the construction of a transmission frame where the FIC channel consists of several Fast Information Blocks (FIBs) and the MSC consists of Common Interleaved Frames (CIFs).

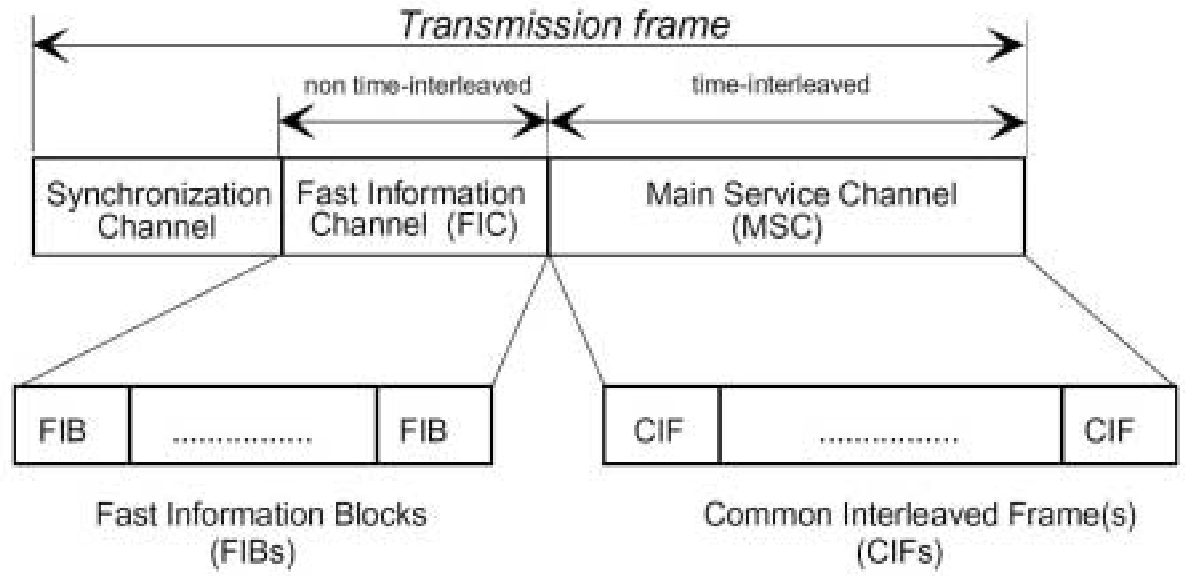

Figure 2-12: Transmission frame consisting of Synchronization Channel, FIC and MSC

The Main Service Channel provides two basic transport modes where data can be transmitted:

- The Stream mode allows a service application to accept and deliver data transparently from source to destination. At any one time, the data rate of the application is fixed to a multiple of 8 kbit/s. The service application shall either supply information on demand, or include a method of handling data asynchronously at a lower rate. Data shall be divided into logical frames. Only one service component shall be carried in one sub-channel.

- The Packet mode allows different data service components to be carried within the same sub-channel. The permissible data rates for the sub-channel are specified as multiples of 8 kbit/s. Data may be carried in data groups or transported using packets alone. An address (10 bit) carried with the packet identifies packets carrying a particular service component within a sub-channel. Packets with different addresses may be sent in any order in a sub-channel. However, the sequence of packets with the same address has to be maintained. Packets have a fixed length with four standard packet length types (24, 48, 72, and 96 bytes). It is permitted to mix packet types of several lengths in a sub-channel provided that there are an integral number of packets per logical frame. Padding packets are used to adjust the data rate to the required data rate (multiple of 8 kbit/s). The links between the service component and the packet address are given in the Multiplex Configuration Information (MCI).

Data which is closely related to the transmitted audio content can be directly attached to the audio frame using the Programme Associated Data (PAD) channel available in every audio frame. For low bandwidth data which is has strong real-time character for the audio data, the two fixed F-PAD bytes can be used. The F-PAD channel provides data rates of 0,667 kbit/s resp. 0,334 kbit/s depending on the audio sampling frequency (48 kHz or 24 kHz). The PAD channel can be extended by using the Extended PAD (X-PAD) which provides a variable length field for additional information. The available length of the X-PAD is chosen by the service provider. [33] recommends to not use PAD and X-PAD for intensive date transport.

Based on the above described transport mechanisms, two data transport types are currently specified for DAB. The “Multimedia Object Transfer Protocol” (MOT) as described in ETSI EN 301 234 [34] is more intended for file / object oriented data transfer and supports all transport mechanisms provided by DAB, i.e. Stream mode, Packet mode and PAD. The transmission of IP datagrams in a DAB packet mode service component is described in ETSI ES 201 735 (DAB Internet Protocol (IP) datagram tunneling) [35] and further referred to as IP tunneling. To address more advanced services which may have the necessity of a return channel, DAB defines in ETSI ES 201 736 (DAB Network Independent Protocols for Interactive Services) [36] the requirements to enable bidirectional communication. [36] supports broadcasting to mobile, portable or fixed receivers with narrowband return channels, e.g. GSM, PSTN, ISDN or DECT, by using IP tunneling for the forward link and PPP for the return link. To do the necessary coordination between the broadcast channel and the return channel (i.e. interaction channel), PSSC messages (defined in [36]) are used either over TCP (port 645) or UDP (port 645) between the UT and the NCU to establish a PSSC session. This can be used for example to re-route all data traffic over the interaction channel if DAB network coverage is lost and the network service provider supports this feature.

2.5.1 Address resolution mechanisms

After the setup of bidirectional communication between the UT and the Service Provider over the DAB network including the return link, the PPP configuration process is initiated. This process uses the Link Control Protocol (LCP) [37] to establish the data link connection and the IP Control Protocol (IPCP) ([38], [37]) to configure the IP address and the type of compression.

As the return link uses PPP, no additional address resolution mechanisms are necessary.

After the establishment of the PPP tunnel, the UT initiates to the NCU a personal DAB service session with a PSSC ClientSetupRequest message where it transmits, among other values, its fixed EUA. If successful, the NCU responses with a ClientSetupConfirmation message which tells the UT its currently assigned EUA together with information about the ensemble to which the UT should tune to receive the personal DAB service session.

For the DAB forward link, no IP address resolution mechanisms are defined in the examined DAB standards. As the UT on DAB level is identified and addressed by the EUA (fixed / assigned) and with its IPv4 address on higher layers, [36] allows the use of the IP address as common addressing scheme for both the DAB and the interaction channel. But [36] does not describe a mapping scheme between EUA and IP address and leaves this to higher layers.

As the EUA can hold up to 15 bytes of data, it could be possible to include the IPv4 address of the UT within the assigned EUA.

2.5.2 Encapsulations technique

The encapsulation of IP datagrams when IP tunneling is used is done by DAB packet mode service components (SC). The IP datagrams are encapsulated in an MSC data group on packet mode transport level. The packet mode SC acts like an Internet data link layer from an IP point of view. The necessary protocol stack is shown in Figure 2-13.

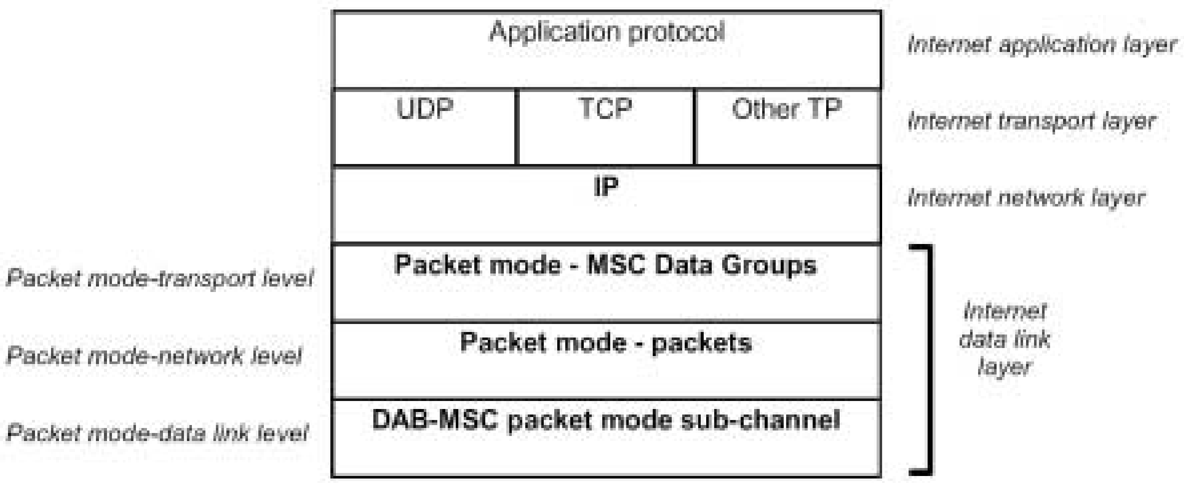

Figure 2-13: IP Tunneling Protocol Stack (DAB packet mode SC)

When encapsulating IP datagrams, one complete IP datagram is put as payload in the MSC data group data field. The maximum size (MTU) allowed for the MSC data group data field is set on the transmitter side and can be in the range of 576 to 8191 bytes. If the IP datagram to send it to large for the MTU, the IP datagram is fragmented on the sender side into IP Fragments. Each of the resulting IP Fragments is put into one MSC data group data fields as payload as displayed in Figure 2-14.

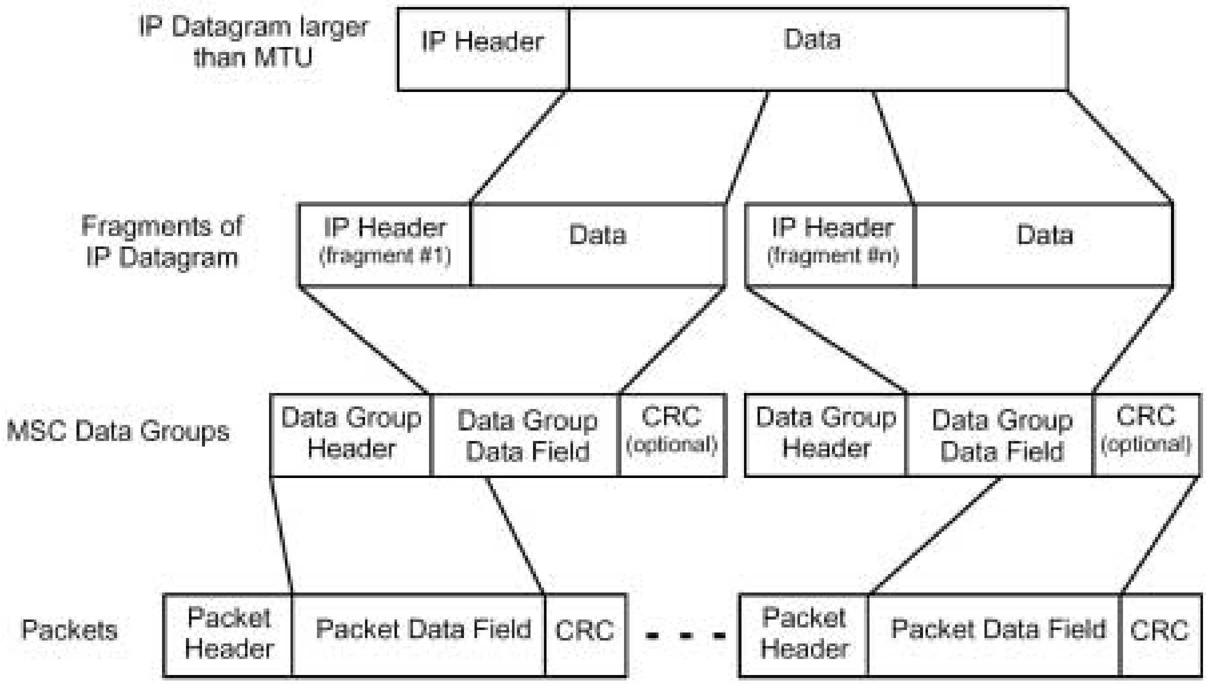

Figure 2-14: Fragmented IP Datagrams encapsulated in MSC data groups

In the MSC data group header, the payload type is coded in the “Data group type” field. The value 59_{dec} ($3B_{hex}$) is reserved for embedded IP packets.

2.5.3 Quality of Service (QoS)

As DAB is able to provide audio data and other data with flexible bit rates and these rates can be changed on the fly, the functionality for providing basic QoS on the broadcasting channel is available. For example, in Packet Mode, the bit rate can be changed in steps of 8kbit/s and padding packets are used if the transmitted data rate not a multiple of 8kbit/s. Nevertheless, QoS is not specifically addressed in [33]. Furthermore, the examined public DAB documents do not address the problems of providing end-to-end QoS over DAB in heterogeneous networks, i.e. when public servers located in the Internet are accessed by the UT.

2.5.4 Service discovery/advertisement

Information about the currently received audio programme and data is distributed via the Service Information (SI) as specified in [33]. The necessary information about the currently used multiplex configuration is shared via the Multiplex Configuration Information (MCI) which is also described in [33]. Both SI and MCI are transported in the Fast Information Channel (FIC). It is also possible to transport additional broadcast data services within the Fast Information Data Channel (FIDC). But, as the FIC has only a limited capacity of 32kbit/s, this is not recommended.

The aim of the SI is to make service access easier in the receiver and to provide value-added function. It includes announcements, service component trigger and frequency information. SI can also be used to announce features associated with other ensembles.

2.5.5 IP Multicast

Although DAB is well suited to support IP Multicast from a technical point of view and IP broadcast and IP Multicast are often named as target IP services, IP Multicast is not addressed in special in the examined public DAB standards.

As DAB is working on a broadcast medium and uses either different sub-channels or even different ensembles to separate the transmitted contents (i.e. programmes), different multicast groups could be bound to different sub-channels or ensembles. While it could be possible that a single UT is able to receive and decode the IP Multicast data from several sub-channels, it is not clear if a UT might be able to receive and decode IP Multicast data from several ensembles at the same time.

Furthermore, issues like the signaling of interest in special multicast groups via IGMP by the UT and the processing of such requests by the service provider are not yet specified in the examined public DAB standards.

2.6 Summary

Several activities can be reported which either concentrate on the transmission of IP over satellite or at least consider satellite links as alternative transmission medium for their main interest (e.g. DAB). As these activities are done in different standardization bodies and groups, we will summarize in this chapter possible interaction scenarios between the ipdvb working group (and in special the currently favoured encapsulation method ULE) and those other investigated groups.

In DAB, several variants of data transmission are taken into account, e.g. MOT, IP data etc., with either unidirectional or bidirectional communication. Examining the public documents about transporting IP data over DAB, this part seems to be not yet fully specified, as important issues like address resolution are not discussed so far. Furthermore, interactions between the DAB standardization group and the ipdvb working group are currently not recognizable and also not very likely. DAB is mainly focused on terrestrial transmission although it includes the theoretical possibility of using satellite links. But, as DAB does not use the MPEG-2 transport protocol at all to deliver its content and the ipdvb working group focuses on the use of MPEG-2, a common basis for working group interaction is missing.

One aim of the ETSI BSM working group is the provision of IP-based services in a BSM satellite network. To address this, a Specialist Task Force (237) was created which will generate technical reports and specifications. ETSI BSM divides its framework in a satellite independent and a satellite dependent part, connected via the SI-SAP (Satellite Independent – Service Access Point). The Satellite Dependent Adaptation Functions (SDAF) below the SI-SAP are intended to adapt the Satellite link dependent functionality (e.g. ULE encapsulation) to the SI-SAP. Therefore, ULE could be relevant for the SDAF if it is used by satellite networks following the ETSI BSM approach. It could be worthwhile for the ETSI BSM working group to have a look at the current ULE specification and the intended work items of the ipdvb WG.

Approaching the ipdvb WG at an early stage of standardization could offer two advantages. First, the BSM WG could already start to study the effects of the current ULE draft on their aims. Second, it is a chance for the ETSI BSM WG to actively contribute their ideas to the ipdvb WG, e.g. in the area of address resolution. Also minor modifications or clarifications to the current ULE draft could still be considered.

