Università degli Studi di Padova

Department of Information Engineering - DEI

Master Thesis in ICT for Internet and Multimedia

Analysis and Implementation of Internet-Based Digital Video Broadcasting (DVB-I) in Hotel Infrastructures

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Abstract

The new technology Internet-Base Digital Video Broadcasting (DVB-I) represents a significant evolution in the context of television broadcasting, and its purpose is to combine traditional television broadcasting and Internet-based services. In fact, it is a standard that is used for the discovery of TV content available on Internet Protocol (IP) networks, integrating also traditional linear channels into a single electronic program guide. This thesis delves into the technical aspects, implementation challenges, and potential impacts of DVB-I on the future of television.
The research explains DVB-I's core components, including service discovery, program information, and content delivery protocols.

This thesis further explores the various specifications related to DVB-I, with a particular focus on Dynamic Adaptive Streaming over HTTP (DVB-DASH). As a key component of the DVB-I architecture, DVB-DASH ensures seamless IP-based video delivery while maintaining the reliability and robustness of traditional broadcast standards. This technology guarantees adaptive streaming, which allows the video quality to change according to the available bandwidth, ensuring smooth and optimum video playback. A DVB-DASH Generator that can be used with the DVB-I discovery service was created during the project, enabling television reception on mobile devices connected to a hotel's infrastructure.

Finally, this thesis identifies DVB-I as a critical stage in the ongoing change of the television business, providing insights for broadcasters interested in exploring this new technology.

Sommario

La nuova tecnologia di trasmissione video digitale basata su Internet (DVB-I) rappresenta un'evoluzione significativa nel contesto delle trasmissioni televisive, e il suo scopoè quello di combinare la trasmissione televisiva tradizionale con i servizi basati su Internet. Si tratta infatti di uno standard che viene utilizzato per la scoperta dei contenuti TV disponibili su reti IP, integrando in un'unica guida elettronica dei programmi anche i tradizionali canali lineari. Questa tesi approfondisce gli aspetti tecnici, le sfide di implementazione e i potenziali impatti di questa nuova tecnologia sul futuro della televisione.
La tesi spiega le componenti principali del DVB-I, tra cui l'acquisizione dei servizi, le informazioni sui programmi e i protocolli di distribuzione dei contenuti.

Questa tesi esplora le varie specifiche relative alDVB-I, con particolare attenzione allo Streaming Dinamico Adattivo su HTTP (DVB-DASH). Come componente chiave dell'architettura DVB-I, il DVB-DASH garantisce una distribuzione video basata suIP senza interruzioni, mantenendo al contempo l'affidabilità e la robustezza degli standard di trasmissione tradizionali. Questa tecnologia garantisce uno streaming adattivo, che consente al video di cambiare qualità in base alla larghezza di banda disponibile, garantendo una riproduzione fluida e ottimale. Nel corso del progetto è stato creato un generatore DVB-DASH, che utilizza il servizio di rilevamento dei canali del DVB-I, il quale consente la ricezione televisiva su dispositivi mobili collegati all'infrastruttura di un hotel.
Infine, questa tesi identifica il DVB-I come una fase critica nel continuo cambiamento del business televisivo, fornendo spunti per le emittenti interessate ad esplorare questa nuova tecnologia.

List of Figures

Acronyms

A/V Audio Video

AAC Advanced Audio Coding

ABR Adaptive Bit Rate

AIT Application Information Table

API Application Programming Interface

AVC Advanced Video Coding

B2B Business To Business

B2C Business To Consumer

BAT Bouquet Association Table

CAT Conditional Access Section

CEA Commission on English Language Program Accreditation

CICAM Common Interface Conditional Access Module

CDN Content Delivery Network

CSR Centralized Service List Registry

CSS Cascading Style Sheets

DASH MPEG Dynamic Adaptive Streaming over HTTP

DLNA Digital Living Network Alliance

DNS Domain Name System

DRM Digital Rights Management

DSM-CC Digital Storage Media - Command and Control

DTH Direct To Home

DTT Digital terrestrial television

DVB Digital Video Broadcasting

DVB-C Digital Video Broadcasting - Cable

DVB-DASH Dynamic Adaptive Streaming over HTTP

DVB-GSE Digital Video Broadcasting - Generic Stream Encapsulation

DVB-I Digital Video Broadcasting - Internet

DVB-IPTV Digital Video Broadcasting - Internet Protocol Television

DVB-MABR Digital Video Broadcasting - Multicast Adaptive Bit Rate

DVB-MPE Digital Video Broadcasting - Multi Protocol Encapsulation

DVB-NIP Digital Video Broadcasting - Native IP Broadcasting

DVB-S Digital Video Broadcasting - Satellite

DVB-S2 Digital Video Broadcasting - Second Generation Satellite

DVB-T Digital Video Broadcasting - Terrestrial

DVB-TA Digital Video Broadcasting - Targeted Advertising

DVB-T2 Digital Video Broadcasting - Second Generation Terrestrial

EIT Event Information Table

EMM Entitlement Management Message

EPG Electronic Programme Guide

ES Elementary Stream

HbbTV® Hybrid Broadcast Broadband Television

NOTE: HbbTV® is a registered trademark of HbbTV Association.

HD High-Definition

HDMI High-Definition Multimedia Interface

HEVC High Efficiency Video Coding

HTML HyperText Markup Language

HTTP Hypertext Transfer Protocol

HTTPS Hypertext Transfer Protocol Secure

IGMP Internet Group Management Protocol

IP Internet Protocol

ISO International Organization for Standardization

ISP Internet Service Provider

LAN Local Area Network

LCN Logical Channel Numbering

LTE Long Term Evolution

MPEG Moving Picture Experts Group

MPD Media Presentation Description

NIF Network Information File

NIT Network Information Table

NR New Radio

OFDM Orthogonal Frequency Division Multiplexing

OIPF Open IPTV Forum

OTT Over-The-Top

PAT Program Association Table

PCR Program Clock Reference

PES Packetized Elementary Stream

PHP Hypertext Preprocessor

PID Packet Identifier

PMT Program Map Table

POC Proof-Of-Concepts

PSI Program Specific Information

PUSI Payload Unit Start Indicator

PWA Progressive Web Application

QAM Quadrature Amplitude Modulation

QoE Quality of Experience

QoS Quality of Service

RAP Random Access Points

RCU Remote Control Unit

REST REpresentational State Transfer

RF Radio Frequency

RTP Real-Time Transport Protocol

SI Service Information

SIF Service Information File

SDT Service Description Table

STB Set Top Box

TDT Time and Date Section

TLS Transport Layer Security

TS Transport Stream

UDP User Datagram Protocol

UHD Ultra-High-Definition

UHF Ultra high frequency

UI User Interface

URI Uniform Resource Identifier

URL Universal Resource Locator

UTC Coordinated Universal Time

VOD Video-On-Demand

XML eXtensible Markup Language

WAN Wide Area Network

W3C World Wide Web Consortium

Contents

Introduction

Television, a medium of entertainment and communication, is a pivotal component in the lives of people because it emerged as a technology that revolutionized how people receive information and visual storytelling. Since its inception, it has undergone a long transformation: from mechanical and electronic systems to high-definition broadcasting and internet streaming platform [DVB08a].

In this technological revolution, Digital Video Broadcasting (DVB) standards emerged as guidelines for digital television transmission [DVB08a]. Standards like Digital Video Broadcasting - Terrestrial (DVB-T) and Digital Video Broadcasting - Satellite (DVB-S) for terrestrial and satellite broadcasting, Digital Video Broadcasting - Cable (DVB-C) for cable transmission, and Digital Video Broadcasting - Internet Protocol Television (DVB-IPTV) for delivering to and through the home via Internet Protocol (IP) networking, are nowadays essential and together represent the current television prospect.
DVB-T ensures that digital television signals are efficiently transmitted over the air to antennas. It uses Orthogonal Frequency Division Multiplexing (OFDM) modulation to ensure reliable signal transmission in metropolitan areas, resulting in consistent and high-quality broadcasts [EBU15b]. High-Definition (HD) and Ultra-High-Definition (UHD) television streams can be transmitted using Digital Video Broadcasting - Second Generation Terrestrial (DVB-T2) (the evolution of DVB-T standard), which has improved error correcting methods and modulation algorithms like 256 Quadrature Amplitude Modulation (QAM) [EBU23a].
On the other side, DVB-S has become the standard for satellite television broadcasting, allowing satellites to send digital television signals to antennas or receiving dishes. This standard is

essential for reaching worldwide audiences with dependable signal transmission over long distances. Because of its large coverage, DVB-S is useful, especially in isolated places where terrestrial broadcasting is difficult [EBU14].
Concurrently, DVB-C is designed for cable television networks, in this way digital television signals can be delivered to homes via cable systems. By using QAM, this standard optimizes the use of available bandwidth, permitting the transmission of a wide range of channels and facilitating On-Demand services like Video-On-Demand (VOD) [EBU15a].
Lastly, DVB-IPTV transforms television transmission by delivering content across IP networks. It provides flexible and scalable access to TV programs on a wide range of devices, including computers and smart TVs [EBU16].
Together, these DVB standards comprise an extensive ecosystem that guarantees flexible and excellent transmission over a range of systems.

The debate between broadcast and multicast/unicast transmissions is central to the transformation of the television industry and the way content is delivered. On one hand, the traditional broadcast model, which sends the same signal to a broad audience, remains efficient for live events or general programming. On the other, the rise of multicast/unicast transmissions opens up new possibilities for personalized content, as seen with Over-The-Top (OTT) Media Services. These services allow consumers to stream content On-Demand across various devices, including smart TVs, smartphones, tablets, and computers. Some of the most well-known OTT providers include platforms like Netflix, Amazon Prime Video, Disney+, and YouTube. But the complete transition to multicast/unicast transmissions is not yet possible. There are several technical and infrastructural limitations, particularly regarding costs. Unicast, in particular, requires significantly more network capacity since each user receives an independent data stream [SA24]. This raises important questions about how network infrastructures, especially in less developed or geographically remote areas, can support this type of distribution.

Another critical issue is content consumption. Films, sports events, and high-quality shows are designed to be enjoyed on large screens, where resolution and detail make a significant difference. In contrast, consumption on mobile devices (mainly smartphones and tablets) has grown, particularly for short or easily consumable content.

The distinction between linear television and the newly popular OTT Media Services is another crucial factor. Linear television has dominated the landscape for decades, but OTT Media Services are revolutionizing how viewers consume content [SA24]. The appeal of OTT lies in its flexibility: it allows users to watch what they want, when they want. But is OTT the right solution for all users? For many, particularly older demographics or those in areas with limited access to high-speed internet, linear television remains a more convenient and accessible option. Additionally, live events like sports, news, and live shows retain a strong draw that does not easily fit into the OTT model.

Public broadcasters are legally mandated to ensure the broadest possible reach of their services, often working with limited resources while balancing the need for innovation with ensuring accessibility. Their responsibility to provide universal access means they must cater to all segments of the population, regardless of geographic or economic differences.
Geographic needs and a country's level of development significantly influence the distribution of content. In many rural or underserved areas, particularly in developing nations, broadband infrastructure remains inadequate, making broadcast that efficiently delivers content to large audiences more practical than unicast, which requires substantial network capacity and high-speed connections.
Moreover, the economic interests of various stakeholders in the television industry, including broadcasters, OTT platforms, and network providers, further complicate the landscape. Each player has different priorities: broadcasters focus on mass accessibility, OTT platforms push for personalized content delivery, and the need for infrastructure development drives network providers. These competing interests create a complex ecosystem where balancing reach, innovation, and economic sustainability remains a significant challenge.

The technical and infrastructural complexity, combined with different user needs, suggests a potential for a hybrid balance, Digital Video Broadcasting - Internet (DVB-I).
DVB-I, the most recent development in DVB standards, combines internet-based services with traditional transmission to provide viewers with interactive features, personalized content, and improved user interfaces [Bur+23].
Broadcast transmission is highly efficient for reaching large audiences with the same content,

such as live events or linear television, but lacks flexibility in personalizing content for individual viewers. On the other hand, multicast and unicast transmissions excel in delivering tailored content to specific users or smaller groups, enabling personalized services like OTT Media Services, but they are more bandwidth-intensive when scaling to large audiences.
Now users want to watch their favourite content on whatever device is to hand: from smartphones, tablets, and laptops to TV sets, set-top boxes, and streaming sticks. DVB-I lets you target all of these devices with the same content offer.
Using a hybrid approach allows broadcasters to deliver both linear television and VOD services in a more scalable and efficient manner. It ensures a seamless viewing experience regardless of whether the content is being distributed via terrestrial broadcast or internet infrastructure, adapting dynamically to the network environment and user needs, ultimately offering greater flexibility and improving the overall user experience.
These results highlight how DVB-I can offer viewers and broadcasters a single unified and future platform [Bur+23].

In this project, carried out during the internship at the Fracarro Radioindustrie S.R.L.[1] company, we focus on the implementation of this new technology. Founded in 1933 in Castelfranco Veneto (VE), Italy, the company is a leading provider in the installation sector for satellite television reception (also digital terrestrial). Among its most technologically advanced products are the D-Matrix and the 3DG central unit. These devices, which fall under the hospitality product category, demodulate, decrypt, reaggregate for services, and re-modulate the signal received from the satellite according to the digital terrestrial standard, allowing distribution to multiple users (such as televisions or set-top boxes).
The primary goal of this project was to develop comprehensive demonstrations that highlight the use and benefits of DVB-I within hotel infrastructures. Our approach began with a comprehensive literature review and a technical description of the DVB standards. This study aimed to provide a clear understanding of how these standards function, their practical applications, and their relevance in the context of modern media consumption.
Using the DVB-I repositories available on GitHub [Dig23] [Dig24], it was possible to create

[1] https://fracarro.com/it/

demonstrations of this technology, analyzing the fundamental aspects.
Concurrently, we also studied the Hybrid Broadcast Broadband Television (HbbTV®) standard, which is necessary to develop TV applications. This standard provides functionalities that improve the watching experience and make it more interactive.

Next, we moved on to the study of the standard related to the reception of media content for mobile devices, like smartphones, tablets, and laptops. Currently, OTT services typically require dedicated client apps, each with its own specific user experience. Rather than forcing users to learn and switch between different user experiences and apps to find and view content, DVB-I enables devices to integrate live and linear services, as well as On-Demand content into a consistent device-native user experience. DVB-I architecture relies on DVB-DASH standard, since it specifies how mobile devices should receive television content. In fact this standard defines the delivery of live and On-Demand television content over the open internet via HTTP adaptive streaming.
To fully grasp this technology, a DVB-DASH Generator was developed during the internship. This allowed a independently creation and management of multimedia content. Within the company's laboratory, various content reception technologies, such as DVB-T, DVB-S, and DVB-DASH, were utilized to effectively test DVB-I, exploring its architecture and the seamless integration between traditional broadcasting and internet-based service transmission.

The use of the DVB-DASH Generator extended beyond the study of DVB-I; it was also explored for potential applications in hotel infrastructures, aiming to enhance the visitor experience. By integrating DVB-DASH technology, hotels could offer guests a more personalized and flexible entertainment system. Instead of being restricted to traditional in-room TV setups, visitors would have the ability to watch personalized TV shows, movies, and on-demand content directly on their smartphones, tablets, or laptops.
This approach would allow guests to seamlessly access entertainment options across their own devices, tailored to their preferences and viewing habits. Such an innovation could significantly elevate the in-room entertainment experience in the hospitality sector, providing greater convenience and choice. Furthermore, by integrating DVB-DASH with existing hotel networks, operators could reduce the need for costly in-room hardware upgrades, while still

offering innovative streaming services that enhance guest satisfaction and differentiate the hotel from its competitors.
Lastly, the DVB-DASH Generator was put to the test and utilized in the laboratory to show how simple it was to integrate with the company's currently available products and evaluate whether it could be used in a real-world demo.

The thesis work is organized in the following way:

- **Chapters 1**: Focuses on traditional broadcast systems, starting with MPEG-2 TS for transmitting compressed video and audio. It also explores HbbTV®, which integrates broadcast and broadband services, and Digital Storage Media - Command and Control (DSM-CC) Object Carousel for delivering data and applications with television content, highlighting how interactive and on-demand services are deployed in broadcast systems.

- **Chapter 2**: Shifts to IP-based content delivery, examining new streaming technologies and architectures like Digital Video Broadcasting - Native IP Broadcasting (DVB-NIP), Digital Video Broadcasting - Multicast Adaptive Bit Rate (DVB-MABR), and DVB-DASH, which enable efficient distribution of broadcast content over the internet. It highlights the advancements that merge traditional broadcasting with modern internet streaming solutions.

- **Chapter 3**: Outlines the specifications of the new DVB-I technology standard, highlighting its key features and innovations. The chapter thoroughly examines its core characteristics, such as the integration of traditional broadcast efficiency with the flexibility and interactivity of IP-based streaming, as well as its ability to support hybrid infrastructures that combine terrestrial, satellite, and internet-based delivery methods. It discusses POC experiments across Europe and insights from the DVB World 2024 conference in Munich, emphasizing DVB-I's potential impact on future broadcasting.

- **Chapter 4**: Provides a detailed account of the various DVB-I demonstrations conducted in collaboration with Fracarro Radioindustrie S.R.L., emphasizing both the study and practical implementation of these technologies. The demonstrations aimed to showcase the real-world applications of DVB-I, particularly in enhancing content delivery across different environments.

Special attention is given to the primary project, the development of a DVB-DASH Generator, which played a central role in the DVB-I Demo architecture. A significant focus is placed on the use of this technology also in hotel infrastructures, where the DVB-I system, combined with DVB-DASH, was tested to improve guest experiences, demonstrating its transformative potential for the hospitality industry.

CHAPTER

1

Adavnced Broadcast Technologies

The main technologies related to the interaction and delivery of digital television services are explained in this chapter. It starts with a complete analysis of the MPEG-2 TS, a broadcast environment standard for data, video, and audio transmission. Additionally, it illustrates how important signalizing is to the management and organization of broadcast content. The chapter then shifts to the use of HbbTV®, a platform that combines broadcast and internet-based content to enable interactive services, for the deployment of applications on televisions. To further improve the interactive experience for consumers, it also looks into the DSM-CC Object Carousel, a protocol for distributing data and interactive applications across broadcast networks.

This chapter sets the technical foundation for understanding how modern television systems deliver both linear and interactive content to consumers.

1.1 MPEG-2 Transport Stream

The MPEG-2 TS is a standard format for transmitting and storing multimedia content such as audio, video, and data. It is an important component in digital television and multimedia distribution systems. For its adaptability, a single operator can use various TS for effective content management and delivery [ISO23].

A Transport Stream is a continuous and synchronous stream composed of 188-byte TS packets.

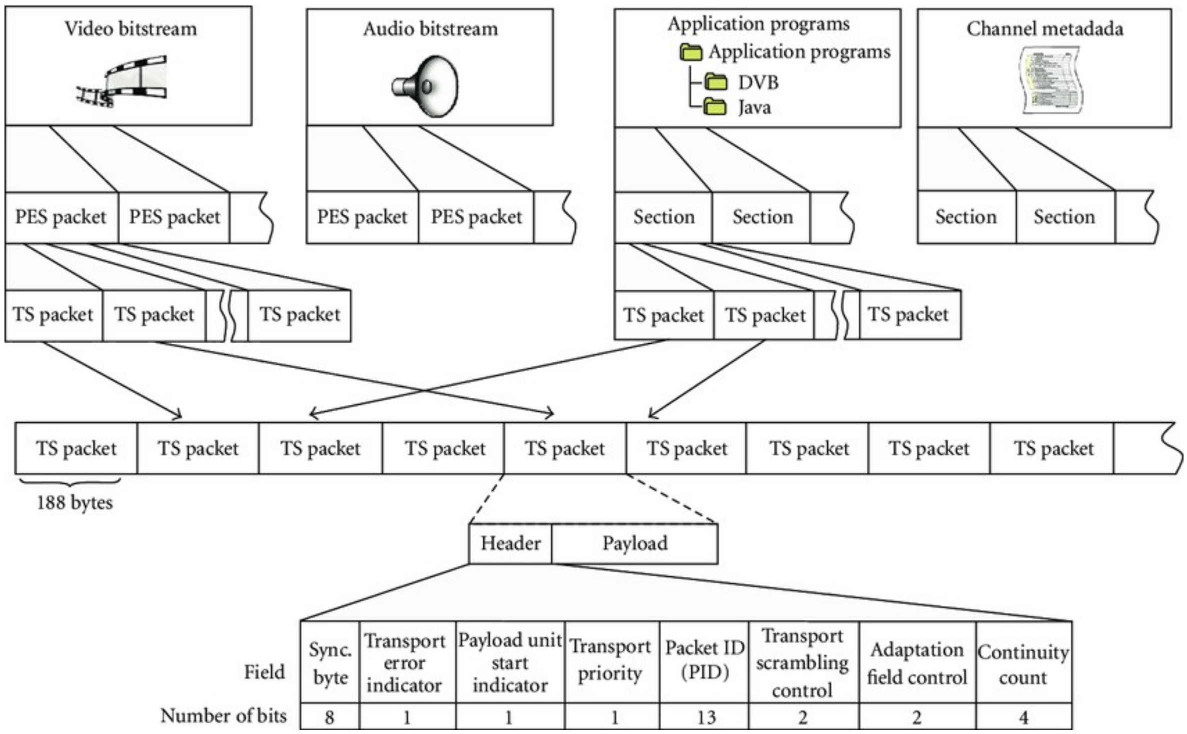

Figure 1.1: Detailed structure of the MPEG-2 Transport Stream. [IN08]

Each TS packet is structured into three main components:

- **4-byte Header:**
  - Sync Byte: This is the first byte of the header and has a fixed value, enabling receivers to synchronize with the stream (example 0x47 in Fig.1.2).
  - Error Indicator: Indicates if any errors are present in the packet.
  - Payload Unit Start Indicator: Shows whether the packet starts a new payload unit.
  - Transport Priority: Indicates the priority of the packet.
  - Packet Identifier (PID): A 13-bit field that uniquely identifies the packet's associated Elementary Stream (ES).
  - Scrambling Control: Indicates if the payload is scrambled.

– Adaptation Field Control: Specifies whether the adaptation field is present, as illustrated in Fig.1.3.

– Continuity Counter: Helps detect lost packets and ensure proper sequencing.

- **Optional Adaptation Field:** This extended header may include additional information such as timestamps (Program Clock Reference (PCR)) and buffer management data. It helps manage synchronization and timing of the stream, and it can vary in length due to its flexibility.

- **Payload:** The payload can be up to 184 bytes long and carries the actual data of the Elementary Stream, which may include audio, video, or other types of data. The main content of the TS packet is contained in the payload.

Figure 1.2: TS packet without adaption field.[Fis03]

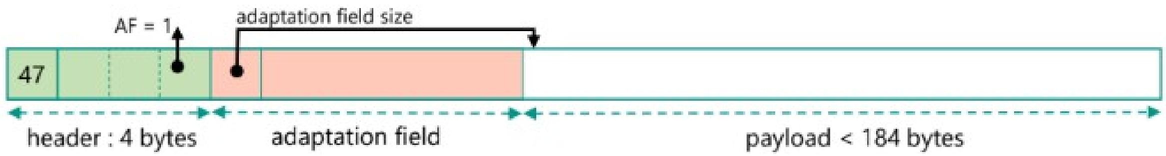

Figure 1.3: TS packet with adaption field.[Fis03]

The Transport Stream is designed to carry a multiplex of up to 8192 independent Elementary Stream. Each ES is uniquely identified by a PID, which is a 13-bit value located in the packet header. This PID allows the receiver to distinguish between different streams with the same TS.

Each ES is a continuous sequence of packets carrying data of a specific type, such as audio, video, or auxiliary data like subtitles and teletext, as evidenced in Fig.1.4. The PID ensures that each ES can be individually accessed and processed by the receiver.

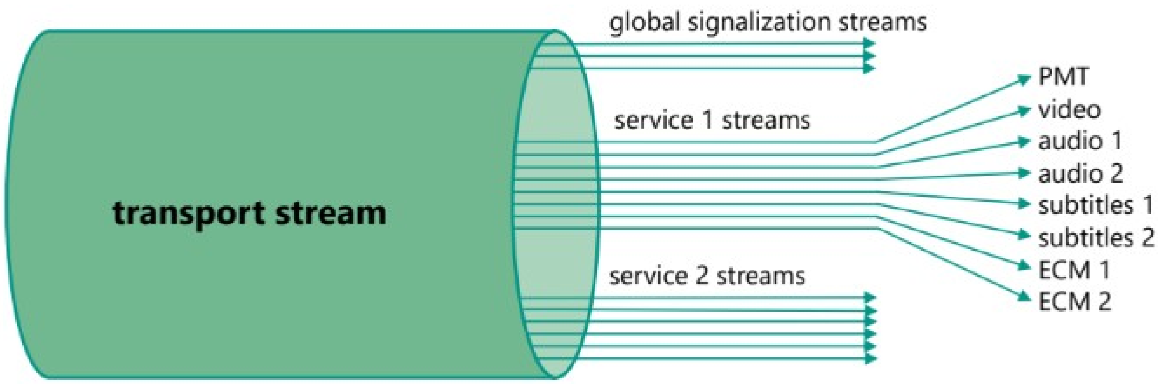

Figure 1.4: Example of Transport Stream.[ISO23]

There are two main types of content with Elementary Stream:

- **Packetized Elementary Stream (PES):** This format is used for audio, video, and other time-sensitive data, as it is shown in Fig.1.1. PES packets encapsulate these types of media in a way that allows for synchronized playback. PES packets can vary in length and include headers that provide timing and synchronization information, essential for maintaining audio-video synchronization.
- **Sections:** Sections are data structures used for metadata and control information, as illustrated in Fig.1.1. These are typically used in Program Specific Information (PSI), which includes tables like the Program Association Table (PAT) and Program Map Table (PMT). Sections help to organize and manage the stream, providing essential information for the proper assembly and decoding of the media content.

