

**ULE ROBUST HEADER COMPRESSION FOR IP-BASED COMMUNICATION
OVER DIGITAL VIDEO BROADCASTING-SATELLITE (DVB-S)**

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UNIVERSITI SAINS MALAYSIA

2007

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by

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**Thesis submitted in fulfilment of the requirements
for the degree of
Master of Science**

August 2007

ACKNOWLEDGEMENTS

My stay at the Universiti Sains Malaysia as a master postgraduate student has been extremely rewarding and fun. I will make an attempt to acknowledge the people who have played a vital role in my life during this stay.

I would like to express my gratitude to my supervisor Dr. Wan Tat Chee and Dr. Rahmat Budiarto, for their invaluable guidance and inspiration throughout my research work. In addition to their support and flexibility, I would like to thank them for their patience during periods of slow progress. I am very happy to have the opportunity to learn from them and interact with them. Their constant feedback and questioning has also taught me how to become a better researcher. I will always cherish their mentoring. In addition, I would like to express my appreciation to Dr. Sureswaran Ramadass for providing me some good facilities in Network Research Group Lab.

It was great to be in the research lab with all my friends. It was a pleasure studying, discussing, arguing, and traveling with them, especially Chen Wei, Kong Yong, Loh Chong, Way Chuang, Usman, Hean Loong, Han Boon, Patricia, Esther, Kuna and Hean Kuan. In addition, I am also grateful for their constructive comments and valuable insights. I would like to especially thank Marie-Jose Montpetit, for providing me good guidance and offering me great references that were instrumental in making better my understanding of MPE and ULE in Network Simulator 2(*ns2*).

Finally, thanks to my parents, whose blessings are always with me, brother, and younger sister for their love and care.

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LIST OF ABBREVIATIONS

AAL5	ATM adaptation layer 5
ARP	Address Resolution Protocol
ARPANET	Advanced Research Projects Agency Network
ATM	Asynchronous Transfer Mode
ATSC	Advanced Television Systems Committee
BER	Bit Error Rate
CBR	Constant Bit Rate
CPCS	Common Part Convergence Sublayer
CRTP	Compress Real Time Protocol
DSM_CC	Digital Storage Media Command and Control
DTH	Direct-To-Home
DVB	Digital Video Broadcast
DVB-C	Digital Video Broadcasting- Cable
DVB-RCS	Digital Video Broadcasting with Return Channel via Satellite
DVB-S	Digital Video Broadcasting over Satellite
DVB-T	Digital Video Broadcasting- Terrestrial
ELAN	LAN Emulation
ELG	European Launching Group
E-mail	Electronic Mail
ESA	European Space Agency
ETSI	European Telecommunications Standards Institute
FC	Full Context
FO	First Order
FTP	File Transfer Protocol
GEO	Geostationary Earth Orbits
GSM	Global System for Mobil Communication
IETF	Internet Engineering Task Force
IP	Internet Protocol
IPHC	Internet Protocol Header Compression
IPv6	Internet Protocol version 6
IR	Initialization and Refresh
ISL	Inter Satellite Links
ITU	International Telecommunication Union
ITU-T	International Telecommunication Union-Telecommunication
LAN	Local Area Network

LEO	Low Earth Orbits
LIS	Logical IP Subnet
LLC	Logical Link Control
LLC/SNAP	Logical Link Control/Subnet Attachment Point
LNA	Low Noise Amplifier
LNB	Low Noise Block
LOS	Line Of Sight
LSB	Least Significant Bits
MAN	Metropolitan Area Network
MEO	Medium Earth Orbits
MoU	Memorandum of Understanding
MPE	Multi-protocol Encapsulation
MPEG-2 TS	Moving Picture Experts Group 2-Transport Stream
MPOA	Multi-protocol Encapsulation over ATM
MTU	Maximum Transfer Unit
NC	No Context
NHRP	Next Hop Resolution Protocol
NPA	Network Point of Attachment
ns2	Network Simulator 2
NSF	National Science Foundation
OBP	On Board Processing
O-mode	Bidirectional Optimistic Mode
OSI	Open System Interconnection
OTcl	Object-oriented Toolkit Command Language
PAL	Phase Alternating Line
PCR	Program Clock Reference
PDU	Protocol Data Unit
PID	Packet Identifier
PMD	Physical Medium Dependent
POTS	Plain Old Telephone Service
PPP	Point to Point
PSTN	Public Switched Telephone Network
QoS	Quality of Service
RF	Radio Frequency
R-mode	Bidirectional Reliable Mode
ROHC	Robust Header Compression
RTT	Round Trip Time

SAR	Segmentation and Re-assembly
SC	Static Context
SHF	Super High Frequency
SNDU	Subnetwork Data Unit
SO	Second Order
TC	Transmission Convergence
TCL	Toolkit Command Language
TCP	Transmission Control Protocol
U.S.	United States
UDP	User Datagram Protocol
ULE	Unidirectional Lightweight Encapsulation
U-mode	Unidirectional Mode
VC	Virtual Circuit
VJHC	Van Jacobson Header Compression
VoIP	Voice over IP
WAN	Wide Area Network
WLSB	Window-based Least Significant Bits
WWW	World Wide Web

LIST OF PUBLICATIONS

“Unidirectional Lightweight Encapsulation with Header Compression for IP Based Satellite Communication over DVB-S”, *ASIAN INTERNET ENGINEERING CONFERENCE (AINTEC) 2007*, Phuket, Thailand, Nov 27-29, 2007

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PEMADATAN KEPALA TEGAP ULE UNTUK KOMUNIKASI BERASASKAN PROTOKOL INTERNET MELALUI PENYIARAN VIDEO DIGITAL- SATELIT (DVB-S)

ABSTRAK

Untuk selama 35 tahun, *Internet* telah berkembang dan bertumbuh dengan pesat. Disebabkan pembangunan yang mendadak, permintaan capaian *Internet* menjadi kian popular di mana-mana saja melalui pelbagai jenis media, termasuklah melalui komunikasi satelit. Sifat komunikasi satelit yang sentiasa wujud di angkasa menyebabkan ia dijadikan kaedah yang sangat sesuai untuk menyediakan perkhidmatan data dan suara (VoIP). Di samping itu, perkembangan dalam penggunaan komunikasi satelit juga telah merangsangkan pertumbuhan perkhidmatan jalur lebar yang menggunakan *Unidirectional Lightweight Encapsulation* dan *Multi-protocol Encapsulation* melalui Satelit Penyiaran Video Digital (*Digital Video Broadcasting-Satellite*).

Tesis ini telah mengemukakan penilaian kecekapan *Unidirectional Lightweight Encapsulation* bersama dengan *Robust Header Compression* (ULE dengan ROHC) bagi paket UDP masa nyata dan bukan masa nyata. ULE dengan ROHC mengabungkan teknik pengkapsulan ULE dan teknik pemadatan kepala paket ROHC, di mana kepala paket UDP akan dipadatkan terlebih dahulu sebelum paket tersebut dikapsulkan ke dalam ULE. ROHC merupakan satu teknik pemadatan kepala paket yang dapat mengurangkan saiz kepala paket yang dihantar melalui rangkaian dengan mengeksploitasikan maklumat bidang kepala paket yang berulang di dalam sesuatu aliran yang sama. Maklumat lebih tersebut akan disimpan ke dalam KONTEK (*CONTEXT*) pada proses pemadatan dan penyahpadatan kepala paket. Paket yang telah menjalani pemadatan kepala akan dihantar ke ULE untuk pengkapsulan dan seterusnya dihantar keluar kepada penerima. Manakala paket yang diterima pada tapak penerima akan dinyahkapsul daripada ULE serta proses penyahpadatan kepala

paket akan dilaksanakan secara merujuk kepada maklumat yang disimpan dalam KONTEK. ULE dengan ROHC dicipta untuk mempertingkatkan prestasi ULE. Dengan menambahkan bilangan paket UDP yang dapat dikapsulkan ke dalam saiz muatan (*payload*) MPEG-2 TS yang terhad, ia dapat membantu meningkatkan kecekapan penghantaran paket dalam rangkaian.