From the latest discussions on the ipdvb mailing list about the charter, it can be concluded that the ipdvb working group will not limit itself to only DVB standards but will also try to address new encapsulation methods over MPEG-2 in a broader sense (e.g. including ATSC) as well as IP address resolution mechanisms. This means that for the corresponding working group from ATSC it could be quite interesting to be aware of the advantages provided by ULE. It is therefore desirable for the ipdvb working group to establish contacts with the corresponding working group from ATSC.

The specification of ULE within the ipdvb WG has no effect on the MPEG-2 standardization as it only utilizes the functionalities provided by MPEG-2 as transport protocol. The MPEG-2 standardization group will therefore see no reason to work with the IETF ipdvb WG and vice versa.

Addendum:

The ipdvb working group has been approved by IESG on the 28th January 2004. With support of this project, the personal ULE draft draft-fair-ipdvb-ule-01.txt (Ultra Lightweight Encapsulation (ULE) for transmission of IP datagrams over MPEG-2/DVB networks) was further worked on and published on the 24th November 2003 as draft-fair-ipdvb-ule-02.txt. In February 2004, draft-fair-ipdvb-ule-02.txt was adopted by the ipdvb working group as WG work item and re-issued as draft-ietf-ipdvb-ule-00.

3 STUDY AND PROTOTYPE IMPLEMENTATION

This chapter will in short describe identified deficiencies within the current specification of MPE and investigate currently proposed new encapsulation methods, e.g. ULE and SE, and compare them with a selection of already existing and deployed encapsulation methods. Next, it will then present the reasons why ULE was selected in coordination with ESA. Finally, the implementation of ULE within the 6WIND OS, starting with the overall architecture, technical integration details, the users view on the provided ULE configuration possibilities etc, and the conducted basic tests are described. More detailed information about the basic test architecture and their results are provided in the document #10, “Basic functionality test report.doc” of this study.

3.1 Study of MPE deficiencies

MPE as described in §2.2.2.3, makes use of the DVB section mechanism. This is quite heavy and has some inherent deficiencies.

Complexity:

Section mechanisms carry its own burden in terms of processing complexity, and what has been optimized for hardware processing is not obvious they're still up-to-date.

Overhead:

The section structure, when using a CRC-32 induces an important overhead of 6 (various fields) + 4 (CRC32) + 6 (MAC address) = 16 bytes.

The insertion of the MAC address is not optional, so when case arise where it is possible to omit it (thanks to upper layer filtering being enough), the MPE definition forbids that extra 6 bytes gain.

Multi-Protocol support:

Although named MPE, it does not provide DIRECT multi-protocol support. The multi-protocol support is provided only through an LLC/SNAP encapsulation.

This non native multi-protocol support can be seen in terms of overhead cost. All protocols not being IPv4 have to pay an extra overhead of 8 bytes. This means that not exotic protocols such as IPv6 and/or ROHC are then associated with a total overhead of 24 bytes.

MTU:

Using the section mechanisms, MPE implicitly inherits the section length field, hence limiting the MTU to a 4080 value. This does not fit the current trend for core links to take off from Ethernet-MTU and provide a much larger MTU (around 8 Kbytes).

3.2 Investigation of improved encapsulation methods

As the needs for a new, simpler encapsulation for IP (and IPv6) datagrams over MPEG-2 networks rose, a community worked together to meet the needs.

Accordingly to the IETF standard process, it produced a BOF at the 57th and the 58th IETF meetings, but a creation of an IETF working group (WG) is expected. It has produced four Internet Drafts, aiming at:

- Requirement list for encapsulation: This should lead to an Informational RFC
- Method(s) of Encapsulation: This should lead to an RFC that would follow the Standard Track
- Address Resolution draft : That states the issues and the possible orientations and should lead to an Informational RFC

3.2.1 Requirements

All requirements are detailed in [28], but we can re-state the main non trivial parts (such as robustness, flexibility, etc ...). The final protocol should include:

- A convergence Protocol
- A way to manage the ‘encapsulated’ datagrams over MPEG-2 TS cells
- Some reflections about address and PID resolution (which need not really be addressed in the encapsulation drafts)

Each has its own requirements:

- General :
    - Protocol support:
        - IP unicast, multicast, broadcast
        - IPv6 unicast multicast
        - IP/IPv6 with compressed headers (e.g. ROHC)
    - Protocol Transparence:
        - It operates below IP level
        - No IP(v6)/UDP/TCP modification

- Convergence protocol:
    - Small overhead
    - Length and type indicators
    - Optional NPA (Network Point of Attachment) when needed for filtering
    - Strong Integrity Check

- MPEG-2 usage:
  - o TS multiplex flushing (possibly out of scope)
  - o TS cell usage efficiency:
    - Overhead
    - Packing

- Address resolution:
  - o Possible mechanism outside the SI table, for IP-only MPEG-2 devices
  - o Allocation of a whole IP flow to a single PID

3.2.2 Ultra Lightweight Encapsulation (ULE)

This encapsulation method, which chronologically speaking is the second (after the SE one), proposes to send IP(v6) packets directly over MPEG-2 Transport Stream, as TS private data, i.e. without any DVB sections mechanisms.

The method is defined in [30], and can be decomposed into two different parts:

- Encapsulating IPv4 / IPv6 packets (and possibly other packets) in to what will be called Subnetwork Data Units (SNDU).
- Transmitting those SNDU over MPEG-2Transport Stream, i.e. the fragmentation over TS cells.

3.2.2.1 SNDU format

```
  .------------------------   SNDU   -------------------------.
+---+--------+------+----------------------------------+--------+
| R | Length | Type |               PDU                | CRC-32 |
+---+--------+------+----------------------------------+--------+

     R  : reserved
```

Figure 3-1: PDU encapsulation in ULE method

The SNDU shown in Figure 3-1includes the whole IPv4 / IPv6 packets with

- A 4 bytes header which includes:
  - o A 2 bytes Length field
    - With a spare bits for reserved for flags
    - Allows at least 16 K-bytes datagrams
  - o A 2 bytes type field, allowing protocol multiplexing
    - Following DIX/IEE assignments for values > 1500
      Currently defined:

- o IPv4
- o IPv6
- ▪ Locally assigned (IANA) for value <= 1500
  Currently defined
  - o TEST
  - o Bridged Ethernet
  - o LLC
- An optional 6 bytes Destination Address Field
- A 4 bytes trailer: a CRC-32 as in Ethernet, which provides the strong integrity check

Actually, the Destination Address Field is MANDATORY for unicast IPv4 / IPv6 packets.

3.2.2.2 SNDU packing over TS cells

ULE provides a method for

- fragmentation and reassembly of SNDU over TS cells
- packing SNDU

```
           +-----------------------------------------------+
           |Encap Header|   Protocol Data Unit    | CRC-32 |
           +-----------------------------------------------+
          /          /                                \       \
         /          /                                  \       \
        /          /                                    \       \
+------+----------+    +------+----------+    +------+----------+
|MPEG-2| MPEG-2   |... |MPEG-2| MPEG-2   |... |MPEG-2| MPEG-2   |
|Header| Payload  |    |Header| Payload  |    |Header| Payload  |
+------+----------+    +------+----------+    +------+----------+
```

Figure 3-2: SNDU fragmentation in ULE method

It makes use of the PUSI field in the MPEG-2 header. This flag indicates that at least one new SNDU starts in the MPEG-2 TS cell. If set, this flag also indicates that the first byte of MPEG-2 payload is a pointer (known as the Payload Pointer) to the start of the new SNDU.

An SNDU that cannot be put in a single MPEG-2 TS cell is fragmented over multiple cells, as shown in Figure 3-2, without any header addition : the fact that the under-lying packets arrive in order, and that packet loss is reasonably seen (thanks to continuity counter) is enough.

```
   +------------------+   +------------+   +------------------+
   |    Subnetwork    |   | Subnetwork |   |    Subnetwork    |
   |       DU 1       |   |    DU 2    |   |       DU 3       |
   +------------------+   +------------+   +------------------+
              \        \  |            |  /         /
               \        \ |            | /         /
                \        \|            |/         /
 +------+--------+--------+------------+----------+
 |MPEG-2| Payload| end of |  L         | Start of |
 |Header| Pointer| SNDU 1 |  F  SNDU 2 |   SNDU 3 |
 +------+---+----+--------+--+---------+----------+
            |              ^ |          ^
 PUSI=1     |              | |          |
            +--------------+ +----------+

         LF = Length Field
```

Figure 3-3: SNDU packing in ULE method

If multiple SNDU are to be stored into a single MPE-2 TS cell (because SNDU are small enough, there is still ONE payload pointer for the first SNDU to start in this cell, the position of the following ones can be deduced from the length field of each SNDU, as shown in Figure 3-3.

```
   +------------------+   +------------+
   |    Subnetwork    |   | Subnetwork |
   |       DU 1       |   |    DU 2    |
   +------------------+   +------------+
              \        \  |            |
               \        \ |            |    End         Stuffing
                \        \|            |   Indicator     Bytes
 +------+--------+--------+------------+------+------+----------+
 |MPEG-2| Payload| end of |  L         | 0xFF | 0xFF |          |
 |Header| Pointer| SNDU 1 |  F  SNDU 2 |      |      |   ...    |
 +------+---+----+--------+--+---------+------+------+----------+
            |              ^ |          ^
 PUSI=1     |              | |          |
            +--------------+ +----------+

         LF = Length Field
```

Figure 3-4: SNDU End Indicator in ULE method

This kind of packing is implicit and therefore very economic. The counterpart is that there must be an end-indicator of some sort for the last SNDU to be carried. This is done with the Length Field semantic overload: a special value (0xFF 0xFF) is reserved and means: no more SNDU. An example; is shown in Figure 3-4.

3.2.2.3 ULE Analysis

ULE is a very good candidate for IPv4 / IPv6 encapsulation over MPEG-2 Transport Streams, for it respects the necessary requirements:

- General requirements are fulfilled
  - Even if not yet defined, support for ROHC can be added in a way that is not dependant from other assignment authorities (such as IEEE)
- Convergence layer requirement are fulfilled
  - Necessary fields are present
  - Convergence overhead is 14 bytes, but can be reduced to 8 bytes when no MAC address filtering is necessary (e.g. the IRD is a single host, and hence IP-level filtering based on destination address is enough)
- MPEG-2 usage requirements are fulfilled
  - SNDU packing for small SNDU allow full usage of MPEG-2 TS cells
  - Framing overhead is minimal: 1 byte per PDU

Moreover this method is:

- Simple and intuitive
- Extensible
  - with reserved flags
  - with locally (IANA) assignable type field values

3.2.3 Simple Encapsulation (SE)

This encapsulation method, which chronologically speaking is the first, proposes to send IP(v6) packets directly over MPEG-2 Transport Stream, as TS private data, i.e. without any DVB sections mechanisms.

The method is defined in [29], and can be decomposed into two different parts:

- Encapsulating IP(v6) packets (and possibly other packets) in to what will be called Subnetwork Data Units (SNDU)
- Transmitting those SNDU over MPEG-2Transport Stream, i.e. the fragmentation over TS cells

3.2.3.1 SNDU format

```
 .----------------------   SNDU   -------------------------.
+--------+------+----------------------------------+--------+
| Length | Type |                PDU               | CRC-32 |
+--------+------+----------------------------------+--------+
```

Figure 3-5: PDU encapsulation in SE method

The SNDU shown in Figure 3-1includes the whole IPv4 / IPv6 packets with

- A 4 bytes header which includes:
    - A 2 bytes Length field, allowing 64 K-bytes datagrams
    - A 2 bytes type field, allowing protocol multiplexing, following DIX/IEE assignments for values. Currently defined:
        - IPv4
        - IPv6
        - MPLS
        - Bridged Ethernet
- A 4 bytes trailer: a CRC-32, not yet defined, but potentially as in Ethernet, which provides the strong integrity check

This is quite similar to ULE method, but some open points remain:

- There is no Reserved bit
- There is no defined support for MAC address inclusion

3.2.3.2 SNDU packing over TS cells

SE provides a method for

- fragmentation and reassembly of SNDU over TS cells
- packing SNDU

The fragmentation for SE is similar to one used in ULE, hence we can in the same way refer to Figure 3-2.

What is different is the framing. It makes use of both the PUSI and the AFC filed in the MPEG-2 header. The PUSI indicates that at least a new SNDU starts in the MPEG-2 TS cell.

The AFC field reflects the presence of Adaptation field. In this encapsulation method, it has two possible values:

- 01 : AF absent
- 11 : AF present

Whenever an SNDU ends in the MPEG-2 TS cell, the AFC is set, and an AF inserted at the beginning of the payload of the TS cell. The adaptation field includes a pointer that defines where the following SNDU starts.

```
        +-------------------+    +-------------+    +-------------------+
        |    Subnetwork     |    | Subnetwork  |    |    Subnetwork     |
        |       DU 1        |    |    DU 2     |    |       DU 3        |
        +-------------------+    +-------------+    +-------------------+
                   \        \   |             |  /          /
                    \        \  |             | /          /
                     \        \ |             |/          /
    +------+----------+---------+-------------+-----------+
    |MPEG-2| Adapt   p| end of |  L          | Start of |
    |Header| Field   t| SNDU 1 |  F   SNDU 2 |   SNDU 3 |
    +------+---------++--------+-------------+-----------+
                     |          ^ |           ^
    PUSI=1           |          | |           |
    AF=11            +----------+ +-----------+

            LF = Length Field
```

Figure 3-6: SNDU packing in SE method

If multiple SNDU are to be stored into a single MPE-2 TS cell (because SNDU are small enough, there is still ONE Adaptation Field for the first SNDU to finish in this cell, the position of the following ones can be deduced from the length field of each SNDU, as shown in Figure 3-6.

```
0             7 8            15 16                            31
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|ad.hdr.length=3| flags      1  | priv.length=1 |    pointer    |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
                               ^
                               transport_private_data_flag
```

Figure 3-7: Adaptation Field format

The encapsulation method allows for one possible Adaptation Field format, as shown in Figure 3-7.

This method still has many open points:

- This usage of Adaptation Field, helps keeping the 4-bytes alignment of SNDU, which can be of interest for hardware processing. However the following packing has no indication about any alignment procedure.
- Adaptation Field is supposed to let synchronisation between video and data occur, BUT:
    - If important, it should be in the requirements
    - There is no clear/foreseen use cases for this requirement
    - As defined in the draft, no room is left for such synchronization
- The management of last byte(s), especially when inserting an Adaptation Field is not possible, or when it consumes all remaining bytes is not defined.

- The packing of many SNDU in a single MPEG-2 TS cell needs to have a sort of End Indicator as in ULE, but it is not currently defined.

All those points were asked on the mailing list, but led to no answer or updates to the draft. These points may seem not to be of the utter importance with respect to protocol philosophy, but are very important for implementation and interoperability purpose, which is after all the main goal of this project.

3.2.4 Comparison with other existing encapsulation methods

3.2.4.1 Data Piping

The exposed methods are very near from data-piping, in the fact that SNDU are direct payload of MPEG-2 packets. One could see them as an extension that provides the definition of a convergence layer.

In fact it goes beyond that: a level of interaction is introduced with the MPEG-2 part itself, through the PSUI and/or AFC usage. This makes possible some optimization for this convergence layer packing.

3.2.4.2 Data Streaming

To compare properly the encapsulation methods with data streaming, the Asynchronous data streaming model should be used. After all, IP packets (native, in MPLS frames, or transmitted with ROHC, etc.) are essentially asynchronous flows.

Here data streaming is of little help, for PES packets don't bring many, apart from an extra overhead of at least 3 bytes, and the lockage of PUSI and AFC semantics. Moreover there still is a need within data streaming for a convergence layer.

If synchronization with video flow was really needed, an Adaptation Field usage might be good, without PES overhead.

3.2.5 Choosing an encapsulation method for implementation

At some points, a decision had to be made. As the interoperability testing is one of the major goals of the project, both consortia had to agree on a common draft to implement.

Implementation of both drafts implies a raise of efforts, not only in terms of development, but also in terms of tests (unitary and interoperability). And especially interoperability session burden should not be duplicated without strong reasons.

