Communication Networks

IPTV Measurement

User Guide

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TMiT

Content

1. Introduction

The purpose of this measurement is for students to become familiar with the network aspects of Internet Protocol Television technology (IPTV), with particular regard to multicast-based IP packet transmission and the network aspects of service quality guarantees. Those performing the measurement will learn about multicast IP transmission, the methods and protocols used to transmit IPTV video streams, and perform measurements to determine the main network parameters characterizing the service and the service quality.

This guide summarizes the necessary theoretical background. The manual must be read before measurement.

Arrangement of the measurement

Fig 1 shows the arrangement of the measurement used in the lab.

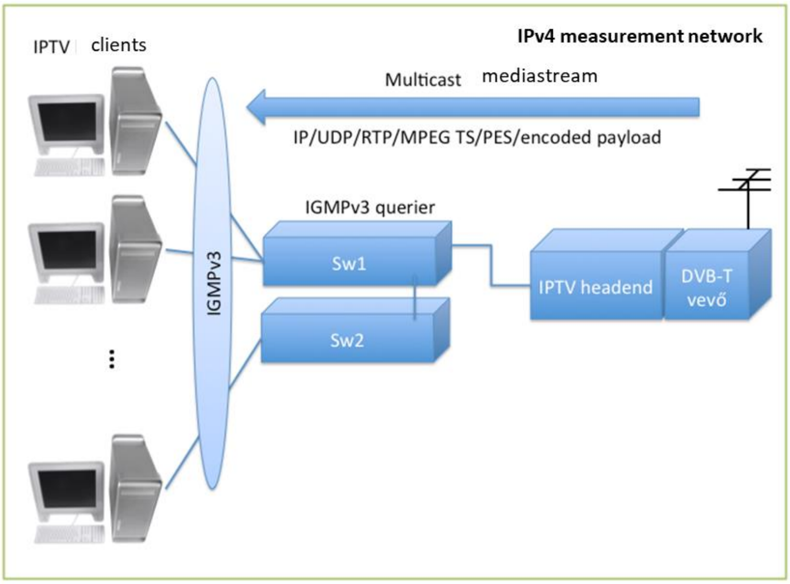

Fig.1. Arrangement of the measurement used in the lab

A DVB-T (Digital Video Broadcasting – Terrestrial) receiver receives the terrestrial digital TV broadcast in real time, which is processed by a Linux server (as an IPTV headend) and creates a real-time video stream from it, in accordance with the technological requirements of the IPTV service. This data stream is then sent to the lab PCs used by the students through Ethernet switches with multicast (IGMPv3) support.

For this version of this measurement, which can also be performed from home, we have adapted all of this in such a way that the questions must be answered on the basis of a short (approx. 10 minutes) pre-recorded slice of the network traffic reaching a lab PC.[1]

[1] Of course, this is not the same as watching live TV through Wireshark, instead you can measure it in your pajamas 😄

2. IPTV services

A brief summary of possible IPTV services:

- Live TV – transmission of live TV and radio broadcasts on an IP network
- Video on Demand – video library: TV shows, movies, series, etc.
- Digital Rights Management (DRM) – legal and technical protection of contents
- Electronic Program Guide (EPG) – electronic program magazine
- Teletext – flip-through electronic newspaper, the data of which is transmitted together with the TV broadcast
- Live broadcast recording (client side)
- Picture in picture (PiP) – The system displays a small picture of another channel's program on the screen of the TV program being watched, typically in a corner
- Time shifting: recording and delayed transmission and playback of a live program
- Multiple recordings + live broadcast at the same time. Internet access bandwidth may be limited.
- Programmed recording based on program magazine
- Running applications – viewing news, weather, exchange rates, sending messages, etc.

3. IP Multicast

Two types of distribution models are used widely for the transmission of media content over an IP network.

In the first model, everyone initiates the viewing of different content at the content provider based on their own needs. This is the so-called Video on Demand (VoD) system. Such service is provided e.g. by Youtube, Netflix, IPTV providers and airlines on board. In this case, the service provider must deliver specific content to the user individually at a given time. Accordingly, dedicated unicast media streams must be forwarded from the server to each client. The resource demand of unicast data transmission scales almost linearly, so the increase in the number of subscribers and active viewers must be followed by the resources available on the server and network side (CPU, memory, bandwidth). The biggest challenge in this distribution model is dealing with intermittent peak loads.

A good example of the second model is the case where a linear program of a TV channel needs to be delivered to subscribers on an IP basis. In this case, we have the opportunity to organize the active viewers of the given TV channel into logical groups and transmit a single data stream to the group, regardless of the number of group members. This model provides extremely good scalability, since the network's task is to deliver only one media stream to each group member. But this requires a special, so-called multicast IP routing. Multicast IP routing - which is completely independent of unicast routing - is built individually by some service providers in their own network in order to serve their subscribers more efficiently. A good example of this is the subject of this measurement, the IPTV service.