Penilaian ULE dengan ROHC dilakukan dengan dua cara, iaitu bahagian analisa teori dan bahagian simulasi. Pada permulaan, kecekapan penghantaran ULE dengan ROHC dinilai secara analisa teori dan keputusan tersebut dibandingkan dengan mekanisme pengkapsulan yang lain. Selepas itu, simulasi dijalankan untuk mengkaji penambahbaikan yang dapat dicapai oleh ULE dengan ROHC dari segi purata masa lengah, truput, purata peratusan paket tersingkir, kesan kadar ralat bit ke atas truput dan overhead. ULE dengan ROHC didapati telah menambahbaikan prestasi rangkaian berbanding dengan ULE sahaja. ULE dengan ROHC dapat mencapai prestasi yang lebih baik berbanding dengan ULE terutamanya untuk saiz paket yang kecil seperti saiz paket yang biasa didapati dalam aplikasi VoIP. Sebagai contohnya, purata masa lengah bagi paket UDP bersaiz 80 bait yang menggunakan ULE dengan ROHC dapat disingkatkan sebanyak 9.6 ms berbanding dengan ULE sahaja dan disingkatkan sebanyak 18.9 ms berbanding dengan MPE. Ini disebabkan saiz kepala paket telah dikurangkan sehingga 1 bait dan saiz packet UDP secara keseluruhannya dapat dikurangkan daripada 80 bait kepada 53 bait, mencapai pemadatan sebanyak 33.75%. Tambahan pula, setelah saiz paket UDP dapat dikurangkan kepada 53 bait, sekurang-kurangnya 3 paket UDP dapat dimuat ke dalam suatu paket MPEG-2 TS (*mod packing*). Ini akan dapat meningkatkan kecekapan penghantaran ULE dengan ROHC 21% berbanding dengan ULE dan juga meningkatkan kecekapan penghantaran 28% berbanding dengan MPE.

Selain daripada itu, keputusan simulasi juga menunjukkan bahawa ULE dengan ROHC dapat memberi prestasi QoS yang lebih baik. Apabila saiz paket adalah 80 bait, purata peratusan paket yang tersingkir bagi ULE dengan ROHC adalah sekitar 9%, iaitu 7% lebih kurang daripada ULE dan 29% lebih kurang daripada MPE. Untuk overhead pula, ULE dengan ROHC dapat mencapai pengurangan sehingga 16.6%, iaitu 2% lebih kurang daripada ULE dan 50% lebih kurang daripada MPE. Kesimpulannya, ULE dengan ROHC telah menunjukkan kemajuan dari segi purata masa lengah, daya penghantaran paket, purata peratusan paket tersingkir, kesan kadar ralat bit ke atas truput dan overhead. Diharapkan keputusan yang dikemukakan dalam tesis ini dapat meningkatkan pemahaman bagaimana menambahbaik prestasi ULE dalam penggunaan sistem sebenar pada masa hadapan.

ULE ROBUST HEADER COMPRESSION FOR IP-BASED COMMUNICATION OVER DIGITAL VIDEO BROADCASTING-SATELLITE (DVB-S)

ABSTRACT

Over a span of thirty five years, the Internet has developed and grown rapidly. Due to its rapid growth, the demand for Internet access today is everywhere and over every possible medium such as satellite communications. The ubiquitous nature of satellite communications makes it an ideal candidate for providing voice or data services through terminals. The growth of satellite communications has led to the development of broadband services using Unidirectional Lightweight Encapsulation and Multi-protocol Encapsulation over Digital Video Broadcasting-Satellite.

This thesis evaluated the effectiveness of Unidirectional Lightweight Encapsulation with Robust Header Compression (ULE with ROHC) for real time and non real time UDP packets. ULE with ROHC combined the ULE mechanism with a ROHC scheme, where the packets in an UDP stream would be compressed before undergoing ULE encapsulation. ROHC is a header compression scheme that can reduce the header sizes of packets transmitted over the network by exploiting the redundancy of header field information in a data stream. The redundant information is saved in a CONTEXT at the compressor and decompressor. The compressor would then send the compressed packet for encapsulation using ULE. At the receiver site, after the ULE de-capsulation, the decompressor would reconstruct the header based on the information in its CONTEXT. ULE with ROHC was developed to enhance the performance of ULE. By increasing the number of the IP/UDP packets that can be encapsulated into the limited payload size of MPEG-2 TS packets, it helped to increase the efficiency of the packets transmission over satellite channels.

The evaluation of ULE with ROHC consists of two parts - theoretical analysis and simulation. Firstly, the transmission efficiency of ULE with ROHC evaluated using theoretical analysis was compared to other encapsulation mechanisms. Secondly, a simulation study was conducted to study the improvements obtained using ULE with ROHC in terms of average delay, throughput, packet drop rate, the effect of BER on throughput and the overhead. ULE with ROHC has been found to significantly improve network performance compared with ULE alone. ULE with ROHC outperformed ULE especially for smaller packet sizes such as those used in VoIP application. For example, the average delay for 80-byte UDP packets was reduced by up to 9.6 ms using ULE with ROHC compared with ULE and reduced by up to 18.9 ms compared with MPE. This was because the UDP packet header size could be reduced to only 1 byte and the overall packet size for the UDP packet from 80 bytes to 53 bytes, achieving a total compression gain of 33.75%. In addition, since the UDP packet size was reduced to 53 bytes, at least 3 UDP packets could be carried using a single MPEG-2 TS packet (packing mode). This improved the transmission efficiency of ULE with ROHC by up to 21% compared with ULE and by up to 28% compared with MPE.

The simulation results also demonstrated that ULE with ROHC provided better QoS performance. When the packet size was 80 bytes, the packet drop rate for ULE with ROHC was around 9% which was 7% lower than ULE alone and 29% lower than MPE. The overheads were also reduced to approximately 16.6% which was 2% lower than ULE alone and 50% lower than MPE. In conclusion, ULE with ROHC has shown improvements in terms of average delay, throughput, packet drop rates, the effect of BER on throughput and overheads. It is hoped that the findings presented in this thesis would contribute to a better understanding of how to enhance the performance of ULE for actual deployed systems in future.

CHAPTER 1 INTRODUCTION

1.0 Background

In the later part of the 1970's, computer to computer network connections were used for load sharing and data interchange. The Internet, which was first established as ARPANET in 1969, initially connected four major computers at universities in the south-western US (UCLA, Stanford Research Institute, UCSB, and the University of Utah). (Walt, 2005)

By the mid of 1980's, the National Science Foundation (NSF) of the USA funded NSFNet as 56 Kbps backbone for the Internet across the country. This network became available to the universities and NSF started providing these universities with network connectivity. In fact network is always constantly changing and growing. Today, the network technology has advanced on all fronts, the World Wide Web (WWW) and the commercialization of the Internet, with increasing quantities of image, video, and audio content, is dramatically changing the traffic patterns on the Internet. Increasing multimedia applications enhanced the demand for bandwidth on the backbone networks and access links. ATM, gigabit, and wireless networks have been designed to overcome the lack of bandwidth and coverage over large distances.