In the MPEG-2 TS, the processes of multiplexing and demultiplexing are necessary for managing and transmitting efficiently multiple streams of audio, video, and data. An ES is created by concatenating the payloads of all TS packets that share the same PID. The ES is divided into smaller packets through a process called packetization, as illustrated in Fig.1.5, where the ES is cut into payloads that become the payloads of TS packets with the same PID. During packetization, the PUSI in the TS header marks the beginning of a new data unit [Fis03]. Multiplexing involves mixing packets from various PIDs to build a complete TS, allowing multiple streams to be transmitted simultaneously. This interleaving of packets from different elementary streams ensures efficient use of bandwidth and resources. On the receiving end, demultiplexing extracts all packets with the samePID from the TS, separating the interleaved streams back into their original ES forms. Depacketization then rebuilds the ES from the packet payloads that share the same PID, restoring the continuous stream for decoding and playback.

These processes, integral to the MPEG-2 TS format, enable the regular and synchronized delivery of multiple streams, making it an important step for digital broadcasting and multimedia applications.

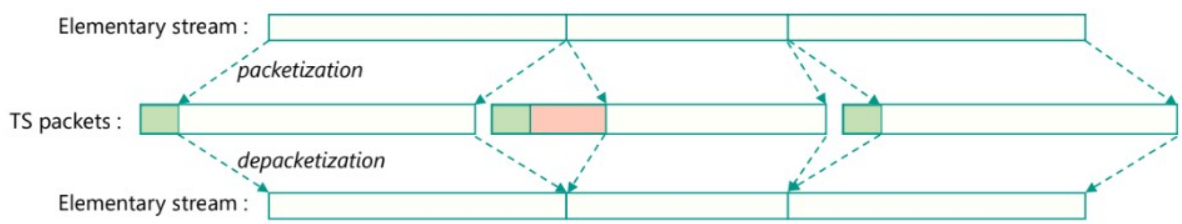

Figure 1.5: Sequence of operations with an Elementary Stream.[Fis03]

1.1.1 Packetized Elementary Stream

A stream of Packetized Elementary Stream (PES) packets is an essential component of the MPEG-2 TS system. Each PES packet can be up to 65,536 bytes in size, providing flexibility in carrying various types of multimedia content. The start of aPES packet is identified by the PUSI bit in the TS header, which signals the beginning of a new PES packet.

PES packets can carry a diverse range of content types, including:

- Video: Formats such as MPEG-2 (H.262), Advanced Video Coding (AVC) (H.264), High Efficiency Video Coding (HEVC) (H.265) and others.
- Audio: Formats like MPEG-2 Layer 2, Advanced Audio Coding (AAC), among others.
- DVB Subtitles: These can be either text-based or bitmap-based subtitles.
- Teletext: Although deprecated, it is still in use and it can be included in PES packets.

Each ES with the TS contains a single type of content. A Video Stream contains video data in one of the supported formats such as MPEG-2 (H.262), AVC (H.264), HEVC (H.265), and

others. An Audio Stream contains audio data for one language, which may include options for audio description and multi-channel audio formats such as stereo or 5.1 surround sound, all with the same PID. A Subtitles Stream contains subtitles for one language, which may include options specifically designed for hard-of-hearing audiences. The Teletext Stream is an exception to the single-content rule; it is a multiplex that can include multiple text streams or ”pages,” providing a range of textual information. This structure ensures organized and efficient delivery of video, audio, subtitles, and Teletext with the MPEG-2 TS system.
The robustness of PES streams in the MPEG-2 TS is enhanced by the ability to detect and handle packet loss through the *continuityCounter*, and by the inherent synchronization patterns with video and audio bitstreams. These features ensure that decoders can effectively manage and recover from packet loss, maintaining the integrity of audio and video streams as much as possible [Fis03].

1.1.2 Section Streams

Section streams in the MPEG-2 TS contain data structures known as ”tables”. Each table is split into one or more ”sections”, which are the smallest data units and can be up to 4096 bytes in size. Every section includes a standard header and a type-specific payload. The type of table is identified by the *tableId* in the section's header. There are two types of section syntax: ”short” and ”long”, determined by a single bit in the header.
Each type of table defines its own syntax and decides whether to use long or short sections. The payload bitstream syntax is unique to each table type. A key element with the tables is the Descriptor, which is a standard substructure consisting of a standard header and a type-specific payload. Most tables utilize generic ”lists of descriptors”, making the structure more versatile and standardized [Fis03].

1.1.3 Signalizing PSI/SI

Signalization in MPEG-2 TS is achieved through PSI and Service Information (SI), and it is crucial for organizing and managing the broadcast content. The importance of PSI/SI signalization lies in enabling receivers to:

• Automatically detect and assemble programs from different streams.

• Ensure seamless navigation of broadcast content across multiple channels and services.

The goal of signalization is to provide a structured framework for efficient content delivery and consumption, ensuring compatibility between broadcasters and receivers, thus enhancing the overall viewing experience. The PSI/SI tables, their definitions, and the PID that corresponds to each one are showed in the Fig.(1.6).

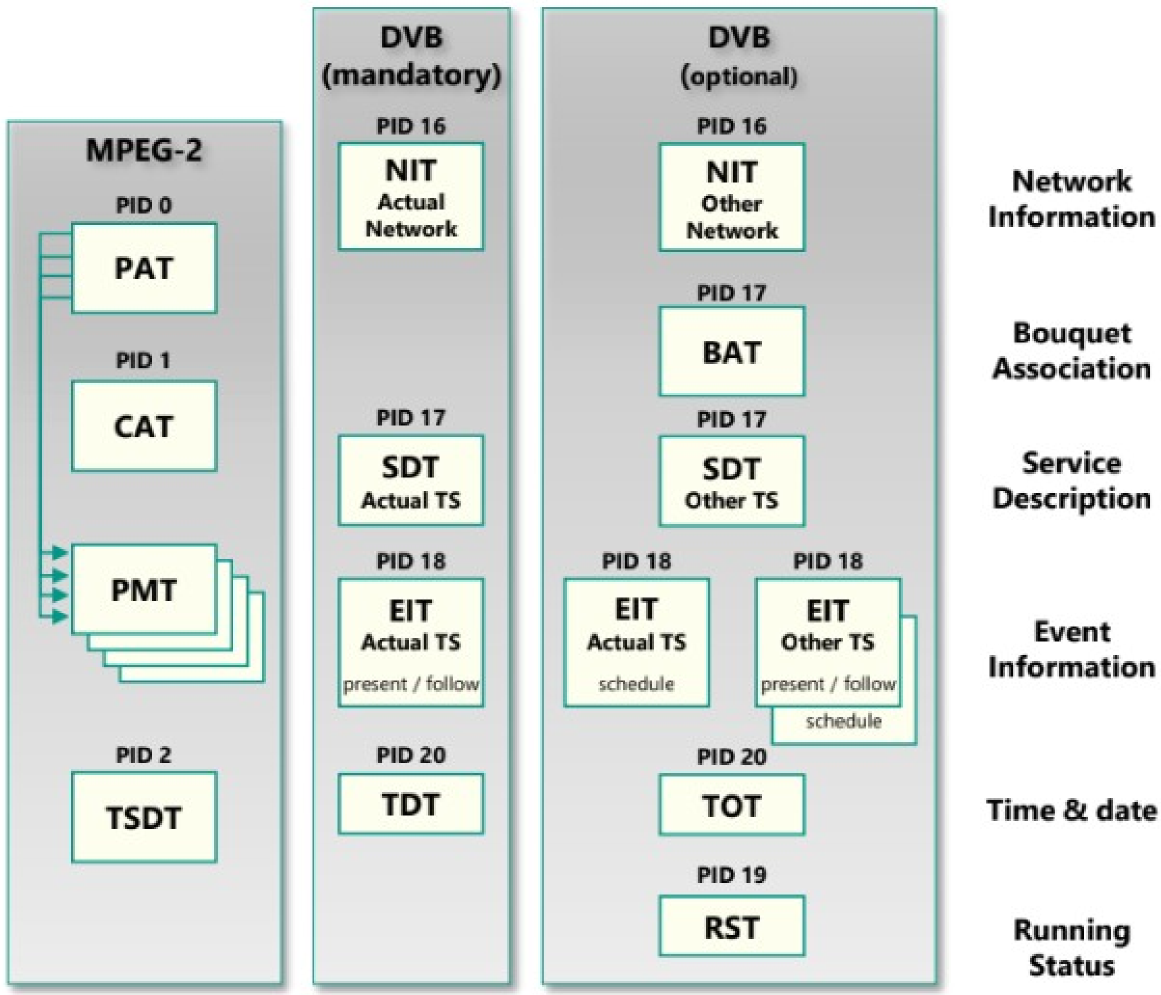

Figure 1.6: PSI/SI tables.[EBU22]

PSI, as defined by the MPEG standard, includes essential tables like Program Association Table (PAT), Program Map Table (PMT), and Conditional Access Section (CAT) that outline the structure of the TS. SI, defined by the DVB standard, is built on PSI by adding more comprehensive service-related information through tables such as Network Information Table (NIT), Service Description Table (SDT), Event Information Table (EIT), and Time and Date Section (TDT). Together, PSI and SI ensure that receivers can properly interpret and manage the content and services with the TS [EBU22].

MPEG-defined PSI

MPEG defined PSI tables that play a fundamental role in structuring and organizing data with the MPEG-2 TS. These tables are [Fis03]:

- **Program Association Table (PAT):** Present in PID 0, it serves as a directory list of all services available with the TS. Each entry in the PATcontains a service ID and the corresponding PID for the associated PMT.
- **Program Map Table (PMT):** Found with the TS, the PMT provides technical details about each service. It includes a list of elementary streams present in the service, along with their PIDs, types (such as audio or video), and additional information provided through descriptors.
- **Conditional Access Section (CAT):** Repeated in PID 1, it is responsible for managing conditional access systems with the TS. It contains a list of Entitlement Management Message (EMM) streams associated with the TS. The CAT may not be present if no EMM streams are present in the TS.

DVB-defined SI

SI extends the PSI with additional details about the services provided in the TS. These include private sections in MPEG terms, offering a broader range of information [Fis03]:

- **Network Information Table (NIT):** Provides details about the network, such as the list of available services and the frequencies they are broadcast on.
- **Service Description Table (SDT):** Describes the services, including service names and other descriptive information.

- **Event Information Table (EIT):** Contains information about current and upcoming events (programs), including start times and durations.
- **Time and Date Section (TDT):** Provides current time and date information for synchronization purposes.

1.1.4 TS Duck

TS Duck (Transport Stream Toolkit) is an open-source software to manage MPEG transport streams. It's used in the digital television broadcasting industry for its features that facilitate analysis, monitoring, and manipulation of transport streams [Lel24].
TS Duck excels in **transport stream analysis** by performing detailed syntax and semantic analysis, ensuring those streams comply with standards such as MPEG and DVB, in fact, it detects and reports errors and inconsistencies.
In terms of transport stream processing, TS Duck allows users to modify, filter, and demultiplex transport stream packets. It offers tools to analyze and adjust the bitrate of various components, to obtain optimal performance and efficiency. The toolkit can also manipulate PIDs, SI, and PSI tables, to control the stream content.
TS Duck allows real-time monitoring of transport streams. This feature is necessary for immediate feedback on stream quality and for identifying issues.
It is compatible with a wide range of digital television standards, making it appropriate for a variety of foreign markets and technologies. Its plugin architecture allows users to extend its functionalities because it's possible to add custom features for specific needs. Users can integrate TS Duck with their existing systems for the analysis.

1.2 HbbTV Application

HbbTV® builds upon the MPEG-2 TS, by adding interactive broadband capabilities. While MPEG-2 TS efficiently transmits video and audio, HbbTV extends this functionality by enabling the integration of broadcast content with web-based applications. This allows viewers to access interactive services, On-Demand content, and personalized features, creating a more versatile and enriched television experience.

HbbTV® is a worldwide initiative designed to integrate broadcast and broadband entertainment services for consumers via connected TVs, set-top boxes, and multiscreen devices. Developed by industry leaders, the HbbTV® specification aims to upgrade the video user experience by enabling interactive services across both broadcast and broadband networks. According to Fig.1.7, HbbTV® incorporates elements from existing standards, including OIPF, ISO, CEA, DVB and W3C.

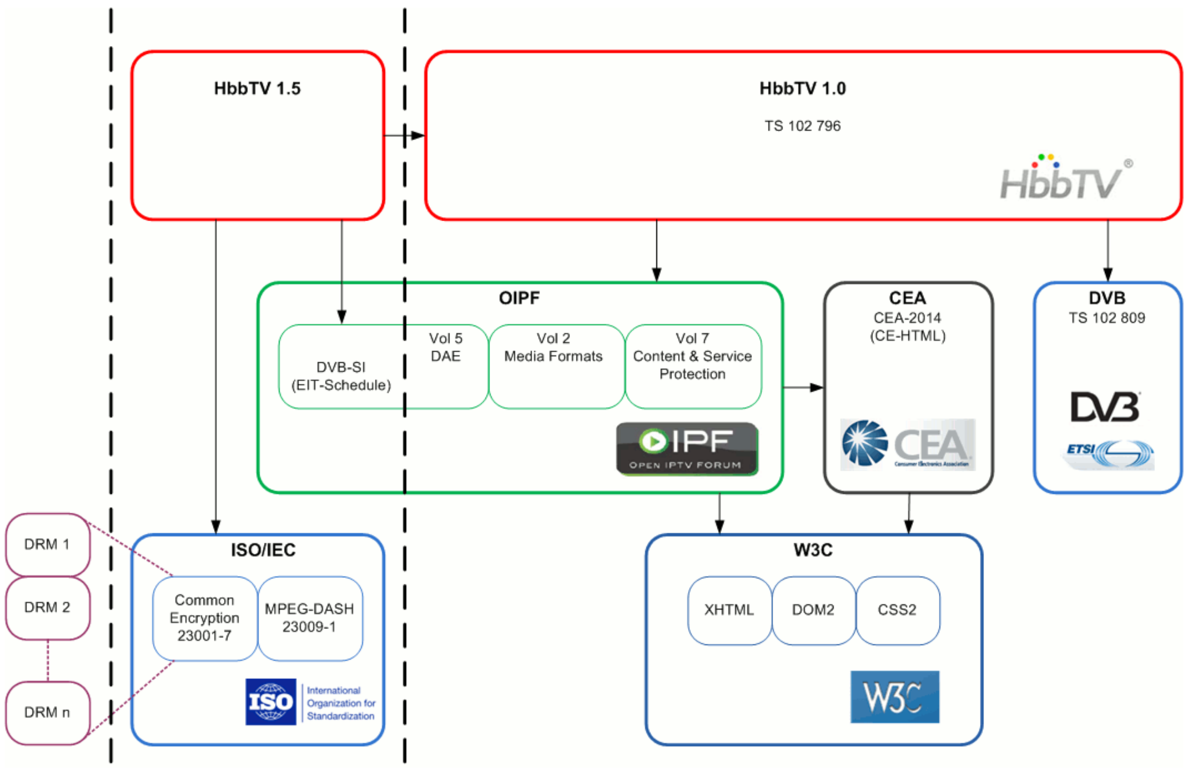

Figure 1.7: HbbTV related standards. [KŠ19]

A HbbTV® Application is a web-based platform that enhances traditional broadcast television by integrating broadband content. These applications are composed of various web technologies, including HTML, JavaScript, CSS, XML, and multimedia files.
The core function of a HbbTV® App is to provide a seamless integration of broadcast content (received via traditional television signals) with additional services and features delivered over the internet. This enables broadcasters to offer interactive services such as:

- On-Demandvideo content (e.g., catch-up TV, movies, or series),
- Interactive advertising (allowing viewers to engage directly with ads),
- Enhanced program guides, offering personalized content recommendations,
- Voting and real-time feedback for live shows or events,
- Second-screen experiences, where viewers can interact with their TV through smartphones or tablets.

These apps function like websites, but are designed specifically for television environments.

1.2.1 Architecture and terminal components

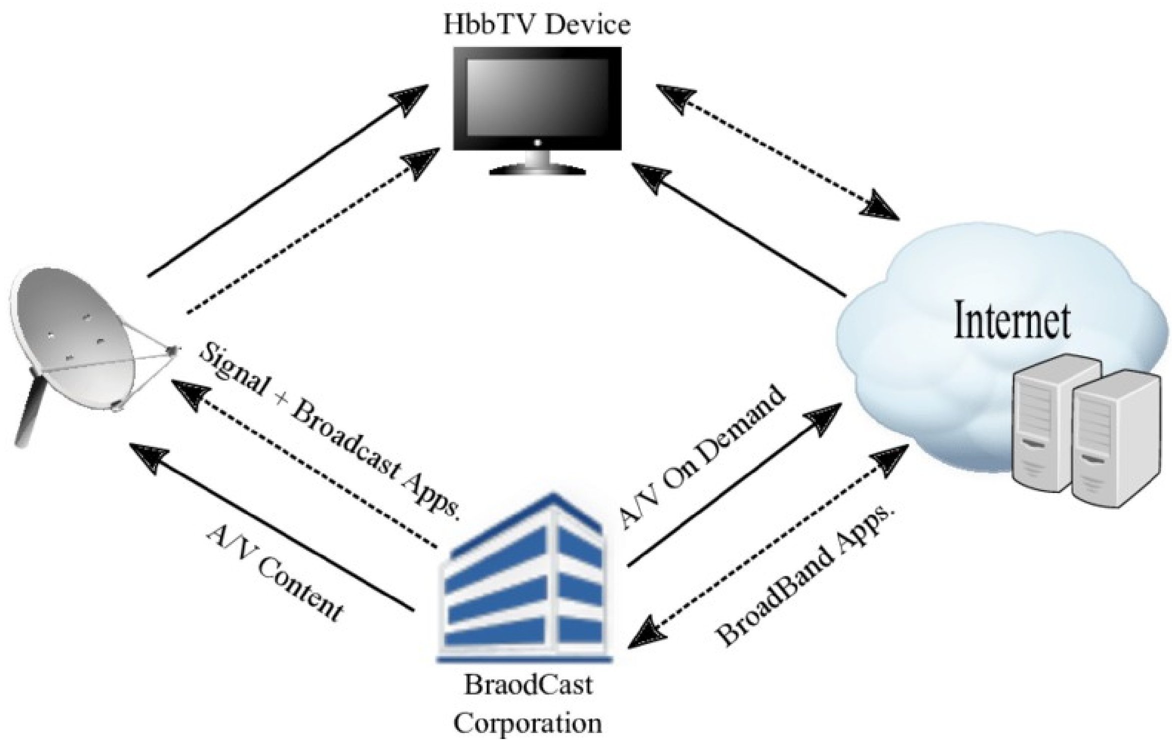

Figure 1.8: Example of architecture. [Lua+18]

The HbbTV standard specifies the components and defines the interfaces that a hybrid broadcast broadband television systems should have. The general architecture of the system is depicted in Fig.1.8. As it is shown in the figure, a main difference with currently dominant smart TV platforms is that the application provider is not related to the device provider. In fact, applications and A/V contents may be provided by the same entity, therefore, they can be perfectly synchronized. This is a main advantage of this new technology with respect to conventional smart TV platforms.

Content providers use broadcast infrastructure to deliver standard A/V content, while applications can be transmitted either through broadcast or broadband channels. This flexibility means that certain applications can still reach audiences with limited broadband access, even if there is no return broadband channel from the user device. This capability remains particularly useful in rural areas.

HbbTV® applications can be categorized as either "Broadcast-indipendent" or "Broadcast-related" [EBU21]:

- **Broadcast-independent applications:** These are not associated with any broadcast service and they are downloaded via broadband. They access all associated data through broadband. Examples include catch-up services and games that don't require access to broadcast resources.

- **Broadcast-related applications:** These are associated with one or more broadcast services or events and they can be launched automatically or upon user request. They may be downloaded via broadband or broadcast, and they can access data through any method. Examples include electronic program guides and teletext-like services that might display broadcast video in a window and they can access other broadcast resources such as EIT metadata.

Compared to conventional web applications, HbbTV® apps offer more limited user interaction, as they typically rely on standard remote controls. However, they excel in providing VOD services and synchronizing with live broadcast content, offering a more integrated and seamless viewing experience.

1.2.2 User Experience

Building on the HbbTV® standard architecture and terminal components, the user experience in HbbTV-enabled systems is designed to seamlessly blend traditional broadcast television with interactive broadband services. This integration offers viewers a more dynamic and engaging experience by providing access to personalized content, interactive applications, and On-Demand , in quantoservices directly through their TV, without the need for additional devices. The users control interactive applications using a user-input device typically supplied with the terminal. This may be a conventional remote control or an alternative input device such as a game controller and touch screen [EBU21]. The end users can access interactive applications via the following ways:

- Accessing a typical broadcast-related autostart application by pressing the visually indicated ”Red Button”.
- Starting a digital Teletext application by pressing the TEXT button.
- Starting a broadcast-independent application through the Internet TV portal of the manufacturer if one is offered.
- Starting an HbbTV® application on the terminal from an already running Companion Screen application.
- Starting an application via a link in the currently running application.
- Selecting a broadcast channel that has a broadcast-related auto-start application that starts in full-screen mode (usually only used on radio or data services).

Implementation of HbbTV applications in broadcast services, which also includes the teletext option, is shown in Fig.1.9. It also illustrates that is possible navigation between different applications and their starting from broadcasting services.

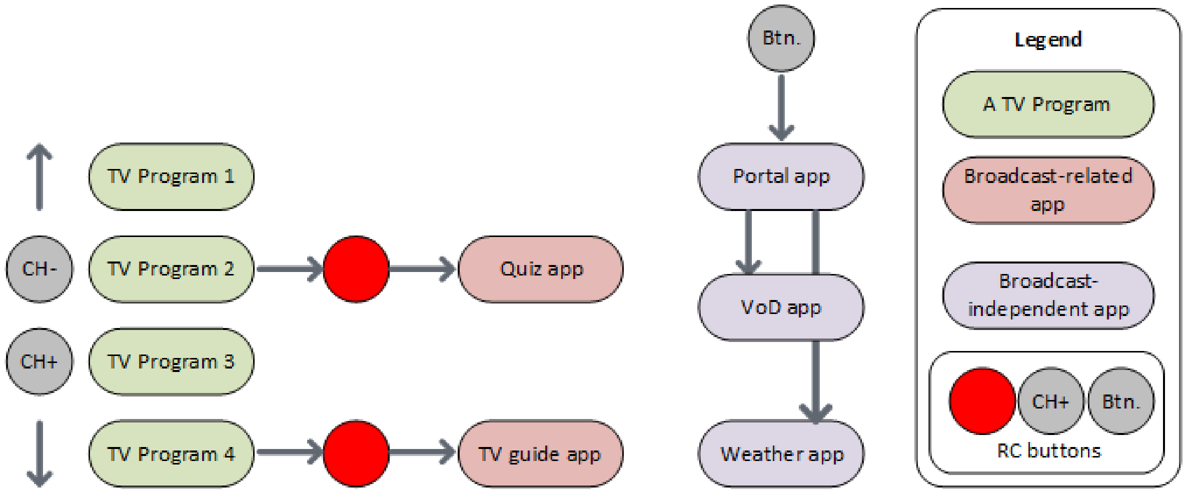

Figure 1.9: Implementation of HbbTV applications in broadcast services. [KŠ19]

”Red button” applications

In general, autostart applications on television services should not display their full user interface automatically. Instead, the user is informed of their availability by the ”Red Button” icon.

Teletext applications

A digital teletext application is a special broadcast-related application that is started by pressing the TEXT button on the Remote Control Unit (RCU). Depending on the provision of a digital teletext application and of standard teletext the reaction on pressing the TEXT button differs.

Broadcast-independent applications

Broadcast-independent applications are started via a running application or an Internet TV Portal. An Internet TV Portal is an application that provides a type of start page where broadcast-independent applications are sorted and offered in an appropriate and useful way to the end user. The Internet TV Portal may be opened by pressing a dedicated Internet TV Button on the RCU.

The type of interactive applications that are listed in the Internet TV Portal is the responsibility of the manufacturer. There may be an option for the user to add broadcast-independent applications via manual URL entry or similar means like apps on mobile phones.

1.2.3 DSM-CC Object Carousel

Digital Storage Media - Command and Control (DSM-CC) specifies a standard format for representing a file system directory structure comprising a root directory or service gateway and one or more files and directories. Object carousels are an important component in HbbTV® applications for delivering multimedia content and interactive services over broadcast and broadband networks. They enable the integration between broadcast streams and internet-delivered content, in this way, the viewer experience can have additional information, On-Demandvideos, and interactive features [EBU21].
A terminal must mount only one carousel at a time for use by the running application, ensuring the latest version of carousel files is available. Although only one carousel is mounted, the terminal may read, cache, and monitor multiple carousels in parallel to reduce loading times. For broadcast-related applications, mounting a new carousel should automatically unmount the previous one and cancel its pending requests, unless a different transport stream is being tuned.