We have to mention that there is a third model. In this model, the content provider delivers the program to the viewers on a peer-to-peer (P2P) network. Previously, e.g. Spotify also used P2P technology to serve music content, and Netflix engineers were also involved in the development of a P2P supported streaming service.

Multicast IP címek

In the case of IPv4 protocol, the address range 224.0.0.0/4 is used for multicast message transmission. This is also called a class D address range, the addresses of it are in the range 224.0.0.0 to 239.255.255.255. In other words, the first four bits of a 32-bit IP address are always 1110. In this address range, unlike usual, an address identifies a *group* of nodes (more precisely, a group of network interfaces), this is the multicast group identifier.

As a matter of interest, we describe - you don't need to know this - how the address range is partitioned:

Address ranges	Name	Purpose
224.0.0.0-224.0.0.255	Local subnetwork	Typically protocol-specific addresses valid within a local network. The domain is managed by IANA [2] .
224.0.1.0-224.0.1.255	Internetwork control block	Protocol-specific traffic that can be transmitted on the public Internet. The domain is managed by IANA.
224.0.2.0-224.0.255.255 224.3.0.0-224.4.255.255 233.252.0.0-233.255.255.255	AD-HOC block	An IANA-managed domain reserved for applications that do not fit into the first two categories.
232.0.0.0/8	Source-specific multicast	Range used for source-specific multicast routing.
233.0.0.0/8	GLOP addressing	Public domain reserved for experimental purposes for content and internet service providers.
234.0.0.0/8	Unicast prefix based multicast addresses	Multicast addresses allocated to organizations with a unicast domain of size at least /24.
239.0.0.0/8	Administratively scoped multicast addresses	A domain reserved for private use within the organization. (Private multicast IP addresses)

During this measurement, a multicast address identifies a TV channel, i.e. the media stream produced from the channel's program is forwarded by the network to the members of the multicast group with the specified class D IP address.

Internet Group Management Protocol (IGMP)

Using the Internet Group Management Protocol (IGMP), IP endpoints and routers can manage multicast group memberships. *IGMP message exchange takes place between the endpoint and the nearest multicast router*. Messages are directly embedded in IPv4 packets. In terms of layer classification, IGMP – like ICMP – is part of the IP protocol stack, and operates in the network layer.

The most important innovation of the v2 protocol version was that it introduced an explicit indication of leaving the group (Leave Group message). In the current v3 version, support for source-specific multicast has also been added. You can read more about this in the description of the PIM protocol. IGMPv2 or IGMPv3 versions are typically used in IPTV systems. The advantage of IGMPv2/v3 compared to the previous version is that the Leave Group message allows the multicast router to stop the traffic sent to the address of the given group with low delay, if there are no active members left in a given network.

IGMPv2/v3 message types

- Membership Query - The multicast group membership of the nodes is queried by the multicast router connected to the network (IGMP querier). It has three subtypes: general query, group query, and group and source specific query.
- Membership Report / Join – Membership(s) report to the multicast router (IGMP querier). The node can subscribe to a multicast group with the same message.
- Leave Group – explicit indication of leaving the group.

To support source-specific multicast, we can specify restrictions (filters) on the address of the source node.

- Include mode: When joining the group, we can specify the address of the source nodes from which we accept the traffic forwarded to the given multicast group
  Attention! *By leaving the list of sources empty, we indicate that we are leaving the group*. (We are not interested in anyone's messages.)

[2] Internet Assigned Numbers Authority, https://www.iana.org/

- Exclude mode: When joining the group, we can specify the address of the source nodes from which we do not accept traffic forwarded to a given multicast group.
  Attention! By leaving the list of sources empty, we indicate that we are joining the group and are interested in everyone's messages.

Our endpoint sends the IGMP Leave and Join messages - framed in green in Fig 2. - to the local IGMP querier router when the *channel change* is initiated in the media player. As a result, our endpoint is transferred from one multicast group to another.

Hint: When analyzing the IGMP traffic, it must be taken into account that other programs and Windows services can generate IGMP messages on our machine besides VLC, so special attention must be paid to the identification of IGMP Leave and Join messages related to channel switching. When analyzing the IGMP traffic visible on the Ethernet interface, it may also appear that the network router queries the nodes' multicast group memberships at certain times (on the lab network, this is a 20-second period): A Membership Query message is received from the router, to which the endpoint responds with Membership Report messages. It is important not to confuse these responses with the Join messages generated when changing channels!

- The multicast router sends General Membership Query messages to the destination address 224.0.0.1. All multicast nodes must listen to this address.
- The endpoint sends Membership Report response messages and Join/Leave messages to the address 224.0.0.22.

Display filter in Wiresharkban

IGMP messages can be filtered with a display filter in Wireshark: ***igmp*** (Fig 2.)