This decision is of course based on technical aspect, but not only. Additional points are also taken into account, i.e.

- draft maturity,
- compatibility with project schedule.

3.2.5.1 Why ULE

The ULE method DOES respect the requirements described in [28].

Moreover, the draft is really alive (i.e. issues can be addressed, responses from the author(s) are received) and progressing well. Furthermore, many open points and issues raised in the -00 version were resolved in the -01version.

So it was agreed by all parties during the September 18th teleconference [32] to implement the -01 version of the ULE method. Even if there are still some open points (see §3.2.5.2) actively discussed on the list [27], each of them has a proposed solution that can be used for interoperability purpose, until a WG consensus is reached.

3.2.5.2 ULE extensions needed for interoperability

Some points are still open in the -01 revision of the ULE draft:

- The Destination Address Indicator has no defined position in encapsulation header
- There is still some contradiction in text with respect to last byte(s) management

So, here are the proposed (on the list) modifications to the draft for those points. Unless explicitly stated otherwise, that's what will be implemented.

Destination Address Indicator

To be inserted within the §4 SNDU Format:

```
.-----------------------   SNDU   -----------------------.
+---+---+-----------------------------------------+--------+
| D | R | Length | Type |            PDU          | CRC-32 |
+---+---+-----------------------------------------+--------+

4.x Destination Field

The most significant bit of the Length Field is a flag indicating
the presence of a destination field, with the following
semantic :
    1 : destination field absent
    0 : destination field present
One exception is transmission of an End Indicator (see 4.y),
in which this bit MUST be set to the value of 1.
```

Last byte management

To be placed in the §5.3 SNDU Packing, and §5.3.1 Encapsulator Packing, wherever a sentence speaks about the last byte(s) management.

```
"If the first two bytes of an SNDU can not be put in TS-cell,
 then, a new TS cell MUST be started."
```

3.2.5.3 Possible ULE extension

Some extensions to ULE are foreseen, i.e. some Greenfield implementations. They are optional, and compatible with the base specifications. They are addressing

- Destination Address removal, and
- New values for type field definition.

Destination Address removal

Although the ULE draft mentions:

```
"The SNDU Destination Address Field is optional.

This field MUST be carried for IP unicast packets destined to
routers. A sender MAY omit this field IP unicast packet and/or
multicast packets delivered to Receivers that are able to utilise a
discriminator field (e.g. the IPv4/IPv6 destination address), which
in combination with the PID value, could be interpreted as a Link-
Level address."
```

We believe that this can also be done in some cases for the addressing of router. For example, when the receiving router is used to link a leaf network, whose delegated prefix is known and where fire-walling rules can be used to accept only the desired packets.

So we'll have in the address resolution tables (foreseen static in the project) a special value for the MAC address: 0x00 0x00 0x00 0x00 0x00 0x00 whose meaning would be in the sender's side to just omit the Destination Address Field.

To be still compatible with the draft, there will be a configuration option on the receiver's side to "allow / forbid reception of unicast IPv4 / IPv6 packets without Destination Address Field present".

New values for type field

For a green-field implementation, a value for ROHC could be used, carved out of the locally defined values.

type field:

- 0x0000 test
- …
- 0x0101 ROHC

3.2.5.4 Addendum

Since the original writing, the ULE specifications have been updated. This led to the personal draft draft-fair-ipdvb-ule-02 which has been later adopted by the working group as working group item and reissued as draft-ietf-ipdvb-ule-00. The working group draft now fully integrates:

- Destination Bit definition, and
- Last Byte clarification.

The proposed 'R' bit in the length field has not been adopted, but there is also currently discussion about its usage for extension headers see § 6.1.2.3.

3.3 Implementation of chosen encapsulation method

3.3.1 Overall Architecture

3.3.1.1 Introduction

The ULE encapsulation is only a way of IPv4/IPv6 delivery over a specific medium, in our case MPEG-2 TS cells. This specification, although rather precise does not solve all problems.

Mainly, it addresses the delivery of IPv4/IPv6 from a purely protocol point of view, and the companion document will also describe a more architectural view. However, the internal architecture, which deals with link to the IP stack, or data structures, is not proposed.

This is the standard way of the IETF, not to delve into internal representation, and focus only on what will finally drive interoperability.

3.3.1.2 Block Diagram

The way IPv4 / IPv6 was designed, they work much better over bi-directional interfaces, which is not the case of the proposed standard. That is why a return link has been envisioned, using SCPC technologies.

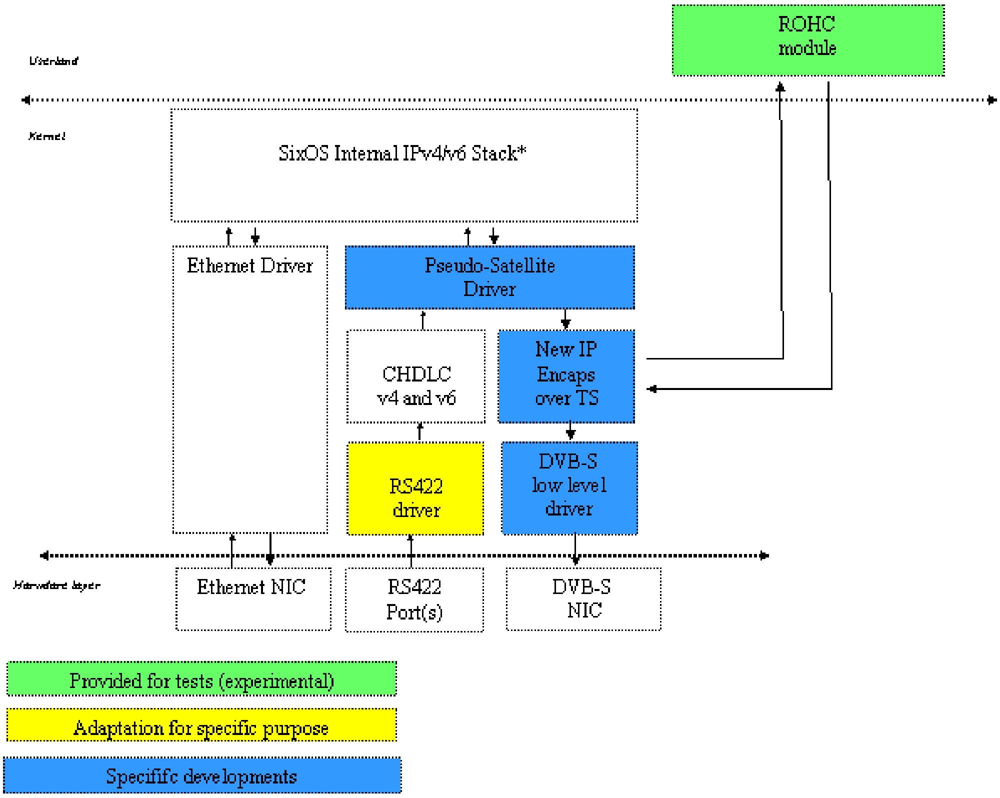

Figure 3-8: Fragmented Internal IP Block Diagram

The trick is here to define an internal architecture that lies below IP level, to offer a logical pseudo-interface that provides bidirectional communications, and that manages then two different Level 2 Accesses: This is what the pseudo satellite driver achieves.

The return link using SCPC, is in itself a purely point-to-point link, (there is a pair of SCPC modems for each DVB receiver), and is also unidirectional. That is why a framing such as CHDLC was chosen rather than some PPP, because of

- its simplicity (no negotiation phase), and
- its ability to run on unidirectional links (by disallowing the keep-alive overhead).

The direct link makes use of the ULE encapsulation. It is a point-to-multipoint technology, which as we'll see in §3.3.1.3, will need IP to be a little bit adapted.

3.3.1.3 IP behaviour

In the architecture we have chosen, each router "sees" the DVB link as a pure bi-directional link, no matter what their position is (DVB sender or receiver).

This kind of link has some properties that may lead IP to behave in an odd manner, or to try to make useless optimization. This is due to the very nature of transmissions:

- The DVB sender can address all receivers, in some broadcast fashion.
- The DVB receiver can only speak to the DVB sender, and hence don't have direct access to

- o broadcast capacities,
- o unicast access to another receiver.

This leads to some modifications of classical IP/IPv6 behavior.

3.3.1.3.1 NBMA mode

NBMA stands for Non-Broadcast Multiple Access. This mode will drive the removal of local routing optimization i.e. the Redirect Messages.

Of course this will also have to be taken into account at a later time, should any routing protocol be deployed over such links. But this point is currently out of the scope of this project, and may be left for further activities.

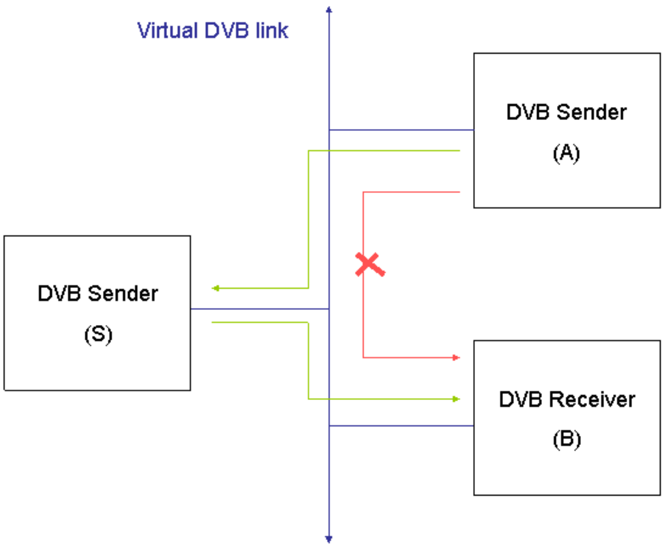

Figure 3-9: Packet Flow between receivers

In Figure 3-9 we can see that whenever receiver A wants to send packets to receiver B, they can not cross directly the virtual DVB link, but instead are to be sent to S which will forward them.

In a normal IP system, this would lead the router S to send to A an optimization message telling him that target B is on-link. This kind of situation is detected when:

- the outgoing interface to forward a packet is the same as the incoming one, and
- the source of this packet is viewed as on-link (i.e. the prefix matches).

This would be done with an ICMP Redirect message (or ICMPv6). So, to avoid Redirect storm, (S) has to be configured, to inhibit those ICMP messages on this kind of link.

3.3.1.3.2 Layer 3 filtering

On the receiving side, the problem is quite different, because packets received through the DVB link should really not be forwarded through the same link (unless there is a big problem in the routing architecture).

However there is a possibility that an encapsulation optimization may lead to such a situation. This would be the case when we decide to omit the destination MAC address in ULE encapsulation, even for unicast packets.

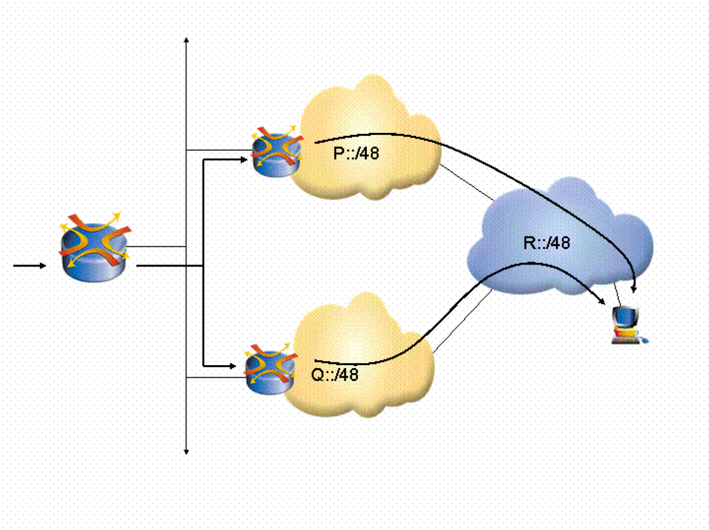

Figure 3-10: Packet Duplication

If we take the example show in Figure 3-10, we can see that for a packet meant for a host in the S::/48 network, the fact that no MAC address is used on the DVB link, will lead to packet duplication. The best way to avoid this situation is to use MAC address omission for unicast packets, ONLY for leaf networks, i.e. for the P::/48 and Q::/48 networks. It might be even safer to allow it ONLY when the leaf network CAN NOT act as a transit network for some other destinations.

This is however not sufficient, because if many receiver leaf networks use the same policy, their access router will be in the Redirect Condition described above. In this case, Redirect Inhibition is not enough, the packet must also be silently dropped.

This can be done with some fire-walling rule combined with some a-priori knowledge of the leaf network prefix, or it can be done in a way close to the RPF checks:

On the DVB interface, if redirect condition is triggered:

- No redirect is sent,
- Initial packet is dropped.

3.3.2 Technical Integration into SixOS

The ULE encapsulation is only a part of an overall mechanism, which can not be provided as standalone software.

This piece of software is integrated into the SixOS, which is a FreeBSD-derived embedded Operating System of the 6WINDGate™ 6200 Series.

3.3.2.1 DVB driver and Cards

The lowest part of the software that had to be integrated into the SixOS was the DVB card driver itself that manages flows at TS-cell level.

3.3.2.1.1 Supported Hardware

It is made for the Computer Modules DVB Master cards (See http://www.computermodules.com/broadcast/broadcast-dvb.shtml)

This single driver can manage both:

- DVB Master III RX™ card
- DVB Master III TX™ card

It is also expected to work on the DVB Master III FD (Full Duplex) cards, but has not been tested on those cards.

3.3.2.1.2 Supported OS

A LINUX version was provided by the card manufacturer. It has been ported from LINUX to FreeBSD 4.8 on a first stage, and then integrated into the SixOS.

Some efforts are currently made to export this ported drivers, to make it be inserted into the official FreeBSD distribution, hence providing support for another satellite card for the FreeBSD community.

3.3.2.2 The Netgraph Architecture

The implementation of the ULE encapsulation and its integration into a virtual interface makes heavy usage of the Netgraph Architecture. This architecture (which is described in http://www.daemonnews.org/200003/netgraph.html) consists of:

- A set of elementary bricks (called nodes), either provided by the system or newly designed ones. Each of them defines its own code, i.e.
    - a list of communication streams (hooks), and
    - a list of external commands.
- A set of tools allowing to:
    - create/destroy nodes,
    - connect two nodes by some of their hooks, and
    - send control messages to nodes.
- An SDK, with a set of primitives for:
    - Sending/Receiving through the hooks,

- o Receiving Control Messages.

Each hook is bidirectional, but only two hooks can be connected together. It implies the use of specific intermediate nodes to allow many-to-one connections.