Terminals should cache object carousel modules before they are needed by applications, storing them in a compressed format. The entire carousel should be loaded with one cycle, provided its size is smaller than the DSM-CC cache. If any part of the carousel is missed during the first cycle, the terminal should retain the acquired data and complete the missing parts in subsequent cycles [DVB17].

Data with a carousel may repeat at different frequencies and should be made available to applications as soon as it is loaded, without waiting for a full cycle to complete. Terminals should handle carousels with long cycle times without timing out. Once the service gateway object module is loaded, all files and their directory objects should be immediately accessible, eliminating the need to wait for additional modules to load.

CHAPTER 2

Next-Generation Broadcast and Streaming Technologies

DVB-I is essential to the broadcasting infrastructure's service discovery process. It functions as a centralized platform for aggregating metadata from various content providers. This allows DVB-I to act as a bridge between content providers and end users, ensuring that clients receive a unified, consistent service list. This service list is adapted to both the type of device being used and the user's geographic location, providing a seamless user experience across different platforms.

This approach reflects the current trend in broadcasting, where traditional linear broadcast services, such as those delivered via satellite or terrestrial signals, are increasingly integrated with IP-based services. As a result, users can access content from both traditional broadcast sources and online streaming services within a single interface, enhancing accessibility and flexibility.

Concurrently, the broadcasting industry is undergoing a significant transformation, moving away from the longstanding MPEG-2 TS format, which has been the standard for delivering content over satellite and cable for decades.   The industry is now embracing a new era of transmission technologies based entirely on IP protocols. This shift is driven by the need for greater efficiency, flexibility, and scalability, as well as the growing demand for higher-quality video content, such as 4K and 8K resolutions.

In response to this evolution, several new standards have emerged to support IP-based broadcasting, including DVB-DASH, DVB-MABR, and DVB-NIP,. These standards are designed to work in harmony, each playing a crucial role in the next generation of broadcasting:

- **Dynamic Adaptive Streaming over HTTP (DVB-DASH)** supports adaptive streaming of video content over standard HTTP networks. It adjusts the quality of the video stream in real-time based on the viewer's internet connection, ensuring a smooth viewing experience even in fluctuating network conditions.

- **Digital Video Broadcasting - Multicast Adaptive Bit Rate (DVB-MABR)** enables efficient distribution of video streams to multiple users simultaneously over IP networks. It optimizes network bandwidth by delivering a single stream to multiple users while still allowing for adaptive bitrate streaming, which ensures that each user receives the best possible video quality based on their available bandwidth.

- **Digital Video Broadcasting - Native IP Broadcasting (DVB-NIP)**facilitates the distribution of video content over IP networks without being tied to a specific type of physical network infrastructure. This allows broadcasters to deliver content seamlessly over a variety of networks, including broadband, mobile, and satellite.

These standards work together to enable broadcasters to move beyond the limitations of traditional transmission methods, offering more efficient, flexible, and scalable solutions for delivering high-quality video content to audiences worldwide.
This shift toward an IP-based infrastructure marks a significant milestone in the convergence of traditional broadcasting and modern streaming technologies, laying the foundation for the future of television and video distribution.

Chapter 2 provides an in-depth exploration of three critical standards in modern IP-based broadcasting:

- DVB-DASH covers the data model and Media Presentation Description (MPD), explaining how adaptive streaming over HTTP allows for real-time adjustments to video quality based on network conditions.

- DVB-MABR delves into the configuration of multicast servers and the rendezvous service, which are essential for optimizing bandwidth and ensuring efficient content distribution to multiple users simultaneously.
- DVB-NIP focuses on the system architecture and overall design, detailing how it enables seamless content delivery over diverse network infrastructures.

Together, these sections provide a comprehensive understanding of the technologies next-generation video broadcasting.

2.1 DVB-DASH

Video streaming applications are indispensable in our daily lives. As new applications using ICTs are developed, the number of smart users grows rapidly. In contrast, limited network resources make it difficult for operators to manage their networks. In this case, consumers want their apps to perform correctly, and operators manage the network by considering both the network status and the user's satisfaction with the service.

DVB-DASH defines the delivery of live and on-demand TV content over the open internet via HTTP adaptive streaming. It builds on MPEG Dynamic Adaptive Streaming over HTTP (DASH), which was the first internationally-standardized adaptive bit-rate HTTP-based streaming solution. This protocol utilizes an adaptive bitrate mechanism in which the receiver terminal requests the segments (the transmission units) of appropriate bitrate according to network conditions [EBU23b].

DASH protocol is built on a client-server architecture, as illustrated in the Fig.2.1. Initially, a DASH server encodes an original video file into various quality levels based on bitrate, resolution, and refresh rate. These encoded streams are divided into several video chunks. When a DASH client uses HTTP/GET to request a video segment, the server responds with the required segment. The client also chooses the quality level for the following segment, which is mostly determined by the buffer state and network capacity [Gaz18].

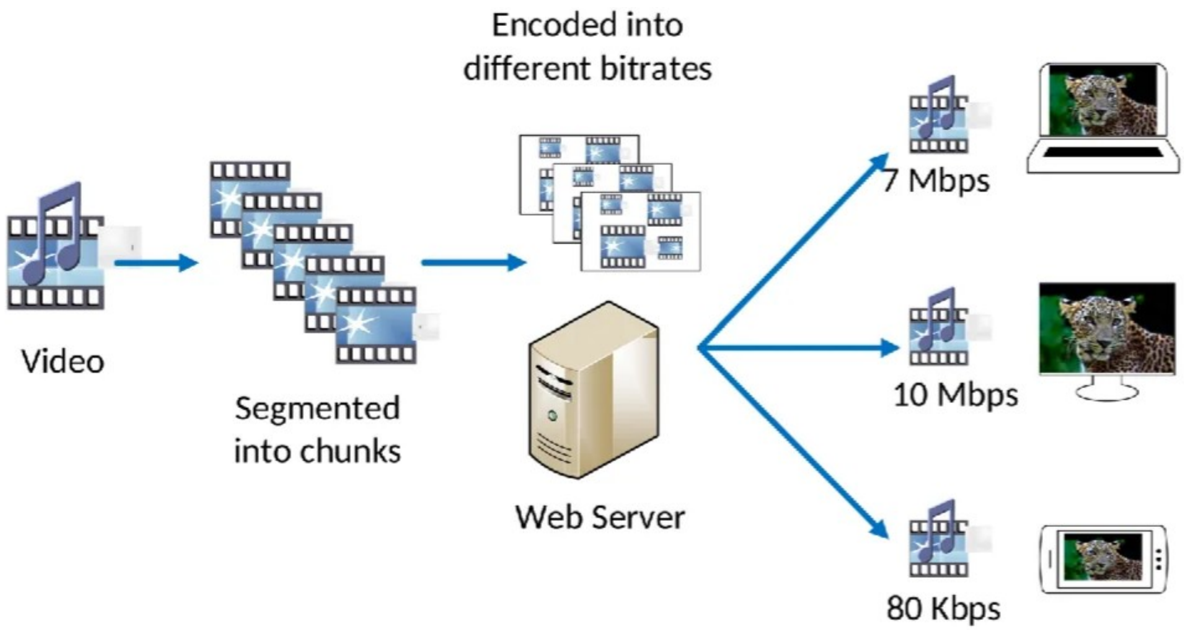

Figure 2.1: Adaptive HTTP Streaming (AHS). [Gaz18]

2.1.1 System Description

DASH establishes XML and binary formats, to facilitate the delivery of continuous media content from servers to clients, enabling also content caching. Two formats are defined [ISO19]:

- **Media Presentation Description (MPD):** This format describes a Media Presentation of the media content. It specifies resource identifiers for segments and it provides contextual information of the media. Resource identifiers can be HTTP-URLs.

- **Segment Formats:** These formats specify the structure of the entity-body of the HTTP response to an HTTP GET request. Segments typically contain coded media data and metadata, which are aligned with the common media formats.

In the Fig.2.2 is assumed that the DASH Client has access to an MPD. The MPD provides sufficient information for the client to provide a streaming service to the user by requesting Segments from an HTTP server and demultiplexing, decoding, and rendering the media streams.

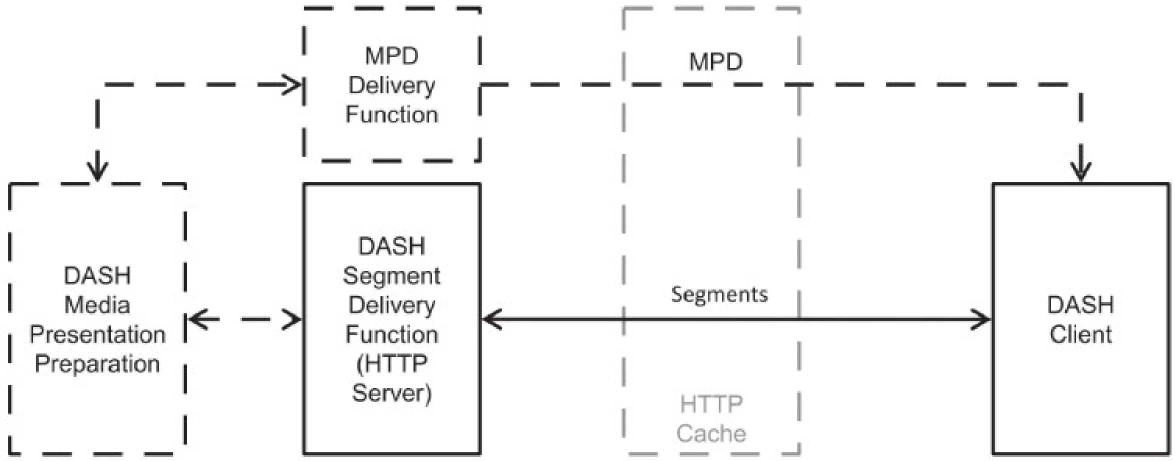

Figure 2.2: Conceptual architecture of MPEG DASH. [ISO19]

Media Presentation Description (MPD)

The Media Presentation Description (MPD) is a document that contains metadata required by a DASH Client to construct appropriate HTTP-URLs to access Segments and to provide the streaming service to the user. A Media Presentation as described in the MPD consists of a sequence of one or more Periods:

- Each Period contains one or more Adaptation Sets. In case an Adaptation Set contains multiple media content components, then each media content component is described individually;
- Each Adaptation Set contains one or more Representations;
- Adaptation Sets, Representations and Sub-Representations share common attributes and elements;
- Each Period may contain one or more Subsets that restrict combination of Adaptation Sets for presentation;
- Each Representation consists of one or more Segments. They contain media data and/or metadata to access, decode and present the included media content. Representations

may also include Sub-Representations, to describe and extract partial information from a Representation;

- Each Segment consists of one or more Subsegments.

The summary of the semantics of the attributes and elements within an MPD element are provided in Table 2.1.

Table 2.1: Semantics of MPD element.[ISO19]

Attribute Name	**Description**
@id	specifies an identifier for the Media Presentation.
@profiles	specifies a list of Media Presentation profiles.
@type	specifies the type of the Media Presentation. For static Media Presentations (@type="static"), all Segments are available between the @availabilityStartTime and the @availabilityEndTime. For dynamic Media Presentations (@type="dynamic"), Segments typically have different availability times.
@availabilityStartTime	For @type='dynamic', this attribute shall be present. In this case, it specifies the anchor for the computation of the earliest availability time (in UTC) for any Segment in the Media Presentation. For @type="static" if present, it specifies the Segment availability start time for all Segments referred to in this MPD. If not present, all Segments described in the MPD shall become available at the time the MPD becomes available.
@publishTime	specifies the wall-clock time when the MPD was generated and published at the origin server.
@availabilityEndTime	specifies the latest Segment availability end time for any Segment in the Media Presentation.
@mediaPresentationDuration	specifies the duration of the entire Media Presentation.
@minimumUpdatePeriod	If this attribute is present, it specifies the smallest period between potential changes to the MPD. This can be useful to control the frequency at which a client checks for updates. From a client perspective, after a client fetches an MPD, it specifies the minimum period during which the MPD remains valid.
@minBufferTime	specifies a common duration used in the definition of the Representation data rate.
	continued on next page

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Attribute Name	**Description**
@timeShiftBufferDepth	specifies the duration of the smallest time shifting buffer for any Representation in the MPD that is guaranteed to be available for a Media Presentation with type 'dynamic'.
@suggestedPresentationDelay	when @type is 'dynamic', it specifies a fixed delay offset in time from the presentation time of each access unit that is suggested to be used for presentation of each access unit.
@maxSegmentDuration	specifies the maximum duration of any Segment in any Representation in the Media Presentation, i.e. documented in this MPD and any future update of the MPD.
@maxSubsegmentDuration	specifies the maximum duration of any Media Subsegment in any Representation in the Media Presentation.

2.1.2 DASH Client Model

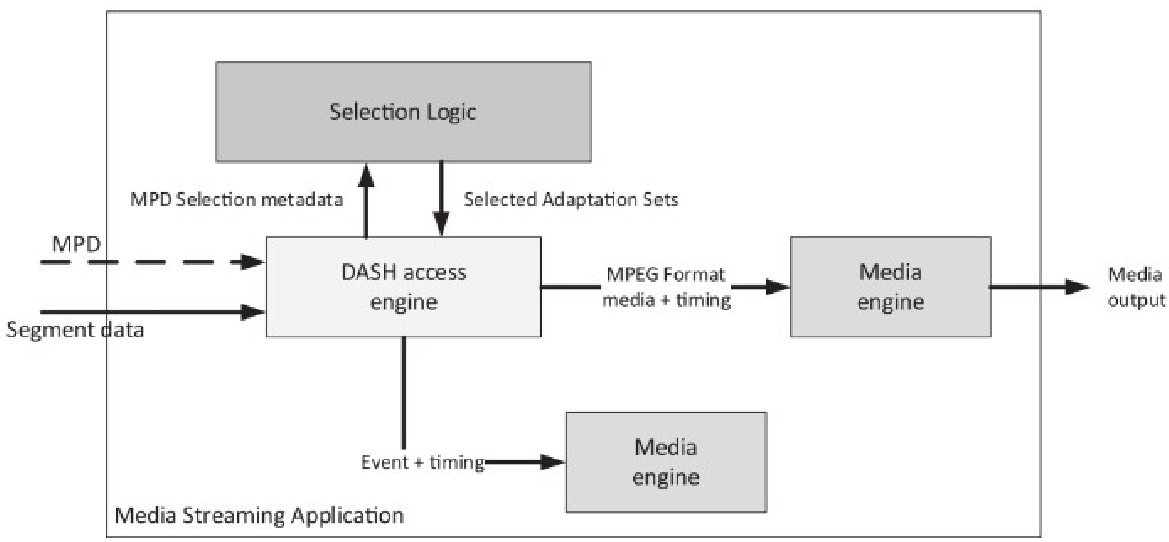

Figure 2.3: DASH Client model. [ISO19]

Figure 2.3 illustrates the components of a conceptual DASH Client model and the relation to other components in a media streaming application. The DASH access engine receives the MPD, constructs and issues requests, and receives Segments or parts of them.

The DASH Client may use metadata provided in the MPD for the selection of media components by communication with the media streaming application. The output of the DASH access engine consists of media in MPEG container formats together with timing information that maps the internal timing of the continuous media to the timeline of the Media Presentation [EBU23b].

In addition, the DASH access client may also receive Events, which are related to the media time. The events may be processed in the DASH Client or may be forwarded to another application in the execution environment of the DASH Client.

2.1.3 DASH Data Model Overview

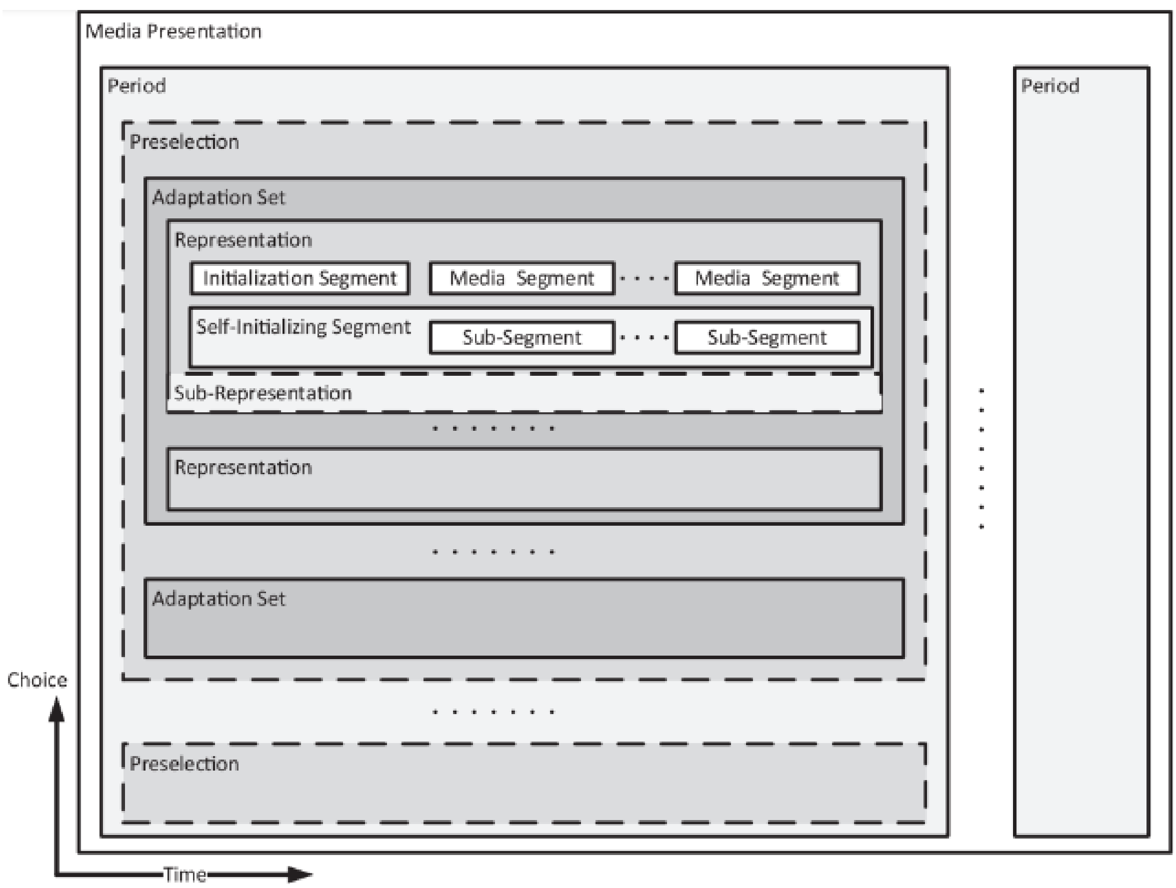

Figure 2.4: DASH High-Level Data Model. [ISO19]

DASH is intended to support a media-streaming model for the delivery of continuous media content in which control lies primarily with the client.
Clients may request data using the HTTP protocol from standard web servers that have no DASH-specific capabilities [EBU23b].
Media Presentation is composed of a single or multiple Periods. These media contents may be completely independent or belong to the same Asset. For example, a Media Presentation is a collection of main programs composed of multiple periods, each assigned to the same Asset and interleaved with an inserted advertisement.

Figure 2.4 describes how DASH Media Presentation is composed. In the horizontal domain, this figure shows the sequence in time of the Media Presentation, and in the vertical domain, it shows the choices offered, to be selected by the DASH Client [EBU23b].

The main components are:

- **Media Presentations:** It outlines the sequence of Periods that constitute the media presentation. Each Period represents a consistent set of encoded versions of the media content available during that period.

- **Adaptation Sets:** With each Period, the material is organized into Adaptation Sets, which represent compatible encoded versions of one or several media contents. For example, there may be Adaptation Sets for video, audio, captions, or other available material.

- **Representations:** Each Adaptation Set contains Representations, which are encoded versions of media parts and they can be delivered. These Representations include one or more media streams and they are sufficient to reproduce the media content. They can be switched dynamically with an Adaptation Set to adapt to network conditions.

- **Segments:** For better accessibility and delivery, the media content with a Representation may be divided into Segments. Initialization Segments contain static metadata, while media Segments contain media samples and they advance the timeline. Segments are accessed via URLs, with availability times used in dynamic presentations.

- **Dynamic vs. Static Presentations:** Static Presentations offer on-demand content with identical availability times for all segments, while Dynamic Presentations, used during live services, have availability times dependent on the media presentation timeline.
- **Self-initializing Segments:** Some media may be organized into self-initializing Segments, which contain both initialization information and media data. These Segments may be subdivided into Subsegments, each containing a number of complete access units.
- **Segment Index:** If Segments are divided into Subsegments, a Segment Index is used for the range of presentation time range and the corresponding byte for each element. In this way, clients can request for individual subsegments.

Low Latency DASH (LL-DASH)

The DASH standard follows a client-driven streaming approach. The client first retrieves a MPD, which outlines the details of the streaming session. It then parses the MPD and selects the most suitable representation, which is an encoded media stream with specific characteristics like bitrate, resolution, or language. Afterward, the client requests media segments from the server, where each segment is uniquely identified by an HTTP address and begins with a Random Access Points (RAP). To ensure real-time playback, the client monitors the download time of each segment, the segment's playback duration, and the buffer level, adjusting to a different representation if necessary [BCL14].
Additionally, the client updates the MPD periodically, as instructed by the server, to fetch new segment information. The DASH Client uses a buffer to handle network jitter and manage encoding constraints when techniques like bidirectional predictive frames or variable bitrates are employed. The MPD's *minBufferTime* attribute (Table 2.1) informs the client about these constraints.

DASH uses the *availabilityStartTime* attribute in the MPD (Table 2.1) to help the client accurately determine when a new segment is ready and send the appropriate request. This attribute specifies the Coordinated Universal Time (UTC) time when the first segment becomes available, meaning that DASH requires synchronization between the server and client using a common UTC clock, unlike other HTTP streaming methods. This synchronization ensures that clients request segments only when necessary and at the right moment [BCL14].

DASH latency is influenced by factors such as segmentation delay, asynchronous segment fetching, download time, and client-side buffering. This concept also applies if segments are divided into smaller chunks, as illustrated in Fig.2.5. By delivering segments in smaller parts via HTTP chunks, segmentation delay can be reduced to the length of a chunk. Moreover, if segments are produced exactly at the times specified in the MPD, the delay from asynchronous fetching can be minimized. In local networks, where jitter is minimal, client-side buffering can be significantly reduced, potentially making DASH suitable for low-latency systems in certain conditions [SW11].

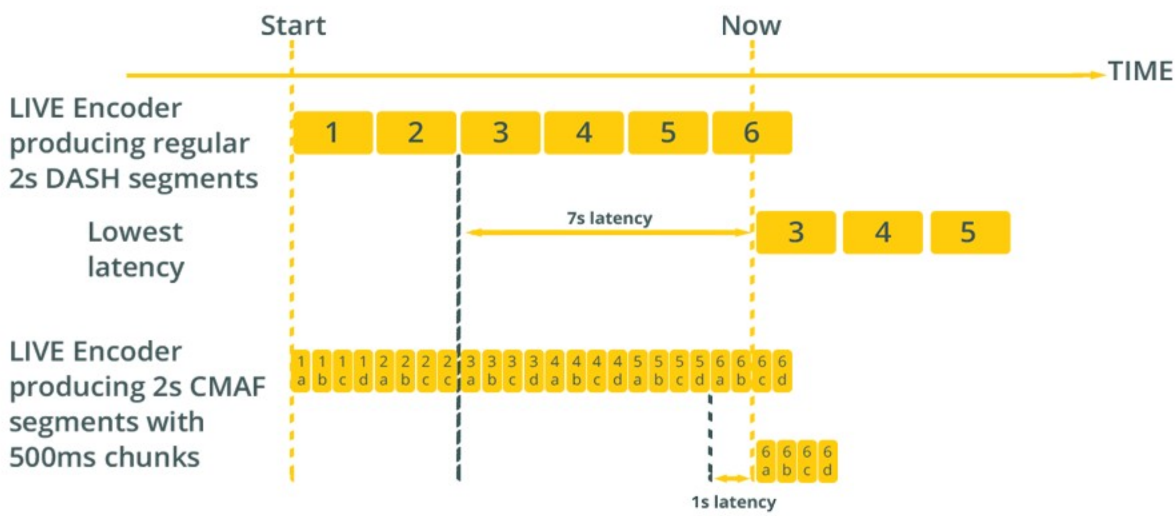

Figure 2.5: DASH vs LL-DASH. [ELI18]

The *availabilityStartTimeOffset* attribute was introduced recently in the MPD, and it denotes the gap between the *availabilityStartTime* (Table 2.1) of a segment and the UTC time when the server can start delivering it, possibly using HTTP chunks. This typically aligns with when fragments of the segment are ready. With this attribute, the client knows that a fragment may be available earlier than the complete segment, allowing it to request the current segment at the right time, avoiding unnecessary waits or HTTP 404 errors when the segment isn't fully produced yet.