In addition to supporting higher quality of network performance and new services, the network designers also aimed to enable networks of all sizes to communicate flexibly with Quality of Service (QoS) guarantees. However, to apply ubiquitous network using terrestrial networks require high capital investment and long implementation time frames. Thus, satellite communications is the ideal solution for providing worldwide Internet services, wide area coverage, and re-configurability.

1.1 Early in Satellite Communications

Satellite communications started to play an important role in United States (U.S.) military earlier in 1946. In 1954, the U.S. military department ran a series of communications experiments using the moon as a reflector. By 1957, the Soviet Union successfully launched Sputnik I. Immediately after launching Sputnik I, U.S military started their satellite communication project.

The rapid development of military communication satellites led to deployment of commercial communication satellite systems. The evolution of computer networks in the early 1970s made satellites communications more prevalent. Current communication satellite systems are more complicated than those in the past and more integrated with a wide range of services, such as fixed networks and mobile networks. Satellite communication can also guarantee the user to have real global coverage, including maritime and aeronautical users.

1.2 Use of Satellite Communications Today

In this present era, satellite communications play a vital role. Satellites communication work as overhead wireless repeater stations that provide microwave communication links between two geographically remote sites (Rizwan, 1997). Most of the satellites operate at a high altitude. This means satellite transmissions cover a wide geographical area over the surface of the earth. Satellites receive incoming signals from the ground station on the earth, then amplify the incoming signals and retransmitting them to receiving stations on the earth using a different frequency.

Most of satellites are referred to as “bent pipes”. This is because they simply rebroadcast whatever signal they receive. Many of these satellites were traditionally used to support applications such as TV broadcasts and voice telephony. In recent years, WAN networks using satellite links have become widespread, where they provide backbone links to geographically dispersed LAN's and MAN's.

Today, the deployments of commercial satellite communication networks demonstrate the promising ubiquitous access to the Internet. Delivering this promise to end users requires integrating satellite communications into the existing Internet transmission links. On the other hand, the evolution of video compression giving a picture quality at data rates of 2Mbps created a great interest and provided a strong market drive for the broadcasters to implement a complete Direct-To-Home (DTH) satellite program delivery infrastructure. For such a system, new and more efficient networks, which offer higher bandwidths using the Digital Video Broadcast (DVB) technology (Farserotu and Prasad, 2000, Koudelka, 2000, Hu and Li, 2001) are promising. Developments in DVB enabled data broadcasting over DVB, such as delivery of Internet services over satellite via high speed transmission using DVB satellite hub station to transmit packet data to the same satellite dish used for TV distribution (EBU and ETSI, 2004).

1.3 Research Motivation

IP based services have become an important requirement today. In this thesis, the research aims at improving the performance and the efficiency of IP transport over DVB based satellite networks.

In order to provide IP transport over DVB, Multi-protocol Encapsulation (MPE) and Unidirectional Lightweight Encapsulation (ULE) methods have been proposed (Fairhurst and Matthews, 2003). MPE provides a mechanism for transport data

networks. It was designed for transport of IP, but it can also be used for transportation of other network protocols using the Logical Link Control/Subnet Attachment Point (LLC/SNAP) feature. However, MPE has some limitations. MPE adds a lot of overhead during the encapsulation process. High overheads result in excessive utilization of bandwidth, and satellite bandwidth is a very expensive resource. Hence, the MPE encapsulation method is generally considered to be not efficient in terms of processing requirement. Therefore, a ULE encapsulation method has been proposed as an efficient alternative to MPE (Fairhurst et al., 2005).

1.4 Problem Statement and Scope of Research

ULE is a new encapsulation mechanism that provides a significant functional benefit over MPE, allowing the encapsulation of a wide variety of packet types using a standard encapsulation header. In this thesis, both MPE and ULE will be studied and their performance will be analyzed using Network Simulator (*ns2*). In order to further enhance the ULE encapsulation, improvements to IP transport via ULE encapsulation over DVB-S will be investigated. The scope of this work is limited to centralized single hop satellite networks.

1.5 Research Objectives

1. To compare the current encapsulation method, Multi-Protocol Encapsulation (MPE) with Unidirectional Lightweight Encapsulation (ULE).
2. To enhance the performance of the ULE by proposing a new encapsulation method Unidirectional Lightweight Encapsulation with Robust Header Compression (ULE with ROHC).
3. To model the satellite Digital Video Broadcasting (DVB) network in Network Simulator version 2.0 (*ns2*) and implement the new proposed ULE with ROHC encapsulation method in *ns2*.

4. To evaluate the MPE and ULE encapsulation with regards to their impact on Moving Picture Experts Group 2 Transport Stream (MPEG-2 TS) over satellite transmission for real time UDP unicast traffic over Unidirectional Links.
5. To optimize the performance of the proposed Unidirectional Lightweight Encapsulation with ROHC method and compare the result with existing encapsulation methods (MPE and ULE).

1.6 Research Methodology

This research has used a combination of theoretical analysis and simulation based experiments to investigate the performance of MPE, ULE and ULE with ROHC. The first step of this research is to identify the performance bottlenecks for MPE and ULE. Two general problems of encapsulation schemes: overhead and transmission efficiency of MPE and ULE were being defined. The ultimate goal of any encapsulation technique is to maximize the transmission efficiency, the transmission efficiency of various encapsulation techniques for MPEG-2 TS Packing and Padding mode were first examined using mathematical model.

The result from this theoretical analysis can provide some ideas on what the research challenges were. Consequently, some solutions could be proposed to address these challenges. In this second step, the theoretical analyses were analyzed to formulate a new solution that can reduce packet overhead and increase the transmission efficiency of ULE.

Once the new solution ULE with ROHC was proposed, the third step involved prototyping and evaluation of the potential solution. MPE and ULE encapsulation models used in this simulation were enhanced and adopted from the versions provided by the European Space Agency (ESA). ULE with ROHC was implemented in *ns2* using a modular design method.

The final step of the research is to analyze and improve simulation results. In this step, some parameters need to be fine-tuned in order to optimize the proposed solutions until the best overall results were obtained.

1.7 Outline of the Thesis

This thesis is organized into six chapters. The organization of each chapter is as follows:

Chapter 1 briefly outlined the background of satellite communication systems, research motivation, research methodology and objectives.

Chapter 2 covers the literature survey of satellite communication systems. It discusses various types of satellite and categorizes them into intended use, orbital altitude and payload size. Advantages and disadvantages for satellite communication systems are also presented. The basic definitions used throughout the thesis are introduced and the fundamental concepts of IP over DVB are discussed. This provides an introduction to the various IP encapsulation mechanisms used to encapsulate IP datagrams into MPEG-2 TS in order to transmit IP packets over DVB networks.

Chapter 3 compares two major IP over DVB-S encapsulation methods, namely MPE and ULE. The theoretical analysis of both encapsulation mechanisms is presented. This naturally leads to a comparison of their strengths and weaknesses. This in turn will motivate the choice for proposing a new encapsulation mechanism named ULE with

ROHC. The introduction of ULE with ROHC is also included in this chapter and is begins by describing the basic design and operation of this proposed encapsulation mechanism.