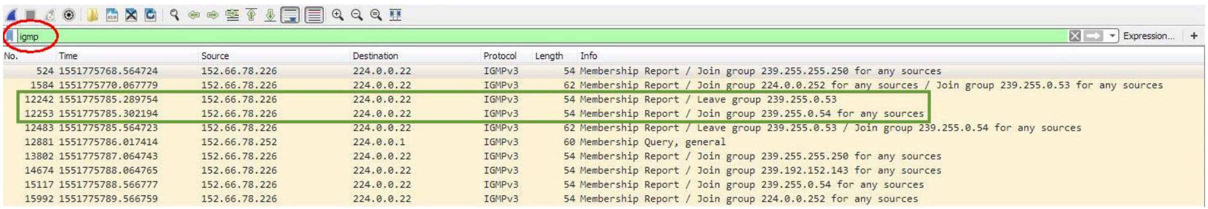

Fig. 2. Packet filtering in Wireshark

The display filter affects only what to display, not the contents of the saved file. If the expression matches it, it will be displayed, otherwise not.

A bit more about display filters:

- logical expressions: matching protocol fields with operators, e.g. ip.src, tcp.window_size
- operators: ==, eq, !=, contains, matches, !
  - E.g. ip.src==192.168.0.0/16, tcp.port eq 25
- sequence of expressions separated by logical switches: &&, ||, and, or,
  - E.g. http.request.uri matches "gl=se$"

More details: see Wireshark display filter reference: https://wiki.wireshark.org/DisplayFilters

IGMP Snooping

By default, Ethernet switches forward the frames sent to the multicast address to all their ports, similar to broadcast traffic (see Fig 3). This operation results in unnecessary bandwidth usage on ports to which no active member of the given multicast group is connected. The IGMP Snooping function of the switches can be understood as an optimization of IGMP layer 2, as a result of which the switch monitors the IGMP messages passing through it (Query, Memebership report/Join, Leave). Based on the information obtained in this way, it creates and maintains an internal IGMP table, in which it records which multicast group's traffic must be forwarded to which ports.

Important: The Ethernet switches in the lab network do not immediately remove the given multicast group/port assignment from the local IGMP table as a result of an IGMP Leave message. Accordingly, when changing channels, in addition to the multicast traffic of the new channel, the multicast traffic of the previous channel will also arrive at our network interface for a given period of time. In Wireshark, it is worth checking how long the traffic of both groups is present on our interface. This information should be kept in mind when examining the channel change time, since if you switch to a channel that you have already watched within this time, the second phase of the channel change (see chapter 4) takes zero time.

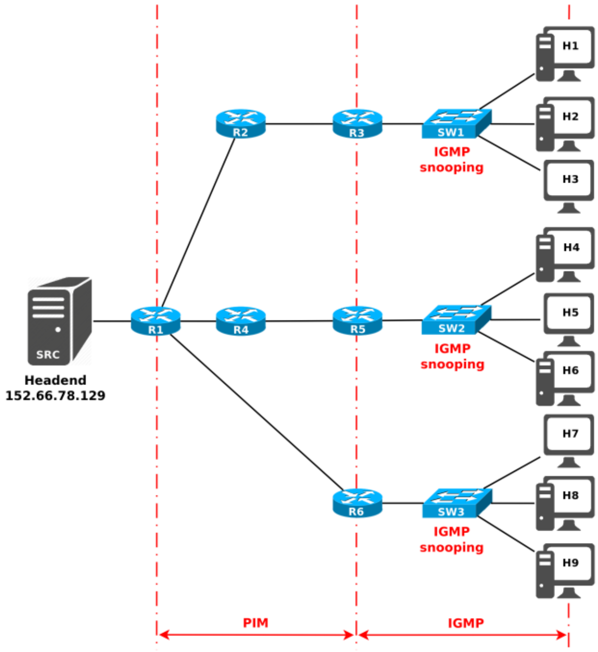

Fig. 3. ábra Multicast network example

Multicast routing - Protocol Independent Multicast (PIM)

PIM is not a single protocol, but a family of multicast routing protocols. *So while IGMP is for communication between the endpoint and the first router, PIM is a routing protocol and is therefore used for communication between routers.* Three versions of it have spread.

- PIM-SM (PIM Sparse Mode) – The multicast tree, the root of which is the so-called Rendezvous Point (RP) router, is built by the protocol based on explicit IGMP requests. The operating model is well suited to serving physically dispersed multicast receivers in a WAN (wide area) network environment.
- PIM-DM (PIM Dense Mode) – In the first step, the multicast traffic is forwarded by flooding the entire network, and later, based on IGMP messages, the forwarding is suspended to the network segments in which there are no active receivers. The protocol builds the multicast tree implicitly with this method. Due to the intensive bandwidth requirements of the flooding transmission implemented in the first phase of operation, the protocol cannot be scaled to large networks and is therefore recommended for use only in small networks.
- PIM-SSM (PIM Source-specific Multicast) – The root of the multicast tree is a predefined source node, for example an IPTV headend. The multicast group is specified with the source identifier/group identifier pair: (S,G), where S is the unicast IP address of the source and G is the multicast IP address identifying the group. Denial-of-service attacks from unauthorized sources within the group can be prevented by explicitly specifying the address of the source.