3.3.2.3 The pseudo-interface Trees

3.3.2.3.1 DVB-Sender side

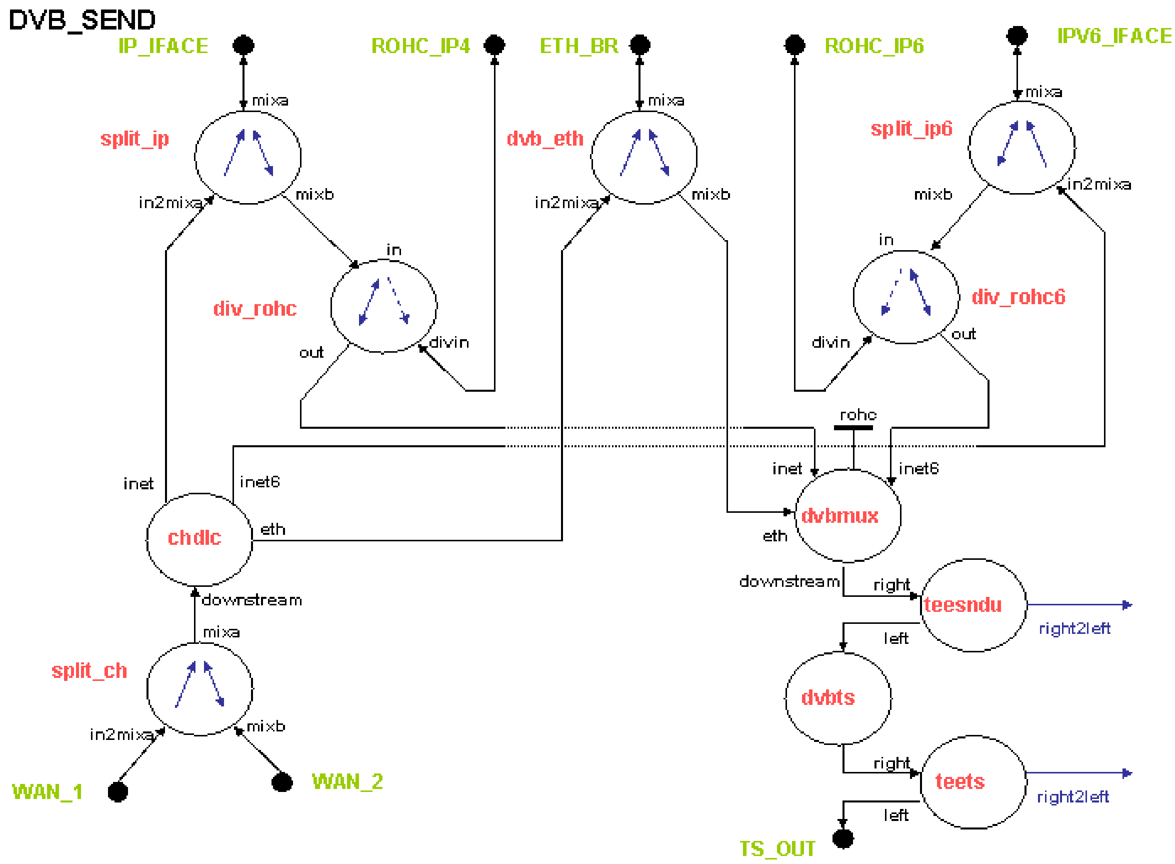

Figure 3-11: Senders Graph

In the Sender Graph as show in Figure 3-11, the upper bullets are:

- IP_IFACE and IPv6_IFACE:

  They are directly connected to the pseudo-interface node. Through those hooks the IP (IPv6) packets are flowing.

- ROHC_IPv4 and ROHC_IPv6:

  They are here to be connected to the **rohc** daemon.

  When ROHC_IPv6 is connected to the **rohc** daemon, each IPv6 packet sent through the interface will be sent to the daemon for computation. It will be re-injected by the very same hook after header compression, and will follow its normal operations.

- ETH_BR is an entry point for inserting full Ethernet frames into the encapsulation machinery. It is meant to be linked to bridging pseudo interface.

The lower bullets are:

- WAN_1 and WAN_2:

  They are linked to the serial card driver; each one addressing a different port. Only received CHDLC/CHDLCv6 packets are expected.

- TS_OUT:

  It is linked to the DVB driver itself but not directly as we'll see in §3.3.2.4), and through that hook, TS-cells are flowing.

3.3.2.3.2 DVB Receiver Side

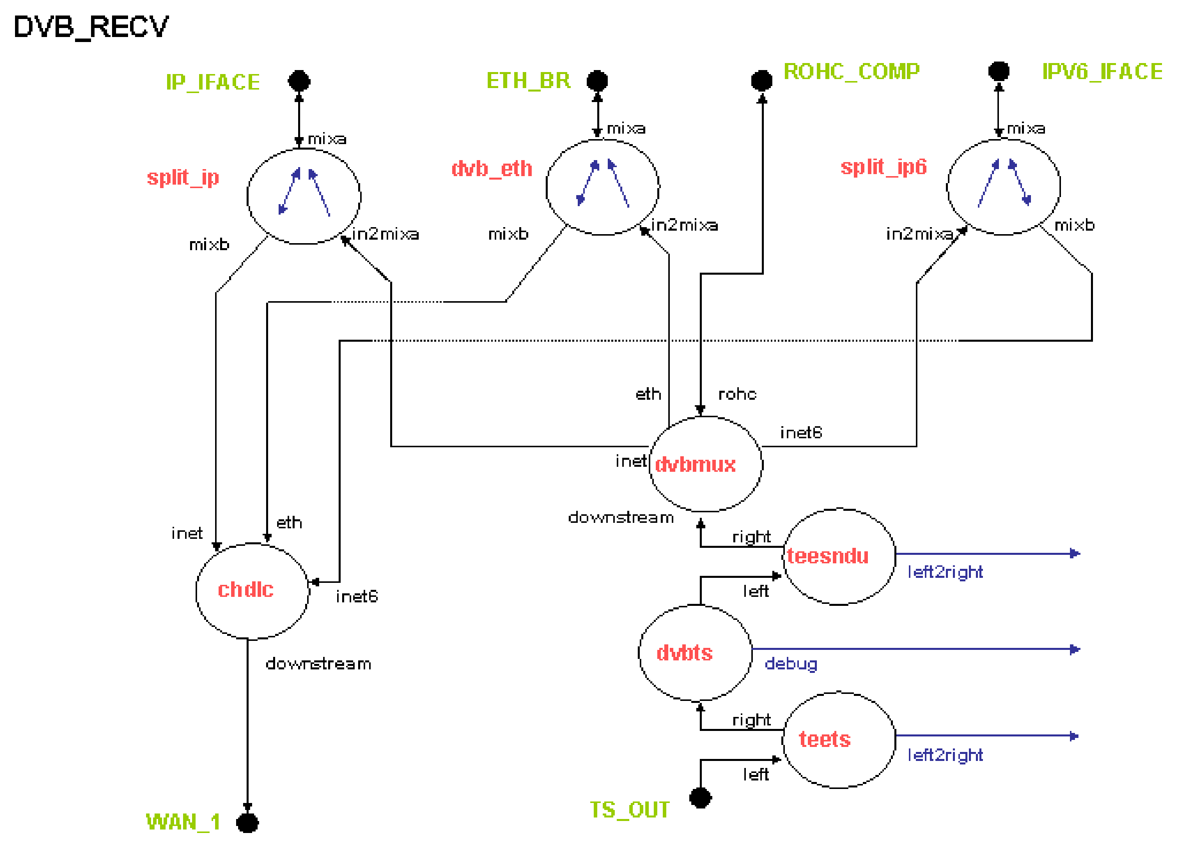

Figure 3-12: Receiver Graph

In the Receiver Graph, as show in Figure 3-12, the upper bullets are:

- IP_IFACE and IPv6_IFACE:

  They are directly connected to the pseudo-interface node. Through those hooks IP (IPv6) packets are flowing.

- ROHC_COMP:

  It is always connected to the **rohc** daemon.

  Received ULE-managed ROHC frames are sent through this link for header decompression. The result is a full IP/IPv6 packet sent back through the same link and then dispatched as would normal ULE have received this IP and/or IPv6 packet.

- ETH_BR is an entry point for inserting full Ethernet frames into the encapsulation machinery. It is meant to be linked to bridging pseudo interface.

The lower bullets are:

- WAN_1 and WAN_2:

  They are linked to the serial card driver; each one addressing a different port. Only received CHDLC/CHDLCv6 packets are expected.

- TS_OUT:

  It is linked to the DVB driver itself, but not directly as we'll see in §3.3.2.4. Through this hook, only TS-cells are expected to flow.

3.3.2.4 Netgraph / DVB driver link

The DVB card driver, as ported from the LINUX world, does not offer netgraph-like entry points. The link between those two elements has been realized using a sending daemon, as shown in Figure 3-13.

It is currently only a proof-of-concept implementation, and it has been checked to not be a critical point with respect to performance. Its integration within the DVB driver itself will be a complex work, more suited to an industrialisation phase.

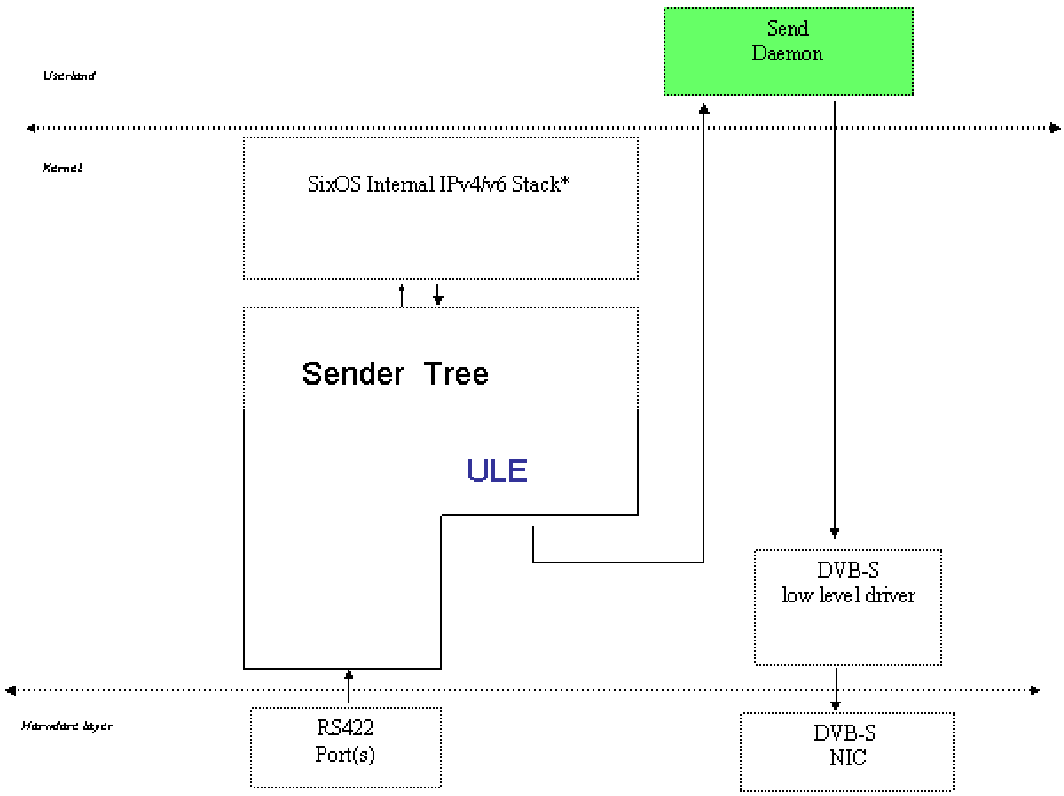

Figure 3-13: Netgraph/Driver link

The sending daemon performs the

- relay of TS cells from the Sender Tree to the DVB driver, and the
- insertion of null TS cells (PID 8191) to guaranty a minimum flow of 1 Mb/s.

3.3.3 User's view

The user will access the DVB system through an integrated CLI that will be described in a separate document.

We will here just give an overview of the DVB related commands:

3.3.3.1 DVB related commands on the DVB-Sender's side:

- **arpentry** prefix mac pid
  This creates in the DVB sender a static association between an IPv4 destination prefix, and a pair of (DVB MAC address, PID value).
  Example:
  ```
  arpentry 10.69.0.0/16 01:02:03:04:05:06 68
  ```

- **ndpentry** prefix mac pid
  This creates in the DVB sender a static association between an IPv6 destination prefix, and a pair of (DVB MAC address, PID value).
  Example:
  ```
  ndpentry 2001:660:3008:1970/64 01:02:03:04:05:06 69
  ```

- **rohc** {none | ipv4 | ipv6 | all}
  This specifies on which flow ROHC is to be activated. Possible values are:
  none - no rohc activated
  ipv4 - rohc only for IPv4
  ipv6 - rohc only for IPv6
  all - rohc for both IPv4 and IPv6
  Example:
  ```
  rohc ipv6
  ```

- **crc32** {enable | disable}
  This allows to skip the CRC32 computation (if de-activated, 4 null bytes will be stored instead).
  Example:
  ```
  crc32 disable
  ```

3.3.3.2 DVB related commands on the DVB-Receiver's side:

- **dvb-mac** mac
  This sets the MAC address of the DVB Receiver, with a 6 bytes value.

Example:
```
dvb-mac 01:02:03:04:05:06
```

- **pid** pid
  This adds a PID that will be accepted for ULE.
  Example:
  ```
  pid 68
  pid 69
  ```

- **crc32** {enable | disable}
  This allows to skip the CRC32 check (considered as always TRUE).
  Example:
  ```
  crc32 disable
  ```

3.3.4 ULE design

3.3.4.1 Functional Decomposition

ULE is indeed made of several distinct components, working each at different levels. We can separate it into two major functional blocks:

- The first one deals with IP and IPv6 packets and transforms them into SNDUs (encapsulation, length, CRC32, etc).
- The second one deals with SNDUs and manages fragmentation/reassembly over TS-cells.

This lead to integrating them into two separate netgraph nodes, hence allowing to insert checkpoints between them (see §3.3.4.4.1).

3.3.4.2 SNDU management

The first node (**dvbmux** in Figure 3-11 and Figure 3-12) is just below the pseudo interface level.

This block performs direct data manipulation on flows and involves no inter-packet or inter-SNDU processing hence no state is ever kept.

3.3.4.2.1 Sending Part

Its input/output are:

- from upper level:
  - IPv4 packets
  - IPv6 packets
  - Compressed IP/IPv6 packets
  - Full Ethernet frames

- toward lower level:
    - fully formed SNDU (including header and trailer)
    - associated PID

It first performs a static address resolution. Static in a sense that no protocol is here involved, a table is just searched. It does not preclude any protocol usage for filling this internal association table.

This lookup provides the destination MAC address and the PID to be used. Here we must note that an add-on to the basic specification was done: a particular value for the MAC address has been chosen to mean that NO MAC address should be inserted into the SNDU.

This value is **`00:00:00:00:00:00`**. Anyway, this value is currently forbidden as a real destination MAC address, hence, this small add-on is:

- Fully compatible with base specs when not used
- Does not interfere nor preclude any real MAC address usage

SNDU is then formed with its header, possible destination MAC address, and a CR-32 is computed.

3.3.4.2.2 Receiving Part

Its input/output are:

- to upper level:
    - IPv4 packets
    - IPv6 packets
    - Compressed IP/IPv6 packets (+)
    - Full Ethernet frames

- from lower level
    - fully formed SNDU (including, header, trailer)

(+) In this case, compressed packets are not directly sent to the pseudo-interface level. They are rather sent to the de-compressor daemon and the result (a full IP or IPv6 packet) is sent to the pseudo-interface level.

The received SNDU is supposed to be correct with respect to length (which is used during reassembly), and no further check is made.

The CRC32 is then (optionally) verified, and if present, destination MAC address checked against local MAC address declaration.

The header and trailer are then removed, and the packet is de-multiplexed accordingly to the type field found in the header.

3.3.4.3 TS-cells management

The first node (**dvbts** in Figure 3-11 and Figure 3-12) is just between the multiplexer level, and then DVB driver level.

This block performs fragmentation and reassembly. It does not perform inter-TS-cells processing. For this purpose, some state is created and kept, associated to PID contexts.

3.3.4.3.1 Sending Part

Its input/output are:

- from upper level:
    - fully formed SNDU (including header and trailer)
    - associated PID
- to lower level
    - TS-cells

It performs fragmentation of SNDU over TS-cells and TS-cells management. To do this it uses a per-PID context that includes

- continuity counter and
- last 'unfinished' TS-cell.

The fragmentation manages the last byte(s) as described in the draft, and in the case of incomplete TS-cells, keep it associated to the context, with a timer set.

This TS-cell will be used for packing if further SNDU using the same PID are available in time. If no other SNDU is available before timer expires, the TS cell is stuffed and sent.

For the sake of testing, this timer is configurable (for example basic tests with were done using a 5 seconds timer) and is by default set to its minimum value which is **1 millisecond**.

As the emission of IP/IPv6 packets through a specific PID is driven by

- IP/IPv6 routing and
- local association table,

a PID usage is assumed to be safe, and so per-PID contexts are created on the fly.