Chapter 4 is concerned with the implementation details of ULE with ROHC. This chapter also covers the simulation technique used for this research. The primary simulation tools used in this research is outlined, and detailed description of the simulation models and simulation parameters used is also given.

Chapter 5, this chapter presents the model verification and validation experiments. A simulation case study demonstrating the improvements of ULE with Header Compression is also included in this chapter.

Chapter 6, this chapter summarizes the contribution of this research thesis. It also covers the overall conclusion, limitations and future work regarding this area of research.

CHAPTER 2 LITERATURE SURVEY

2.0 Introduction

This chapter intends to give a description of several developments related to the transmission of IP data over satellite networks. The fundamental concepts of IP over MPEG-2/DVB networks and IP datagram encapsulation methods will be discussed. Besides, DVB-S and MPEG-2 system architectures, MPE, ULE and header compression concept is included as well.

2.1 Terminology

A communication satellite functions as an overhead wireless repeater station that provides a microwave communication link between two geographically remote sites. The term communication link here is equivalent as satellite link. A satellite link is defined as a communications subsystem that involves a link between a transmitting earth ground station and a receiving earth ground station via a communications satellite with some specified attributes such as capacity, direction, and quality.

In general terms, the satellite link can be a logical connection between two components in a network and it also can be defined as a specific instance of a channel. The satellite link can be Unidirectional (one way) or Bidirectional (two ways). In satellite networks, all the outgoing traffic and incoming traffic will be sent or received via the satellite channel. The satellite Channel is a carrier frequency used for satellite transmission and it also can be defined as a medium where information is transmitted from a sender to a receiver.

2.2 Advantages of Satellite Communication Systems

2.2.1 Coverage

A satellite is able to provide a large coverage area to the earth user, the size of the coverage area depends on which orbit is the satellite stays in. In general, the higher the orbit where the satellite stays in, the larger the size of area can be covered. For example a single GEO satellite can cover up to 30% of the Earth's surface (Arthur, 1945). This will benefit the users to communicate with each other from every part of the world, especially for an area whose population is very sparse. On the other hand, the satellite can be the only alternative to provide communication for those areas that no terrestrial communication supported or the local terrain that is hard to install a ground-based network.

2.2.2 Availability

In wireless environment, there are many obstacles and reflectors in the wireless propagation channel. This explains why the wireless communication link experiences more multi-path fading. Hence, the wireless environment will experience signal fluctuation which is also known as Rayleigh Fading (Sklar, 1997a, 1997b). As a result, wireless communications difficult to provide the direct Line Of Sight (LOS) links required by the higher frequency band compared to wireless communication links. Whereas, satellite communication channel suffers lesser multi-path fading because the majority of the satellite links between the ground terminal and the satellites are at high elevation angles. This will prevent LOS communications from being blocked by any obstacles such as mountain, hills, buildings, moving vehicles and others.

2.2.3 Broadcast / Multicast Capability

Most of the satellite-based networks offer broadcast and multicast transmission over satellite link. It can be done by sending an uplink signal to the satellite from the earth station; the satellite receives and retransmits the signal to a certain coverage

area. A receive station which is within the satellite coverage area will be able to receive the signal. Hence, information can be transmitted to many users through a common channel without replication of the information for each individual user.

2.2.4 Flexibility

The configuration flexibility of satellite network offers the operators to run their duty more easily. Once the satellite is launched successfully and the satellite network is working or operating well, the ground-based network configuration can be easily adapted to accommodate new users and remove others from the system.

2.2.5 Cost Independence with Distance

Every receive station within the satellite coverage area can receive the same signal; it does not depend on the location of the receive station. Therefore, the cost of accessing to the satellite resources is independent on the location of the receive station. On the contrary, the terrestrial link whereby the costs to get such services fully depend on the distance from the service provider.

2.2.6 Reliability

Compared to other terrestrial links (fiber) or wireless links, satellite links are more reliable as it offer communications to people living in terrestrially underserved areas. Satellites are less subject to interference and outages than fiber, and can be tailored to meet specific requirements. Satellite links only require maintenance at the ground station like end user terminals and there are less prone to disabling through accidental or malicious damage. For example, Intelsat (European Satellite) has a satellite reliability rate more than 99.9% (Edelson et al., 1977).

2.3 Disadvantages of Satellite Communication Systems

2.3.1 Cost

High capital is needed to launch a satellite into space. Satellite Communication needs a proper and careful planning before a satellite can be launched. These procedures might consume a lot of money. In certain situations, a single satellite might not be enough to provide a good coverage area. For example, the LEO-based satellite, to provide global coverage, it needs more than 40 satellites, and the entire network must be deployed prior to service provision. This, in fact, requires a huge investment.

2.3.2 Deployment Lead Time

As mentioned above, to launch a satellite system into space, it might take several years for a successful plan and design. The satellite development team members need to have a long term planning and they must estimate precisely the communication services that may be needed in the future. This is due to the adaptability of the satellite system which is a very important and must be carefully considered to make sure that the satellite is useful and able to fulfill user demands in the future.

2.3.3 Propagation Delay

Satellite links introduce long propagation delay which will affect the performance of TCP, especially in the case of GEO satellite links. The connection over GEO satellite links incurs round trip delay approximately 500 milliseconds. These long round trip delays place numerous constraints on the system performance and bring a big impact to the TCP application. This is because TCP senders heavily depend on timely ACK feedback for error recovery or traffic rate adjustment. TCP needs to be configured correctly in order to use the satellite links, otherwise it will result in ineffective use of the available capacity. Numerous techniques have been proposed and are going on to be developed to improve the performance of TCP over Satellite (Partridge and Shepard, 1997, Tardif, 1994, Joo and Wan, 2000, Mitchell, 2003).

2.4 Satellite Communication Fundamentals

2.4.1 Satellite Network Topology

To analyze the characteristics of the satellite communication links, the characteristics of the satellite network topology should be studied first. Satellite network topology is the physical shape of the satellite network. There are three main network topologies used for broadband systems, Bent Pipe Point to Point, Bent Pipe Point to Multipoint and On Board Processing (OBP) topology. Irrespective of the type of orbit used, the satellite network can be any of these three topologies. The type of orbit only affects the complexity of the physical implementation. However, the satellite payload used in the topology can be transparent or it may have an OBP and switching capability. The word transparent is a term used to describe satellite systems that do not alter the basic format of the signals they receive before retransmitting them, but OBP is opposed to transparent satellite systems, the OBP satellite systems usually implemented digitally, and may include signal regeneration.

2.4.1.1 Bent Pipe Point to Point Topology

Bent Pipe Point to point topology typically comprises of a dedicated one-way or two-ways link connection between a large gateway earth and a single user terminal, which delivers the selected content directly to the end users. In Point to point topology, satellites may have a two-ways or one-way transmission of signal whereby the uplink and downlink or just the downlinks take place over satellite (Broadband Satellites, 2006). The earth station transmitter will deliver signals to the satellite receiver, then transmitting down to the receive earth station via the transmitting antenna. Usually, no change is made to the signal except an amplification to overcome the large path losses and a frequency conversion to separate the up and down links. The downstream signal delivery is delivered to the client via a direct downlink, or in some cases, a downlink located at a local Internet Access provider who in turn delivers the data to the requesting user.

2.4.1.2 Bent Pipe Point to Multipoint Topology

Bent Pipe Point to Multipoint topology is an evolution of the Point to Point concept. The satellite of this topology can be designed as one-way or two-ways satellite systems. This topology is characterized by having a large gateway earth station which transmits one or more high data rate forward link broadcasts to a large number of small user terminals. These broadcasts contain address information which allows each user terminal to select those transmissions intended for.