Of the 3 above, the PIM-SM and PIM-SSM versions are used in IPTV systems.

4. IPTV stream overview

Main features of SD and HD video streams

The properties of individual video streams transmitted on IPTV may differ from each other, with this, we have summarized a few typical values in the table below.

Property	SD	HD
Bandwidth requirement	1,8 - 2,5 Mbit/s	7 - 9 Mbit/s
Image resolution	720 x 576 képpont	1920 (1440) x 1080 képpont
Video codec	H.264/MPEG4 AVC	
Voice codec	AAC, AC3	
Media container	MPEG-2-TS (ISO/IEC 13818-1)	
Transport protocol	Real-time Transport Protocol (RTP), UDP	
Transmission model	IP multicast	

Protocol stack and media codecs

- IPv4/IPv6
- IGMPv3/MLDv2/PIM
- UDP
- RTP/RTCP
- MPEG-2 Transport Stream
- H.264/H.265 (video codec)
- AAC/AC3 (voice codec)

Constant bitrate (CBR) mode audio and video encoding: the media encoder produces the compressed media stream with a constant bit rate at its output. In this mode, the current compression rate is independent of the current complexity of the media content. The advantage of the method is that the bandwidth requirement of the compressed media stream is constant, so it can be used with good efficiency when transmitting on a transmission channel with limited bandwidth. The disadvantage is that the compression of complex audio and video parts can result in a worse Quality of Experience (QoE). In the latter case, quality degradation can be compensated for by setting a higher encoding speed, if the available bandwidth of the transmission channel allows this.

Variable bitrate (VBR) mode audio and video coding: the media encoder produces the compressed media stream at its output at a variable speed corresponding to the current complexity of the media content. Compared to the CBR mode, the advantage of variable bit rate compression is that the encoder has the possibility to adjust the current data rate to the complexity of the audio or video part. By definition, the encoder uses a higher data rate to compress a more complex segment. For media content encoded in VBR mode, the maximum bit rate can be determined, as well as the average bit rate per time unit that can be interpreted (calculated).

H.264 The most important advantage of the H.264 (also known as MPEG-4 AVC) video encoder over the H.262 (MPEG-2) encoder is that roughly half the data rate is sufficient to achieve the same Quality of Experience. This is a particularly important factor when transmitting HD broadcasts, since instead of 15-20 Mbit/s, 7-9 Mbit/s bandwidth is sufficient to achieve the desired quality of encoding.

In the case of an IPTV service, the elementary video stream is transmitted with H.264 encoding embedded in MPEG-2 Transport Stream (MPEG-2 TS) format.

5. MPEG-2 Transport Stream

MPEG-2 TS is not a compression process, it is merely a frame format, so it has no effect on the quality of the video encoding and the resulting bandwidth requirement. In this chapter, we will try to present the MPEG-2 TS format in a short, yet comprehensible manner. It is important to understand this, because a broadcast recorded in this form will have to be analyzed during the measurement.

The "Systems" layer of the MPEG-2 standard[3] defines two storage/transmission formats. Program Stream (PS) is designed for storage when the probability of data loss is low, so it uses large packets. This is used, for example, on DVD discs. Transport Stream (TS), on the other hand, is designed for network transmission, where the probability of error is higher, so the packets are smaller. (At the same time, Blu-ray discs also use the latter.) In the following, we will only deal with the latter, the Transport Stream, i.e. MPEG-2 TS.

MPEG-2 TS is therefore a standard container format for the bundled transmission of motion picture, sound and program information, as well as service information messages (program news, teletext, subtitles, etc.). It is widely used in DVB[4] and IPTV systems to transmit TV channels. Multiplexed (bundled) transmission creates the opportunity to synchronize elementary image and sound streams in time.

In order to effectively reserve network resources (to ensure QoS), service providers typically transmit MPEG transport streams with a constant bit rate (CBR). Unlike DVB systems, in the case of IPTV, to each TV channel a dedicated MPEG-2 Transport Stream is allocated, in which the video stream, one or more audio streams, as well as subtitle and teletext information belonging to the TV channel are transmitted as a media stream. This also means that each TV channel uses a separate multicast IP address.[5]

It may seem like a matter of detail, but it's good to know that some of the rest is actually described in the MPEG-2 TS standard, but other things (e.g. the program guide) are not from the MPEG-2 TS but from the DVB standard. This is understandable, since e.g. there is no program guide on a Blu-ray disc. This is also why some of the Wireshark filters presented later start with the prefix ***mpeg_***, while others start with the prefix ***dvb_***

The first concept to be introduced should be the ***program***. More specifically, according to the MPEG-2 standard it is "Program", according to DVB it is "Service", and in everyday speaking it is simply a TV channel. One or more programs can be transmitted in a single MPEG-2 TS stream

Several ***elementary streams*** (Elementary Streams, ES) are associated with a program. One such stream is video with a suitable video encoding. This includes one or more audio streams (so that you can switch between languages), and you can also use e.g. subtitles in different languages also in separate streams. There can also be teletext data in an elementary stream, which is quite outdated, but is still used.