For this to work, the server must either send out the fragment as soon as it is generated or keep the client waiting until the full segment is ready. If the *availabilityStartTimeOffset* (Table 2.1) is set to when the first fragment is available, latency can be reduced to the duration of that fragment [BCL14].

2.2 DVB-MABR

Traditional DVB employs transmission methods like satellite, cable, or terrestrial broadcasting, where a single signal is broadcast to many receivers simultaneously, delivering the same content to all users at once. However, the industry is shifting toward transmission technologies built entirely on IP protocols, driven by the demand for greater efficiency, flexibility, and scalability. Digital Video Broadcasting - Multicast Adaptive Bit Rate (DVB-MABR) is an IP-based solution that uses multicast over IP networks, combining conventional broadcast methods with adaptive bitrate streaming. This allows video quality to adjust to network conditions, enabling efficient distribution of content to multiple users over IP networks, such as for live streaming services.

Nowadays, most video delivery use unicast streaming, because it adapts to network conditions and it utilizes existing network technologies like HTTP and Content Delivery Network (CDN). Moreover, the use of Dynamic bitrate adaptation provides regular streaming even when network conditions change.
For large audiences, which concurrently receive the same linear media stream, multicast packet replication at Layer 3 (Network and Switching) reduces redundancy. Unicast streaming remains preferable for unsynchronized media consumption or smaller audiences DVB-MABR combines media encoding and packaging with point-to-multipoint distribution, and it designs scalable linear media distribution systems.

2.2.1 Reference Architecture

In the DVB-MABR system, media requests are made through HTTP, in this way users can ask for specific media content. The concept of UNICAST-ABR is based on segmenting the video into multiple parts, with each segment encoded at different quality levels and bit rates. This allows the system to adapt to varying network conditions and deliver the best possible quality to the user.

However, in the context of CDNs and IP-based devices, each user corresponds to a unique video streaming session. This means that when a user requests to stream a video, the CDN initiates a separate stream from its servers to that specific user's device. This individualized approach can reduce the Quality of Experience (QoE), particularly when network congestion or bandwidth limitations affect streaming quality [DVB24a].

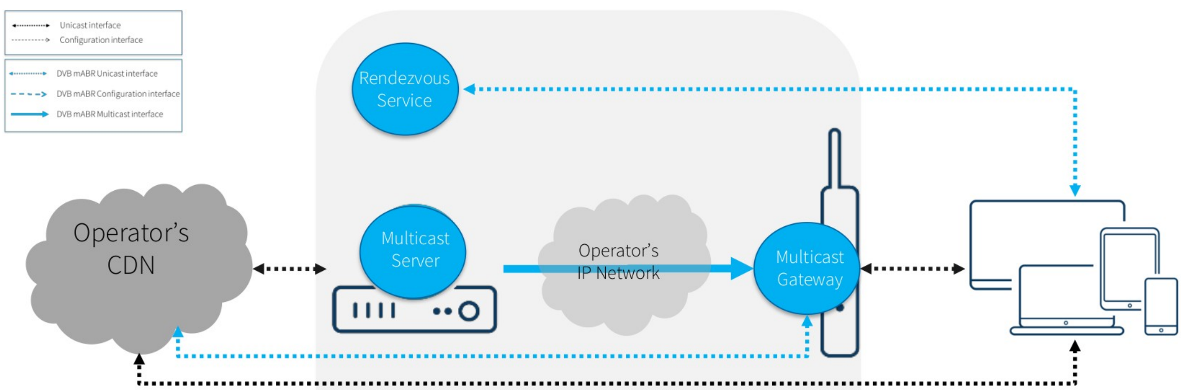

Figure 2.6: Multicast ABR Architecture. [DVB24a]

Multicast Server Configuration

In each home or zone, coverage is provided by a residential gateway, with the terminal located behind it. The Multicast Server, as illustrated in Fig.2.6, operates by communicating with the CDN, it requests content and suddenly forwards it. The Multicast Server is situated on the operator's side, while the Multicast Gateway connects numerous IP devices.
Once the Multicast Server is configured, a specific number of streams are transmitted through a Multicast PIPE to deliver multiple services downstream. The Multicast Gateway configuration is updated to reflect the available streams, and it is connected to a Multicast PIPE, facilitating the connection between the LAN hosts and the WAN.

For out-of-band configuration of Multicast Gateway, a simple REST HTTP API is used to send XML configuration files, for remote control.

In-band configuration involves the Multicast Server configuring and transmitting gateway-specific settings directly over the multicast interface.

The player functions as the entity that requests and receives video from aURL. It decodes and displays the video, while the application manages all other functionalities.
To access the correct Multicast Gateway, the player sends a request to a Rendezvous Service, that redirects the request via a HTTP mechanism [DVB24a].

Rendezvous Service

The Rendezvous Service is a mechanism that helps client devices to discover and connect to multicast streams provided by the CDNs, as shown in Fig.2.6. When a client device wants to access a video stream, it first discovers available services through methods likeDNS-based service discovery.
Then it contacts a Rendezvous point, which provides information about the multicast groups to join. Using the Internet Group Management Protocol (IGMP), the client joins the appropriate multicast group and it starts receiving the video stream, which is transmitted in an adaptive bitrate format to adjust quality based on network conditions. The access control function monitors the player's content access attempts. Before redirecting the request to the Multicast Gateway, it confirms the successful transmission across the multicast interface to begin video playback [DVB24a].
In PiggyBack Multicast Gateway Configuration, the Rendezvous Service provides just-in-time configurations that the Multicast Gateway interprets and implements, enabling effective content delivery to the player.
In different deployment scenarios, the Multicast Gateway utilizes both unicast and HTTP:

- HTTP Unicast Repairing allows the gateway to retransmit missing content segments from the CDN, when packets, delivered over multicast, are corrupted.
- HTTP Unicast Assistance helps the Multicast Gateway, fetching segments, which the server did not deliver or that are not cached locally. This approach remains hidden from the player and it is particularly CPU-friendly when gateway resources are constrained.

In Co-Located mode, the Rendezvous Service can be situated anywhere, often with telecom operator premises or on the same host as the Multicast Gateway, optimizing operational efficiency and resource utilization [DVB24a].

2.2.2 Deployment Models

Multicast Gateways are deployed in various network configurations to facilitate multicast-to-unicast conversion for efficient content delivery [DVB24a].

- **Network Edge Device Deployment:** Multicast Gateways are placed upstream of terminal devices that do not supportIP multicast reception with the home network. They convert multicast traffic to unicast for delivery to multiple homes, ensuring all traffic on the access network becomes unicast.

- **Home Gateway Device Deployment:** Multicast Gateways are integrated into home gateway devices, such as routers, provided by ISPs, as illustrated in Fig.2.7. They perform multicast-to-unicast conversion for multiple terminal devices with the same home network, allowing each terminal device to receive content individually.

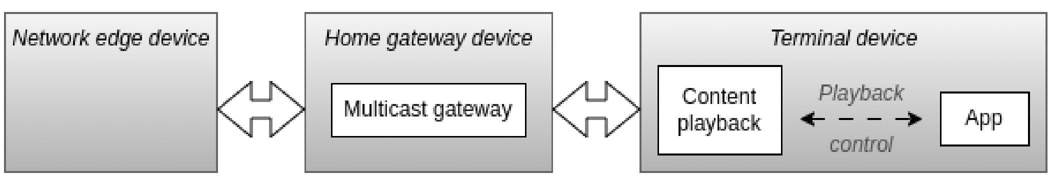

Figure 2.7: Multicast gateway deployed in home gateway device. [DVB24a]

- **Terminal Device Deployment:** Terminal devices supporting IP multicast reception with the home network include both Multicast Gateway and Content playback functions. Each terminal device loads its application for controlling linear playback. However, in this deployment model, Multicast Gateway functions serve only the host terminal device, potentially leading to quality issues if the home network predisposes full multicast support.

2.3 DVB-NIP

Digital Video Broadcasting - Native IP Broadcasting (DVB-NIP) represents an evolution in satellite and terrestrial television broadcasting. In fact, this standard, no longer considers the MPEG-2 TS layer, but it defines a protocol stack that is entirely based on IP. This new broadcast signal provides professional and consumer applications. The first includes distribution to CDN caches, mobile or broadcast tower sites, public hotspots, and transportation hubs, while the second application contains Direct To Home (DTH) broadcasting to IP-based in-home devices [DVB24c].

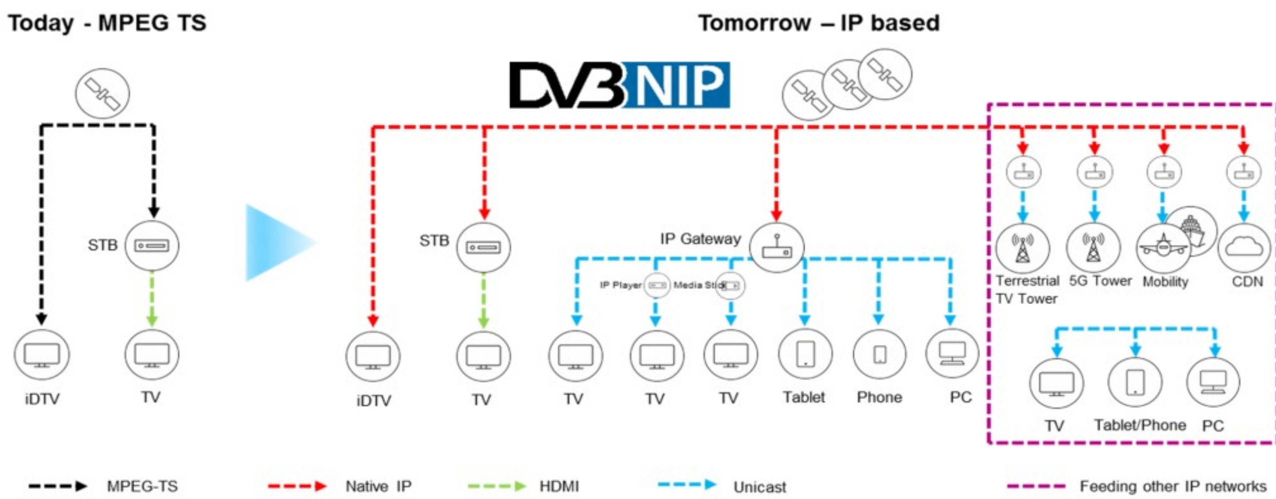

Figure 2.8: The future of video delivery.[Mig24]

2.3.1 System Description

The DVB-NIP system distinguishes itself from traditional Transport Stream-based architectures by integrating with IP infrastructures. Instead of relying on a dedicated DVB encoding platform, content is sourced from the same content preparation and hosting platforms used by OTT providers. This allows for the reuse of streams from OTT cloud headends, eliminating the need for a separate broadcast headend for traditional DVB distribution. As a result, the system enhances compatibility with modern IP devices like smartphones, tablets, and PCs. OTT headend functions can operate in the public cloud or within the premises of a technical or commercial operator, with DVB-MABR defining the interface between the OTT content platform and the DVB-NIP architecture [DVB24c].

In fact, DVB-NIP combines the advantages of both IP unicast and multicast distribution, making it effective in both connected and offline scenarios, including those with a return path. Key features include the delivery of live linear television and radio services through both broadcast and hybrid methods using new codecs. The system supports content delivery to homes or CDN edge caches, while also offering VOD services in professional environments. Additionally, DVB-NIP incorporates an extended content guide based on DVB-I functionality, enabling multiscreen device support, whether or not the devices have broadcast tuners. This makes it a versatile solution for modern, IP-based content distribution [DVB24c].

2.4 System Architecture

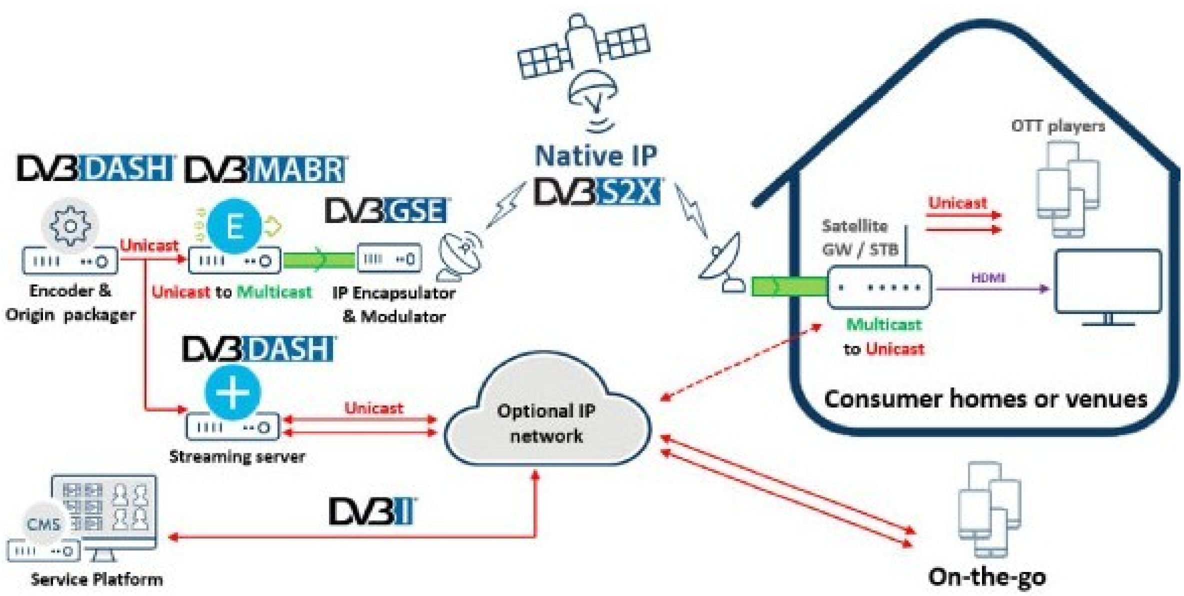

Figure 2.9: Native IP scheme. [EBU16]

DVB-NIP is based on DVB's IP-based standards, as illustrated in Fig.2.9, adapting them for broadcast networks. For instance, DVB-I is employed for service discovery and program metadata, DVB-DASH is utilized for A/V coding and packaging, and DVB-MABR is used for multicast distribution [EBU16].

To facilitate the transition from existing DVB networks to this new IP-based one, DVB-NIP includes an optional backward-compatible mode. This mode uses Digital Video Broadcasting - Generic Stream Encapsulation (DVB-GSE) to carry IP packets with an MPEG-2 TS, which is particularly useful in scenarios involving DVB-S2, as evidenced in Fig.2.9. This compatibility doesn't render the current infrastructure obsolete [DVB08a].

Layered System Design

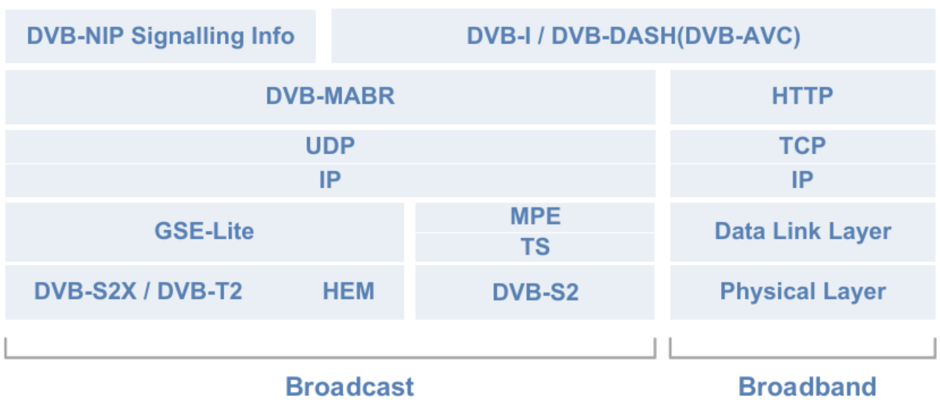

Figure 2.10: DVB-NIP protocol stack. [DVB24c]

The DVB-NIP Broadcast System relies on a layered system architecture. At the top of the Native IP stack, as illustrated in Fig.2.10, there is the DVB-I service discovery and metadata layer, which informs receivers about the services available on broadcast and broadband networks.

DVB-NIP services can be grouped into different DVB-I Service Lists from various operators on the broadcast network. These lists include DVB-DASH-based services, which can be delivered by DVB-MABR protocols on the broadcast network or using HTTP/HTTPS requests via the broadband network.

DVB-NIP defines an announcement channel mechanism and signaling tables: the Network Information File (NIF) and the Service Information File (SIF). The NIF provides information about different streams and their physical parameters, while the SIF provides information on the location of services and metadata with those streams. In this way, broadcast receivers can choose between the relevant streams and channels.

Signaling and A/V services are carried over IP multicast using protocols like DVB-MPE, with DVB-S2, and DVB-T2 managing the physical transmission layers, as shown in Fig.2.10.

Receiver Deployment Models

DVB-NIP can support three deployment models using the same broadcast streams.

- **Deployment Model 1 (DM1):** It's a Business To Business (B2B) model, that involves edge cache receivers at the border of telecom networks, connected with DVB broadcast network. These receivers can be located at local CDN caches, broadcast transmitter nodes, cruise ships, and planes, in this way they are used by clients, using DVB-I service discovery, through public or private IP networks.

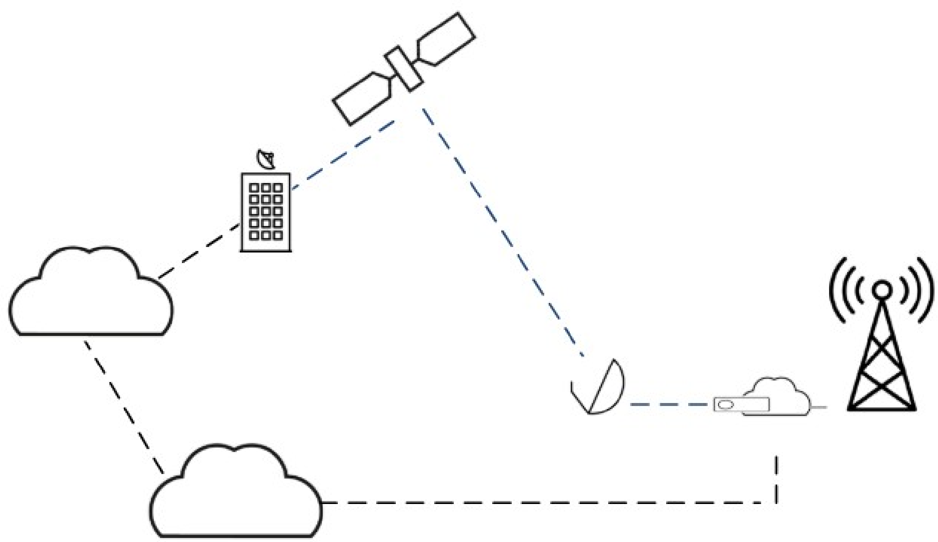

Figure 2.11: Example of a Professional Edge Cache receiver at the edge of a CDN network. [DVB24c]

- **Deployment Model 2 (DM2):** This Business To Consumer (B2C) model targets next-generation TV sets with the capability of Native IP broadcast reception, directly integrated into their systems. These TVs access Native IP services like traditional DVB Transport Stream systems but it uses also DVB-I functionality and DVB-DASH delivery. They adopt hybrid television services, combining broadcast and broadband, and providing consistent services to the end-user.

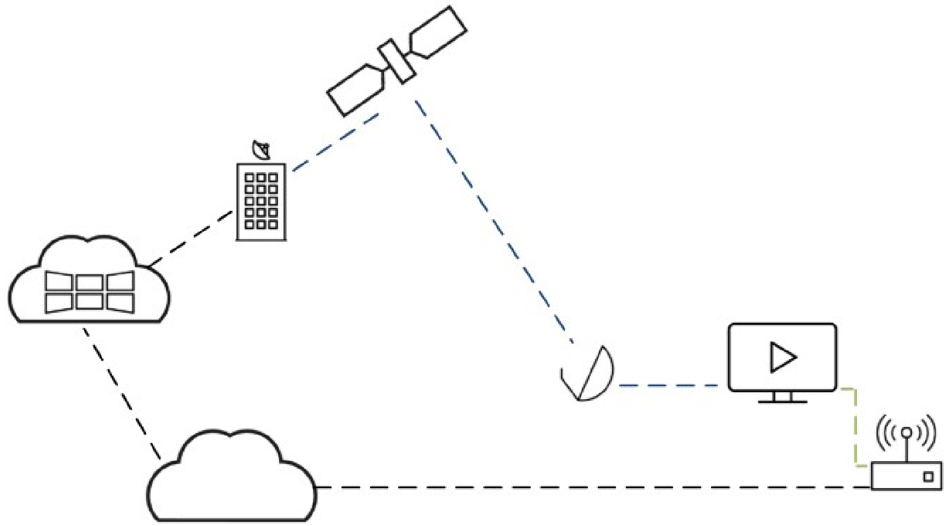

Figure 2.12: Simplified view of Deployment Model 2. [DVB24c]

- **Deployment Model 3 (DM3):** It's another B2C model, but this scenario delivers services directly to all IP consumer devices at home through a Native IP Gateway function. This gateway can be in a device such as a STB, an antenna adapter, or an ISP router.

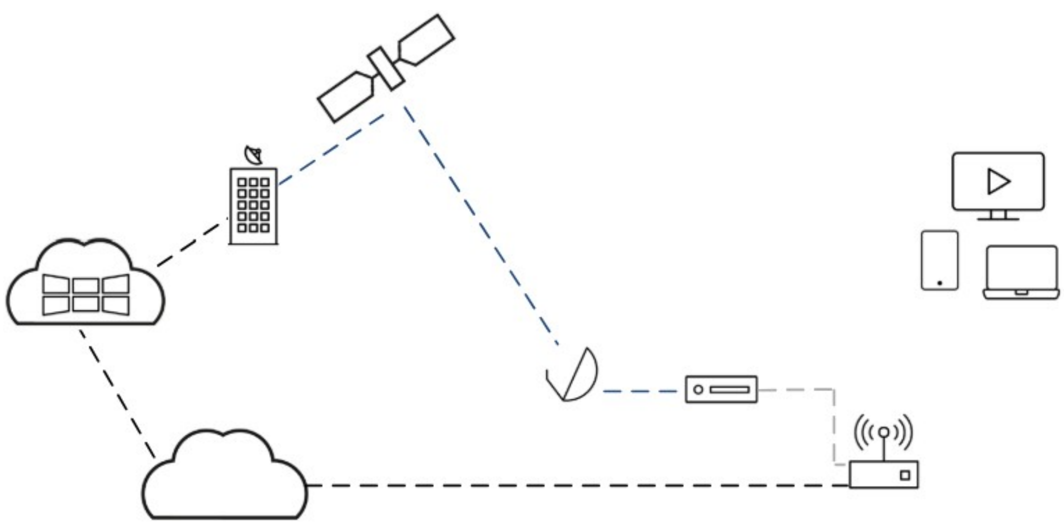

Figure 2.13: Simplified view of Deployment Model 3. [DVB24c]

CHAPTER

3 Internet-based Digital Video Broadcasting (DVB-I)

Over the past few years, the Internet has developed into a communication system that can handle the distribution of services, such as live and on-demand video streaming, to large audiences. Various streaming strategies have been developed to reach large-scale spectators, trying to avoid viewing difficulties due to different network circumstances. With the same goal as previous approaches, DASH seeks to avoid buffering and even brief service outages by enabling users to choose between multiple representations of the same content depending on the strength of their connection at the time. Furthermore, OTT streaming is becoming increasingly popular and could eventually take the place of traditional television distribution.

It is difficult for content suppliers to deal with the variety of streaming platforms because there are no standards that guarantee compatibility between consumer devices and services, due to a wide range of various operating systems. This situation makes it challenging to guarantee each user has a consistently high-quality experience [Ric+21].

The work on internet-centric standards inside the DVB Project started in mid-2019. Since then, DVB-I has been approved for defining metadata and discovery of streaming services and is currently standardized. Adopting DVB-I allows viewers to seamlessly discover and watch television content, whether it is delivered via terrestrial, satellite, cable broadcast, or any broadband network, including fiber, 5G, and future technologies. With DVB-I, users can access their favorite content on any device at hand, even if it is a smartphone, tablet, laptop, TV, set-top box, or streaming stick, ensuring a consistent experience across all platforms, as illustrated in Fig.3.1.

DVB-I supports everything from live and linear television to on-demand content, box sets, and even interactive apps, providing a unified, user-friendly interface for all content types. Additionally, service lists can be customized to meet the specific needs of different markets or use cases, allowing regulators and operators to tailor offerings to benefit consumers, broadcasters, and content providers alike.

Figure 3.1: Common service offering across any internet-connected device. [Pro23]

The chapter discusses the DVB-I standard, focusing first on its architecture and service discovery mechanisms. It then provides implementation guidelines for DVB-I, detailing best practices and technical considerations. Lastly, the chapter explores DVB-I deployments, highlighting the POC by Mediaset in Italy and a similar initiative by German broadcasters, concluding with developments up to the DVB World Congress.

3.1 DVB-I Standard

The DVB-I Standard is made up of several key components that allow for user interaction, content delivery and service discovery, hence facilitating flexible television broadcasting. This section is divided into subsections, starting with the DVB-I reference architecture, followed by Service Discovery, Service Lists and Content Metadata, and Service List Providers. It concludes with a discussion on Implementation Guidelines.

