Digital Photography ...

Personal Communications

CD Video Storage

KEEP
CALM
AND
GET READY FOR THE
NEXT BATTLE

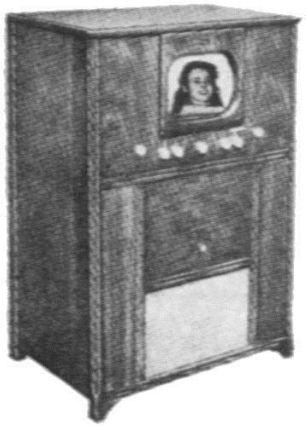
TÉCNICO LISBOA

DIGITAL TELEVISION: FIRST GENERATION

Fernando Pereira

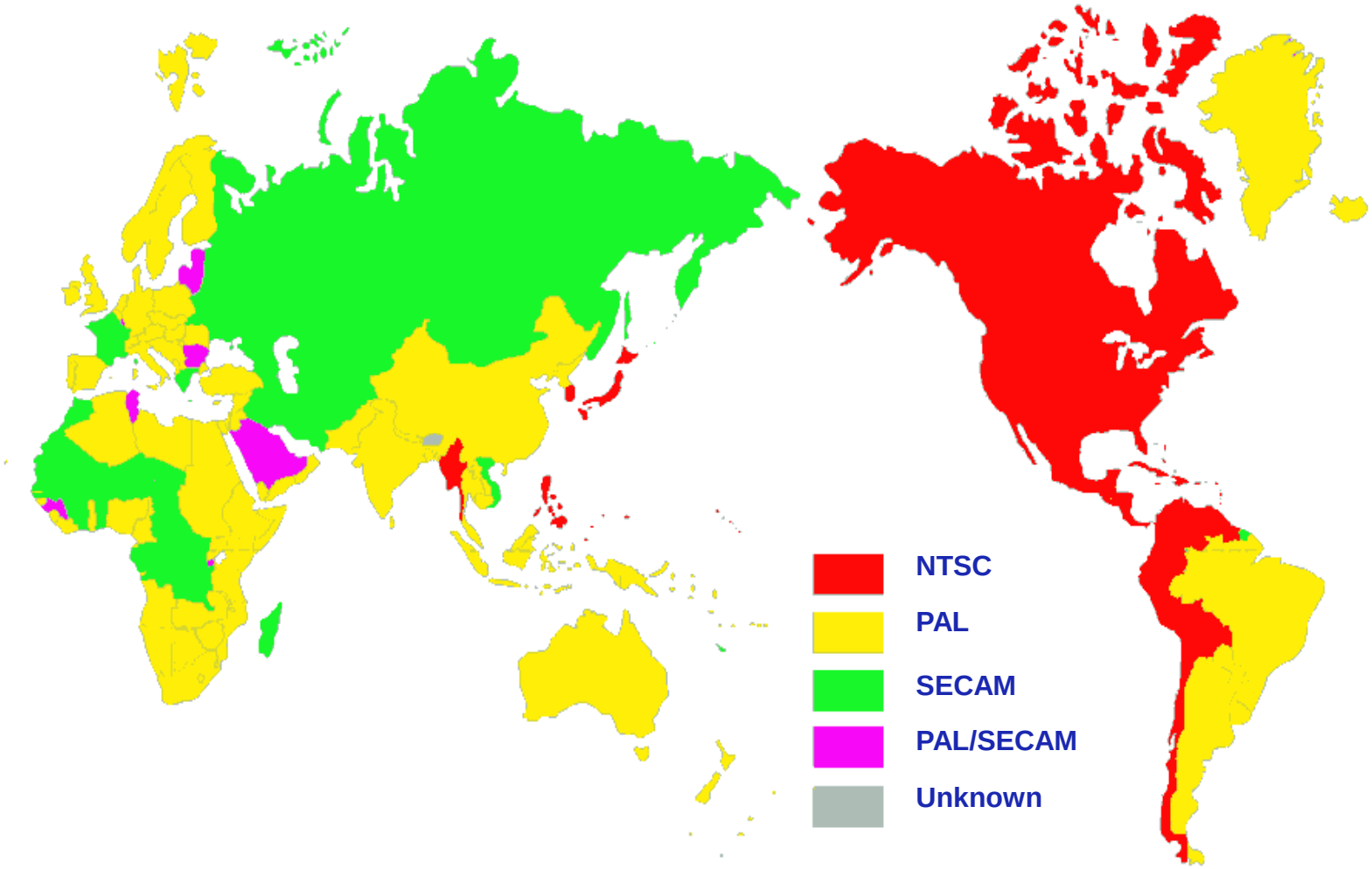
Instituto Superior Técnico