The elementary streams are broken down into packets, thus creating the – you would never figure it out! – elementary stream divided into packets (***Packetized Elementary Stream***, PES) . The length of a PES packet is variable, also with a variable length header.

Elementary streams, and therefore PESs, do not only belong to programs, but there are some that belong to the entire MPEG-2 TS stream. An example is the Program Association Table (PAT) listing the programs in the stream).

Understandable? Probably not much. A picture always helps, I drew one quickly. So see Fig 4.!

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[3] For those who really can't find better reading material: ISO/IEC 13818-1 is the name of the standard, and it's certainly not cheap: https://www.iso.org/standard/75928.html

[4] Digital Video Broadcast

[5] I want to emphasize, it's really important for measurement.

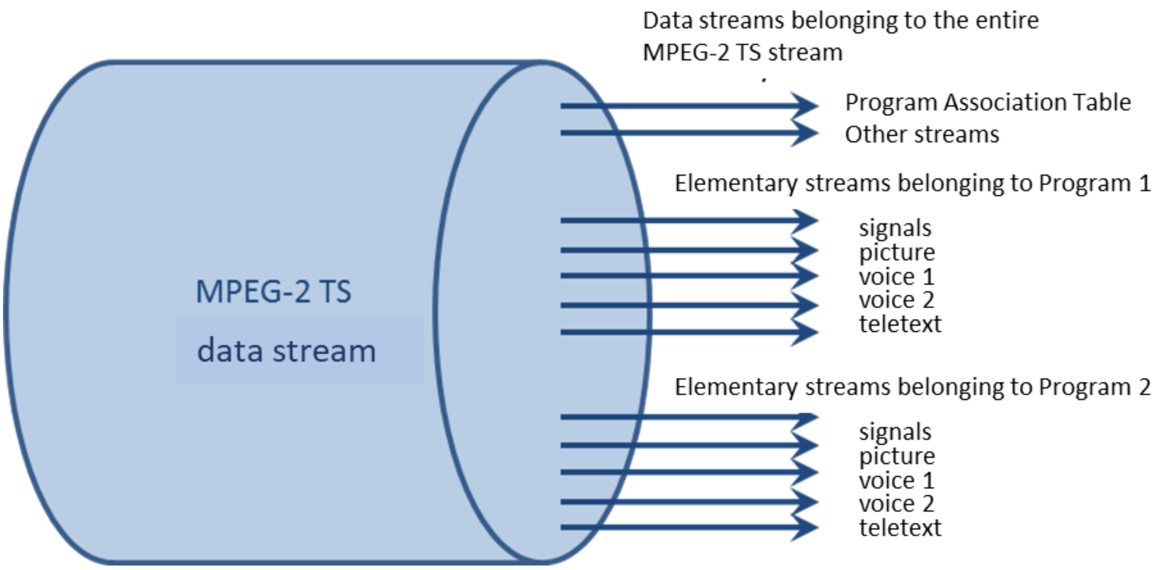

Fig. 4 Structure of MPEG-2 TS. Arrows indicate elementary streams

A TS packet

Elementary streams (e.g. an audio stream with a constant data rate) are divided into larger PES packets, as we wrote above. An audio PES packet e.g. approx. 3.5 kilobytes in the downloaded data file for the measurement, while a video PES packet is approx. 7.5 KB. These PES packets are broken down into even smaller units, the TS (transport stream) packets.

These TS packets are only 188 bytes long and their length is fixed. Of these 188, 4 bytes are the header and 184 are the payload. More precisely, it is possible to use a so-called "adaptation field", which is actually a kind of extended header, and which takes additional bytes from the 184 bytes of the payload.

Since the format of the 4-byte header of the TS packet is not too complicated, and it will be useful to know during the measurement, so we put it here.

Field	Length (bit)	Explanation
Sync byte	8	Synchronization byte. Its content is always hex 47, which is the ASCII code of the letter G.
Transport Error Indicator	1	Its value is 1 if the packet is corrupted
Payload unit start indicator (PUSI)	1	1 at the beginning of a new PES packet, otherwise 0.
Transport priority	1	1 if the packet has a high priority
Packet Identifier	13	**PID. *This is important!*** Packets marked with the same PID belong to a PES. In Fig 4. therefore, each arrow has a PID.
Transport scrambling control	2	Indicates encryption. 00 = not encrypted.
Adaptation field control	2	Indicates whether there is an additional header (adaptation field). 01: no adaptation field, only payload 10: there is only an adaptation field, no payload 11: there is an adaptation field and payload 00: this is currently not an allowed combination
Continuity counter	4	This four-bit counter increases by one for every TS packet with a given PID. It helps to notice when a TS packet is lost.