3.1.1 Architecture

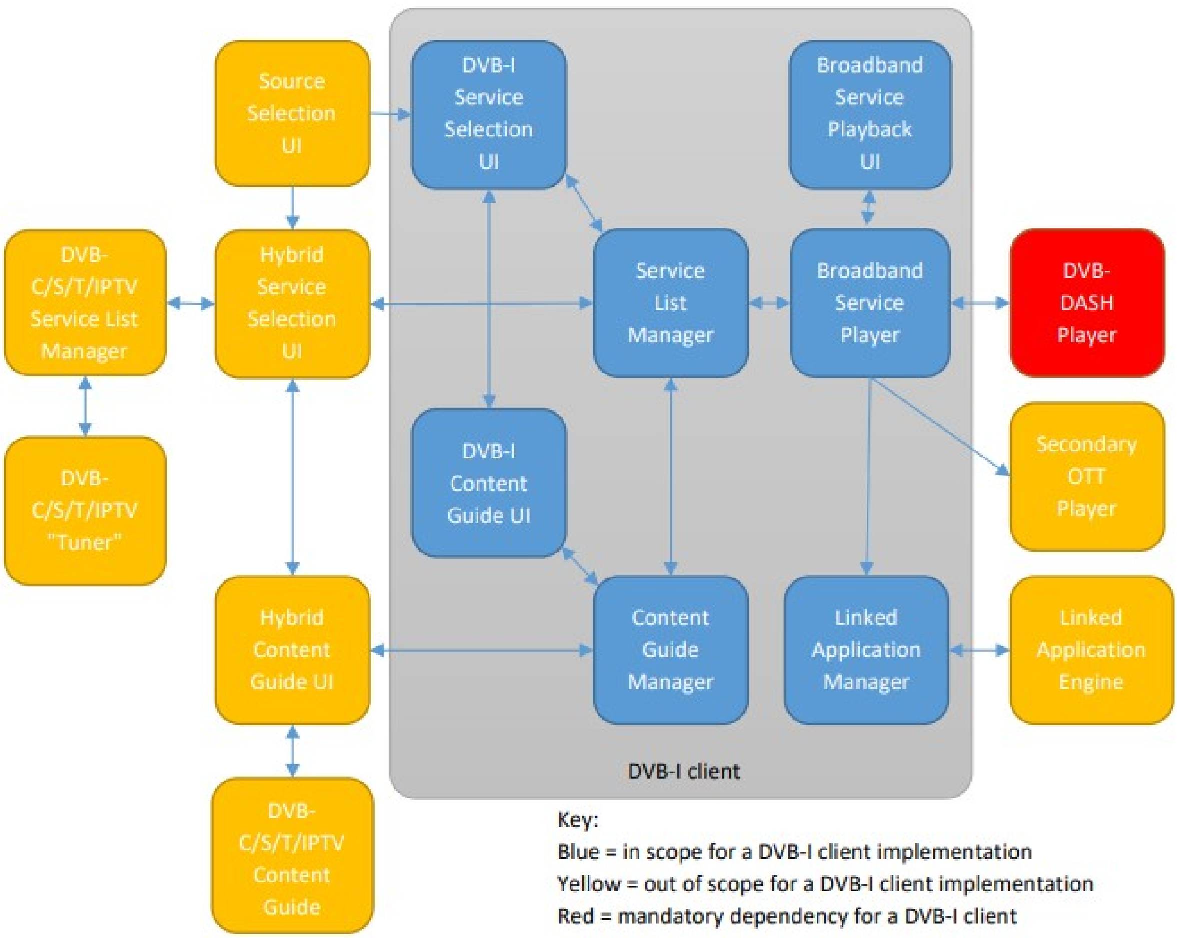

Figure 3.2: Conceptual model of a DVB-I client. [DVB24d]

The Source Selection User Interface (UI) in DVB-I clients, as shown in Fig.3.2 allows users to choose between various inputs, sources, or apps. A device can host multiple DVB-I clients, each potentially appearing multiple times with different branding and showing different Service Lists. Some sources may combine DVB-I channels with other channels like DVB-C/DVB-S/DVB-T or DVB-IPTV, and the UI may also include non-DVB-I options such as HDMI or DLNA. The DVB-I Service Selection UI lets users view and select services, though not all clients have this feature and may use a hybrid UI.

The Service List Manager discovers and manages Service Lists from servers, directing the service player for DVB-I services. For DVB-C/DVB-S/DVB-T or DVB-IPTV devices, a similar manager handles Service Lists, including Radio Frequency (RF) channel scans and proprietary DVB-IPTV lists.

The DVB-I Content Guide UI provides access to service content information, but some clients may use a hybrid guide UI. This content data is retrieved and managed by the Content Guide Manager, who may also incorporate it into the guide user interface.

Using players and application managers, the Broadband Service Player oversees the lifecycle of services via a broadband network. The Broadband Service Playback UI manages playback features and displays player status and response codes. The DVB-DASH Player and Secondary OTT Player handle DVB-I services via DVB-DASH and other OTT content, respectively.

The DVB-C/DVB-S/DVB-T or DVB-IPTV Tuner plays services from these sources, potentially using SAT>IP instead of a local tuner. The Linked Application Manager identifies and interfaces with engines to present linked applications, which might need to start before video and audio. The Linked Application Engine runs these applications, such as HbbTV® on TVs or HTML5 webpages on other devices.

Service Lists

A single Service List is intended to reach viewers in several geographical locations, including different nations and areas. Targeting can be implemented at many metadata levels in the Service List hierarchy.

At the highest level, Service Lists can be configured to cater to entire countries or specific regional segments within those countries. This regional targeting capability is flexible across several metadata components within the Service List, as shown in Fig.3.3:

- Entire Service List: The entire array of services can be customized to align with the preferences and regulatory requirements of different regions or countries.
- Specific Service(s): Individual services listed in the Service List can be targeted to specific geographic areas, ensuring relevant content delivery.
- Specific LCN Table(s): LCN tables, which organize channel listings for ease of use, can also be adapted to meet regional preferences or comply with local regulations.

Service Lists incorporate detailed definitions outlining the regions they target, specifying which services or LCN tables are relevant to each specific area. This flexibility enables media companies and service providers to efficiently customize their content for a wide range of geographical audiences, increasing viewer happiness and engagement in different areas.

DVB-I Service List		
Version	@version="1"	Mandatory
Name	<Name>Italian Example Services</Name>	Mandatory
Provider Name	<ProviderName>RAI</ProviderName>	Mandatory
Logo	<RelatedMaterial xsi:type="tva:RelatedMaterialType"> <tva:HowRelated href="urn:dvb:metadata:cs:HowRelatedCS:2019:1001.1"/> <tva:MediaLocator> <tva:MediaUri contentType="image/png"> https://dvbi.rai.tv/static/list-logo.png </tva:MediaUri> </tva:MediaLocator> </RelatedMaterial>	*Optional*
Region(s)	<RegionList version="1"> <Region countryCodes="ITA" regionID="ID-IT"> <RegionName>Italy</RegionName> </Region> </RegionList> <TargetRegion>ID-IT</TargetRegion>	*Optional*
LCN Table(s)	<LCNTableList> <LCNTable> <LCN channelNumber="3" serviceRef="tag:rai.it,2019:rai-3"/> </LCNTable> </LCNTableList>	*Optional*
Service(s)	<Service version="1"> ... </Service>	*Optional*

Figure 3.3: Service List Example. [DVB24d]

A single Service List can cater to various types of client devices, including IP-only devices

and hybrid TV devices. Hybrid clients are capable of receiving DVB-DASH services over IP, as well as DVB terrestrial, satellite, or cable services simultaneously.
In practical terms, a Service List can define a channel lineup using a combination of different delivery methods, such as IP-based streaming and traditional terrestrial broadcasts. Each service within the Service List can have multiple Service Instances, each representing a different delivery method. For example, a service may have one instance for IP streaming and another for terrestrial broadcast, as illustrated in Fig.3.4.

Hybrid clients are designed to align the delivery parameters and service metadata of each Service Instance with the services and Digital Video Broadcasting Service Information (DVB SI) detected on terrestrial, satellite, or cable interfaces. This guarantees that consumers may access their preferred services through a seamless experience across all of the delivery mechanisms that their devices support.

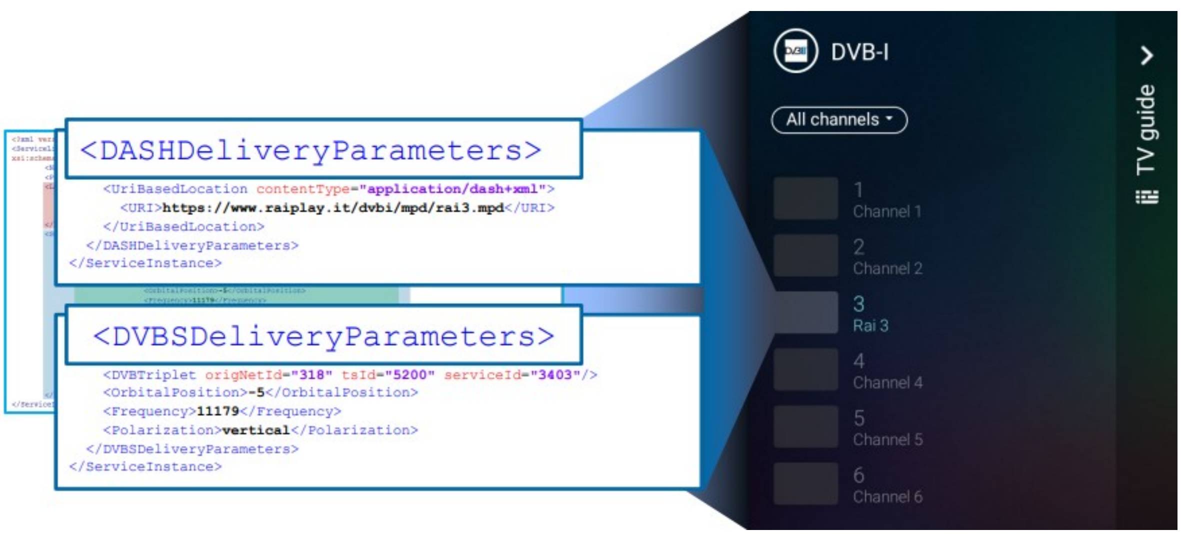

Figure 3.4: Hybrid Service List Example. [DVB24d]

Availability windows for Service Instances are necessarily linked to their delivery methods. Each Service Instance can encompass multiple availability parameters, including specific periods defined from start date/time to end date/time, and intervals set for certain days of the week, specific times of day, or recurring schedules, as illustrated in Fig.3.5. These parameters ensure that services are accessible to viewers according to their preferred delivery method and within specified time frames, optimizing viewer engagement and service reliability across different platforms and schedules.

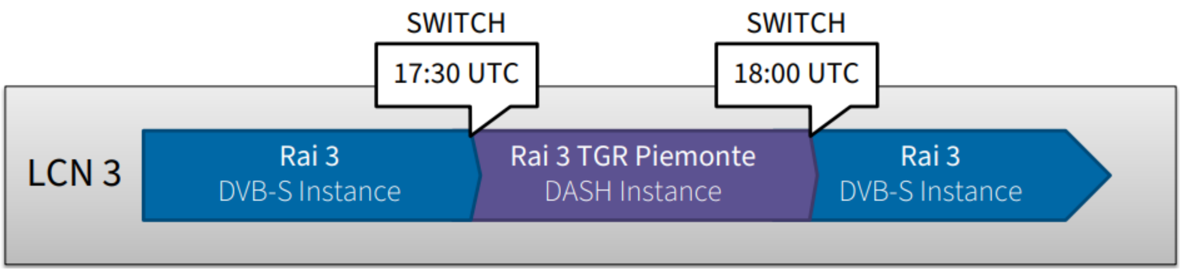

Figure 3.5: DVB-I Client switches to the higher priority DASH Service Instance when it becomes available. [DVB24d]

3.1.2 Service Discovery

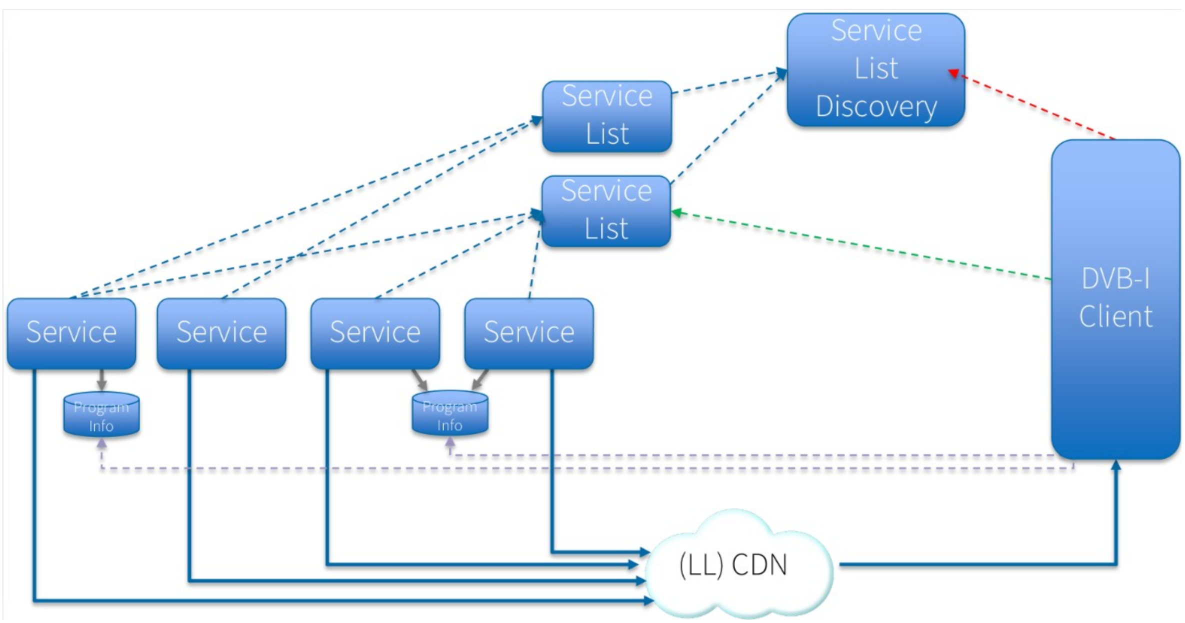

Figure 3.6: DVB-I concepts. [DVB24d]

DVB-I provides an advanced network feature that lets users find Service List Providers by contacting potential providers and getting complete Service Lists back. Users can access an organized assortment of content thanks to the platform's chosen collection of services.

When searching for Service Lists based on a country, regulator, genre, language, or provider, Service List Registries receive HTTP queries and XML answers. This process is known as Service List Discovery, as illustrated in Fig.3.6. A Service List is a curated collection of services with their ordering, availability (both periodic and location-based), and delivery methods. Delivery methods indicate broadcast and broadband access methods, which can be reconciled with local channel scan data or other manifests such as SAT>IP or DVB-IPTV. Additionally, it supports the signaling of applications, deep links, and playlists. Using XML replies and HTTP queries, content metadata is maintained to provide now/next summary program information, program details for programs that run for a maximum of 28 days, complete program information, and program groups like box sets or siblings.

Service Lists Provider

Broadcasters, network operators, regulators, independent third parties separate from content creation and distribution, and private groups or individuals, are examples of Service List Providers. These providers support both horizontal ecosystems like DTT Free-To-Air TV and vertical ones like DTH PayTV, as well as smaller local ecosystems like community organizations. They can target different viewers based on geography, language, market segment, and platform.

Operators still face the same issues that need to be resolved, such as balancing requests from various service providers, legal constraints, user demands, and commercial objectives. Delivery of content and Service Lists are separated further, necessitating the role of the Service List Provider as an authenticator of services, as shown in Fig.3.7. This guarantees that delivery parameters are precise and that users receive the services they expect from reliable providers. Both client devices and service providers need to trust the Service List Provider; this confidence must be built by operational protocols, technological tools, and regulations.

DVB-I expands upon Internet-friendly standards to guarantee that Service Lists and other metadata arrive at the client undisturbed, from the intended provider and with privacy preserved. Because technological building pieces have already been implemented, this strategy is easy to support and gains from existing knowledge and best practices. All metadata requests and answers are handled using REST APIs over HTTPS; client compatibility for TLS v1.3 is necessary. It is also advised to use DNS over TLS, or DNS over HTTPS to improve security and reliability.

An example of Service List queries is: *http://registry/query? param & param...*
Query parameters (plural (OR) and combined (AND)) could be:

- TargetCountry – Service Lists intended for specific countries
- Language – Service Lists containing specific languages
- Genre – Service Lists containing specific genre*
- Provider Name – Service Lists provided by a specific organization
- RegulatorListFlag – identified “official” lists of services

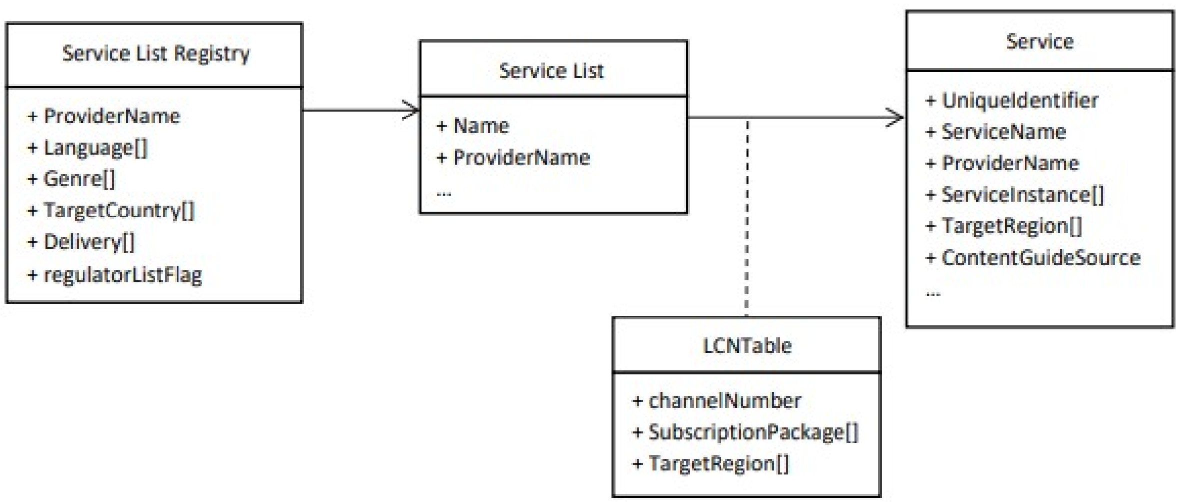

Figure 3.7: Service List Provider relationships. [DVB24d]

The system defines geographic regions based on coordinates or postal codes, withLCN Tables optionally mapped to these regions. It includes parameters for DVB-C / DVB-S / DVB-T / DVB-IPTV / DVB-DASH delivery and media formats, as well as signaling for supplemental items such as out-of-service banners and interactive applications. Time-based availability periods are specified for event-based services or service interworking. Program metadata can be sourced individually or in aggregate.
There are three methods to discover and retrieve DVB-I Service Lists:

1. **Built-in / out-of-band provisioning of a Service List URL**: This can come from a known and trusted Service List Provider, available either at device installation or dynamically on the fly.

2. **Broadcast signaling of Service List URL**: This involves a URI linkage descriptor in the first loop of NIT or BAT.

3. **Service List Registry Query**: Users can query for available Service Lists using parameters such as country, language, provider name, and whether the provider is a regulator.

Clients may be pre-provisioned or privately provisioned with known Service List URLs or Service List Registry URLs. These URLs can be defined and provided by national or regional regulators, network operators, broadcasters, manufacturers, or other entities managing a Central Service List Registry.

The URI linkage descriptor in the first loop of NIT or BAT contains a *private_data_byte* loop with a *DVB-I_info()* element that indicates the *end_point_type*. If the *end point type* is 0x01, the signaled URI links to a DVB-I Service List; if it is 0x02, the signaled URI contains a query to a Service List Registry.

A single service may have a distinct channel number and be included in numerous Service Lists. These lists may be itemized in multiple registries and may be found through a Service List registry. It is also feasible to have Service Lists that are only used by clients that are already aware of the Service List URL and are not promoted by any Service List registry. Once every 24 hours, a DVB-I client should check for an update to an installed Service List.

Content Metadata

Requests for both summary and detailed information are made possible by the REST APIs, which provide program and series information. Users have access to a catch-up plan that covers the previous 28 days as well as a linear timetable that can be seen up to 28 days ahead. TV Anytime criteria are used to profile these answers. The APIs provide provisioning choices for any service or provider in addition to search capabilities by category and series.

The server also can produce graphic elements that work with the user interface. Complete information about services, including acquisition techniques and related metadata like names, IDs, and LCNs, are provided by the APIs. Both DASH and broadcast systems offer delivery parameters and media formats, with availability based on time and geography.

3.1.3 Implementation guidelines

The DVB-I implementation guidelines standard offers a comprehensive framework for the deployment and management of both traditional broadcasting and Internet-based television services, ensuring seamless interoperability and integration across several platforms and devices. By adhering to these standards, service providers and device makers may ensure that their offerings are compatible with the DVB-I infrastructure and facilitate a smooth transition from traditional broadcasting to internet-based television services [DVB24b].

For a DVB-I client to successfully provide the level of functionality expected by users of linear television services, it must address several functional requirements that apply to the interface between the DVB-I client and the DVB-DASH player. These requirements include Adaptation Set Selection, Parental Access Control, Network Timeshift, and Handling multiple Service Lists. Multiple Service Lists can be handled by the DVB-I client in a few different ways.
Only one Service List may be supported by a DVB-I client. When installing and configuring a media consumption device that integrates the DVB-I client, only one Service List may be implicitly chosen. Moreover, a DVB-I client may allow the user to choose one Service List from a limited number of options during installation; reinstalling the client would be necessary to change the Service List. An alternative would be for a DVB-I client to allow the user to select one Service List at a time from a limited number of available possibilities.
Furthermore, a DVB-I client may allow the user to choose a Service List by searching a Service List Registry. In scenarios where the DVB-I client enables users to switch between Service Lists at any time, it may also enable users to create user-defined lists of services from any available Service Lists. Finally, a DVB-II client may support choosing multiple Service Lists and merging them into a single list.

A typical service installation

A DVB-I client begins by offering the user a choice of language and country options, which are crucial for the UI and installation context. For hybrid DVB-I clients, it is beneficial to scan available broadcast signals before selecting and installing a DVB-I Service List. Relevant DVB-I Service Lists might be found in broadcast service information, and the choice of DVB-I Service List may be influenced by available broadcast signals and services [DVB24b].

Additionally, all available broadcast services can be mapped to DVB-I services during the installation of a selected DVB-I Service List. When installing a DVB-I Service List, whether chosen by the user or automatically, the client should first determine the applicable region and/or subscription package, if these mechanisms are utilized by the Service List.

Next, the client should decide which services to install by verifying that each service meets multiple criteria, such as the inclusion of a service instance and/or a linked application where HowRelated@href is set to *urn:dvb:metadata:cs:LinkedApplicationCS:2019:1.2*, the supported service instances applying to the selected subscription package, and the service applying to the selected region.

For clients using LCNs, such as TVs, the allocation for services depends on the use of LCN tables. If they are used and multiple tables are defined, the client should select the relevant table based on the region and/or subscription package, using the unique ID of each service to find the corresponding LCN in the selected table. For services without a corresponding allocation, the client can allocate one in an ”overflow range” (e.g., 800+ or 1000+), which may vary by region and/or broadcast medium. If LCN tables are not used, the client may allocate using its own method, such as assigning them in the order services are listed in the Service List XML, starting from 1.

A DVB-I player needs to know when one program ends and the next begins for several reasons, including displaying correct summary information (e.g., current program details shown when a user presses the ”info” button on a TV) and applying appropriate parental access controls for the new program.

3.2 DVB-I Deployments

Around the world, DVB-I is being implemented through several trials and pilot programs that combine internet-based services with traditional broadcasting. These projects, which are being carried out in Italy, Germany, Ireland, Spain, Iran, and other nations, are aimed at improving TV functionality, standardizing the user experience, and investigating novel applications for hybrid broadcast and broadband contexts. Every experiment adds significant knowledge and advances technology in the direction of DVB-I technology's wider worldwide acceptance [Pro23].

With the help of several partners, Mediaset, in Italy, has been fundamental in creating use cases and growing into an entire commercial trial.

At the same time in Germany, broadcasters manufacturers and software companies aim to develop standardized DVB-I future scenario features. They include hybrid services, Digital Rights Management (DRM) solutions, regional channel sorting, and an integrated EPG.

While in Ireland (RTÉ's Saorview platform), there is a proof of concept using DVB-I to enhance the DTT platform features. It includes IP fallback EPG integration with on-demand content and extended LCN listings.

Concurrently in Spain, there was a public test of DVB-I with a custom DTT multiplex, which demonstrated DVB-I Service List integration over DTT during the Mutua Madrid Open tennis tournament.

Lastly, in Iran, a pilot conducted in 2020 evaluated DVB-I's feasibility including a Persian-language Service List with 60 service instances. The plans involve integrating DVB-T/DVB-T2 and OTT services into DVB-I.