3.3.4.3.2 Receiving Part

Its input/output are:

- to upper level:
  - fully formed SNDU (including header and trailer)
  - SNDU length being checked

- from lower level:
  - bunch of TS-cells

The very first thing to do is to cut the TS-cell bunch into separates TS-cells to process them individually. They are then checked (Error flag, continuity counter, etc.) and reassembly is done, using pieces of information found in a per-PID context:

- continuity counter,
- working SNDU, and
- ULE status (IDLE, …)

Not all PIDs are free for ULE usage, and more over, the received DVB flow can not really be trusted, so the per-PID contexts MUST NOT be created on the fly. They are hence statically created by configuration (see §3.3.3.2).

3.3.4.4 Debugging Tools

3.3.4.4.1 Dumps Facilities

The software architecture was meant to provide dump facilities at various levels. This is helpful for debugging purpose and/or protocol analysis. Such dumps will be intensively used for the basic tests and also for the interoperability tests, should problems arise.

Examples will be provided, on a ping made from the DVB encapsulator to the DVB decapsulator:

```
ping6 -c 1 -s 10 crochet6
```

IP level

As the whole software provides an interface abstraction, those dumps are made at IP (IPv6) level using the classical tcpdump tool:

```
tcpdump -n -i dvb0 -vvv -s 1000 –x

17:24:32.723224 2001:660:3008:1789::5 > 2001:660:3008:1789::6: icmp6: echo
request (len 18, hlim 64)
                         6000 0000 0012 3a40 2001 0660 3008 1789
                         0000 0000 0000 0005 2001 0660 3008 1789
                         0000 0000 0000 0006 8000 97cb 06b8 0000
                         3ff1 b4d0 000b 086a 0809
17:24:32.795875 2001:660:3008:1789::6 > 2001:660:3008:1789::5: icmp6: echo
reply (len 18, hlim 64)
                         6000 0000 0012 3a40 2001 0660 3008 1789
                         0000 0000 0000 0006 2001 0660 3008 1789
                         0000 0000 0000 0005 8100 96cb 06b8 0000
                         3ff1 b4d0 000b 086a 0809
```

SNDU level

Those dumps are made thanks to a tool able to get a grip on the specific hooks defined for this purpose (see Figure 3-11 and Figure 3-12):

- `teesndu: left2right -` for reception
- `teesndu: right2left -` for emission

```
tdvb.sh dump sndu-out

0000:  00 44 86 dd 01 02 03 04 05 06 60 00 00 00 00 12  .D........`.....
0010:  3a 40 20 01 06 60 30 08 17 89 00 00 00 00 00 00  :@ ..`0.........
0020:  00 05 20 01 06 60 30 08 17 89 00 00 00 00 00 00  .. ..`0.........
0030:  00 06 80 00 9d 37 06 c2 00 00 3f f1 b6 88 00 08  .....7....?.....
0040:  01 3f 08 09 72 82 f1 f0                          .?..r...
```

TS-cell level

On the reception side, two sub-levels are available:

- all TS cells (as a very least resort, because null TS cell padding makes it of little value), or
- only TS cells whose PID has been declared as ULE enabled.

Those dumps are made with help of a tool able to get a grip on the specific hooks defined for this purpose (see Figure 3-11 and Figure 3-12):

- `teets: right2left -` for emission
- `teets: left2right -` for reception of all TS cells
- `dvbts: debug -` for reception of TS cells associated to an correct PID

```
tdvb.sh dump ts-out

0000:  47 40 44 21 00 00 44 86 dd 01 02 03 04 05 06 60  G@D!..D........`
0010:  00 00 00 00 12 3a 40 20 01 06 60 30 08 17 89 00  .....:@ ..`0....
0020:  00 00 00 00 00 00 05 20 01 06 60 30 08 17 89 00  ....... ..`0....
0030:  00 00 00 00 00 00 06 80 00 3e 73 06 cb 00 00 3f  .........>s....?
0040:  f1 b8 8f 00 07 5d f4 08 09 7e 1e 50 65 ff ff ff  .....]...~.Pe...
0050:  ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff  ................
0060:  ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff  ................
0070:  ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff  ................
0080:  ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff  ................
0090:  ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff  ................
00a0:  ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff  ................
00b0:  ff ff ff ff ff ff ff ff ff ff ff ff              ............
```

3.3.4.4.2 Counters

To follow the ULE process, a several counters are available:

- at MUX level (i.e. managing SNDU):
  - received and sent (from/to lower) packets (i.e. SNDU) and bytes
  - received (from lower) invalid SNDU
  - received (from lower) too short SNDU
  - received (from lower) unknown SNDU types
  - received and sent (from/to upper) IP packets
  - received and sent (from/to upper) IPv6 packets
  - received and sent (from/to upper) Ethernet Frames
  - received and sent (from/to upper) MPLS Frames
  - received (from lower) ROHC frames
    - received ROHC frames, successfully decompressed into IPv4 packets
    - received ROHC frames, successfully decompressed into IPv6 packets
  - sent (from upper) ROHC frames (also incrementing the IP/IPv6 packet counter)

- at TS cell level:
  - received and sent (from/to lower) packets (i.e. TS cells) and bytes
  - received (from lower) invalid TS cells
  - received (from lower) too short TS cells
  - received (from lower) TS cells with MPEG Error set
  - received (from lower) TS cells with Continuity Counter error
  - received (from lower) TS cells with no associated PID
  - received (from lower) TS cells with wrong AFC

- received (from lower) TS cells with wrong Payload Pointer

```
tdvb.sh get-stats
Rec'd response "getstats" (5) from "dvbmux:":
Args:   { recvOctets=0 recvPackets=0 recvRunts=0 recvUnsupported=0
recvInvalid=0 xmitOctets=2536 xmitPackets=36 memoryFailures=0 recvTest=0
recvUnreach=0 IPtoupper=0 IPfromupper=18 IP6toupper=0 IP6fromupper=18
ETHtoupper=0 ETHfromupper=0 MPLStoupper=0 MPLSfromupper=0 ROHCtoupper=0
ROHCfromupper=0 ROHC_IPv4=0 ROHC_IPv6=0 }
Rec'd response "getstats" (6) from "dvbts:":
Args:   { recvOctets=0 recvCells=0 recvRunts=0 recvInvalid=0
xmitOctets=6392 xmitCells=34 memoryFailures=0 SNDUtoupper=0
SNDUfromupper=36 MPEGerr=0 Counter=0 noPID=0 wronfAFC=0 wrongPP=0 endSNDU=0
}
```

3.3.5 Basic tests

Basic Tests and results are provided in a separate document (Name: “Basic functionality test report”, document number: #010). Here, we will just provide a quick overview over selected tests.

They are mainly articulated around three main axes:

- Host-to-Host tests (IP/IPv6 level):
  Merely a few ping and ping6 from one host behind the DVB Sender to one other host behind the DVB receiver. This will validate:
  - correct IP and IPv6 over MPEG-2 encapsulation
  - end-to-end bidirectional connectivity
    - SCPC return link
    - DVB pseudo interface

- Router to Router tests (SNDU level):
  The dumps will be provided at SNDU level.
  This will be done with one ping and one ping6, with and without destination MAC address insertion. This will validate:
  - SNDU creation (length, payload type) for IPv4
  - SNDU creation (length, payload type) for IPv6
  - SNDU MAC address management
  - CRC32

- Router to Router tests (TS-cell level):
  The dumps will be provided at TS-cell level.
  This will be done with ping(s) and ping6(s), with a selected set of payload sizes that

will cover the various cases of fragmentation/reassembly over TS cells, as described in ULE. This will validate:

- Tiny packets packing
- Last byte(s) management for packing
- Padding

4 INTEROPERABILITY TESTING

The intention of this chapter is to describe roughly the work done for the preparation of the interoperability tests as the test architecture, test cases and test results are summarized in a separate document "Interoperability test report v1.4.doc" which is Deliverable D 3.1 and document #009 in the Documents list.

The first version of the "Interoperability test report" was created by IABG, discussed with ESA during the Implementation Review Meeting on 12th December 2003 in Paris. The comments received from ESA have been integrated and the document distributed to the of Joanneum Research team to solicit their comments. The received comments have been integrated, together with a finer specification of the necessary test setup and initial configuration parameters.

The data collected during the interoperability tests (e.g. TS-cell dumps from the 6WINDGates, packet interarrival measurements for VoIP transmission and video streaming) have been processed and evaluated by IABG and 6WIND and the results have also been contributed to the interoperability document, as separately attached files. These files ("Packet interarrival measurement results.zip" and "ULE Salzburg Dumps 6WIND 02 2004.tgz") have been uploaded to eProject by IABG.

Furthermore, IABG and 6WIND have prepared the collected data and compiled an Interoperability Test Report for the ipdvb WG. The focus of this additional dissemination document was to give other interested parties the possibility to compare locally collected TS-cell dumps with the TS-cells collected during the interoperability test in Salzburg and to derive from this comparison if their implementation is compliant to the 6WINDGate (6WIND) or the ODG (Open DVB Gateway, GCS Salzburg). The document ("ipdvb WG Interoperability Test Report.pdf") has been uploaded to the project webpage hosted by ESA and the availability (together with a link) has been announced to the ipdvb WG via mail.

4.1 Specification of interoperability test scenarios

The interoperability test scenarios are specified in detail in the "Interoperability test report" document #009.

4.2 Implementation of the interoperability test scenarios

The implementation of the interoperability test scenarios are given in the "Interoperability test report" document #009.

4.3 Execution of interoperability test

The execution of the interoperability test scenarios along with the results are described in the "Interoperability test report" document #009.

4.4 Summary of the interoperability test

Summarizing, the interoperability tests have been very successful. They involved

- two different types of DVB-S sender (6WIND and ODG), and
- three different types of DVB-S receiver (6WIND, Pent@Value and TechnoTrend),

and demonstrated the complete functionality of ULE for all of them.

Furthermore during the VoIP and video streaming test scenarios the packets have been locked on the receiver side in order to post process them concerning their packet interarrival statistics.

5 DEMONSTRATION OF ADVANCED NETWORKING

As the Ultra Lightweight Encapsulation (ULE) specification aims at being an IP encapsulation technique which helps to implement the native transmission of IPv4 and IPv6 packets over MPEG-2/DVB networks, it needs to be verified that the developed ULE implementations are usable in realistic scenarios which go beyond the test cases used for the Interoperability tests (see Chapter 4). Possible scenarios, which could apply to satellite ISPs networks or teleport providers, are:

- Transmission of bulk IPv4 and IPv6 unicast traffic
- Transmission of real-time IPv4 and IPv6 unicast traffic
- Transmission of real-time IP Multicast traffic

Moreover, it is useful for this project to also demonstrate scenarios which might only be possible due to the used specific internal implementation design, i.e. which make use of the fact that within the 6WINDGate a unidirectional DVB-S and serial interface are combined into a bidirectional virtual dvb interface. Possible examples are:

- Use of ISAKMP and IPsec over the bidirectional virtual link
- Use of PIM-SM for IPv6 over the bidirectional virtual link

5.1 Investigation of demonstration scenarios

Taking the above described scenarios which are of interest for satellite ISPs and teleport operators into account, the following list of demonstration scenarios has been investigated:

- Transmission of bulk IPv4 / IPv6 TCP unicast traffic
- Transmission of real-time IPv4 / IPv6 UDP unicast traffic
- Transmission of IPv4 / IPv6 Multicast traffic with static IP Multicast routing
- Transmission of IPv6 Multicast traffic with dynamic IP Multicast routing
- Transmission of secure IPv4 / IPv6 unicast traffic
- Enforcing Quality of Service on IPv4 / IPv6 unicast traffic
- Transmission of IPv4 / IPv6 unicast traffic with ROHC

5.2 Specification of demonstration scenarios

The demonstration scenarios have been specified as described in the document #020 “Advanced Networking Demonstration - v1.1.doc”.

5.3 Integration of demonstration scenarios

The demonstration scenarios have been integrated as described in the document #020 “Advanced Networking Demonstration - v1.1.doc”.

5.4 Execution of demonstrations

The demonstration scenarios have been executed as reported in the document #020 “Advanced Networking Demonstration - v1.1.doc”.

5.5 Summary of the Advanced Demonstrations

Summarizing, the Advanced Demonstrations have been done very successful. They involved

- the demonstration of transmitting IPv4 / IPv6 unicast,
- the demonstration of transmitting of IPv6 multicast,
- the demonstration of transmitting of IPv4 / IPv6 unicast with IPsec,
- the demonstration of transmitting IPv4 / IPv6 unicast with QoS rules enforced, and
- the demonstration of transmitting IPv4 / IPv6 unicast data with ROHC.

The latter demonstrations with IPsec and ROHC have been extended on request of ESA to also make use of VoIP over IPv4 / IPv6 or of iperf simulated VoIP over Ipv4 / IPv6.

All demonstrations showed that the ULE protocol is able to encapsulate and transmit a broad variety of typical IPv4 / IPv6 traffic. The demonstrations furthermore showed that the ULE implementation within the 6WINDGate is able to make use of the advanced IP functionalities of the 6WIND SixOS, i.e. IPsec or QoS. Additionally it was demonstrated that the ULE implementation of 6WIND with the additional feature of combining the unidirectional DVB-S links and the serial link into one logical dvb0 interface enables the use of even more advanced functionalities, i.e. IPsec or IP Multicast routing without modification to those services.

All demonstrations and tests which are required to reach the goals of the Advanced Demonstration (e.g. showing the usage of ULE in typical ISP / Teleport scenarios) have been defined, integrated and executed successful.

6 CONCLUSION, DISSEMINATION AND RECOMMENDATIONS FOR FURTHER DEVELOPMENTS

In this chapter we will draw conclusions and present lessons learned from what has been done and achieved by this project with respect to ULE implementation, achieved standardization, and manufacturer awareness. Furthermore, the broad dissemination activities of this project are summarized. Finally, possible next steps are proposed and recommendations are given which address the areas “Analysis of ULE performance”, “Standardization”, and “Deployment”.

6.1 Conclusions and lessons learned

This chapter presents the conclusions and lessons learned from this project, categorized into the subjects ULE implementation, IETF Standardization, manufacturer awareness, and DVB-S TX / RX card integration.

6.1.1 ULE Implementation

In summary, it can be stated that the current version of ULE is already in a mature state, which allows its implementation along with successful interoperability tests and demonstration of more advanced usages. Another indicator for this is also the adoption of the latest personal ULE draft (which was basically implemented during this project) by the established ipdvb working group as working group draft. The working group now intends to further progress the draft, i.e. discusses if modifications and/or extensions are necessary and justified by user requirements. Furthermore, the ULE activities have been recognized by the ETSI BSM working group and contacts have been established.

Due to the wide dissemination activities, several manufacturers either declared their interest to implement ULE (e.g. Thales Broadcast & Multimedia, WISHnet, and Efficient Channel Coding) or have already presented products (e.g. Data Planet International). Additionally, other projects (e.g. SATIP6, INSC, SILK) have also stated their interest in ULE.

6.1.1.1 ULE base specs implementation and interoperability testing

The implementation of ULE within 6WIND’s SixOS has been done successfully. This was proved by the interoperability tests with the Open DVB Gateway (ODG) of GCS and the ULE implementation for TechnoTrend and Pent@Value DVB-S receiver cards and the advanced demonstrations.

The implementation phase of ULE itself was not a very difficult one, because the used ULE specification was relatively clear and precise. The standard IETF process, i.e. giving some weight to early implementers during the discussions on the mailing list about open issues and necessary clarifications, proved to be efficient as it supported the evolution of the ULE specification along with the implementation.

The successful interoperability tests were strongly supported by the prior preparation work, i.e.:

- intensive discussion on the working group mailing list about necessary clarifications and precisions
- definition of common test cases which addressed all corner cases of the specification
- exchange of full hex dumps captured on ULE and TS cell level for verification

It can be underlined that the preparation of interoperability tests in such detail is strongly recommended. Furthermore, it proved to be helpful that the implementers where able to debug and recompile their software on the fly to quickly fix minor interpretation issues.

6.1.1.2 ULE usage in advanced demonstration

The integration of ULE in 6WIND's full fledged 6WINDGate router system which also provides additional services like IPsec, static IP Multicast routing, and DiffServ QoS successfully showed in the advanced demonstrations that such services can be easily provided over links using the ULE encapsulation method. When making use of the advanced integration of the DVB-S link and a serial return link in the SixOS, i.e. combining both to a logical bi-directional dvb0-interface, it was possible to show that advanced services which require bi-directional communication, like ISAKMP negotiation, or dynamic IP Multicast with PIM-SM, can be transparently deployed over such links.