The Final Target: Telepresence

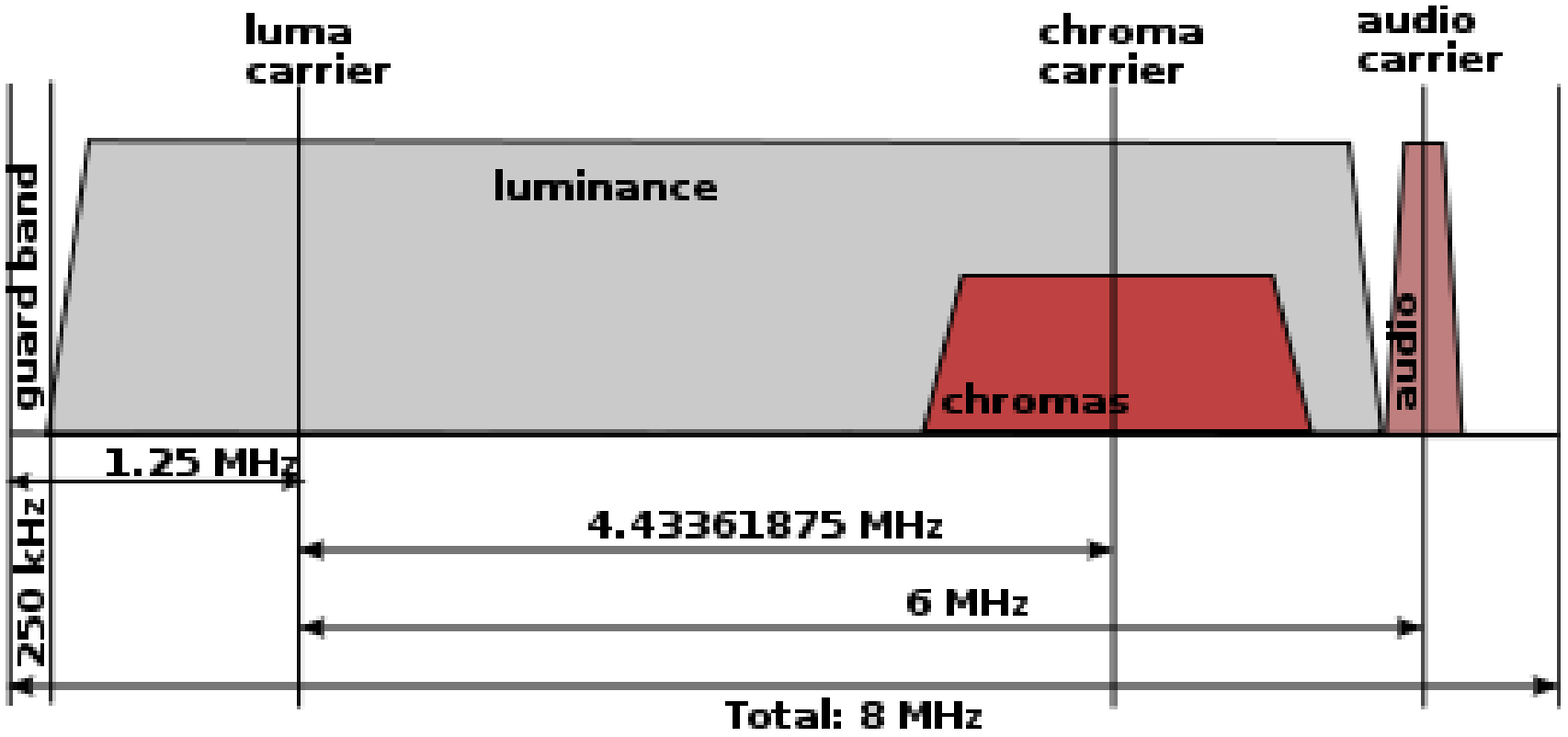


Growing sensation of immersion

The Analogue TV World



Analogue TV Spectrum



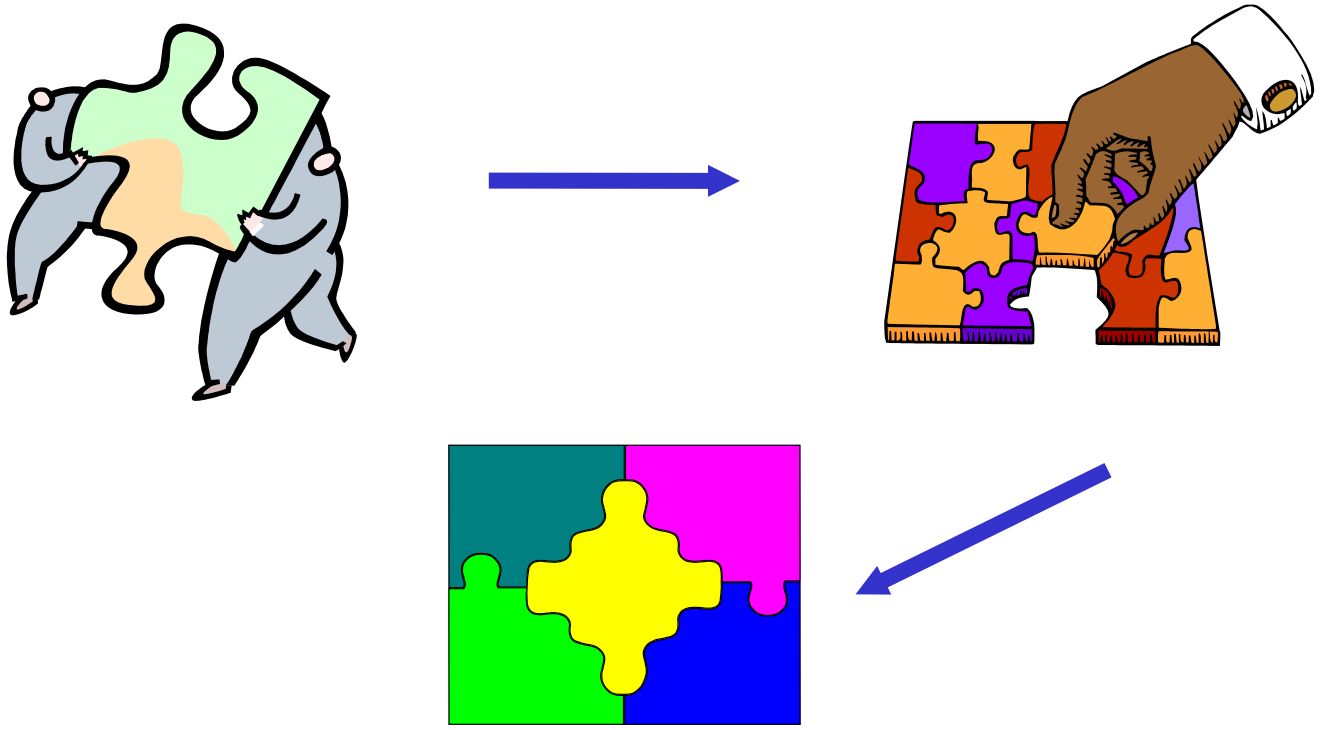
TÉCNICO LISBOA

Portuguese Analogue TV

11th March 1957 - 26th April 2012