2.4.1.3 On-Board Processing (OBP) Switching Topology

The OBP switching topology is an improvement in spectrum sharing and this topology has the satellite being the focus of a star network. The OBP in the payload de-multiplexes the uplinked trunk and splits it into downlinks intended for particular geographical areas (Broadband Satellites, 2006). The term On-board Processing (OBP) means that the signal from the ground is not only translated and re-amplified prior to retransmission like what conventional bent pipe point to point topology usually does, but it is processed down to baseband via on-board decoding and demodulation (Wittig et al., 1995). The OBP switching topology can improve the overall link performance at the receiving station because the signal from the ground station will be down-converted and de-modulated, then the signal will be modulated, multiplexed and up-converted again to be transmitted at the downlink. Thus, the uplinks signal with the distortions and noise will have no effect on the downlink transmission.

2.5 Data Transmission over Satellite

The growing use and demand of computers to access the Internet has resulted the users looking forward to the Internet access almost anywhere in the world. In the future, connectivity or Internet access is expected to be provided in whatever location. Along with the emergence of data transmission over satellite technologies, the connectivity or a Wide Area Network (WAN) link to the home Local Area Network (LAN) from anywhere on the earth becomes feasible.

Currently, there are many point to point satellite technologies used for data transmission. Single Channel per Carrier (SCPC) and Multiple Channel per Carrier (MCPC) are the examples of the conventional transmission mode for voice and data communications via satellite. These two techniques are beyond this study; this is due to the fact that SCPC and MCPC do not allow sharing of the bandwidth among multiple VSATs. This makes these two techniques uneconomical.

The current technologies which support IP networking over satellite are Digital Video Broadcasting over Satellite (DVB-S) and Asynchronous Transfer Mode (ATM) (EBU and ETSI, 2004). For example, the Astra satellite system is a geostationary satellite system using DVB MPE to transmit IP packets, with a reverse channel of IP over ATM. With current technologies, it seems that geostationary satellite systems are the most popular technologies in use today, and in this study only geostationary satellites are considered.

Many researchers have studied satellite communications over geostationary satellites. One of the most popular issues is TCP over satellite links. However, in this study, only the performance of the link layer encapsulation of IP packets and the way to improve its performance will be considered. Higher layer optimizations are assumed to be addressed by existing research given above.

2.5.1 Digital Video Broadcasting

DVB is a set of standards that define digital broadcasting using existing satellite, cable, and terrestrial infrastructure. In the early 1991s, the DVB is known as the European Launching Group (ELG). But later, the ELG was officially inaugurated in September 1993 as DVB. Today, the DVB projects consist of a voluntary group of currently more than 220 organizations which have joined forces to make possible the development of standards for DVB in all parts of the world.

DVB systems are developed through cooperative in the working groups of the Technical Module. Members of the groups are drawn from the general assembly of the project. Once the standards are published, DVB will publish the standards through European Telecommunications Standards Institute (ETSI), there are available at a nominal cost for anyone, world-wide. Open standards free manufacturers to implement innovative as well as value added services. In fact, there are several DVB standards for different transmission media. Some of which are:

1. Digital Video Broadcasting- Satellite (DVB-S)
2. Digital Video Broadcasting- Cable (DVB-C)
3. Digital Video Broadcasting- Terrestrial (DVB-T)

2.5.2 Digital Video Broadcasting- Satellite (DVB-S)

According to (EBU and ETSI, 1997a), the DVB-S system has successfully provided attractive packages for the various audiences, and the main motivation for using DVB bent-pipe system is the availability of terminals with reasonable prices which conform to the standards. Furthermore, bundling of the IP services with other services such as video allows attracting more users.

DVB-S is the common and most popular of the DVB specifications family, and many countries in the world have adopted services based on DVB-S. The DVB-S has long been used in point-to-point, point-to-multipoint and mobile satellite data communications systems for the users. DVB-S is defined as the functional block of equipment performing the adaptation of broadband TV signals, from the output of the MPEG-2 transport multiplexer, to satellite channel characteristics (EBU and ETSI, 1997a). This DVB-S system is designed to cope with a range of bandwidth transponder with different bands. There are several European satellites compatible to carry DVB signals, for examples, HISPASAT, EUTELSAT series, ASTRA, TELE-X and others.

The DVB-S system is design to comply with (EBU and ETSI, 1997a) and it is directly compatible with MPEG-2 coded TV services. The modem transmission frame is synchronous with the MPEG-2 multiplex transport packets. The video, audio, control data and user data are all inserted into fixed length MPEG-2 transport stream packets (MPEG-2 TS). Then some processes are applied into the DVB-S system in order to reduce the sensitivity of the signal to the errors. Today, the DVB-S system has many options for sending MPEG-TS packets over satellite links that is commonly used for Digital TV (EBU and ETSI, 2003), therefore the end-user terminal only received DVB-S frames from the satellite, but did not have the ability to send any traffic towards the satellite. However, in 1999, the ETSI proposed a standard for a return channel via satellite, the DVB-RCS, which make satellite terminals with the ability to transmit traffic towards the satellite. The Figure 2.1 below illustrates the DVB-S topology.

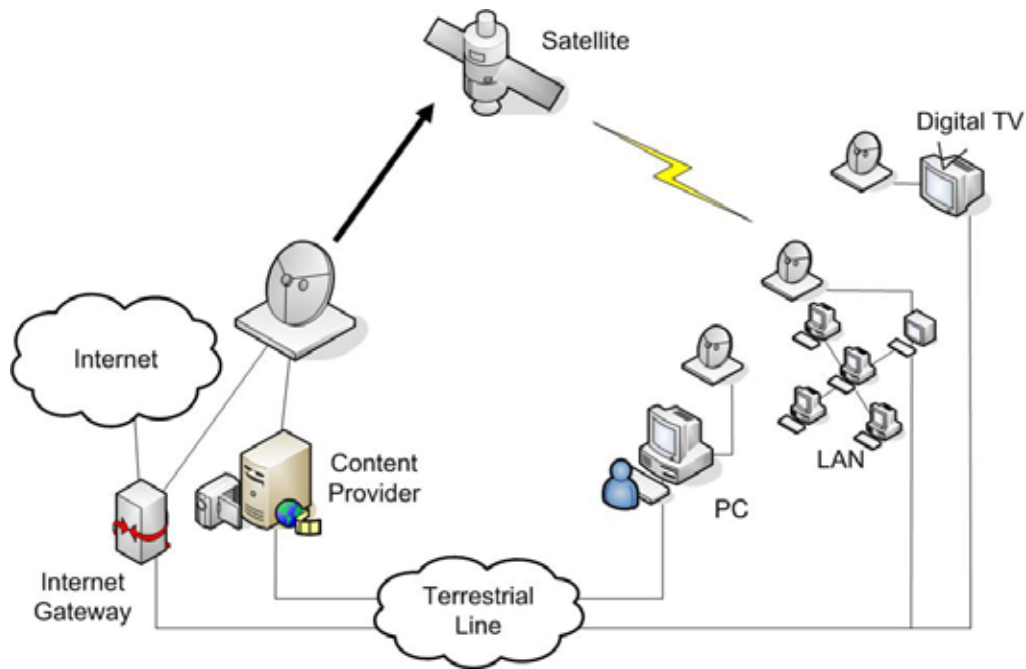


Figure 2.1: DVB-S topology (Ong et al., 2005)

2.5.3 Digital Video Broadcasting-Return Channel Satellite

DVB with Return Channel via Satellite (DVB-RCS) has been standardized enabling full independency to the terrestrial network. DVB-RCS is a new standard modified from DVB-S by adding an additional standard on creating an interactive return channel using satellite. Figure 2.3 shows the DVB-RCS topology. The DVB-RCS has a broadcast channel in forward link and point to point (PPP) channel in return link.