3.2.1 Proof Of Concepts

Mediaset Trial

To create use cases for an end-to-end chain that fully complies with DVB-I and related standards, Mediaset started building a DVB-I POC. The intention behind this project was to eventually develop into a full-scale commercial solution [Bra23].

Mediaset, which also served as a service provider, coordinated the POC with the participation of numerous partners in the activities. The diagram in Fig. 3.8 shows the partners in the proof of concept together with the use cases that were put into practice, and a complete test was created to accurately prove the complete chain.

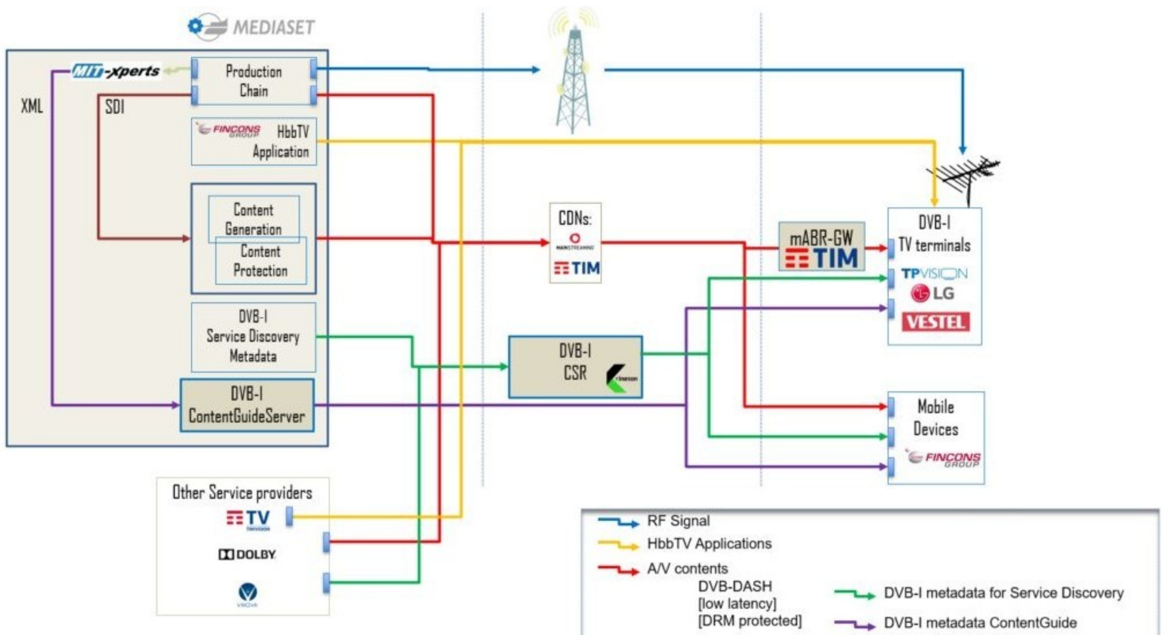

Figure 3.8: High-Level Architecture. [Rio22]

A high-level architecture was created in the Mediaset POC for DVB-I to handle the majority of DVB-I components required for a market trial. A CSR, service discovery metadata, content guide metadata creation, and a HbbTV® application, are some of the important components of the system.

In addition, the system supports QoS monitoring, DVB-MABR streaming, and DRM.

The proof of concept addresses several topics, such as the creation and protection of DVB-DASH

content, regulatory considerations, and support for TV terminals as the primary screen and mobile devices as a secondary screen.
To effectively manage content distribution, the network infrastructure consists of DVB-MABR servers and a Low-Latency CDN.

The purpose of POC is to simplify the search and consumption of DVB-I services on compatible devices, ensuring an easy transition from traditional television viewing to contemporary streaming services. This includes features such as zapping, a uniform channel list managed by the CSR, and remote control functionality. The architecture aims to align DVB-T and DVB-I timing latency using DVB-DASH low latency specifications, which helps to reduce the gap between RF and IP distribution. In addition, the system supports multicast services to alleviate IP traffic congestion on telecom networks.

Overall, the high-level architecture of Mediaset's DVB-I POC demonstrates a robust framework for distributing broadcast content over IP networks, while maintaining the user experience and quality of service associated with traditional television broadcasting.

It underlined the possibilities of hybrid television services, which allow customers to use an integrated platform to access both interactive and on-demand services and traditional broadcast programming. A complete strategy, encompassing everything from content production and management to distribution and user experience, was secured by these partnerships.

Phase 2 of Mediaset's POC was also introduced in Q4 2023 to test and profile more use cases and further aid in the development of the DVB and HbbTV® standards. For new broadcasters interested in taking part in the Market Trial, this offers a valid testing environment [Bra23].

Germany Trial

The "DVB-I Pilot Germany" project, which ran from September 2022 to March 2023, provided a proof of concept for the technical functions of the DVB-I standard. Twenty-one broadcasters, companies, and organizations, participated in this pilot, as illustrated in Fig.3.9, including both German and international associations [VS23].

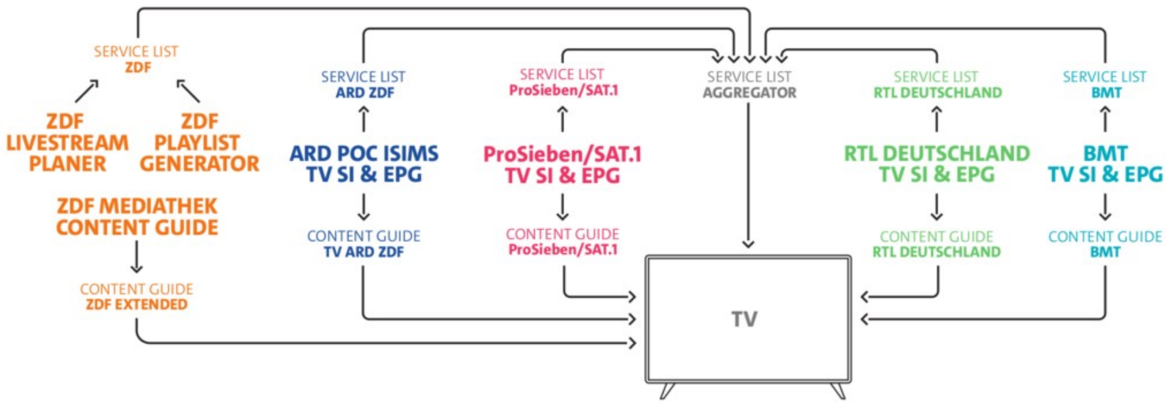

Figure 3.9: Service List and Service List aggregator infrastructure. [VS23]

Subscription-based services and DVB-I Service Lists with DRM are features of the architecture shown in Fig.3.9. To guarantee that customers may safely access and utilize subscription-based services, this example demonstrates how DRM solutions can be connected to manage access control and content protection.

German POC project is renowned for adding extra event channels to the service range in a dynamic manner. Because of this flexibility, special event channels can be included during the broadcast period to give viewers timely and pertinent content that is relevant to current events.

Through the use of region-specific LCN tables, the pilot also provides channel sorting that is customized to an area. With the help of this feature, viewers are guaranteed to receive channels that are relevant to their location and context. Depending on the unit, region selection can be done directly from the menu or by entering the postcode, allowing for a customized viewing experience.

Direct connections to media libraries improve the EPG and make it easier for users to obtain VOD content. With just a few clicks, customers may use this tool to watch pre-released episodes, access previously released content, and catch up on missed programming.

Playlists in DVB-I architecture create a linear service by combining videos of specific genres, such as news or themed compilations. Users can explore across these playlists, which makes for an engaging and dynamic content experience.

The German POC project offers radio channels in DVB-I along with television services, and it comes with VisualRadio applications made for big screens. These apps increase the overall engagement of radio programs by adding interactive and educational visual elements to the radio experience.

The German POC project intends to showcase a unified Service List that is customized for the German market and reflects requirements that might be specified by a regulatory agency. This comprehensive strategy highlights a seamless service experience that satisfies customer expectations as well as legal requirements.

To ensure that DVB-I clients receive program sorting that is appropriate for their location, the pilot also made clear the necessity of a technical-organizational entity managing the Service List aggregation.

5G Implementation

The DVB Project has been concentrating on internet-centric standards since 2019. One of these standards is DVB-I, which offers a broadcast-like user experience on internet-enabled devices by standardizing metadata and discovery for streaming services. It completes the set of OTT streaming standards, which also includes DVB-DASH for adaptive streaming and DVB-MABR for multicast adaptive bit rate streaming. If the client has a sufficient tuner, DVB-I can combine with regular DVB broadcasting, enabling flexible delivery of content.

Reliable solutions are needed in light of the fast increase in mobile data traffic, of which video content accounts for an important portion. Previous attempts at mobile broadcasting, such as Digital Video Broadcasting – Handheld (DVB-H), failed because of resistance from manufacturers. The advent of Further Evolved Multimedia Broadcast Multicast Service (FeMBMS) in LTE seeks to address this demand, however, it presents new options due to the rise of 5G and its extension to broadcast services,standardized in 3rd Generation Partnership Project (3GPP) releases. Based on LTE, 5G Broadcast is currently in testing and can handle the growing mobile data traffic, especially video, which is expected to exceed 300 exabyte (EB) monthly by 2026 [HRB21].

Real-Time Transport Protocol (RTP) is used by the DVB Project's 5G Broadcast systems to transport video data. For browser compatibility, this protocol must be converted to a web-friendly format like DVB-DASH. A local configuration, as illustrated in Fig.3.10, entails employing a 5G Broadcast system to broadcast video, ffmpeg (a command-line tool to convert multimedia files between formats) to transform RTP streams into DASH segments, and a local HTTP server to provide the content. The goal of this configuration is to provide videos through popular web browsers seamlessly.

The project aims to test and integrate 5G broadcast further, with the possibility of expanding to 5G New Radio (NR) High Tower High Power (HTHP) broadcast. It is anticipated that the DVB-I and 5G standards will facilitate a range of use cases, encompassing both mobile and fixed devices, by merging broadcast and unicast delivery methods to optimize service distribution.

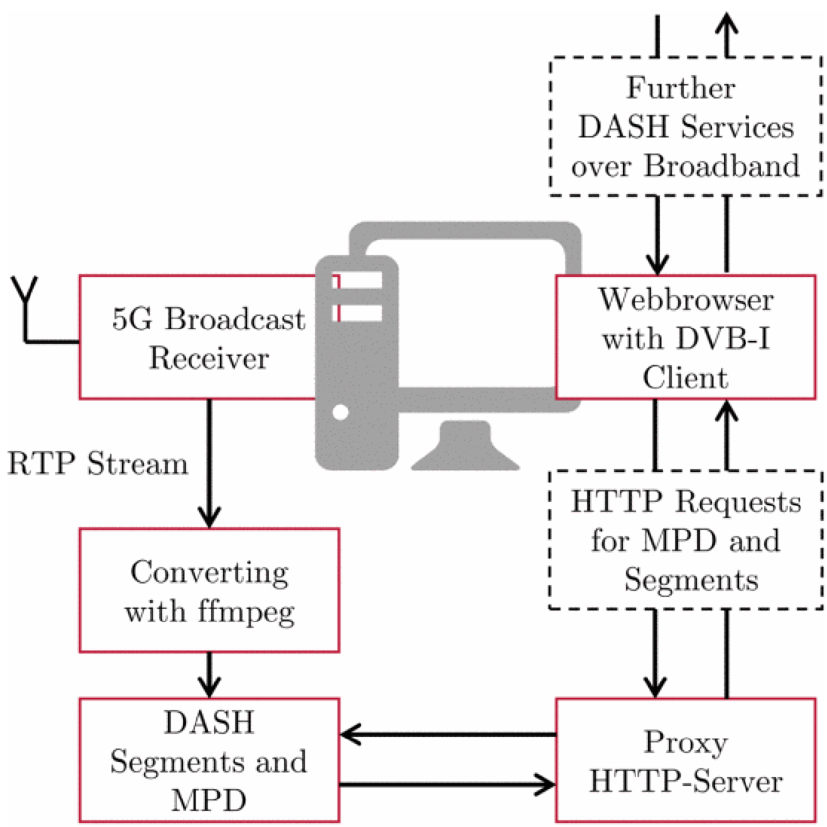

Figure 3.10: Overview of interface for enabling LTE-based 5G broadcast signals in theDVB-I reference client. Real-time conversion and delivery ofDASH segments allow the usage of the video service inside common web browsers. [HRB21]

The evolution of 5G NR focuses on individual cell services instead of free-to-air broadcasting and contains preliminary capabilities for a Multicast-Broadcast Service (MBS). To maximize spectrum usage, 5G NR employs OFDM, which allows a broad variety of carrier frequencies with varied Subcarrier Spacing (SCS) to accommodate different bands.

Future 5G NR improvements, according to this method, may be able to resolve existing issues and create a reliable broadcast mode for cellular networks.

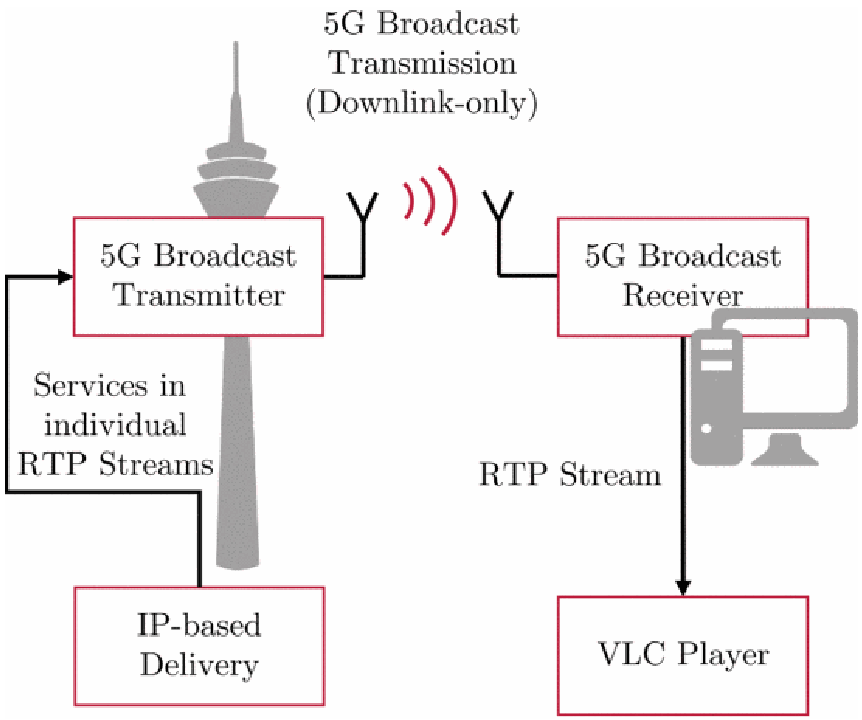

Figure 3.11: Overview of the LTE-based 5G broadcast transmission system. The transmitter is fed with individual RTP streams for each video service. [HRB21]

In summary, the goal of the current research and testing is to successfully include broadcast capabilities into cellular networks. Working together, the DVB-I and 5G broadcast modes have the potential to resolve interoperability problems and improve video service delivery.

3.2.2 DVB World 2024

DVB World is an international broadcasting industry reference event that brings together significant stakeholders such as technology providers, broadcasters, policymakers, and industry

experts, as shown in Fig.3.12. The main objective of this platform is to present the most recent developments and trends in DVB standards and technologies. The occasion gives participants a forum to talk about and share their perspectives on developing broadcast technology.
DVB World is also a networking platform where industry experts can work together, discuss new regulations, and investigate ideas that could influence the direction of digital broadcasting in the future. By addressing both technical and commercial aspects, the event helps the industry adapt to changes in consumer demand, technology, and broadcasting standards.

Figure 3.12: The demos at DVB World 2024. [Pro24]

To improve content delivery and user experience, the DVB World 2024 conference, held in Munich in March 2024, focused on the convergence of traditional broadcast and internet-based technologies. It also highlighted significant advancements and problems in the DVB sector.

ARD talked about the increased expenses and carbon footprint that come with using OTT services more frequently. Although HbbTV® is an essential link to non-linear programming, it is severely lacking in integration into the business plans of major players such as Apple TV, Vodafone, and Sky. A 40% loss of potential reach and opportunity is the result of this gap.

ZATOO discussed their efforts in integrating DVB-I clients into both Mediathek and HbbTV® applications, building on the subject of merging broadcast and broadband. With this strategy, consumers will be able to watch content from both traditional broadcast and broadband sources in a seamless manner.

The Japanese broadcaster NHK carried on the conversation on enhancing content delivery by reiterating their dedication to providing each viewer with reliable information. They emphasized efforts to enhance content discovery, which will increase viewing options and decrease the number of prospective viewers lost. To improve access and reach, innovations like content-sharing links and systematized content discovery were implemented.

BROADPEAK added to the discourse on content delivery by talking about the SVTA Open Caching Initiative and DVB-MABR, with particular attention to the distribution cache situated near the end user terminal. They outlined the difficulties in implementing multicast video streaming services over the Open Caching API, emphasizing the intricacies of CDNs.

G&L investigated new developments in content delivery by optimizing DVB-I Service Lists through the use of CDN edge computing. They introduced dynamic content organization approaches that enable effective and personalized content distribution and monetization strategies. These techniques are based on contextual considerations, session monitoring, and device segmentation.

ESA demonstrated how they have innovated to use beam hopping on Non-Geostationary Satellite Orbit (NGSO) to increase the reach of DVB. This development enhances coverage and efficiency by enabling low latency and large capacity. They also talked about how DVB standards have been incorporated into satellite technology, showing notable performance improvements and expanded geographic coverage.

QUALCOMM showcased their work on unified service discovery between DVB and 5G Broadcast, showing the world's first 5G Broadcast integration on a commercial smartphone that complies with specifications. This was in line with the conference's focus on incorporating new technologies and represented a major milestone in broadcast technology.

SVP (V-NOVA) offered multi-layer solutions to meet the problem of bandwidth constraints and the requirement to service multiple devices. The growing demand for high-definition and ultra-high-definition content requires systems that can effectively reuse encoded data layers to provide higher-quality video streams while maintaining compatibility with current receiver bases and optimizing transmission costs.

EUTELSAT discussed the DVB-NIP application, which provides travelers with personalized video services through a mobile app connected to in-vehicle Wi-Fi, to demonstrate the useful applications of DVB technology in mobility. This invention highlights the adaptability of DVB standards by giving passengers an inexpensive and practical entertainment choice.

By talking about DVB technology's use in education, particularly in places like Southeast Asia and Sub-Saharan Africa, ENENSYS elaborated on the technology's social effects. They want to link disconnected schools and assist remote learning efforts by offering virtual classrooms and instructional information via satellite, demonstrating the potential of DVB to alleviate educational disparities.

Last but not least, YOUVIEW concentrated on Digital Video Broadcasting - Targeted Advertising (DVB-TA), stressing the cooperation needed for dynamic ad insertion in VOD scenarios and ad replacement in linear services. By enhancing user engagement and advertising efficacy, their work on DVB-TA specifications and signaling rules demonstrates how DVB standards may be used for business advantages.

Overall, the DVB World 2024 conference highlighted the continuous innovations and efforts made by numerous organizations to progress DVB standards, incorporating new technologies to enhance user experience, content distribution, and operational efficiency. The talks emphasized how DVB technology may be used for a wide range of purposes, from enhancing conventional broadcast services to creating new interactive and customized viewing experiences [Pro24].

CHAPTER

4 Analysis and Implementations of DVB-I

Hotel entertainment has evolved significantly since The Roosevelt Hotel in New York City first installed TVs in guestrooms in 1947. The television system gathered up on-air programs and tested them for audio and visual quality before distributing them to each room.
Initially, hotels provided a small selection of channels. As cable and satellite television became more widely available, visitors started to ask for more options. VCRs first debuted in hotel rooms in the 1980s and 1990s, enabling visitors to rent and watch movies whenever it was convenient for them. Subsequent pay-per-view offerings provided convenient access to adult content, sports events, and movies.
Many hotels have upgraded to smart TVs, allowing access to top streaming services and enjoy entertainment on their own devices, given also the availability of internet, especially Wi-Fi. To respond to this demand, hotels now provide casting solutions or in-room TVs with streaming services.

Nowadays, hospitality TVs have become smart hubs for guest experiences, branding, and communications. They offer control over room functions like lighting, streaming content, and ordering room service. As guests are accustomed to advanced home technology, they expect similar or better tech-enabled experiences in hotels, necessitating a single point of control for their in-room technology needs.

This chapter covers several topics, including the project objectives and the various demos developed. It begins with the DVB-I System Architecture and the steps that led to the full implementation and study of DVB-I technology. Next, the chapter explores HbbTV® applications and the development of some of them. Finally, the main project, the DVB-DASH Generator, is discussed in detail. The goal of this project is to enable mobile devices to access DVB-DASH services generated by the 3DG Box, a device developed by Fracarro Radioindustrie SRL.

4.1 Project objective

The objective of this thesis, carried out during the university internship at the Fracarro Radioindustrie S.R.L company, is to develop demonstrations of DVB-I, showing the applications of this new technology within hotel infrastructures.
The primary goal is to bridge the gap between traditional television and modern mobile technologies. Incorporating this technology into hotel infrastructures should enhance the guest experience. Guests can stream TV shows straight from their cellphones, which will help the hotel industry expand its in-room entertainment offerings.

Today, to distribute signals received from satellite dishes and terrestrial antennas to multiple devices in a hotel (such as televisions or set-top boxes), the 3DG Box device is used. The primary function of the 3DG Box is to receive DVB-S and DVB-T signals, mux them (combine multiple signals into one), and distribute them via coaxial cable, using DVB-T technology, to the TVs within the structure supported by this device.
A new feature has been recently added, enabling further conversion of signals from the 3DG Box into DVB-DASH standard. This technology works with MPD manifests and M4S chunks, which are hosted on a web server. This allows any mobile device connected to the network, such as phones, PCs, and Smart TVs, to access multimedia content. This has significantly expanded the user base that can benefit from the service.
The objectives are:

1. **Device Compatibility**: By converting signals to DVB-DASH, multimedia content can

be accessed by a wide range of devices, including smartphones, tablets, laptops, and smart TVs. This means guests can enjoy content not just on the room TV but also on their devices.

2. **Adaptive Streaming**: DVB-DASH adjusts the quality of the video stream in real time based on the viewer's network conditions. This ensures a smooth viewing experience with minimal buffering, even on slower connections.

3. **Scalability**: The use of web server hosting for manifests and m4s chunks allows for efficient distribution of content to a large number of users simultaneously without significant strain on the network.

4. **User Experience**: With the ability to access content on multiple devices, guests have more flexibility and control over their viewing experience, enhancing overall satisfaction.

5. **Integration with Existing Infrastructure**: DVB-DASH can be seamlessly integrated with existing DVB-S and DVB-T infrastructures, allowing hotels to upgrade their services without extensive overhauls.

Nowadays, a content provider could implement a server that hosts multimedia files, which are compatible with the DVB-DASH standard. At the moment in Italy, Mediaset is the only provider in developing this option for a selection of its channels [Rio22].

For this reason, the goal of this project is for mobile devices to be able to receiveDVB-DASH services generated by 3DG Box, which contains channels from a list of personalized services, as well as those provided by external content providers who also use this new technology. The difference is that in this way users, with their mobile devices, will be able to receive channels generated even by providers that have not yet adapted to DVB-DASH, because 3DG Box converts each channel, from a customized list, into a DVB-DASH service. In fact, in hotel infrastructure, the list of channels is personalized, including those from foreign providers.

The incorporation of DVB-DASH in the 3DG Box not only enhances the current capabilities but also positions the system for further expansion. By integrating external content providers, the system broadens the range of available content, giving guests access to live television, on-demand movies, and specialty channels from various sources. This expansion significantly enriches the guest experience by offering a wider selection of high-quality multimedia content. Furthermore, by using DVB-DASH, the 3DG Box is prepared for the future and will be able to meet the increasing demand for flexible and adaptable content delivery. The 3DG Box's DVB-DASH functionality ensures that the hospitality entertainment system can adapt to the growing popularity of streaming and IP-based content distribution, keeping its strength and attractiveness despite technological advancements.

The development of the final project was achieved through three progressive phases, each contributing to a deepening of expertise and capabilities.
An understanding of the basic architecture and operation of internet-based broadcasting systems was made possible by the first phase, that we refer to as the DVB-I System Architecture. This stage made it easier to understand this new technology, which integrates internet protocols with traditional broadcast channels, creating a more flexible and reliable distribution system. Building on this foundation, the second phase "HbbTV® Application Streaming" implemented hybrid broadcast broadband television apps. This addition improved user experience and made interactive services possible.
The creation and delivery of adaptive streaming video via the 3DG Box device constituted the last phase of the DVB-DASH Generator. The creation of MPD manifests and M4S chunks was made possible by the use of a transcoding card, guaranteeing high-quality streaming.

With each step, the project moved closer to becoming a complete media distribution system while simultaneously gaining specialized technological skills.

4.2 DVB-I System Architecture

An extensive analysis of the DVB-I standards and the data on the official DVB Project website was conducted during the initial phase of the project. Next, we proceeded to the examination and application of the official open-source code associated with this new technology initiative. In reality, the code for creating a DVB-I Client and DVB-I CSR has been made available on Github by Sofia Digital [Dig23][Dig24], a Finnish company officially commissioned by DVB

Project for the realization of these parts. We have developed a comprehensive demonstration of the architecture of this new technology, which can be readily adjusted and changed based on requirements, thanks to the indications and information discovered.