1. táblázat. A TS csomag fejléce

We highlight the packet identifier from the table above: within the transport stream, each elementary stream and information table has a unique identifier, this is the PID. TS packets with the same PID belong to a PES (or to a stream describing the information table).

Where are we? We have data streams (e.g. the output of an audio codec), we break them into PES packets, and then further into small TS packets. By putting these one after the other in some order, we get the MPEG-2 TS data stream.

However, these 188-byte TS packets must be transmitted over the IP network. It would be wasteful to put only one TS packet in an IP/UDP/RTP packet (the payload/header ratio would be too bad), so several TS packets are encapsulated into an IP/UDP/RTP packet. It is also not good if the IP packet is too large (then it does not fit into an Ethernet frame), so during the measurement we will see that there will be seven TS packets in one RTP packet.

MPEG-2 TS information tables

We mentioned that an MPEG-2 TS data stream also carries signals in addition to data. Each signal type is included separately in the stream, with its own PID. We will now take a brief look at the most important of these:

Program Association Table (PAT): This is where the decoding starts. Its PID is: 0. This table contains the identifiers of the TV channels (programs) transmitted in the transport stream: it contains the program number and the PID of the program's PMT (see below). (This is part of the MPEG-2 standard.)

Program Map Table (PMT): Each program (TV channel) has its own PMT, which is a table containing the PID identifiers of the elementary streams belonging to the given program. (This is part of the MPEG-2 standard.)

Network Information Table (NIT): It provides information about the broadcasting network. Its PID is fixed (decimal) 16. (This is part of the DVB standard.) It is not needed for the current measurement.

Service Description Table (SDT): It provides information about the programs, for example, who owns the program (TV channel) and what is the name of the program. Its PID is fixed (decimal) 17. (This is part of the DVB standard.)

Event Information Table (EIT): The EPG (Electronic Program Guide) subsystem prepares the program guide based on the information from the EIT table. The table contains the names, start time, duration and brief description of the programs. Its PID is fixed (decimal) 18. (This is part of the DVB standard.)

Program Clock Reference (PCR): Reference clock used to synchronize elementary streams. It belongs to a program, its PID is contained in the PMT. (This is part of the MPEG-2 standard.) This is not actually an information table anyway, just an adaptation field that is included in some of the TS packets.

MPEG-2 TS and Wireshark

A few hints for measuring with Wireshark.

If Wireshark did not recognize that the captured traffic (packet series) is an RTP media stream, in the "Analyze" menu, you can set it to decode the UDP payload as an RTP packet in the "Decode As" section of the "Analyze" menu (Fig 5. and 6.). Make sure that the UDP port is 5004, because this is not the default for this menu item! After that, the RTP header and the MPEG-2 TS header embedded in RTP will appear in the protocol hierarchy (Fig. 7.).

In Wireshark, MPEG-2 TS packets are marked with the standard's official identifier: ISO/IEC 13818-1.