In a DVB family, data can be transferred by using fixed size MPEG-2 Transport Stream to carry packetized data in the forward link. Meanwhile, in the case of the DVB-RCS system, different type of encapsulation schemes can be used on the return links to transport the packet. On DVB-RCS links, either MPE/MPEG-2 TS or AAL5/ATM can be used.

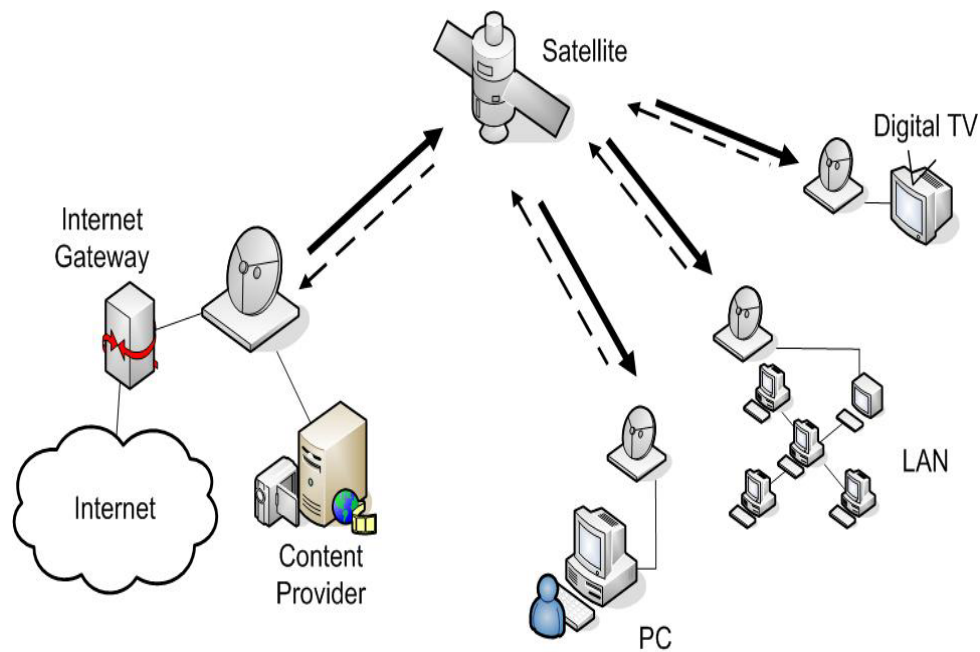


Figure 2.2: DVB-RCS topology (Courville et al., 2005)

2.5.4 DVB Data Link Standard

2.5.4.1 MPEG-2 Overview

MPEG-2 is the newly formed standard for high quality of video and audio compression which is applicable to high quality of real-time conferences. MPEG-2 standards define how to encode audio and video. Besides, they also define how these components are combined into a single synchronous transmission bit stream. The MPEG-2 Systems Standard provides the means of multiplexing several types of multimedia information into one Transport Stream (TS) that can be transmitted over a variety of transmission media (ISO/IEC, 2000). The MPEG-2 Transport Stream (MPEG-2 TS) was designed for transporting MPEG-2 over an environment or transmission channels whereby the error usually occurs.

2.5.4.2 MPEG-2 TS

Traditionally the MPEG-2 TS is designed to carry multiple Programs in a stream that contains compressed video and audio data (Yoshimura, 2002). For the video data compression, the scenes with a lot of motion in pictures are normally encoded with a higher bit rate than scenes with less motion. The compression causes a variable data rate of each TV program. Bursty and fluctuating characteristic of variable-bit-rate (VBR) of compressed video traffic requires allocation of extra bandwidth to achieve delay and bit-error-rate (BER) requirements of DVB (Yilmaz, 2002).

Besides, a MPEG-2 TS cell can be used as a container for the IP packet with added encapsulation header to allow the information to be adequately processed. This allows the MPEG-2 TS bearer network to become a hop in an IP network. Data broadcasting is seen as an important extension of the MPEG-2 based DVB-S. Examples for data broadcasting are downloading of software over satellite, the delivery of Internet services over broadcast channels (IP tunneling), interactive TV and others. A simple overview of the packet stack is given in Figure 2.3 below.

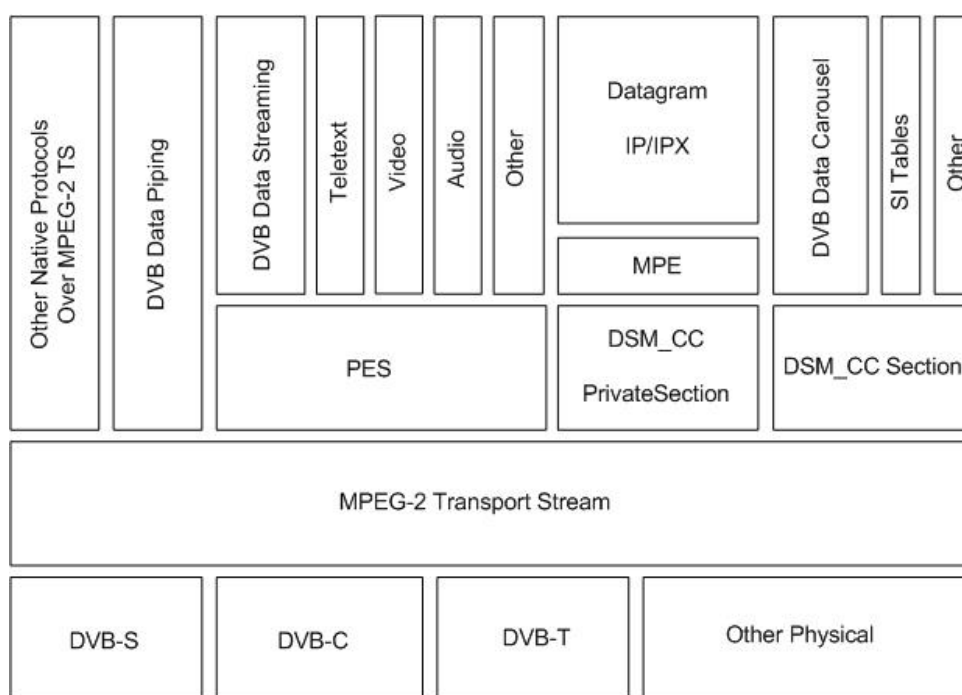


Figure 2.3: DVB Protocol Architecture (Montpetit, M. J. et al. 2005)

The TS is a stream that consists of consecutive and relatively short fixed-length TS packets. The MPEG-2 TS packet length is 188 bytes. Each TS packet structure starts with fixed length of 4 bytes TS header followed by 184 bytes adaptation field as a header extension and payload (data section). The TS packet header starts with a unique 8 bit Synchronization byte (0x47). Another field in the TS header, which plays an important role in the operation of the TS, is the 13-bits Packet Identifier (PID). The PID determines to which program a TS packet belongs to and is also unique for all programs. The transport_error_indicator can be used to notify the decoder about possible errors so that errors concealment techniques can be implemented. The format of the MPEG-2 TS is described using the Figure 2.4 below:

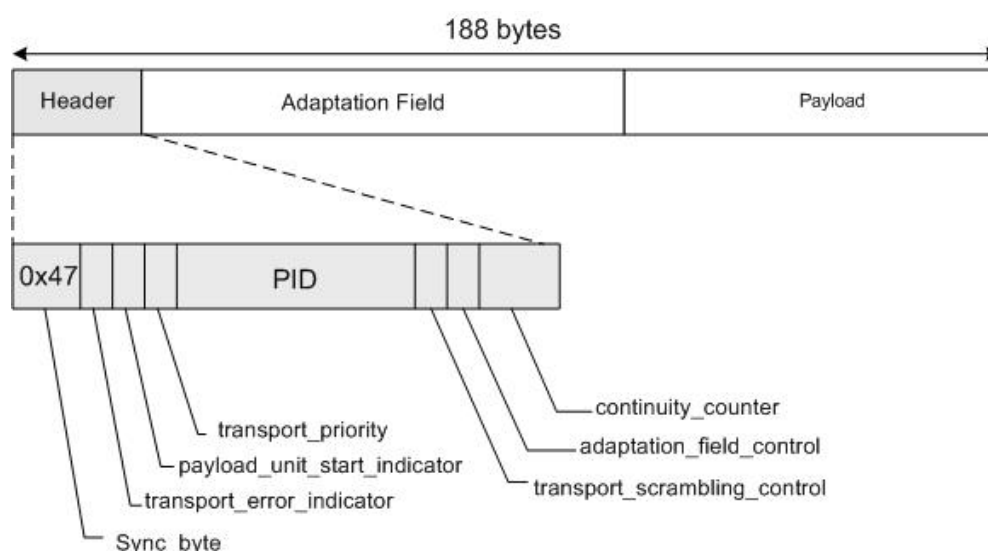


Figure 2.4: Transport Stream and Header Structure (Yoshimura, 2002)

The Adaptation Field contains various types of information to be sent, such as splice countdown used to indicate Program Clock Reference (PCR) and edit point. It is also used as stuffing. Stuffing means that if the payload unit finishes before the end of a TS packet payload, stuffing procedure will fill the remainder of TS packet payload with bytes with value 0xFF, and it will always keep the TS packet in 188 bytes. Figure 2.5 below illustrates the Adaptation Field format and structure:

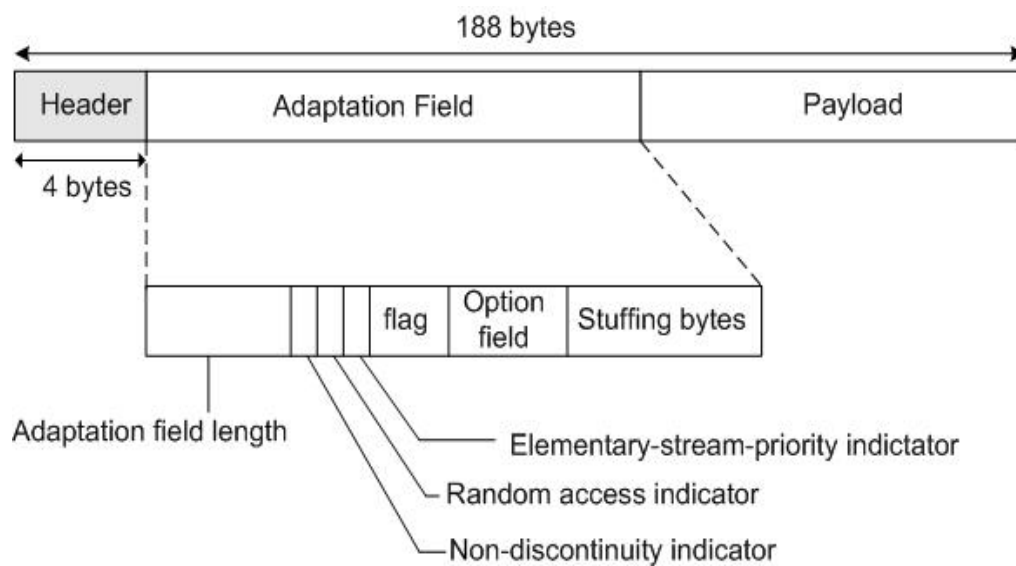


Figure 2.5: Adaptation Field Structure (Yoshimura, 2002)

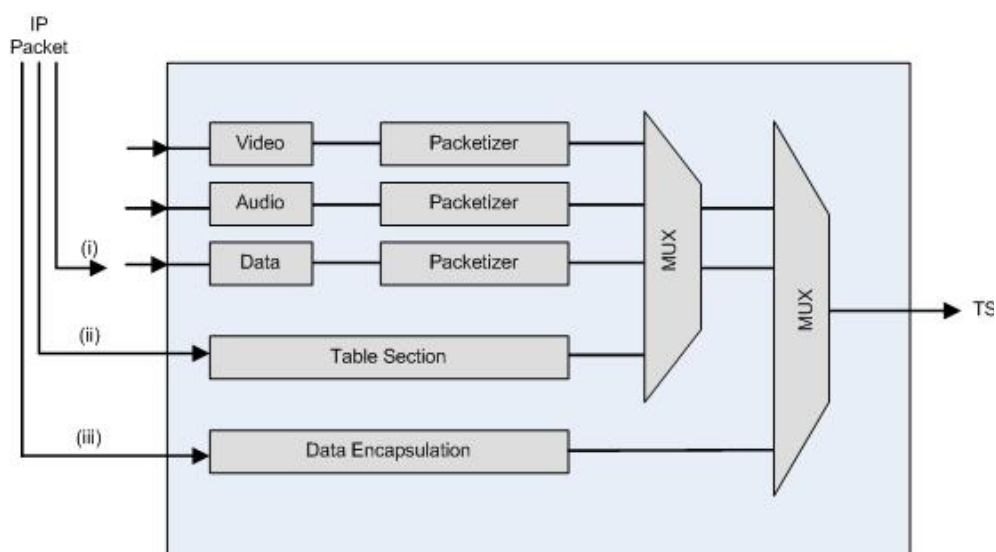


Figure 2.6 Functional Block Diagram of a DVB System (EBU and ETSI, 1997a)

Over the years, there are many encapsulation methods have been used to transmit data over DVB.

1. Data Streaming

The IP packet is encapsulate into PES packets by mapping an IP packet into a PES packet payload.

2. Data Piping

Data packet encapsulate directly into MPEG-2 TS packet, this mode can be used to transport ATM/AAL5 over MPEG-2 TS.

3. Multi-protocol Encapsulation

IP packets encapsulate into Digital storage medium–command and control table section packet.

4. Unidirectional Lightweight Encapsulation

IP packet encapsulate directly into MPEG-2 TS packet, which is also known as ULE.

2.5.5 IP over MPEG-2 TS Approaches

DVB-S systems support high speed Internet access on a number of DVB satellite TV delivery systems. The digital Low Noise Amplifier (LNA) or Low Noise Block (LNB) which is a special type of amplifier used in communication systems to amplify very weak signals captured by an antenna can be used to build a high speed simplex data transmission system. The return connection from the end user back to the server center can be established by using the existing terrestrial infrastructure. This kind of system may provide low cost, high bandwidth Internet connectivity to whoever is located within the satellite footprint.