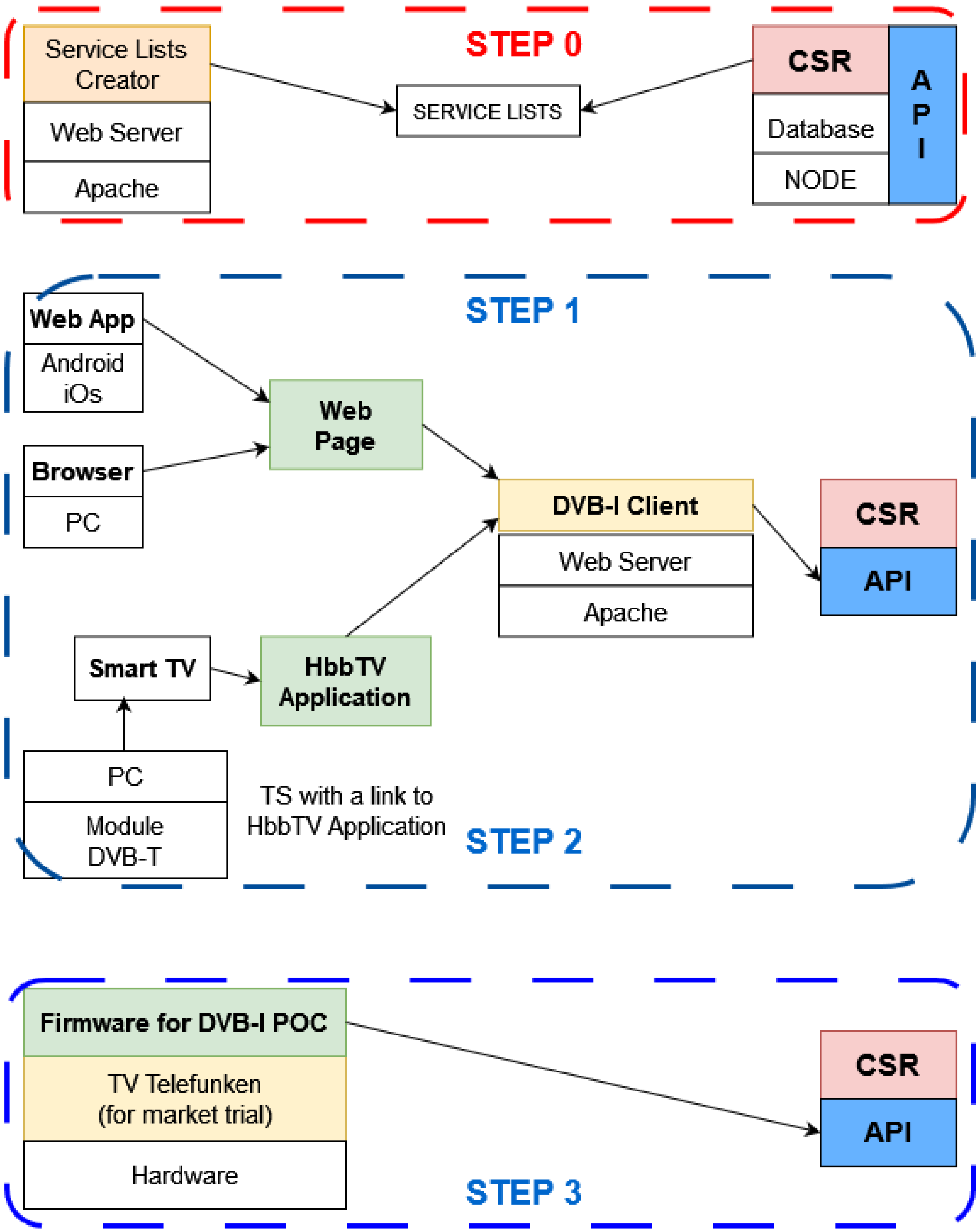

Figure 4.1: DVB-I Demo Steps.

After comprehending the functions and roles of each component of this architecture, we tested this technology across a range of devices, including PCs, smartphones, and smart TVs.
Figure 4.1 represents the DVB-I System Architecture, implemented to simulate the characteristics of the new standard DVB-I. As we can easily see, the implementation of this architecture is divided into 4 steps for gradual construction.
The main steps are:

- STEP 0: Implementation of DVB-I CSR and filing of service lists, generated by the Service Lists Creator;

- STEP 1: Implementation of DVB-I Client as a Web page, both for web apps on mobile devices and for PC browsers;

- STEP 2: Implementation of DVB-I Client as HbbTV® Application for TV Smart;

- STEP 3: Testing the architecture with a prototype TV (developed by Telefunken, for Mediaset Market Trial) with a software upgrade for the DVB-I compatibility.

This system architecture is centralized around the red block, CSR, which is responsible for storing various service providers and their respective service lists detailing the providers' offerings. To tailor service lists to our specific characteristics and technologies, we use a Service List Creator (the orange block).

The blue block is crucial for bidirectional communication between the CSR and the DVB-I Clients, who request the service lists.
Two other main components are represented by the yellow blocks, which denote the clients interfacing with services via this new standard. These clients can use the prototype Telefunken TV or the DVB-I Client interface compatible with various devices. The associated green blocks illustrate how services are accessed through the APIs of the DVB-I CSR: mobile devices and PCs via a web page, smart TVs via an HbbTV® Application, and Telefunken TVs through a firmware update that integrates DVB-I features.

Step 0

A database containing a list of providers and a connection to the related service listings was first created (in the local network). The description (name, country, language, genre, mode of delivery, and list of regulators) can be customized for each provider. Specifically, the tag URI is the URL that points to the service list's XML file that is stored in the Service List Creator, a web server implemented with Apache, as illustrated in Fig.4.2.

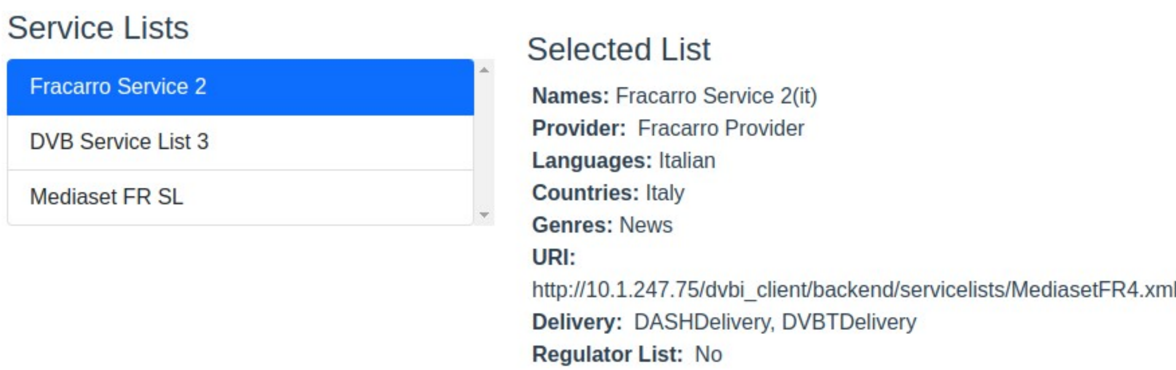

Figure 4.2: Central Service Registry.

The second part of this step was the implementation of the Service List Creator. It is a web server that supports PHP and it has a folder containing several XML files that represent the various service lists. However, the fact that customized service lists can be created makes this section crucial.

Each service list includes a list of streaming services with relevant features and characteristics, separated according to the different broadcast formats (DVB-T, DVB-S, and DVB-DASH). Therefore, it is possible to define the name, version, referent provider, and LCN for each service.

The important point is that a single service might have multiple service instances, and each of them explains the type and characteristics of streaming.

To illustrate which service type the device needs to select, the same service, "RTL 102.5," is described in two service instances (DVB-DASH service in Fig.4.3, and DVB-T service in Fig.4.4), each with a different priority number. For this reason, the priority 2 service instance only takes over when the prerequisites for priority 1 are not met, such as an unreliable internet connection. On the other hand, if there is interference on the receiving antenna, the priorities can be switched. These are a few of the DVB-I standard's latest benefits.

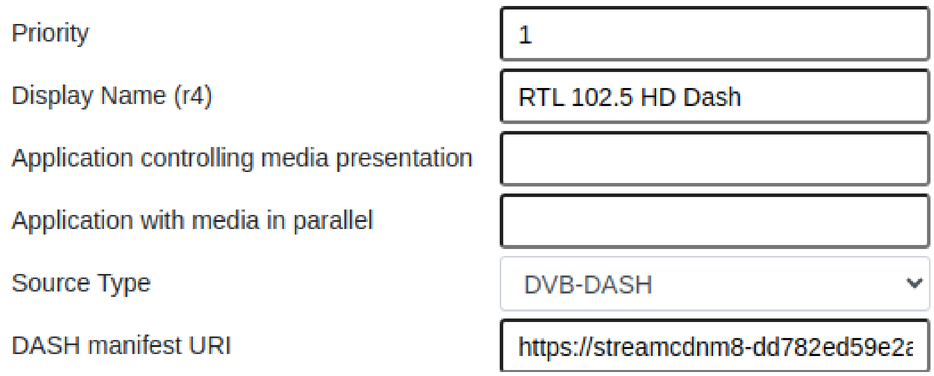

Figure 4.3: DVB-DASH service.

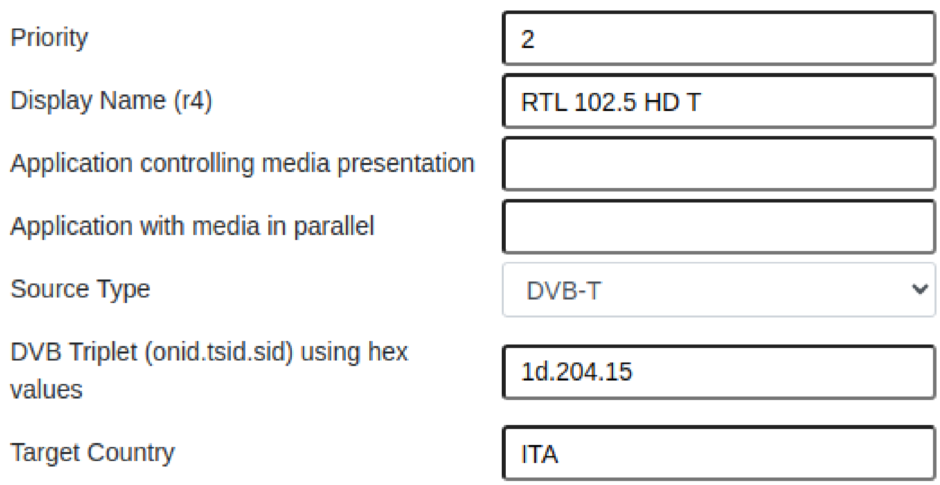

Figure 4.4: DVB-T service.

Step 1

Let's examine the frame Step 1 and Step2, with the yellow and two green blocks, in the middle of Figure 4.1. This part refers to a generic device's DVB-I Client. The frontend source code for the DVB-I Reference Client is available on GitHub. It comprises a common repository containing the necessary files to build the framework used in both the web page and HbbTV® application implementations.

The web page version, designed for PCs and mobile devices, is implemented using a Progressive Web Application (PWA) built with HTML and JavaScript, as illustrated in Fig.4.5. This version is hosted on a web server and is compatible with web apps and browsers. The related code is then modified to point to the DVB-I CSR with the customized list of providers to ensure proper implementation.

Figure 4.5: Example of Android application.

The user interface that allows a user to watch streaming services is shown in Fig.4.5. The list of available channels is located in the right portion of the screen, while the name of the currently playing channel and a menu with various options are located in the left bottom half. ”Settings” holds greater significance as it allows for the selection of alternative service lists with different services and the obtaining of streaming data, including latency, as illustrated in Fig.4.6.

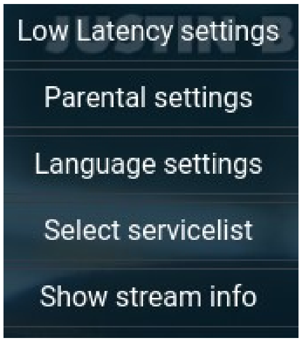

Figure 4.6: Main setting functions.

The interface visualization is identical for browsers and Web Apps. As of right now, the only available software is a PWA, which may be appropriately customized with an icon for the device using the ”Add to Home screen” option.

Step 2

Figure 4.7: Example of HbbTV application.

Figure 4.7 shows the second possible implementation: a HbbTV® Application for Smart TV. For launching the HbbTV® Application, the AIT of the transport stream is modified by inserting a link to the web server of the application. Then an antenna cable is connected to the television, so through it, the transport stream is sent. Specifically, the signal is generated by another PC, having a special Ultra high frequency (UHF) card for generating this type of signal. In this way, it’s possible to send a previously modified, via the software TS Duck (sec. 1.1.4), transport stream, contained in a flash drive.

A standard Smart TV can be used to evaluate signal reception, but a HbbTV® Emulator on PC is the best option as it allows you to see the different jQuery calls made to the CSR. The streaming visualization is different from the Web Page implementation of the previous stage because it enables interaction between the application's buttons and the remote control. Likewise in this instance, displaying the configuration functions is accessible by clicking the yellow button.

Step 3

The Telefunken TV TE32553B45V2DZ/E is a member of the TV series that Telefunken produced in conjunction with Mediaset's Market Trial to experimentally integrate the new DVB-I technology. Thanks to a firmware update, these TVs contain a link pointer to a Mediaset service list that has been predefined.
The television is connected to both a terrestrial and satellite antenna, from which it receives a list of services that can be integrated with other Internet-based services. With the firmware update for a certain range of services, there will be more options to broadcast the signal. In this way, if a given form of transmission is unable to maintain adequate requirements, other types of transmission take over.

The CSR pointer can be changed, though, such that it points either directly to the user'sCSR or to a customized service list. The first possibility differs from the last one, in that it offers the option to select from a variety of suppliers, as the Fig.4.8 illustrates.

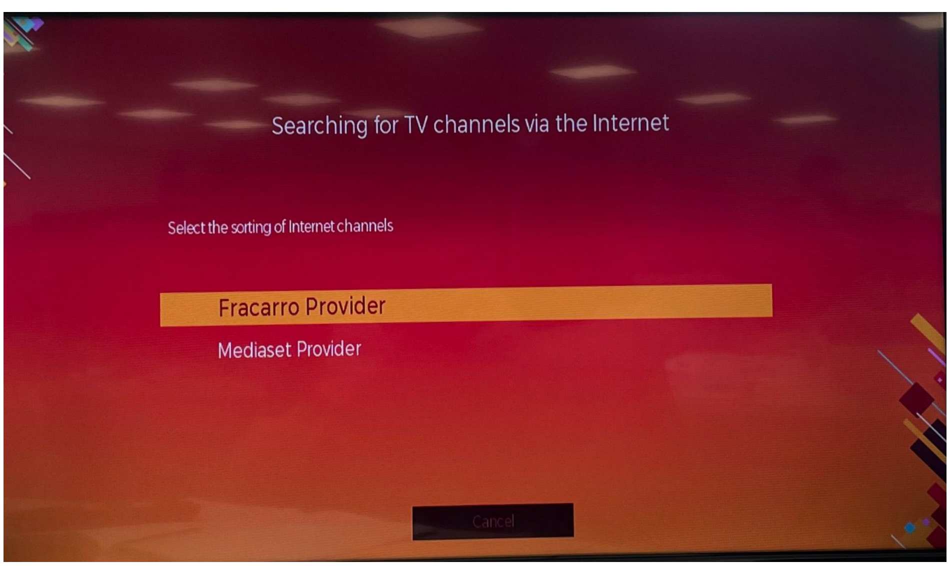

Figure 4.8: List of available providers.

Upon selecting the provider, the TV displays the remaining streaming services listed in the corresponding service list. It displays the number of services that are delivered over the internet utilizing the common DVB-DASH protocol, as shown in Fig.4.9.

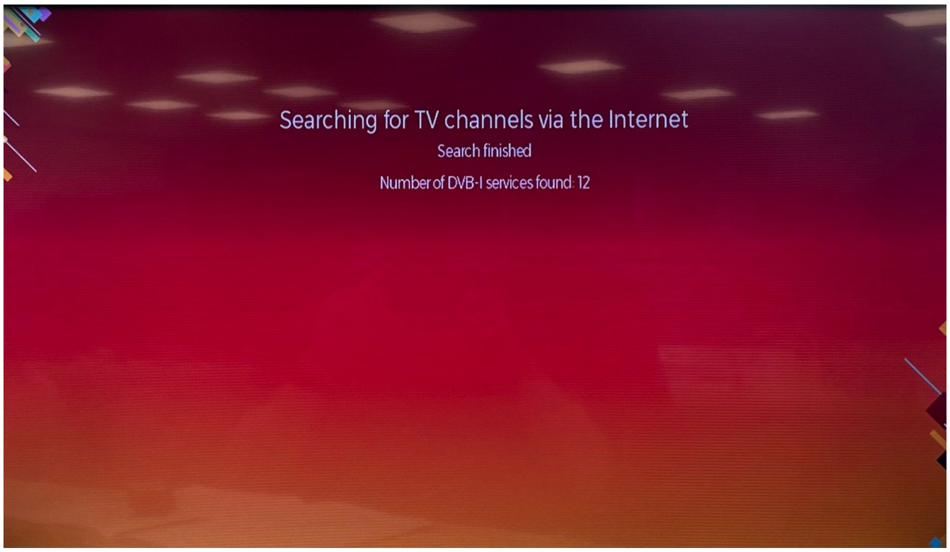

Figure 4.9: Number of available channels through DVB-I.

These procedures have made it possible to learn how to apply the new DVB-I standard while emphasizing the functions of its core parts. Through this example, it has been possible to show how essential DVB-DASH may be to a hotel's infrastructure, which is already equipped with other technologies.

4.3 HbbTV Application Streaming

Television has evolved beyond being a linear medium, thanks to the advent of HbbTV®. This technology has revitalized television, merging the interactivity of the internet with the experience of watching TV. The development of DVB-I further demonstrates the growing importance of HbbTV®, confirming its role in the future of television.

HbbTV® applications leverage the internet to deliver high-resolution images, text, and various interactive features. Viewers can easily access program guides, participate in quizzes, read lyrics, and obtain additional information with just a push of a button on their remote controls.

These applications can seamlessly integrate with or operate independently from broadcast content, providing flexibility for advertisers to target their audiences either in conjunction with specific programs or separately.

In 2020, the HbbTV® Association introduced the Targeted Advertising Specification (HbbTV-TA), enabling new advertising models and more precise targeting methods. Advertisements within the HbbTV® standard are crafted using web technologies such as HTML, CSS, Media Source Extensions (MSE), Encrypted Media Extensions (EME), and Timed Text Markup Language (TTML). These ad applications have their URLs, typically hosted on cloud servers.

The application URLs are transmitted via an AIT in the broadcast signal, as illustrated in Fig.4.10. The TV reads this signal, connects to the servers, and accesses the application URLs, ensuring seamless interaction and integration with broadcast content.

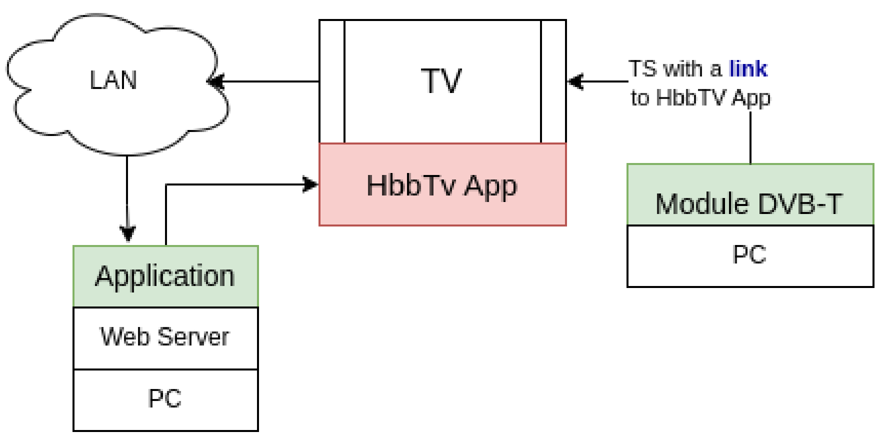

Figure 4.10: Signalling HbbTV App.

A similar mechanism was observed in the transport stream released by the DVB Project, which contains the HbbTV® application necessary for the proper functioning of DVB-I technology in smart TVs. By analyzing the test stream using TS Duck software, the pointing link in the AIT tables for the DVB Project's application was identified.
As the next step, this link was modified to direct to a customized application stored in the company's web server. The aim was to maintain the application's functionality while altering the advertisements and graphics. This approach enables the original transport stream to be customized, tailoring it to specific hotel infrastructures.

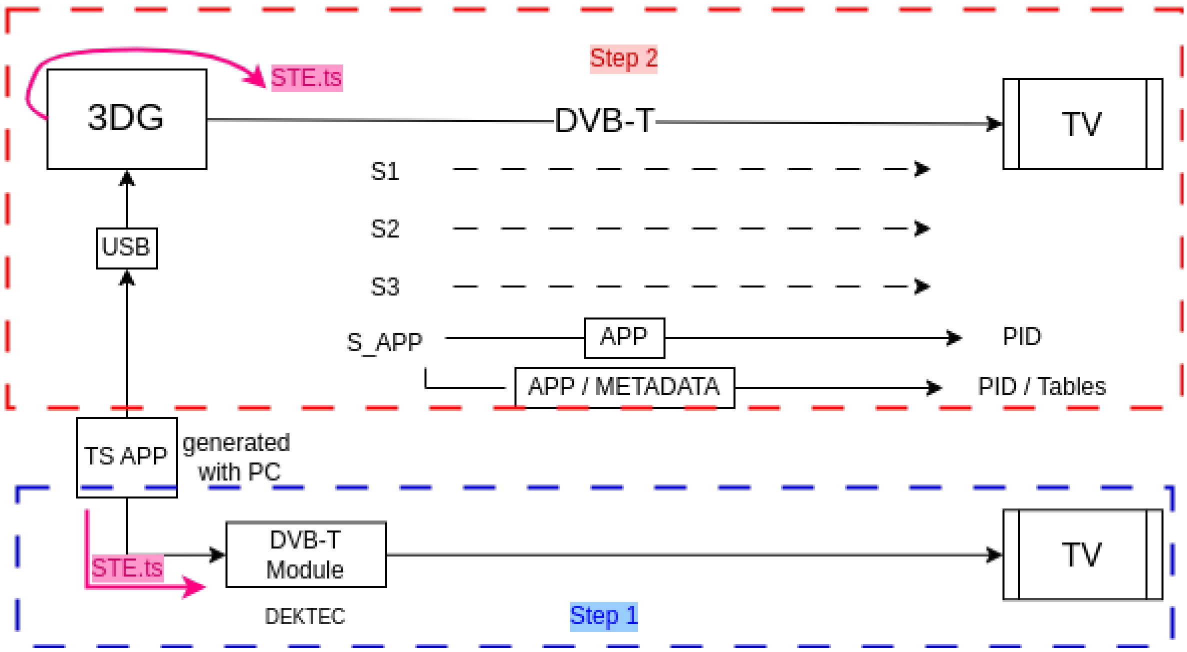

Figure 4.11: Complete Implementation Architecture.

Figure 4.11 illustrates the steps and components involved in creating and using an HbbTV® application.

First, a PC equipped with a cable TV Octa Tuner Card (TBS-6209) was used to modify the transport stream. This setup allowed the modified stream to be sent directly to the TV's antenna receiver via the tuner card.

A key advantage of this approach was the convenience of modifying the HbbTV® app directly on the same device, using appropriate development environments. The transport stream (STE.ts, represented in fuchsia in the figure) was then adjusted to point to the application hosted on a web server. This multimedia content was subsequently transmitted to the TV via a coaxial cable.

For correct reception, the TV was synchronized to receive a single stream from the external source according to DVB-C technology.

In the second phase, the 3DG Box device was utilized. This device receives services from multiple sources, processes them, and then transmits them via DVB-C technology. Normally, the 3DG Box receives channels from DVB-T and DVB-S. Using its user interface, a customized list of channels is selected and transmitted through the coaxial output to one or more televisions within the hotel infrastructure. Additionally, the device allows for the insertion of multimedia content via USB.

To integrate the HbbTV® application, the transport stream containing the pointer to the HbbTV® app was added to a flash drive and inserted into the 3DG Box device. This enabled the integration of multimedia content into the customized list of outgoing services, ensuring all connected TVs could receive and play the application.

This setup allows for the addition of theHbbTV® application to every service available from the device, as the incoming channels are modified before transmission. Consequently, hotel infrastructure can fully customize all television services, enhancing the viewing experience for guests. This customization not only improves television viewing but also allows for the inclusion of hotel services, such as in-room ordering or displaying the program of available activities, creating a more interactive and engaging experience for guests.