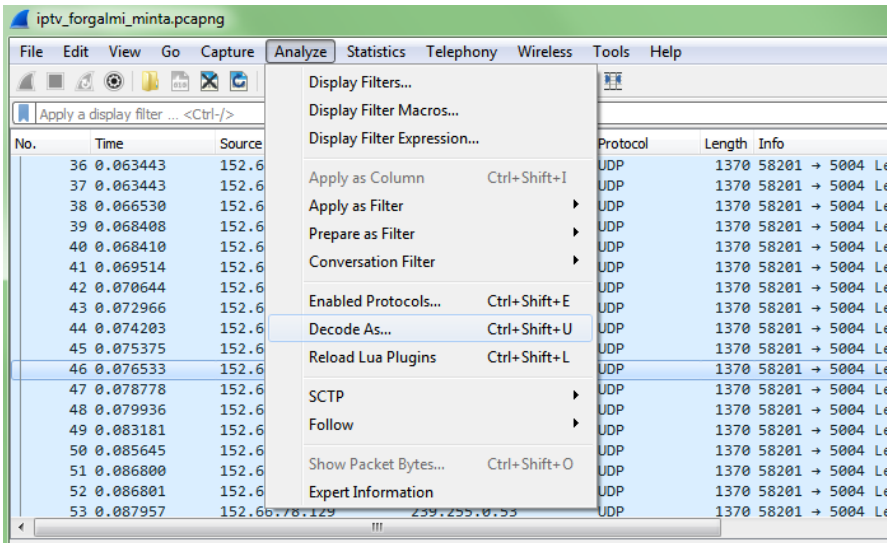

Fig 5.: Decoding an RTP header in Wireshark

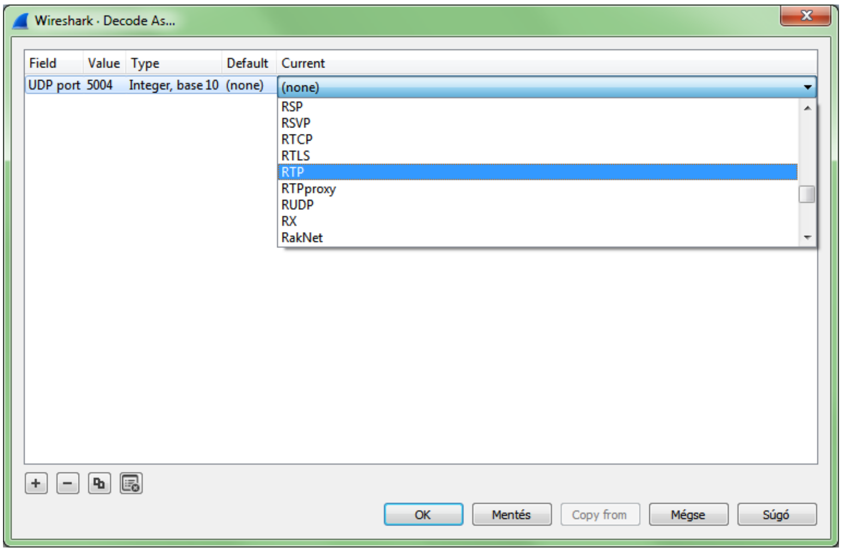

Fig. 6.: Traffic arriving at port UDP/5004 is decoded as an RTP message

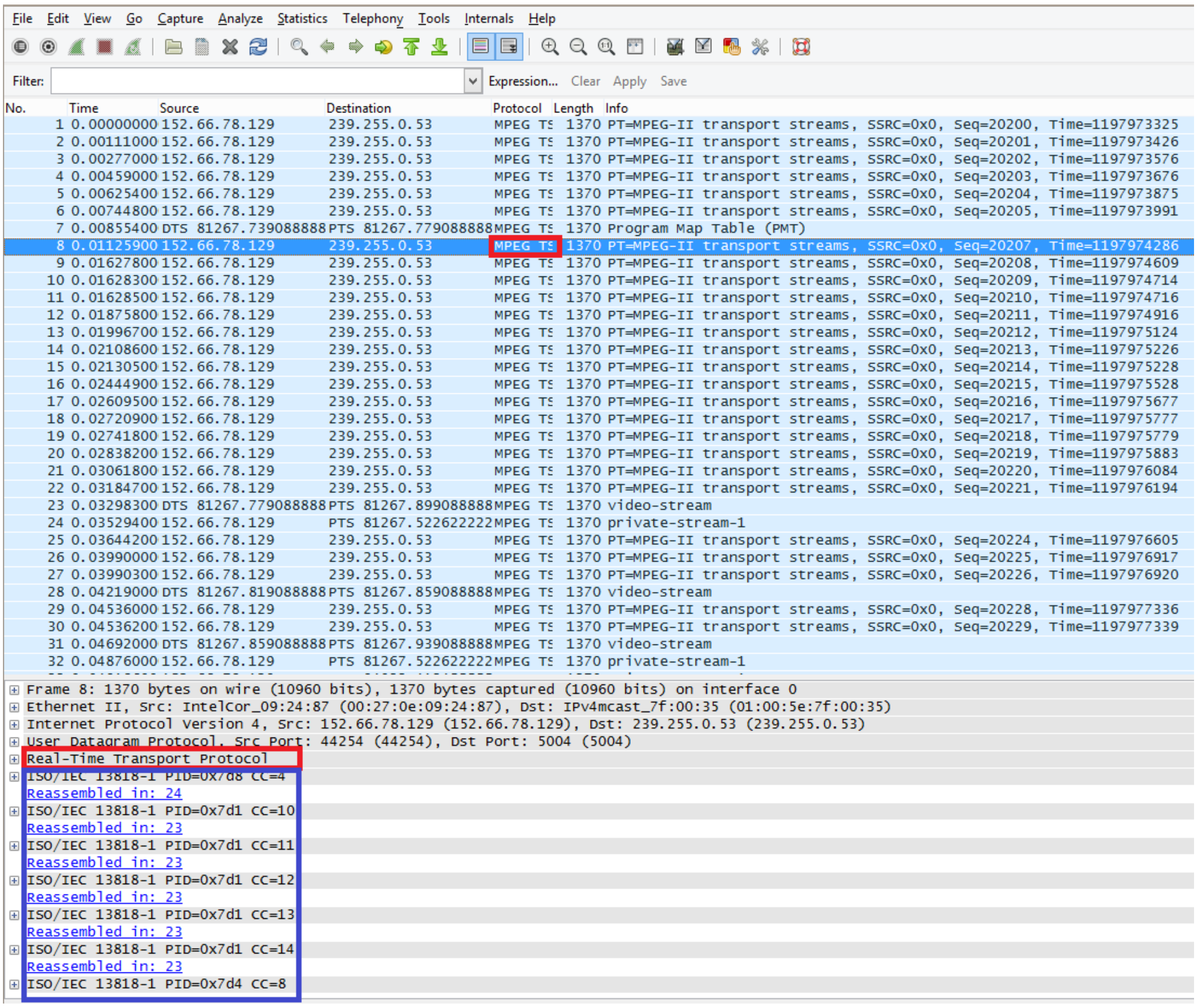

Fig. 7.: MPEG-2 TS packets embedded in the data part of an RTP packet

The individual information tables can be filtered with a display filter in Wireshark. As a result of the filtering, only those RTP packets that contain the given information table are displayed.