The DVB system specified by the European Broadcast Union (EBU) is based on the cell-oriented packet transmission system defined by International Organization for Standardization (ISO/IEC, 2000) and MPEG-2 Systems Standard (EBU and ETSI, 1997b). The first DVB standard described a transmission scheme based on MPEG-2 (Motion Picture Expert Group 2) video compression and transmission schemes, using MPEG-TS (MPEG-Transport Stream). This transmission scheme was adapted for satellite-based delivery through DVB-S (DVB transmission via satellite) that defined a

series of options for sending MPEG-TS packets over satellite links which is commonly used for Digital TV today. The first generation of DVB-S was not intended to carry IP data since it was designed to exclusively transport MPEG-2 TS packets. The transport of IP datagrams over DVB-S was later introduced by encapsulating them into MPEG-2 TS packets.

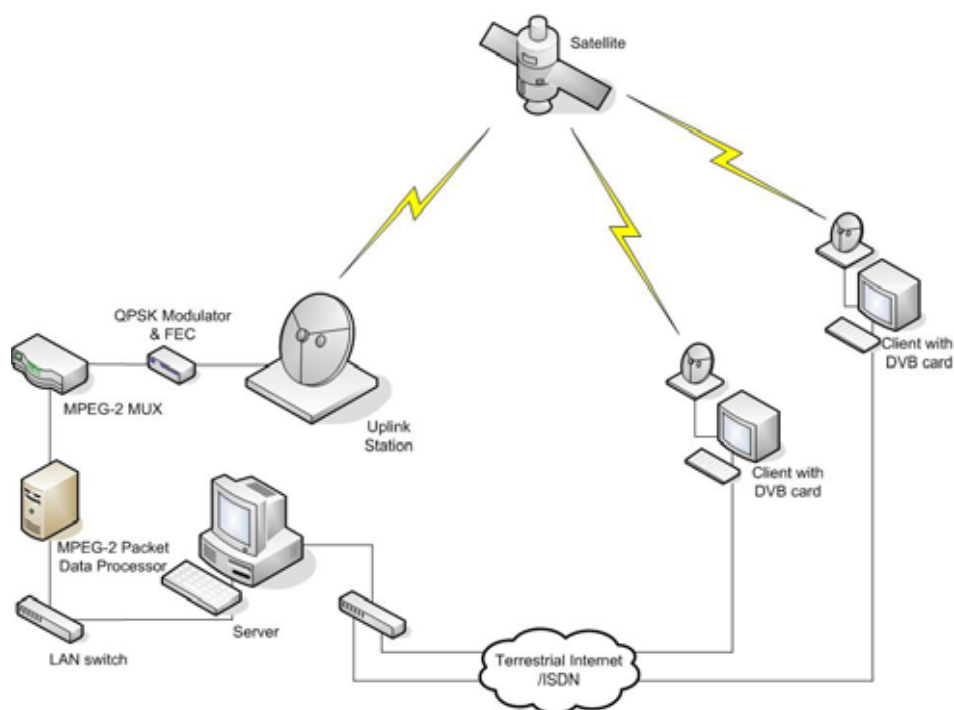


Figure 2.7: Internet Delivery Using DVB

In order to support such features, a numbers of manufacturers supply DVB-S receiver card with data capability and gateways at the uplink station to packetize the data to be sent. In an effort to standardize these services, the DVB specification has identified several different application areas with different requirements for the data transport, which was been explained in previous sections (Section 2.5.4). In the following section, 3 encapsulation methods will be explained in details.

1. Multi-protocol encapsulation (using Multi-Protocol Encapsulation) (MPE)
2. Data piping (using Unidirectional Light Encapsulation) (ULE)
3. Data piping (using ATM/AAL5) (ATM/AAL5)

2.5.5.1 Multi-Protocol Encapsulation (MPE)

The most common method employed to carry Internet Protocol is MPE. The DVB MPE (EBU and ETSI, 2004) format is compliant with the Digital Storage Media Command and Control (DSM_CC) section format for private data. In order to carry IP packets in the MPEG-2 stream, there is a section named datagram section which defined by DSM-CC to support any type of OSI layer 3 networking protocol. However DVB has optimized the section format to make it easier to use MPE with IP datagrams. Figure 2.8 illustrates the packet format of MPE encapsulation method.

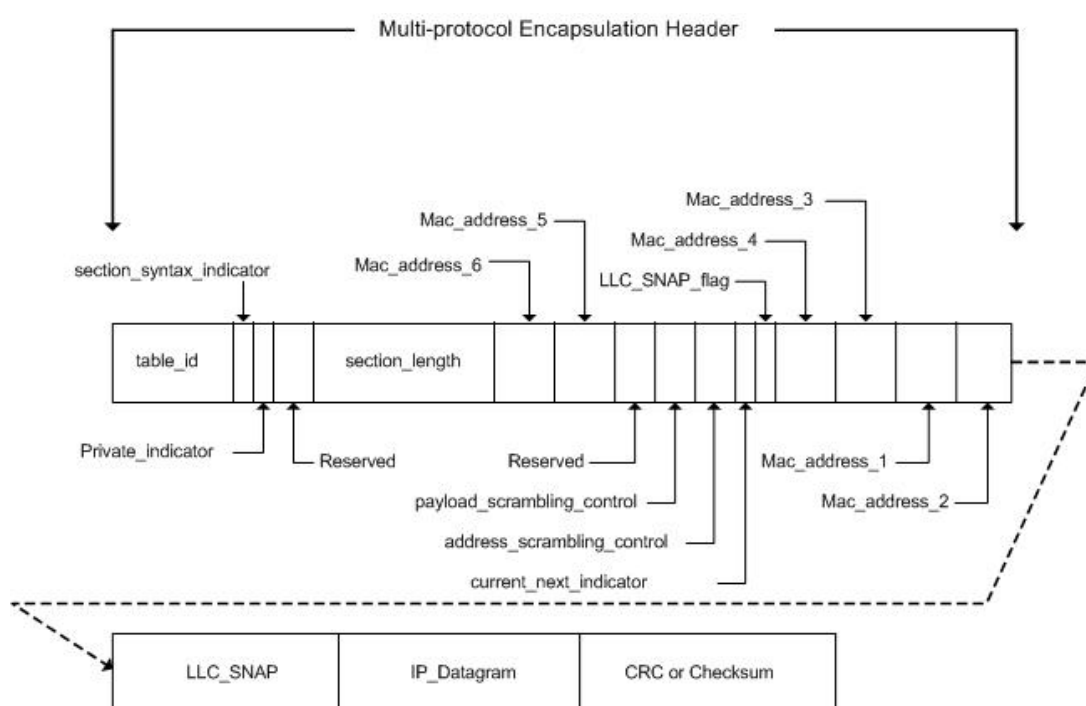


Figure 2.8: MPE Packet Format (Collini-Nocker and Fairhurst, 2004)

The MPE method provides a mechanism for transporting data network protocols on top of the MPEG-2 Transport Streams in DVB networks. In addition, it also can be used for transporting any kind of OSI layer 3 networking protocol by using the LLC/SNAP encapsulation. It supports unicast, multicast and broadcast. Since the research focuses on IP only, the LLC/SNAP encapsulation for MPE won't be examined further in any details. In MPE, it contains several MAC addresses fields, these 48-bit MAC addresses are used for addressing receivers. However, DVB does not specify how these MAC addresses are allocated to the receivers.