Only few modifications where needed in the internal SixOS architecture to integrate QoS and IPsec over the logical dvb0-interface. These changes were mainly caused by implementation specific issues, i.e. they were linked with the 'dynamic' nature of the interface. However, apart from this very specific issue, the achieved bi-directional design of the dvb0-interface gave access to all interesting and advanced features (e.g. ISAKMP negotiation, or dynamic IP Multicast with PIM-SM) without specific developments.

Summarizing, it can be said that providing a well designed abstraction of a classical and well-known interface (e.g. Ethernet, point-to-point, etc.), which does take into account the necessities of IP-based protocols, can easily utilize the advanced functionalities of a standard system without additional modifications.

6.1.2 IETF Standardization

6.1.2.1 Status

This project has provided a great support for IETF standardization of the selected ULE encapsulation method. Along with the other consortium, and with remarkable support from the IETF WG chair, good progress has been made. Achievements are the

- creation of an IETF Working Group for IP over DVB (ipdvb), and
- adoption of personal ULE draft draft-fair-ipdvb-ule-02.txt as a working group item.

Currently, the ULE draft is clearly targeted to become a RFC approved by the IESG. The two implementations done by this project and the other consortium clearly support this goal as at least two independent implementations are required before becoming RFC.

6.1.2.2 Draft/RFC support

The current status of the ULE specification does not yet mean that the work is finished. Standardization in general is a long process, and many discussions are still to be held on the IETF ipdvb mailing list.

Before advancing to RFC status, if subsequent modifications were adopted by the IETF ipdvb working group, some more interoperability tests would be definitely required.

6.1.2.3 Draft/RFC evolution

There are still some open points about the ULE encapsulation. Recent discussions on the mailing list have shown potential interest in security features (e.g. scrambling / encryption) and in FEC features, both taking place at ULE level.

Whether those specific features will be needed and standardized is not yet decided, but what is more important is that this clearly shows that ULE would benefit from being extendable and if possible in a backward-compatible way.

This led to interesting discussions on the mailing list for the opportunity of "extension headers" and their possible format.

Two propositions for this extension mechanism are now merged and offer the combination of low overhead and backward compatibility for future implementation:

- 1 bit in ULE header to indicate presence of extension headers (taken from the length field)
- One or several extension headers before the actual payload. Each extension header has the same 'internal' header:
    - 2 bit for extension header chain management
        - 1 bit for presence of a next extension header
        - 1 bit for the behavior in case of a unknown extension header (skip or drop packet)
    - 6 bits for type (from a specific namespace)
    - one byte for length
    - "payload" of the extension header

This allows extension to be added in a smooth way with an overhead of 2 bytes per extension. It furthermore permits, thanks to the length field and the behavior bit, that some extension headers can be parsed blindly and therefore provides some backward compatibility with implementations which do not understand all extension headers.

6.1.2.4 Address Resolution

This necessary topic has not yet been addressed by the ipdvb working group. It would be beneficial to have some mechanism and protocol developed which allows for more flexibility than SI tables do, especially if we keep in mind some advanced features of IPv6 (e.g. Address Autoconfiguration or Privacy Extensions (RFC 3041)).

From what has been investigated until now, a general and unique solution is probably not possible, because ULE defines the forward way and makes no assumption on the return path. Nevertheless, it would be beneficial to describe some general framework of satellite networks, which summarizes common architectures and deployments. The main differences will not be related to the return link itself, but rather to its properties like:

- present or not,
- broadcast or not,
- bunch of Point-to-Point return links,
- …

This would, in a second step, allow developing solutions addressing the specific needs and possibilities of the described architectures and deployments. One specific goal for IPv6 could be to re-use as much as possible from the wide functionality provided by the Neighbor Discovery Protocol.

If possible, the mechanisms and protocols used for address resolution could furthermore provide hooks to do

- PID selection
- Encapsulation selection (MPE or ULE)
- DVB-MAC address selection
- …

for both unicast and multicast.

The area of address resolution would also be a good place to spend some more effort on thoughts about the semantic of DVB MAC addresses as introduced in the ULE encapsulation method. For instance, an automatic multicast mapping close to what exists for IPv4/IPv6/Ethernet (as already seen in other encapsulation methods) could be proposed. This would allow better MAC address filtering.

6.1.2.5 Manageability of ULE

To be deployable in larger scales, a system must be manageable. Furthermore, it should be manageable by standardized protocols and provide the possibility to be integrated into already deployed management environments.

To reach an equal level of manageability like other IP components (e.g. routers) do, the ipdvb working group should define and standardize a Management Information Base (MIB) for ULE. This would for example allow the management of ULE capable equipment via SNMP.

Currently, nothing has been done in this area, but to reach an industrial level, this gap has to be filled.

6.1.3 Manufacturer awareness

The work done in this project, i.e. the implementation of ULE, execution of interoperability tests, execution of advanced demonstrations, strong support for the foundation of the ipdvb working group within the IETF, active work on the ULE specification, dissemination, etc. has led to a large awareness of several system and platform manufacturers. Within this project and a parallel study sponsored by ESA, the router manufacturer 6WIND and the IP/DVB gateway manufacturer GSC [39] developed the first interoperable platforms using the ULE encapsulation method. As GCS used DVB-S receiver cards based on Hauppauge and Pent@Value, ULE enabled drivers for these cards are also available. In late January 2004 Data Planet International [40] announced the availability of their new IP/DVB gateway dpi4506 which implements both ULE and MPE. Three other companies, namely Thales Broadcast & Multimedia [41], WISHnet [42], and Efficient Channel Coding [43] have also indicated their interest in implementing the ULE specification. Furthermore, the SATIP6 project [57] also indicated its interest to include an implementation of ULE within their demonstrator.

6.1.4 DVB-S TX / RX card integration

The interoperability tests of the new encapsulation method with another implementation and the advanced demonstrations have been important parts of this project. To let them take place in a realistic environment, i.e. being as close as possible to real usage, it was necessary to use real DVB-S TX and RX cards and modulators / demodulators.

This led to the integration of new hardware into the SixOS, namely the DVB Master III TX and RX card from Computer Modules. It must be stated that integrating new hardware can only be successful if the card manufacturer is able and willing to provide constant support to the implementers. Very basic support was received during the initial porting of the Linux card drivers to FreeBSD. Such porting work was a matter of low-level drivers, and even if not very easy, it is quite a well known issue.

Nevertheless, it must be noted that the card usage lead to some other open issues, that could not be solved until the end of the project. They were mainly:

1. Minimum rate for receiver synchronization
2. Buffering effects in both sender and receiver sides
3. Unpredictable stalls of DVB-S sender driver / sender card which resulted in full communication breakdown over the DVB-S link

The first problem was merely seen during internal tests in which both cards have been connected directly via their ASI interface, i.e. no modulator / demodulator included. Thorough investigations showed that the receiver lost the carrier if the transmission rate went below 700 / 800 Kb/s. This characteristic was not described in the card's technical specifications. The proposed and implemented workaround was the implementation of a 'minimum bandwidth' function on the sender's side, providing enough NULL TS cells to avoid the carrier loss in cases of bursty IP traffic.

The second technical issue led to several problems:

- High delay times between sender and receiver if sending over the DVB-S link is done in low bit rates

- Buffering effects leading to significant jitter for bursty traffic
- Buffering effects, that made it impossible for the receiver to properly use the PID filtering on card-level

It was quite difficult to report those problems to the manufacturer, because in the classical usage of such cards (i.e. sending / receiving of constant traffic flows such as TV / video), the related problems simply don't appear. They are only visible in cases of low transmitted / received data rates and bursty traffic flows which are not unusual for IP traffic.

The associated workarounds are the already described 'minimum bandwidth' function, and the implementation of a configuration option for the receiver buffer size. This still leaves a possible trade-off between high responsiveness (low buffer size) and low CPU utilization (high buffer size). In most scenarios, i.e. without CPU expensive work like encryption / decryption, the higher CPU utilization due to smaller receive buffers can be neglected on the used 6WIND platform.

The important lesson learnt from these issues is that not all DVB-S cards and / or firmware's are not yet equally suited for transmission / reception of IP traffic.

The third problem was only discovered during long running stress tests and could not be totally solved despite all efforts made. 6WIND was able to integrate a workaround in such a way that the SixOS tries to reset card and card driver if it recognizes the error condition. The workaround is only able to reduce the effect of the problem, but could not remove the cause, which is yet unknown. Possible bug places could be the card driver (either original or ported), card's firmware, or card's hardware. Without strong support from the card and driver vendor, this problem is nearly unsolvable for 6WIND. It is hoped that with the publication of the ported driver to the BSD Open Source community, its usage in other system environments and public code reviews might help to increase the stability and quality of the driver.

6.2 Dissemination activities

In order to push IPv6 deployment on satellite networks, besides solving the technical issues it is also important to increase the awareness on this subject. Involving the critical mass and the key player will be a requirement here to help increasing and disseminating experience in this area, to raise funding for performing the outstanding tasks, to get equipment manufacturer integrating required and helpful IPv6 functionality, and to initiate user to ask for advantageous IPv6 network services over satellite networks.

Due to the operation of an own Teleport and the participation in numerous IPv6 research activities IABG has a long-term experience in dissemination activities in the area of satellite communication and IPv6. 6WIND as a router vendor has also long-term experience to disseminate its plans and activities to integrate new hardware or services into their product portfolio. In the following the main dissemination activities done for the scope of work addressed in this project are summarized.

6.2.1 Fora and Task Forces

Fora and Task Forces are often founded in order to promote new technologies and push their deployment, and represent therefore a meeting place of many key players. For this reason the work done in this project has been disseminated in the following relevant fora and task forces.

6.2.1.1 Global IPv6 Forum

The Global IPv6 Forum [39] is a world-wide consortium of leading Internet vendors, Research and Education Networks with a clear mission to promote IPv6 by dramatically improving market and user awareness of IPv6, creating a quality and secure Next Generation Internet and allowing world-wide equitable access to knowledge and technology. To achieve this it establishes an open, international forum of IPv6 expertise, share IPv6 knowledge among its members, promote interoperable implementations of IPv6 standards and resolve issues that create barriers to IPv6 deployment.

The Global IPv6 Forum organises a couple of international IPv6 Forum events per year, provides white papers to different IPv6 relevant areas, establishes liaisons to other IPv6 relevant bodies, such as ETSI, the UMTS Forum or 3GPP, and actively discusses IPv6 relevant aspects among the Forum member on its mailing list.

Information about the work addressed in this project has been announced over the Global IPv6 Forum mailing list along with a pointer to the project webpage hosted at ESA. The Global IPv6 Forum turned out to be an excellent dissemination place, as much feedback has been received in response to this announcement, which led in turn to further dissemination activities in other areas, such as the Delay Tolerant Networking Research Group.

6.2.1.2 European IPv6 Task Force

The European IPv6 Task Force [45] which includes representatives of European ISPs, telecom operators, mobile operators, equipment supply industries, research networks, and key “application” sectors develops a comprehensive action plan, aiming at ensuring the timely availability of IPv6. Thereby it specifically focuses on IPv6 in Europe. Members of the European IPv6 Task Force currently mainly work on a voluntary basis with the support of some minor European Commission funds. One of its latest activities is to found national IPv6 Task Forces in Europe in order to broaden the basis for IPv6 activities and to be better able to address national interests and requirements.

Information about the work addressed in this project has been announced over the EC IPv6 Task Force mailing list along with a pointer to the project webpage hosted at ESA. Also the dissemination within the EC IPv6 Task Force led to feedback. However, compared to the IPv6 Forum this feedback has been lower, and came to a big extent from individuals, which are also present within the IPv6 Forum. This is not surprising, as the Global IPv6 Forum covers the whole world and not only Europe, has liaisons with other fora and organisations, such as ETSI, the UMTS Forum or 3GPP, and more members actively promoting IPv6.

6.2.1.3 National IPv6 Task Forces

Efficient promotion of IPv6 deployment has to be accommodated to regional conditions, such as different key industries, different Internet penetrations, different behaviour of using the

Internet, or different laws. In order to address national issues as well as to involve the critical mass in fostering the deployment of IPv6 in Europe, the European IPv6 Task Force promoted the founding of national IPv6 Task Forces. The different national IPv6 Task Forces establish a solid fundament for the work initiated by the European Task Force.

Information about the work addressed in this project has been announced over the German IPv6 Task Force [46] mailing list along with a pointer to the project webpage hosted at ESA. Furthermore the German IPv6 Task Force members have been informed about this work during on of its regular teleconferences. Information about the project has been published also on the official news page of the German IPv6 Task Force, ipv6-net.de [47]. As the German IPv6 Task Force has only a very small number of members compared to the Global IPv6 Forum, the area of dissemination has been limited. Furthermore it has to be noted, that beside IABG and Deutsche Telekom no major players in the satellite business, like DLR, ND SatCom or Fraunhofer are currently represented in the German IPv6 Task Force. However, the publishing of information on ipv6-net.de certainly reached a broad, German speaking audience.

6.2.1.4 IPv6 cluster

Given the integrated nature of the European Commission program, projects are encouraged to work together, to pool and to collectively build on their individual results whenever it makes sense to do so. Project clusters, each with their own specific objective, will be actively supported and encouraged in so far as they add value to the results of the IST program seen as a whole. The IPv6 cluster [48] provides a platform for all EC funded IPv6 relevant projects in order to inform each other about the status, to identify synergies and to initiate and force co-operation. The EC funded 6Link project has the responsibility to organise and run the IPv6 cluster meetings.

Information about the work addressed in this project has been announced over the IPv6 Cluster mailing list along with a pointer to the project webpage hosted at ESA. Furthermore information about the project has been published also on official IPv6 Cluster webpage. To this webpage several news are added each week, causing it to be one of the most interesting international webpages with IPv6 information. The IPv6 Cluster turned out to be an excellent dissemination place. A main reason for this is that it is possible for everyone to subscribe to the IPv6 Cluster mailing list, while the mailing list of the Global IPv6 Forum and the European and national IPv6 Task Forces are not open to the general public.

6.2.1.5 Delay tolerant Network Research Group (DTNRG)

The Delay-Tolerant Networking Research Group (DTNRG) [49] is concerned with how to address the architectural and protocol design principles arising from the need to provide interoperable communications with and among extreme and performance-challenged environments where continuous end-to-end connectivity cannot be assumed. Examples of such environments include spacecraft, military/tactical, some forms of disaster response, underwater, and some forms of ad-hoc sensor/actuator networks.

As honorary chairman of the Global IPv6 Forum, Vint Cerf put the DTNRG in contact with this project activity in order to investigate commonalities. However, further discussion with the DTNRG has shown, that they also have a strong interest in IPv6, but that their area of work are links with much worse (concerning packet loss, delay and jitter) characteristics, as found in satellite networks.

6.2.2 Standardisation bodies

6.2.2.1 Internet Engineering Task Force

The Internet Engineering Task Force (IETF) [50] is the standardization body for Internet protocols. Contrary to many other standardization bodies the IETF does not have organisations as members, but individuals contributing to standardization process without any membership fees. These individuals represent a good mixture of universities, operators, vendors, and consultants.

The IETF subdivides its work into working groups (WG), which have their individual, focused charter, and are organized into several areas (e.g. Internet, routing, transport, security, etc.). These areas are managed by Area Directors, which are members of the Internet Engineering Steering Group (IESG).

Ipdvb BOF

Recently a new WG has been proposed to the IETF in the Internet area, which investigates new encapsulation mechanisms to carry IPv4 and IPv6 over MPEG-2, as well as IP address resolution issues in MPEG-2 networks.

During the Minneapolis IETF meeting in November 2003 the 2nd ipdvb Bird of a Feather (BOF) meeting has been hold to further discuss the charter [51] of a possible WG, as well as to present the current status of drafts. At this occasion the WG chair has been informed about the intension of demonstrating these new encapsulation techniques within this project and to execute interoperability tests if another implementation is available.