- Filtering of RTP packets containing a PAT table: ***mpeg_pat***
- Filtering of RTP packets containing a PMT table: ***mpeg_pmt***
- Filtering of RTP packets containing a EIT table: ***dvb_eit***
- Filtering of RTP packets containing a SDT table: ***dvb_sdt***
- Filtering of RTP packets containing a TS packet with a PCR adaptation field: ***mp2t.af.pcr***
- Filtering of RTP packets containing an elementary stream with a given PID: ***mp2t.pid ==*** *value*

6. IPTV service network metrics

IP-level elementary network metrics affecting the quality of experience of the transmitted media:

- Delay
- Jitter
- Packet loss
- Packet reordeing
- Throughput

Complex network metrics affecting the quality of experience of the transmitted media:

- MDI (media delivery index) – double metrics
    - delay factor
    - media loss rate

Other metrics affecting service quality:

- Channel change time (zap time)
- EPG loading time

7. Playout buffer on the receiving side

Media decoders on the receiving side typically wait for the arrival of media packets at their input with a fixed data rate. However, the IP packets of the video and audio streams do not reach the recipient with a fixed delay due to the operation of the network. IP-based networks do not guarantee the level and variation of network delay. The variation of the transmission delay is called Packet Delay Variation (PDV) in the literature, but the name jitter is also common. As a result of network jitter, a sequence of packets sent at fixed time interval on the source side already appears at the receiver with variable arrival intervals

The effect of this fluctuation can be significantly reduced by including a so-called playout or de-jitter buffer. Packets are entered into this buffer with variable arrival intervals, but are read out from there at a fixed bit rate. However, the negative effect of using the buffer is that it increases the delay, which should be kept low for real-time applications. An important planning aspect is therefore the correct choice of the buffer size, knowing the network jitter and the expected delay.

8. Channel change

Let's see what all has to happen from the initiation of the channel change - when we switch to another TV program - to the point where the image of the new program appears on the screen.

1. *IGMP group change*. In the network layer, the client initiates leaving the multicast group belonging to the given program (IGMP *Leave Group* message to therouter), and then joins the multicast group of the new program (*Membership Report / Join*).

2. *Expansion of multicast distribution tree.* If the client is the first active member in the group in the client's network, the local router must request the multicast media stream from the router located above in the multicast distribution tree, i.e. the multicast tree must be expanded.
3. *Endpoint buffering.* When the media stream arrives at the client, the player application must fill the playout buffer to the specified level before playback begins.
4. *Arrival of PMT information table.* The client must wait for the arrival of the PMT table so that it can distribute the elementary streams transmitted in the Transport Stream to the corresponding decoders based on the information in the table.
5. *Arrival of a video key frame.* Finally, the condition for starting the decoding of the H.264 video stream is that a reference video frame (I frame) arrives in the elementary video stream, which can be referred to when decoding subsequent differential video frames.

Note to point 5.: No other frames are needed to decode the key frame, but at least one reference is definitely needed to decode the differential frames. Therefore, when changing channels, you must wait for a key frame to start the decoding process. This delay is not constant, but an upper estimate can be given for the worst case. In the case of IPTV systems, a key frame is typically added to the stream with a period of 1-2 seconds, so we can expect a maximum delay of this amount in the case of point 5.

The channel change time is therefore influenced by the above five factors, of which the first four must be analyzed and recorded during the measurement.

9. Control questions

If you try to answer these questions, you can check how well you have understood the contents of this document.

1. How does multicast-based IP communication differ from unicast-based communication?
2. For which services should multicast communication be used instead of unicast? What advantages can we expect then?
3. How does the IP endpoint manage multicast group memberships? Which IGMP message types are you using for this?
4. With whom does the IP endpoint communicate during IGMP message exchange?
5. What is the IGMP Snooping function? Which network devices does it work on?
6. Which versions of the IGMP protocol are used in IPTV systems? Why?
7. Why do we use MPEG Transport Stream to transmit media content with IPTV technology?
8. List at least three elementary stream types that can appear in an MPEG Transport Stream.
9. Describe the elementary network QoS metrics that determine the quality of the IPTV service.
10. In IPTV and DVB systems, which kind of audio and video encoder do service providers typically use?
11. What is the typical bandwidth requirement for SD and HD broadcasts in the case of an IPTV service?
12. What is the receive-side playout buffer? What are its positive and negative effects?
13. In the case of IPTV, which factors affect the channel switching time?
14. List at least two MPEG-2 TS information tables and briefly describe their content.
15. Is it worth multicasting the media traffic generated by the Video on Demand (VoD) service to the subscriber? Why?