DSM-CC Object Carousel

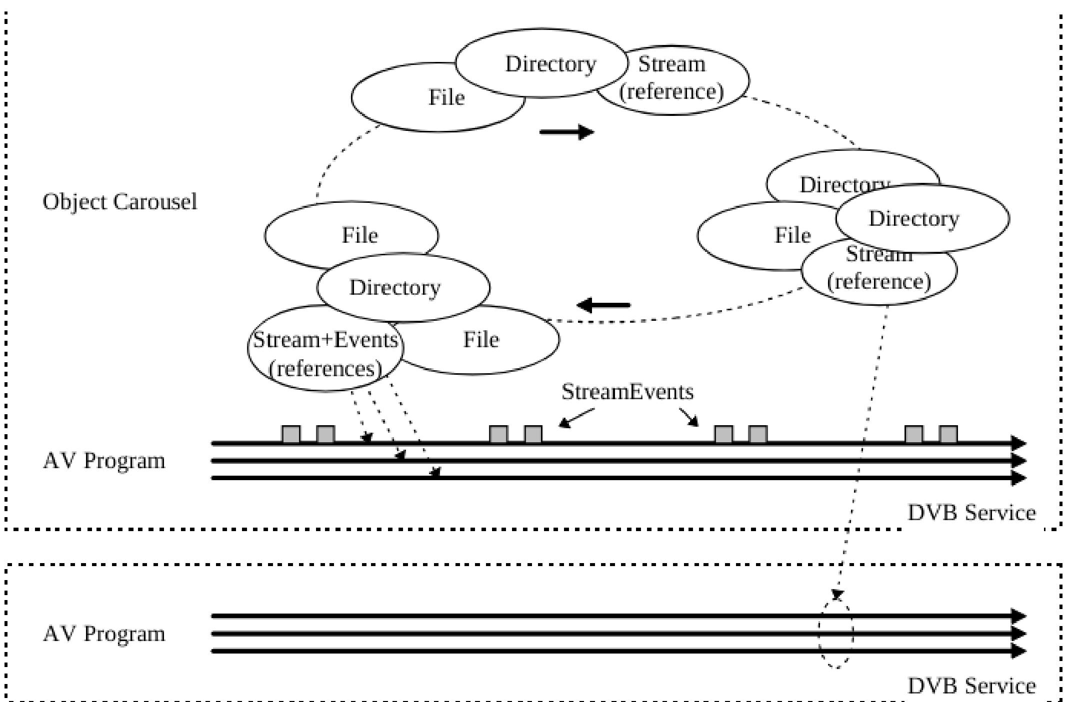

Figure 4.12: Example of including object carousel specification in DVB Services.

The functioning of HbbTV® apps within TVs relies on the television software to load the application files. These devices receive the transport stream containing the application's link in the AIT table and require a network connection to download the necessary files for running the application. However, this network integration is still being implemented in many hotel infrastructures, posing a challenge.
To address this issue, an older yet effective technology can be employed. This technology allows TVs to operate without relying solely on a network connection for downloading application files, ensuring seamless operation of HbbTV® apps even in environments where network integration is incomplete.

DSM-CC object carousels are used to transmit a structured group of objects, such as directories, files, and streams, from a server to clients, as illustrated in Fig.4.12. The server continuously inserts these objects into the transport stream using the object carousel protocol. Directory and file objects contain actual content, while stream objects reference other broadcast streams and may include DSM-CC event information that can trigger DSM-CC applications. This structured transmission ensures that all necessary components are delivered to the clients efficiently.
The object carousel is an integral part of a DVB service, facilitating the organization and delivery of broadcast content and events. This system ensures efficient and structured transmission of multimedia content and associated data within a DVB service. By leveraging the object carousel protocol, continuous and organized content delivery is achieved, enhancing the overall efficiency and effectiveness of the broadcast service.
DSM-CC sections use a specific format with a maximum length of 4096 bytes. Each section includes 12 bytes of overhead, allowing 4084 bytes for the actual payload. Up to four sections can be included in a singleTS packet. This efficient use of the transport stream packets ensures that the sections are transmitted without unnecessary fragmentation, facilitating smooth data delivery.
When packing DSM-CC sections containing **mpe!** datagrams, each new section starts in the same TS packet as the previous one if space allows. By default, the last TS packet of a DSM-CC section is padded (stuffed), and the next section begins in the subsequentTS packet

of the same PID. This method optimizes the use of available space within TS packets and maintains a continuous flow of data.

Another phase in the development of the HbbTV® app involved the study and implementation of a DSM-CC Object Carousel. This was necessary due to the lack of network connectivity in some hotel TVs. This effort resulted in the creation of a script that ensures seamless operation of the DSM-CC Object Carousel with the previously developed HbbTV® application.
This script automates the creation of a DSM-CC carousel from a directory of files, performing data compression, generating DSM-CC modules, converting them to sections, and assembling these sections into a transport stream for HbbTV® broadcasting.

The process begins with reading the contents of the provided directory and converting each file into a structured DSM-CC module, complete with the appropriate metadata. These modules are temporarily stored, then compressed and converted into sections to prepare them for inclusion in a transport stream. The resulting transport stream is suitable for HbbTV® broadcasting, organizing various types of content (video, audio, data) within a program and ensuring they can be accessed by a receiver.

```
PMT, TID 2 (0x02), PID 1031 (0x0407)
Version: 1, sections: 1, total size: 78 bytes
- Section 0:
  Program: 1 (0x0001), PCR PID: 2064 (0x0810)
  Elementary stream: type 0x02 (MPEG-2 Video), PID: 2064 (0x0810)
  Elementary stream: type 0x03 (MPEG-1 Audio), PID: 2068 (0x0814)
  Elementary stream: type 0x05 (MPEG-2 Private sections), PID: 2001 (0x07D1)
  - Descriptor 0: Application Signalling (0x6F, 111), 3 bytes
    Application type: 16 (0x0010), AIT Version: 1 (0x01)
  Elementary stream: type 0x0C (DSM-CC Stream Descriptors), PID: 2002 (0x07D2)
  - Descriptor 0: Stream Identifier (0x52, 82), 1 bytes
    Component tag: 13 (0x0D)
  Elementary stream: type 0x0B (DSM-CC U-N), PID: 2003 (0x07D3)
  - Descriptor 0: DSM-CC Association Tag (0x14, 20), 13 bytes
    Association tag: 0x000B (11), use: 0x0000 (0)
    Private data (8 bytes): 80 00 00 00 FF FF FF FF
  - Descriptor 1: Stream Identifier (0x52, 82), 1 bytes
    Component tag: 11 (0x0B)
  - Descriptor 2: DSM-CC Carousel Identifier (0x13, 19), 5 bytes
    Carousel id: 0x00000001 (1)
    Private data (1 bytes): 00
  - Descriptor 3: Data Broadcast Id (0x66, 102), 2 bytes
    Data broadcast id: 0x0123 (291, HbbTV Carousel)
```

Figure 4.13: Example Analysis of a Transport Stream Containing aDSM-CC Object Carousel.

Figure 4.13 represents the analysis of a TS, where the content is organized into various types such as video, audio, and data, with specific identifiers and descriptors managing their access and synchronization. The PMT lists all streams associated with a program and their PIDs, while the PCR PID provides synchronization timing for these streams. Each data stream is identified by a unique PID and categorized by its elementary stream type (e.g., video or audio), while descriptors add metadata, such as stream identification and application signaling. In this analysis, key descriptors include the Application Signalling Descriptor (0x6F) for application-related information, the Stream Identifier Descriptor (0x52) for component identification, the DSM-CC Association Tag Descriptor (0x14) for associating streams with services, the DSM-CC Carousel Identifier Descriptor (0x13) for carousel data mechanisms and the Data Broadcast Id Descriptor (0x66) indicating HbbTV® Carousel data broadcasts.

This study and implementation of HbbTV® have highlighted its critical role in modern television, particularly within related environments. Our tests demonstrated how various applications function under different conditions while consistently meeting their goals. The technology's application, even in emerging standards likeDVB-I, underscores its potential to unify and enhance the television viewing experience.

4.4 DVB-DASH Generator

DVB-DASH is the first international standardization initiative in the field of HTTP adaptive streaming. Similar to its vendor equivalents, its objective is to enable end users to take advantage of video streaming services at the best possible quality, given the limitations of the end device and the network.

To this end, DVB-DASH provides a collection of protocols for segmenting, encoding, and storing video content in several media representations on legacy HTTP servers, all accompanied by a MPD file.

Client applications periodically estimate the available bandwidth and the capacity of the playout buffer. Based on the information requested in the manifest file, they request segments that best fit their needs.

The goal of this project was to research and implement these new technologies by combining all of the knowledge and skills that were acquired in the previous months.
The purpose is to enable mobile devices to access DVB-DASH services produced by 3DG Box device. These services will comprise channels selected from a list of customized services. In addition to those offered by outside content providers who will also be utilizing this new technology. The distinction is that, because 3DG Box transforms each channel from a customized list into a DVB-DASH service, customers will be able to access channels created even by providers who have not yet transitioned to DVB-DASH through their mobile devices. Therefore, we tried to implement this new feature that would allow us to access television services on mobile devices and integrate them with already-existing infrastructures like DVB-S and DVB-T, by using the 3DG Box device.
In fact, compatibility and integration are this project's main objectives. For this reason, when developing the system architecture, we considered the elements of the hotel infrastructure that were already in place in addition to the inclusion of mobile devices.

System Architecture

Figure 4.14 illustrates all the key components of a typical system architecture. It highlights the three primary sources of television transmissions: DVB-S, DVB-T, and from IP networks. The latter leverages the recently introduced DVB-I standard, which integrates service lists connected to DVB-DASH services from external providers.
At the center of the figure is the 3DG Box device, realized by Fracarro Radioindustrie S.R.L., now equipped with the innovative "DVB-DASH Generator" capability. This central component plays a pivotal role by performing two essential functions.
Firstly, it employs the traditional DVB-C technology to transmit television signals. Using the DVB-C, the 3DG Box enables the distribution of a customized service list to the in-room televisions within a hotel infrastructure, ensuring guests have access to a tailored selection of channels.
Secondly, it extends the reach of these personalized television services to mobile devices. By utilizing DVB-DASH for multimedia content transmission and DVB-I for service discovery,

the system allows the same curated content to be accessed on mobile devices, ensuring a seamless viewing experience across different platforms.

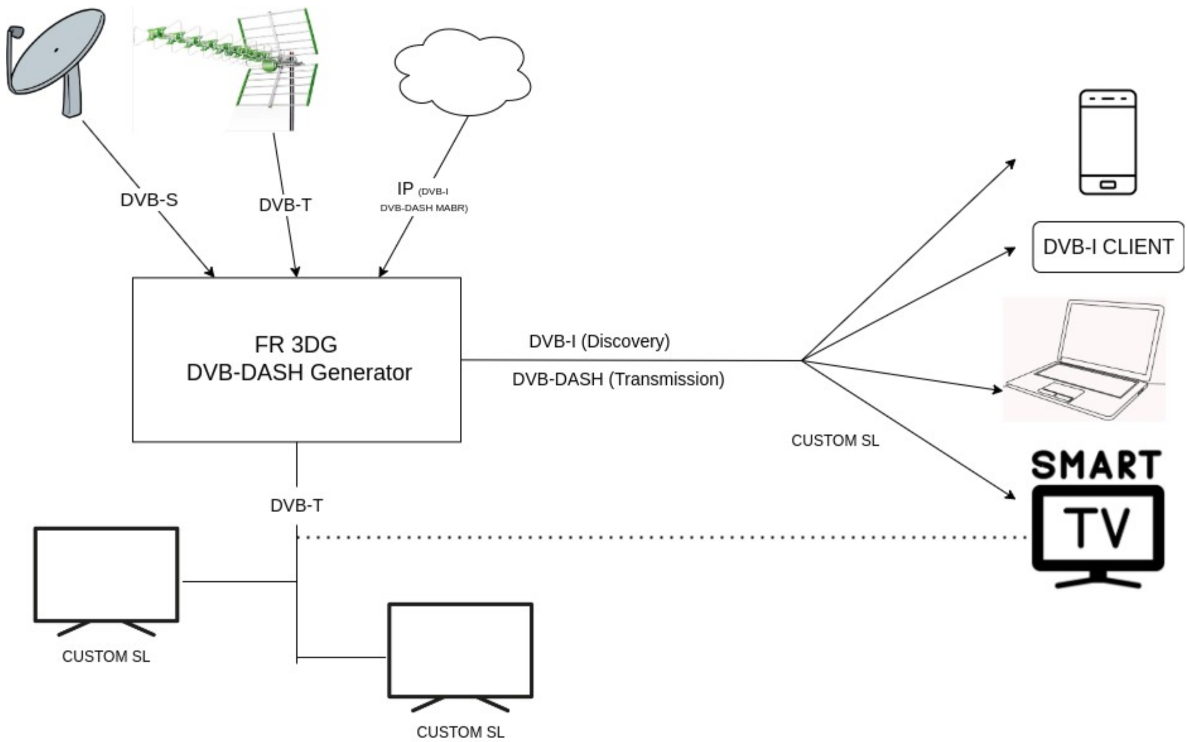

Figure 4.14: System architecture with all the related components.

Figure 4.15 introduces an important addition to the system architecture: the integration of the Mediaset Pilot on DVB-I. Until now, the system has primarily relied on traditional methods of receiving television services through antennas and satellite dishes. However, these methods have a significant limitation: if the conditions for signal reception are poor or disrupted, the entire local architecture could fail, resulting in a complete loss of service.

To address this vulnerability, the figure also outlines a section dedicated to external content providers. This section is crucial for ensuring service continuity, particularly in scenarios where traditional reception methods are compromised. By incorporating external content providers into the network, the system can maintain uninterrupted transmission of television services over the Internet.

The personalized service lists generated for mobile devices will not only include pointers to locally generated channels but will also feature links to the web server addresses of these external content providers. These providers deliver television services using theDVB-DASH standard, which is fully compatible with the system's mobile streaming capabilities.

This approach fosters a collaborative network that bridges emerging technologies, such as DVB-I and DVB-DASH, with the existing project framework outlined in this thesis. By doing so, the system enhances its resilience and flexibility, ensuring that users can access a consistent and high-quality television experience, whether through traditional reception methods or via network-based content delivery. This integration represents a significant step forward in the evolution of television broadcasting, aligning with the growing trend toward internet-based content distribution.

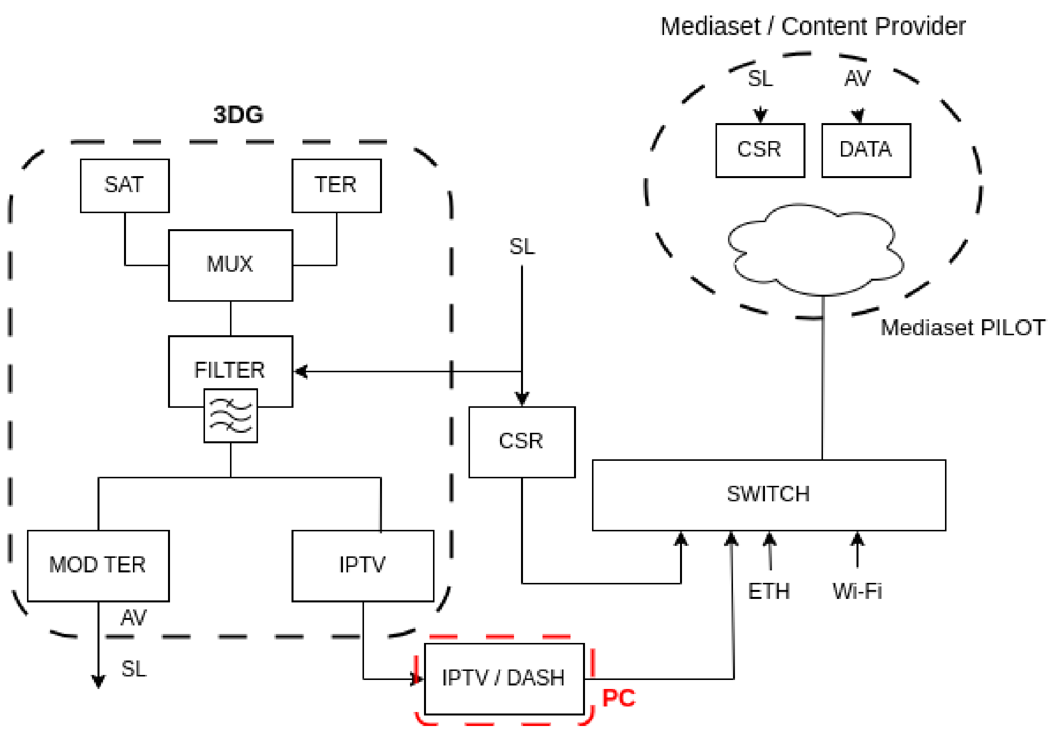

Figure 4.15: 3DG features and elements.

Figure 4.15 provides a detailed view of the central component from the previous figure (4.14): the "FR 3DG DVB-DASH Generator". This section consists of multiple specialized elements, each with distinct functions critical to the overall operation of the system.

The 3DG Box begins by receiving television signals viaDVB-T and DVB-S. These signals undergo transcoding, a process that converts the incoming signals into an MPEG-2 TS, allowing them to be combined (muxed) into a unified stream. This stream is then filtered through a personalized service list, ensuring that only the selected channels are transmitted. The final output is sent through a terrestrial module, which broadcasts these tailored services to the televisions within the hotel infrastructure.

One of the notable features of the 3DG Box device is its ability to transcode television services into individual MPEG-2 TS. These streams are encapsulated in UDP packets, each containing seven TS, and directed to specific addresses. In the figure, it is represented as the arrow named ”IPTV”.

However, the multimedia content of the UDP address is not compatible with mobile devices connected to the network. To address this, the system extracts the MPEG-2 TS packets and transcodes them into the more modern DVB-DASH format. This task is performed by an external PC connected to the 3DG Box, through the central unit module, as illustrated in Fig.4.15. The PC queries the module to obtain the M3U playlist, which contains the addresses of the converted channels. It then retrieves the multimedia streams and begins the conversion process, transforming the packets into DVB-DASH format. This involves creating the MPD files and generating the M4S chunks, which are necessary for DASH streaming.

Given the high number of channels and the need for simultaneous conversions, the system employs a specialized video transcoding card, the AMD Alveo MA35D Media Accelerator[1], as shown in Fig.4.16. This hardware is specifically designed to handle the intensive processing required for efficient video transcoding.

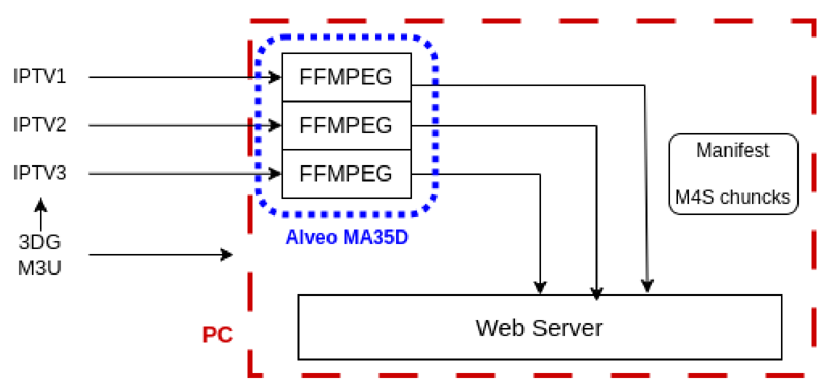

Figure 4.16: Detail of PC functions.

[1] https://www.amd.com/en/products/accelerators/alveo/ma35d.html

Once the conversion is complete, the generated elements, including the MPD files and M4S chunks, are uploaded to a web server. These resources are then made accessible via a user interface, allowing users to stream the content seamlessly.
To manage storage efficiently, the system utilizes a circular buffer of defined size, ensuring that storage capacity is optimized without compromising the availability of recent content.

The outcome successfully met the anticipated objectives, as it was possible to stream television content on various mobile devices, including smartphones, tablets, and PCs, which were used for testing purposes. In a controlled testing environment, the television service was streamed concurrently on both a television connected to the 3DG Box and on multiple mobile devices. This demonstrated the system's capability to deliver content seamlessly across different platforms.
Furthermore, the testing process showed several key functionalities, such as the ability to switch between different channel lists without causing any interruptions or discontinuities in the streaming service.
The primary objective of the project, which was to integrate the functionality of converting traditional television content into DVB-DASH format for mobile devices through the 3DG Box, was successfully achieved.
Moving forward, the next phase of development will focus on refining the user interface to ensure an intuitive experience. Additionally, further testing will be conducted in a more complex and realistic setting, such as a hotel infrastructure, where the technology can be evaluated under conditions that simulate high user density. The purpose of these tests will be to assess the system's performance when accessed by multiple users simultaneously, identify any potential issues, and implement strategies to ensure consistent and high-quality service delivery to all users, regardless of the load on the system.

In conclusion, this project aims to enable mobile devices to seamlessly access DVB-DASH services produced by the 3DG Box device. This technology offers a selection of channels from a customized list and content from external providers adopting DVB-DASH. The innovative aspect lies in the 3DG Box's ability to convert any channel into a DVB-DASH service, allowing users to access content from providers who have yet to adopt this technology.

By doing so, we aim to facilitate access to television services on mobile devices, while ensuring smooth integration with existing infrastructure, such as DVB-S and DVB-T. The focus on compatibility and integration has been central throughout the system's development, as we considered the existing hotel infrastructure and the incorporation of mobile devices to create a user-friendly and efficient solution.

CHAPTER

5 Conclusion and Future Works

This thesis has provided a comprehensive study on the advancements and potential of the DVB-I standard, with a particular focus on its role as Service Discovery between DVB-T, DVB-S, and modern broadcasting technologies, such as DVB-DASH, DVB-MABR and DVB-NIP. The research examined how DVB-I provides a scalable and adaptable platform, allowing users to access high-quality television services across different devices without requiring extensive infrastructure changes.

Furthermore, the thesis provided the implementation of a DVB-I Demo Architecture, designed to enable practical use of the technology and assess its key features and performance in a realistic scenario.

Lastly, the work detailed the improvements made to the 3DG Box by implementing DVB-DASH Generator, enabling efficient streaming of content to mobile devices over IP networks.

5.1 DVB-I

The research demonstrated that DVB-I offers a flexible and scalable platform, enabling users to access high-quality television services across a wide range of devices, including smartphones, tablets, and smart TVs. Moreover, it allows broadcasters to reach a broader audience without significantly modifying existing infrastructure.

By utilizing DVB-DASH, traditional broadcast services can be delivered over the internet, facilitating a seamless and unified experience across both broadband and broadcast networks. This study highlighted key aspects of the DVB-I standard, including its architectural implementation, the role of Service Lists, the functionality of Service Discovery, and the integration of DVB-I with DVB-DASH, along with existing DVB standards such as DVB-S, DVB-T, and DVB-C. These elements collectively showcase the potential of DVB-I to harmonize traditional and IP-based broadcasting.

The recent DVB-I deployments, primarily led by Mediaset in Italy and through the collaboration of German broadcasters in Germany, represent a significant drive for developing and implementing this new technology. These initiatives are driving progress and contributing to the realization of DVB-I's potential, positioning it as a key innovation in the future of broadcasting.

5.2 DVB-DASH Generator

The use of the DVB-DASH Generator was the primary goal of my project, which was completed when I was an intern at Fracarro Radioindustrie SRL.

With the addition of DVB-DASH technology, the 3DG Box has seen a notable improvement as DVB signals may now be transformed into a format that is appropriate for adaptive streaming over IP networks. With this update, multimedia content can now be sent to a variety of mobile devices, including smartphones, PCs, and smart TVs, in addition to traditional televisions. The DASH standard makes use of MPD files and M4S chunks hosted on a web server to enable dynamic streaming of content that adjusts to the viewer's device and network conditions. The testing showed that the system can deliver television content across platforms without interruptions, even when switching between different channel lists.

With this development, the 3DG Box's capabilities have advanced significantly and are now in line with the growing need for mobile, flexible, on-demand video viewing that still makes use of the current infrastructure.

5.3 Future Works

Even though this study has shown the benefits and possibilities ofDVB-I, there are still several areas that need to be examined and upgraded.

Improving DVB-I service discovery procedures could be the main focus of future work to guarantee quicker and more precise service identification across various networks and devices, especially in heterogeneous situations. Research should be done to see how DVB-I can work with emerging standards and technologies like 5G, and edge computing to improve service delivery, reliability, and personalization. Future studies could investigate sophisticated adaptive streaming techniques and algorithms to optimize QoE for users, especially under variable network conditions.

With the transition to IP-based delivery, ensuring secure transmission and protection of content becomes even more critical. Future work could explore advanced security protocols to safeguard the fruition of IP-based services against potential threats.

By addressing these areas, DVB-I can continue to grow as a transformative technology in the broadcasting industry, creating a more accessible and immersive experience for users worldwide.

Looking ahead, several areas for future improvement have been identified for the DVB-DASH Generator. First, enhancing the 3DG Box's signal processing capabilities to support advanced formats such as Ultra HD (4K) and HDR could meet the rising demand for higher-quality content.

Cloud-based distribution solutions could be explored to further expand the service, allowing users to access content from any location with an internet connection.

By continuing to innovate, the 3DG Box can remain a leading solution for distributing multimedia content across a range of devices and platforms, adapting to the ever-changing landscape of media consumption.

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