Already before the 2nd BOF, both 6WIND and IABG actively participated in the open discussion on the ipdvb mailing list, which has led to several significant improvements of the initial ULE specification (draft-fair-ipdvb-ule-00.txt). The most important points are:

- Fragmentation/Reassembly over TS cells
    - discovery of corner cases
    - clarification of all cases
    - addition of an example section
- Extension Header, presence and processing
    - definition/precision about the D bit (MAC address)
    - former E bit, now under discussion
- CRC32 computation
    - added polynomial definition
    - added some clarification of computation processing (direct/reverse)

- o addition of an example section

These activities demonstrated to the IETF that there is real interest in the working group goals and considerably helped the foundation of the ipdvb working group in January 2004.

Pana WG

Control of network access is an important mean to provide network security and allow for billing of network use. While there are many network access control mechanisms used for different link layer technologies, the goal of PANA [52] is to define a protocol that allows clients to authenticate themselves to the access network using IP protocols. Such a protocol would allow a client to interact with a site's back-end AAA infrastructure to gain access without needing to understand the particular AAA infrastructure protocols that are in use at the site.

During the Minneapolis IETF meeting in November 2003 the work of this project has been discussed with the PANA WG chair. As PANA also supports IPv6, his main interest has been to investigate the possibility of using PANA authenticate clients accessing a satellite network. As PANA requires a bi-directional connectivity between clients and authentication server, DVB-S / RCS have been identified as possible scenarios for a PANA deployment.

6.2.3 Other projects

In order to identify possibilities for common demonstrations, to exploit synergies, and to allow for mutual use of results, it is important to disseminate the scope of work of this project to appropriate other ones.

6.2.3.1 6NET

The 6NET project [53] is funded by the European Commission and focuses to demonstrate the necessity of IPv6 in order to allow for a continued growth of the Internet. Of course as a European Commission funded projects one of its goals is to place the European research and industry in a leading position for the deployment of IPv6. 6NET is led by Cisco, and involves mainly the research networks of Europe as partners. It will build a native IPv6-based network with both static and mobile components between the member research networks.

The scope of work of this project has been discussed in detail with Peter Kirstein from UCL, one of the strategic 6NET partners, who in turn transferred the information into the project. As 6NET will establish a big native IPv6 network with many services, it is one excellent candidate for a common demonstration. In such a case an IPv6 capable satellite network could be a wireless extension of 6NET in order to reach areas outside the terrestrial coverage of 6NET.

6.2.3.2 Euro6IX

Similar to 6NET also Euro6IX [54] is funded by the European Commission and focuses to support the rapid introduction of IPv6 in Europe. Of course also Euro6IX as a European Commission funded projects has the goal to place the European research and industry in a leading position for the deployment of IPv6. Euro6IX is lead by Telefonica (administrative) and Consulintel (technical) and involves contrary to 6NET mainly the commercial ISPs. It will build a native IPv6-based network between the member ISPs.

The scope of work of this project has been discussed in detail with Jordi Palet from Consulintel, who in turn transferred the information into the project. As Euro6IX also will establish a big native IPv6 network with many services, it is another excellent candidate for a common demonstration. In such a case an IPv6 capable satellite network could be a wireless extension of Euro6IX in order to reach areas outside the terrestrial coverage of Euro6IX.

6.2.3.3 SEINIT

The Security Expert Initiative (SEINIT) [55] is funded by the European Commission and focuses on the definition of new trust and security model, as well as on new security policies, which allow a more efficient addressing of today's and future threats in the Internet. For this purpose SEINIT intends to make use of IPv6 benefits to the maximum possible extent. Furthermore SEINIT also contributes to the core research initiatives towards eEurope-2005.

As a member of the SEINIT consortium, IABG disseminated information about the scope of work of this project has within the SEINIT consortium. For many partners especially the influence of IPv6 security protocol issues on satellite networks has been a major point of interest as well as the investigation of deploying SEINIT results in this project's demonstrations.

6.2.3.4 SILK

The originally NATO funded SILK project [56] focuses on the provision of highly cost effective, global Internet connectivity to the Caucasus and Central Asia through state-of-the-art satellite technology. For this purpose a satellite hub has been installed at Desy in Hamburg, connecting all the remote SILK partners with a DVB-S based forward and a SCPC based return link to the Central European research networks.

The scope of work of this project has been discussed in detail with Peter Kirstein from UCL, one of the strategic SILK partners, who in turn transferred the information into the project during a SILK Board Meeting in November 2003. Additionally information has been directly exchange with Desy. SILK currently only offers IPv4 Internet access to the SILK partners. As many of them have also an interest in IPv6, the SILK network is an ideal environment for deploying the IPv6 over satellite work done in this project. Instead of a short time demonstration this would serve a real user community over a longer period. Many of the SILK partners therefore declared at the SILK board meeting their strong interest in a corporation with this project.

6.2.3.5 SATIP6

The Satellite Broadband Multimedia System for IPv6 (SATIP6) project [57] is funded by the European Commission and focuses on the evaluation and demonstration of key issues for the integration of satellite-based access networks into the Internet. IP will serve here as the common end-to-end protocol allowing interoperability for services and transport technology within integrated networks. In addition SATIP6 will also investigate the integration of satellite technologies in Next Generation Networks based on IPv6.

The scope of work of this project has been discussed in detail with Bernhard Barani from the European Commission, who is in charge of SATIP6 on the Commission side. The first impression of the SATIP6 team has been that much of the work done in this project has already been done by SATIP6. Looking closer to the work plans and deliverables of both projects it turns out, that this isn't true. While SATIP6 focused strongly on the DVB-S/RCS architecture and investigate enhancements and modifications allowing for a more transparent and efficient integration of IPv6, this project does a broader approach, focusing of several satellite architectures, identifying the deficiencies for deploying IPv6, and proposing appropriate transition mechanisms. Furthermore on of the key aspects of this project is the execution of trials using new IP over MPEG-2 encapsulation techniques, an area not addressed at all by SATIP6.

However, SATIP6 and this project have a big potential to complement each other. Therefore an ongoing discussion seems to be valuable.

6.2.3.6 INSC

The Interoperable Networks for Secure Communications (INSC) project [58] is a NATO project, in which 8 NATO nation plus NATO itself investigate the benefits of IPv6 in tactical networks. One of the main tasks is the verification of results in an IPv6 testbed connecting all the different partners. The phase 1 of this project, which concludes end of January 2004, has split the work into different tasks, addressing the main areas of research, like applications, management, security, routing, QoS, mobility, subnetworks, and directory services.

As a member of the INSC project, IABG disseminated information about the scope of work of this project within the INSC partners. This work has been mainly interested for the subnetwork WG of INSC. Within phase 1 of the project the subnetwork WG identified and investigated satellite communications as one of the relevant network technology for military networks. Due to budget restriction it was not possible to integrate satellite links into the INSC demonstration testbed. This is the reason why the subnetwork WG is even more interested in the outcome of this project.

6.2.3.7 New Media Support Centre (NMSC)

The New Media Support Centre (NMSC) is a European facility, possibly geographically distributed, and intended to provide support to the satellite telecommunications markets development via standardised testing system/simulation support and applications support capabilities. New Media services are understood as integrated services that go outside the conventional boundaries of Multimedia, Mobile, Navigation, Earth Imagery, etc, as they are currently implemented. ESA has funded several study activities addressing the technical and operational requirements for a NMSC.

As a member of one of the NMSC consortia, IABG disseminated information about the scope of work of this project within the own NMSC consortium, as well as during the Final Presentation. As future satellite network will be able to support IPv6, it is valuable to the NMSC work to understand, which of the new features affect them or can be exploited.

6.2.4 Manufacturer

In order to deploy IPv6 over satellite it is first required, to implement IPv6 in the relevant products. Therefore it is important to educate satellite equipment manufacturer concerning the missing but required IPv6 functionality in their products, to show the possible benefits and deployment scenarios, and thereby to push their motivation to perform the implementation work.

6.2.4.1 SkyStream

SkyStream is a major manufacturer of DVB-S equipment, for the DVB-S encapsulation as well as for the DVB-S decapsulation side. Currently their DVB-S products do not support IPv6. This would mean using SkyStream one would need to tunnel IPv6 within IPv4 over the DVB-S link, a costly overhead without any benefit.

The scope of work of this project has been discussed in detail with the technical sales director of SkyStream. This discussion aimed to highlight the missing IPv6 functionality in their products, as well as to show the already present interest for IPv6 over satellite.

6.2.4.2 Mentat

Mentat is a major manufacturer of PEP equipment. Their PEP product SkyX Gateway operates on the basis of TCP splitting, has therefore to be placed on both sides of the satellite link, and is completely transparent to the end user. Currently the SkyX Gateway does not support IPv6. This would mean using SkyX Gateways one would need to bypass them with IPv6 traffic. This will place restriction on the network architecture, and loose the complete performance enhancement functionality for any IPv6 traffic.

The scope of work of this project has been discussed in detail with the technical sales director of Mentat as well as with a local distributor. This discussion aimed to highlight the missing IPv6 functionality in their products, as well as to show the already present interest for IPv6 over satellite. Mentat indicated, that they also act as provider of TCP/IP stacks for big customers like Sun or Lucent, and therefore have already an own TCP/IPv6 stack. This will go in future also into their SkyX product line.

6.2.4.3 Tellique

Tellique is another manufacturer of PEP equipment. Their PEP product also has to be placed on both sides of the satellite link, and acts as HTTP and FTP proxy for the clients. Currently it does not support IPv6. This would mean using Tellique equipment no performance enhancement functionality for any IPv6 traffic would be possible.

The scope of work of this project has been discussed in detail with the Tellique. This discussion aimed to highlight the missing IPv6 functionality in their products, as well as to show the already present interest for IPv6 over satellite. Tellique has been highly interested in this work and indicated to investigate possibilities to integrate IPv6 in their products.

6.2.5 Provider

Many providers are affected in one way or the other with IPv6 over satellite. As classical ISPs they often extend their network with satellite links at one of their POPs. Offering IPv6 to their customer the satellite link would also be required to support IPv6.

6.2.5.1 German Telecom

During the IETF meeting held in Minneapolis in November 2003 the scope of work of this project has been presented to the representatives of the German Telecom, who are responsible for maintaining and expanding their backbone network. One reason for currently not deploying IPv6 is the still ongoing process of investigating efficient transition scenarios as well as profitable applications. For this reasons there was a strong interest in this work concerning the possibility of new application scenarios.

6.2.6 Conferences and exhibitions

Dissemination has also been done within exhibitions and relevant conferences. Such conferences and exhibitions could be used in order to inform about promote the pilot demonstration foreseen within this project and thereby increase the visibility of the whole project.

6.2.6.1 Cebit Satellite Exhibition Istanbul

At the end of October 2003 IABG had a booth at the Cebit satellite exhibition in Istanbul. During this time several discussions about IPv6 over satellite and the work addressed in this project have taken place with visitors. Summarizing the interest in IPv6 over satellite has been very small. The main interest of the most visitors has been in reliable and cheap Internet over satellite provision. Due to the numerous earthquakes in this area, which cause many failures on terrestrial links, satellite technology plays a major role as backup solution for basic Internet provision.

6.2.7 Other areas of dissemination

6.2.7.1 Hellassat

Hellassat is a Greek and Cyprian company, which launched a new satellite in May 2003. During the Istanbul Cebit exhibition end of October 2003 the scope of work of this project has been presented to both CEOs of Hellassat. As beside operating an own satellite they also are involved in Internet business, e.g. as founder of the first Cyprian ISP or as board member of the Romanian telecom, they showed a strong interest in this type of activity and asked to be kept updated about the future progress of the project.

6.2.7.2 Driver Availability

A new form of dissemination to the open source community has been done in this project. The driver of the selected DVB card (DVB Master III, [59]) has only been provided by Computer Modules for the Linux kernel. This driver has been ported by 6WIND to FreeBSD 4.8 and later to the SixOS.

With permission of Computer Modules a greater distribution was obtained by making the drivers ported to FreeBSD 4.8 publicly available, hence giving another Operating System access to a new DVB card.

The official availability announcement for FreeBSD was done in:

http://www.freebsd.org/news/status/report-oct-2003-dec-2003.html

This sources provide both reception and transmission drivers. It is hoped that the open source community will benefit from the driver release as well as the driver itself with respect to enhancements, testing on a greater variety of systems, etc.

6.2.7.3 Global IPv6 Launch Event

One 6WINDGate 6221 including the DVB card [59] from Computer Modules was presented during the Global IPv6 Launch Event in Brussels [60] at the ESA demonstration booth.

6.3 Recommendations for future work

This chapter tries to look ahead and to recommend possible next steps to further pursue the work which has been started during this project with respect to ULE analysis, standardization, and deployment.

As seen during the evaluation of the interoperability test results, the packing mechanism of ULE can have effects on the packet interarrival time and jitter (see Figure 6-1). As visible in the sender diagram (Sender: 6WIND, left side of Figure 6-1) which was taken on the sender side before ULE encapsulation, the main packet interarrival time around 0.03 seconds (30 ms). On the receiver side (Receiver: TechnoTrend, right side of Figure 6-1), the main packet interarrival time is between 0.035 and 0.04 seconds but also a considerable amount of packets has an interarrival time of zero seconds, i.e. they arrive with directly after one another. This could be caused by the packing mechanism as specified in ULE.

Figure 6-1: Packet Interarrival time for VoIP for IPv4 using 6WIND as DVB-S sender and TechnoTrend as DVB-S receiver

It would be beneficial for the further ULE standardization process to investigate the influence of packing on the packet interarrival time and jitter for various representative packet flows. As changing packet interarrival times and jitter can have negative effects on jitter sensitive applications and data streams (e.g. Voice over IP or video streaming), it would be worthwhile to investigate the effects of packing on such applications. But, not only flows from jitter sensitive applications and data streams alone must to be examined in such investigations. In many real usage scenarios for ULE (i.e. being used in a teleport uplink / downlink interconnecting networks and connecting networks to the Internet), it is not guaranteed that jitter sensitive data streams are sent alone over a dedicated satellite link. Especially mixing such packet streams with traffic flows having other characteristics (e.g. FTP download / upload, HTTP web browsing / download, SMTP Mail transfer, Database or Directory Server replication, etc.) can have effects on the packet interarrival time and jitter which must yet be investigated.

Another valuable input to the further analysis of overall ULE performance would be the comparison of ULE processing delay / processing power consumption with MPE based processing delay / processing power consumption on identical implementation platforms with comparable settings. Equipment that could be used in this scenario is for example the dpi4506 from Data Planet International as is provides both MPE and ULE on the same platform. Using a real implementation together with reproducible generated traffic flows and patterns would provide more comparable and realistic numbers than only simulation tools can.

The standardization of ULE has just started within the IETF, i.e. the IETF ipdvb working group was approved by the IESG on the 28th January 2004 and the personal draft draft-fair-ipdvb-ule-02.txt was adopted and re-issued by the ipdvb working group in late February 2004. This means that until the ULE specification has been progressed to RFC and supporting documents addressing a framework and protocol for address resolution have been proposed, lots of work is still to be done. This is particularly visible in the latest discussion on the ipdvb mailing list which addresses reasons and possibilities for adding extension headers to the current ULE specification. Ideas have been brought forward that it would be interesting / beneficial to support security (i.e. scrambling or encryption) and Forward Error Correction (FEC) on ULE level. Different proposals how to include extension headers into the ULE specification and how to provide some sort of backwards compatibility have been discussed. It is now necessary for the ipdvb working group to receive more feedback and information on strong use cases and scenarios which require e.g. encryption / scrambling or FEC on ULE level that can not be provided by other means e.g. scrambling and FEC on link layer or security at IP layer. This requires effort and contribution from other standardization groups (e.g. DVB-RCS, DVB-S2), but also from vendors and possible users to put forward their requirements and usage scenarios.

As many user groups (e.g. teleport operators, satellite equipment manufacturers) often rely on stable standards before they integrate new equipment, protocols and mechanisms, supporting the ipdvb working group in its ongoing work on the ULE specification and to proceed it to RFC status is essential to further push the deployment of ULE, as many vendors and manufacturers only consider RFCs for implementation in their products.

Another issue which must be solved before the ULE encapsulation is acceptable for end users, teleport operators and satellite equipment manufacturers is the availability of a standardized Management Information Base (MIB) for ULE. Providing no standardized MIB and therefore no integrable vendor independent management solution for larger equipment installations could well turn out as missing critical piece. Furthermore, providing support for dynamic not pre-configured address resolutions mechanisms for IPv4 / IPv6 unicast and multicast addresses within an address resolution framework and protocol which might make use of functionalities only provided by ULE (e.g. support for extension headers) could also push the deployment of ULE.

Standardization efforts outside IETF would be the adoption of ULE in the ETSI-BSM architecture and the linkage of ULE with the ETSI DVB-S standards as an alternative to MPE. This would require further active dissemination of the ongoing ULE activities from within the ipdvb working group to the ETSI-BSM working group and the responsible Specialist Task Force. Linking the ULE encapsulation method with the ETSI DVB-S standards will definitely require more work and combined efforts from major vendors and users. An indispensable requirement for this step would be the ULE approval as RFC by the IESG.

The interoperability tests and advanced demonstrations have shown that ULE is ready for a wider deployment. A first proposed step could be the usage of ULE in R&D projects like other ESA projects or EC projects (e.g. SATIP6). In a second step, available ULE implementations could be used in pre-commercial projects with support of ESA, e.g. within the SILK or the Asian Pacific WIDE project. Successful usage of ULE equipment in such networks and installations would then pave the way to its commercial deployment by teleport operators, satellite ISPs and end users.

7 SUMMARY

The main intention of this project has been to support the specification, implementation, and interoperability testing of a new proposed MPEG2 encapsulation method. Furthermore, the suitability of the new encapsulation method has been shown with advanced demonstrations, using typical satellite network scenarios. At the end of the project, the obtained results as well as recommendations about possible next steps to further support the new encapsulation method have been presented and proposed.

Furthermore, this project has contributed to the standardization process within the IETF, i.e. aided to the foundation of the IETF ipdvb working group and participated in its discussions. This working group addresses the development of new protocols allowing a more efficient transport of IP over MPEG-2 networks and therefore a better integration of IP in satellite networks.

In order to create a sufficient level of awareness, the project activities and results have been disseminated to a broad range of fora, task forces, projects, manufacturers, exhibitions, and ISPs.

INVENTORY OF IP-OVER-DVB RELATED ACTIVITIES AND DEVELOPMENTS

The first step in this project has been to look at relevant activities in different standardization groups and bodies with respect to their relation to the transmission of IP data over satellite networks. These included

- ETSI and the currently published standards / documents for MPEG2 / DVB-S
- IETF and the currently published documents of the new evolving ipdvb working group
- ETSI and the currently published standards / documents for SES - BSM (Satellite Earth Stations and Systems - Broadband Satellite Multimedia)
- ATSC and the currently published standards / documents for MPEG2 / Data Broadcast Standard
- ETSI and the currently published standards / documents for DAB (Digital Audio Broadcast)

The investigations done on each activity first provided an overall summary on the system architecture / protocol design as they are presented by the respective standards / documents, and then described the different approaches taken with respect to address resolution, routing, IP encapsulation, Quality of Service (QoS), service discovery / service advertisement, and IP Multicast. Finally, possible interactions between these activities and the ipdvb working group with a focus on ULE have been outlined.

STUDY AND PROTOTYPE IMPLEMENTATION OF EMERGING IP-OVER-DVB ENCAPSULATION METHODS

As next step of the project, the deficiencies of the current Multi-Protocol Encapsulation (MPE) have been analyzed and compared with the features of the new proposed encapsulation methods (i.e. Ultra Lightweight Encapsulation (ULE) and Simple Encapsulation (SE)). Based on this analysis and in coordination with ESA and another parallel project (lead by Joanneum Research along with the Computing Science Department of the University of Salzburg and GCS, as well as the University of Aberdeen and EMS

Technology) the ULE specification has been selected for implementation. Based on this decision, 6WIND implemented the ULE specification and integrated it inside their SixOS software, which is used as Operating System on their 6WINDGate routers. Furthermore, 6WIND ported and integrated the driver for the selected DVB Master III TX and DVB Master III RX cards into their SixOS. Finally, basic functionality tests have been executed between a 6WINDGate acting as DVB-S sender and a 6WINDGate acting as DVB-S receiver using the ULE encapsulation method.

Deficiencies of MPE

The identified deficiencies of MPE, which make it less efficient to be used within emerging and advanced satellite network scenarios, have been categorized in the subjects complexity, overhead / efficiency, multi-protocol support, and MTU support.

Implementation of ULE and Integration into SixOS

The ULE specification has been implemented as separate encapsulation method and integrated into 6WINDs SixOS above the low-level driver for the selected DVB Master III TX / RX card. For this purpose first the driver for the DVB Master III card from Computer Modules has been ported from Linux to FreeBSD and has then been integrated into the newest SixOS branch. Using advanced feature of their SixOS, 6WIND implemented functionality to combine the unidirectional DVB-S link with a serial interface, providing a logical interface (called dvb0-interface) offering bi-directional communication link to upper layer protocols, e.g. IPv4, IPv6, or Robust Header Compression (ROHC). The necessary higher level configuration functionalities have been integrated into the 6WINDs interactive and error checking Command Line Interface (CLI). Already available services like IPsec with ISAKMP negotiation, QoS using DiffServ, Protocol Independent Multicast – Sparse Mode for IPv6, have been enhanced to operate over the logical bi-directional dvb0-interface. To support interoperability testing, advanced debugging and packet capture facilities have been integrated into the DVB Master III card driver, the ULE implementation and the logical dvb0-interface, e.g. allowing the capture of transmitted and received packets on IP level, ULE SNDU level and TS cell level.

Basic functionality tests

The correct implementation and integration of ULE inside 6WINDs SixOS has been proved with basic functionality tests in which 6WINDGate 6221 router with DVB Master III TX card acted as sender and a 6WINDGate 6221 router with DVB Master III RX card served as receiver. The used test scenarios proved correct IPv4 / IPv6 end-to-end connectivity, correct ULE functionality, and correct TS cell level functionality.

INTEROPERABILITY TESTING OF IP/DVB GATEWAY AND IRD UNIT EQUIPMENT

As the ULE specification has also been implemented independently by parallel which was also sponsored by ESA, the next step in the project has been the execution of interoperability tests. The test setup consisted of two main scenarios, where first the 6WINDGate acted as DVB-S sender and a Linux-PC with either TechnoTrend or Pent@Value DVB-S receiver cards included served as DVB-S receiver. Second, the OpenDVB Gateway (ODG) from GCS (Austria) acted as DVB-S sender and a 6WINDGate served as DVB-S receiver. The executed tests included the transmission of different IPv4 / IPv6 packet stream pattern to verify basic end-to-end connectivity and to trigger various special cases with respect to SNDU packing in TS cells. Furthermore, emulated VoIP and video streaming traffic over IPv4 and IPv6 has been transmitted to evaluate packet interarrival times.

The overall conclusion derived from the interoperability tests is that all implementations are fully interoperable.

DEMONSTRATIONS OF ADVANCED NETWORKING

After having implemented and integrated ULE in the 6WINDGate's SixOS and having successfully executed interoperability tests, the next task was the demonstration of advanced networking functionalities over links using the ULE encapsulation method. For this, scenarios have been developed which representatively address issues that are of typical interest to satellite ISP's, teleports providers or end users.

The demonstration scenarios consisted of

- Transmission of UDP (VoIP) and bulk TCP traffic via IPv4 / IPv6
- Transmission of IPv6 Multicast traffic (VoIP) with dynamic IPv6 Multicast routing using Protocol Independent Multicast – Sparse Mode (PIM-SM)
- Transmission of IPsec secured VoIP traffic (IPv4 / IPv6) with ISAKMP negotiation
- Transmission of VoIP traffic (IPv4 / IPv6) and bulk UDP traffic with DiffServ QoS enforced
- Transmission of VoIP traffic (IPv4 / IPv6) and bulk UDP traffic (IPv4 / IPv6) with ROHC over the ULE enabled DVB-S link

All scenarios have been successfully executed and have therefore demonstrated that the ULE encapsulation method is already suitable for wider usage in other R&D projects or in pre-commercial projects.

CONCLUSIONS AND RECOMMENDATIONS FOR FURTHER DEVELOPMENTS

As last task in this project, the achieved results have been summarized and conclusions have been drawn. Additionally, several recommendations for possible next steps in the areas ULE analysis, standardization and deployment have been presented by this project.

APPENDIX A) REFERENCES

[1] ETSI TR 101 984 v1.1.1: "Satellite Earth Stations and Systems (SES); Broadband Satellite Multimedia; Services and Architectures", ETSI Technical Report, November 2002

[2] ETSI TR 101 985 v1.1.2: "Satellite Earth Stations and Systems (SES); Broadband Satellite Multimedia; IP over Satellite", ETSI Technical Report, November 2002

[3] ETSI TR 102 155 V1.1.1 "Satellite Earth Stations and Systems (SES);Broadband Satellite Multimedia; IP interworking over satellite; Addressing and routing", ETSI Technical Report, April 2003

[4] ETSI TR 102 156 V1.1.1 "Satellite Earth Stations and Systems (SES);Broadband Satellite Multimedia; IP interworking over satellite; Multicasting", ETSI Technical Report, April 2003

[5] ETSI TR 102 157 V1.1.1 "Satellite Earth Stations and Systems (SES);Broadband Satellite Multimedia; IP interworking over satellite; Performance, Availability and Quality of Service", ETSI Technical Report, July 2003

[6] "Specialist Task Force 237: Broadband Satellite Integration and Interworking of IP Networks", Web page, http://portal.etsi.org/stfs/ses/STF237.asp, last visit September 2003

[7] draft-fair-ipdvb-req-03.txt "Requirements for transmission of IP datagrams over MPEG-2 networks"; G. Fairhorst, H. D. Clausen, B. Collini-Nocker; Work in progress; June 2003

[8] draft-clausen-ipdvb-enc-01.txt "Simple Encapsulation for transmission of IP datagrams over MPEG-2/DVB networks"; H. D. Clausen, B. Collini-Nocker, H. Linder, G. Fairhorst; Work in progress; May 2003

[9] draft-fair-ipdvb-ule-01.txt "Ultra Lightweight Encapsulation (ULE) for transmission of IP datagrams over MPEG-2/DVB networks"; G. Fairhorst, B. Collini-Nocker; Work in progress; October 2003

[10] draft-fair-ipdvb-ar-00.txt "Address Resolution for IP datagrams over MPEG-2 networks"; G. Fairhorst, M.-J. Montpetit; Work in progress; June 2003

[11] ISO/IEC 13818-1; "Information Technology - Generic coding of moving pictures and associated audio information: Systems"; year 2000

[12] ISO/IEC 13818-1 "Generic coding of moving pictures and associated audio informations : systems". 2nd Edition December 2000

[13] ISO/IEC 13818-6 "Generic coding of moving pictures and associated audio informations : part 6 extension for DSM-CC". September 1998

[14] ETSI EN 301 192 v1.3.1 "Digital Video Broadcasting (DVB); DVB specifications for data broadcasting". May 2003.

[15] ETSI TR 101 202 v1.2.1 "Digital Video Broadcasting (DVB); Implementation Guideline for Data Broadcasting". January 2003

[16] ETSI EN 300 468 v1.5.1 "Digital Video Broadcasting (DVB); Specifications for Service Information (SI) in DVB systems" May 2003

[17] ATSC A/90 : "ATSC Data Broadcast Standard" July 2000.

[18] ATSC A/91 : "ATSC Recommended Practice : Implementation Guidelines for the ATSC Data Broadcast Standard" June 2001

[19] ATSC A/92 "ATSC Standard : Delivery of IP Multicast over ATSC Data Broadcast" January 2002

[20] ATSC A/95 "ATSC Standard : Transport Stream File System Standard" February 2003

[21] ATSC A/65 "ATSC Standard: Program and System Information Protocol for Terrestrial Broadcast and Cable" 2000.

[22] IETF RFC2327 "SDP : Session Description Protocol" April 1998

[23] IETF RFC2974 "Session Announcement Protocol" October 2000

[24] IETF RFC112 "Host extension for IP Multicasting" August 1989

[25] IETF RFC2464 "Transmission of Ipv6 packets over Ethernet networks" 1998

[26] Reference of IP-over-DVB WG : http://www.erg.abdn.ac.uk/users/gorry/ip-dvb/

[27] IP-over-DVB mailing list: ip-dvb@erg.abdn.ac.uk, archive available at http://www.erg.abdn.ac.uk/ip-dvb/archive/

[28] IETF `<draft-fair-ipdvb-req-03.txt>` "Requirements for transmission of IP datagrams over MPEG-2 networks" June 2003

[29] IETF `<draft-clausen-ipdvb-enc-00.txt>` "Simple Encapsulation for transmission of IP datagrams over MPEG-2/DVB networks" May 2003

[30] IETF `<draft-fair-ipdvb-ule-01.txt>` "Ultra Lightweight Encapsulation (ULE) for transmission of IP datagrams over MPEG-2/DVB networks" October 2003

[31] IETF `<draft-fair-ipdvb-ar-00.txt>` "Address Resolution for IP datagrams over MPEG-2 networks" June 2003

[32] A1-4372-18092003 : "MoM_coordination_teleconference_18_Sep_2003_v1.doc" September 2003.

[33] ETSI EN 300 401 V1.3.3; "Radio Broadcasting Systems; Digital Audio Broadcasting (DAB) to mobile, portable and fixed receivers"; May 2001

[34] ETSI EN 301 234 V1.2.1; "Digital Audio Broadcasting (DAB); Multimedia Object Transfer (MOT) protocol"; February 1999

[35] ETSI ES 201 735 V1.1.1; „Digital Audio Broadcasting (DAB); Internet Protocol (IP) datagram tunnelling"; September 2000

[36] ETSI ES 201 736 V1.1.1; "Digital Audio Broadcasting (DAB); Network Independent Protocols for Interactive Services"; September 2000

[37] IETF RFC 1661; "The Point-to-Point Protocol (PPP)"; W. Simpson; July 1994

[38] IETF RFC 1332; "The PPP Internet Protocol Control Protocol (IPCP)"; G. McGregor; May 1992

[39] GCS company webpage, http://www.gcs-salzburg.at/

[40] Data Planet International company webpage, http://www.dpi-ag.de/index.html

[41] Thales Broadcast & Multimedia company webpage, http://www.thales-bm.com/

[42] WISHnet Inc. company webpage, http://www.wishnet.co.jp/en/index.html

[43] Efficient Channel Coding (ECC) Inc. company webpage, http://www.eccincorp.com/

[44] Global IPv6 Forum, http://www.ipv6forum.com

[45] European IPv6 Task Force, http://www.ipv6-taskforce.org/europe.php

[46] German IPv6 Task Force, http://www.ipv6tf.de/index2.php

[47] News page of the German IPv6 Task Force, http://www.ipv6-net.de/

[48] IPv6 Cluster, http://www.ist-ipv6.org/

[49] DTNRG Webpage, http://www.dtnrg.org/

[50] IETF Webpage, http://www.ietf.org

[51] Ipdvb WG charter, http://www.erg.abdn.ac.uk/ip-dvb/charter.html

[52] PANA WG charter, http://www.ietf.org/html.charters/pana-charter.html

[53] 6NET Webpage, http://www.6net.org/

[54] Euro6IX project webpage, http://www.euro6ix.com/

[55] SEINIT project webpage, http://www.seinit.org/

[56] SILK project webpage, http://www.silkproject.org/

[57] SATIP6 project webpage, http://satip6.tilab.com/

[58] INSC project webpage, http://insc.nodeca.mil.no/ifs/files/startframe.html

[59] Product webpage DVB Master III, Computer Modules Inc., http://www.computermodules.com/broadcast/broadcast-dvb.shtml

[60] Global IPv6 Launch Event webpage, http://www.global-ipv6.net/