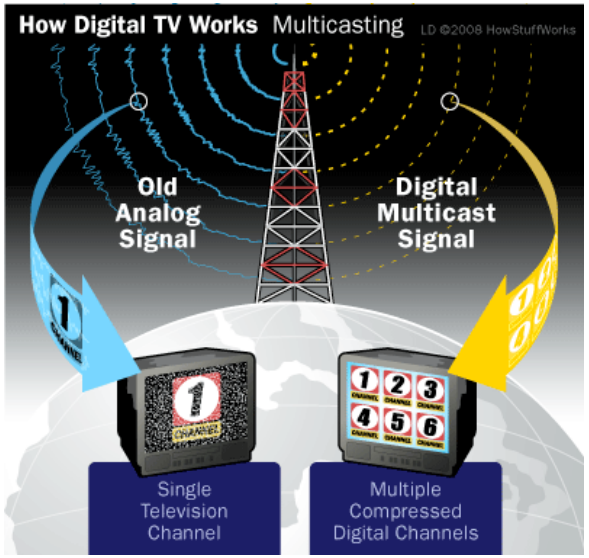
Digital TV

TV Digital: What is it Really ?



All the information – video, audio, data - arrives to our houses as a discrete sequence of (pre-defined) symbols which together allow to resynthesize the original information with a target quality !

Why Digital TV ?



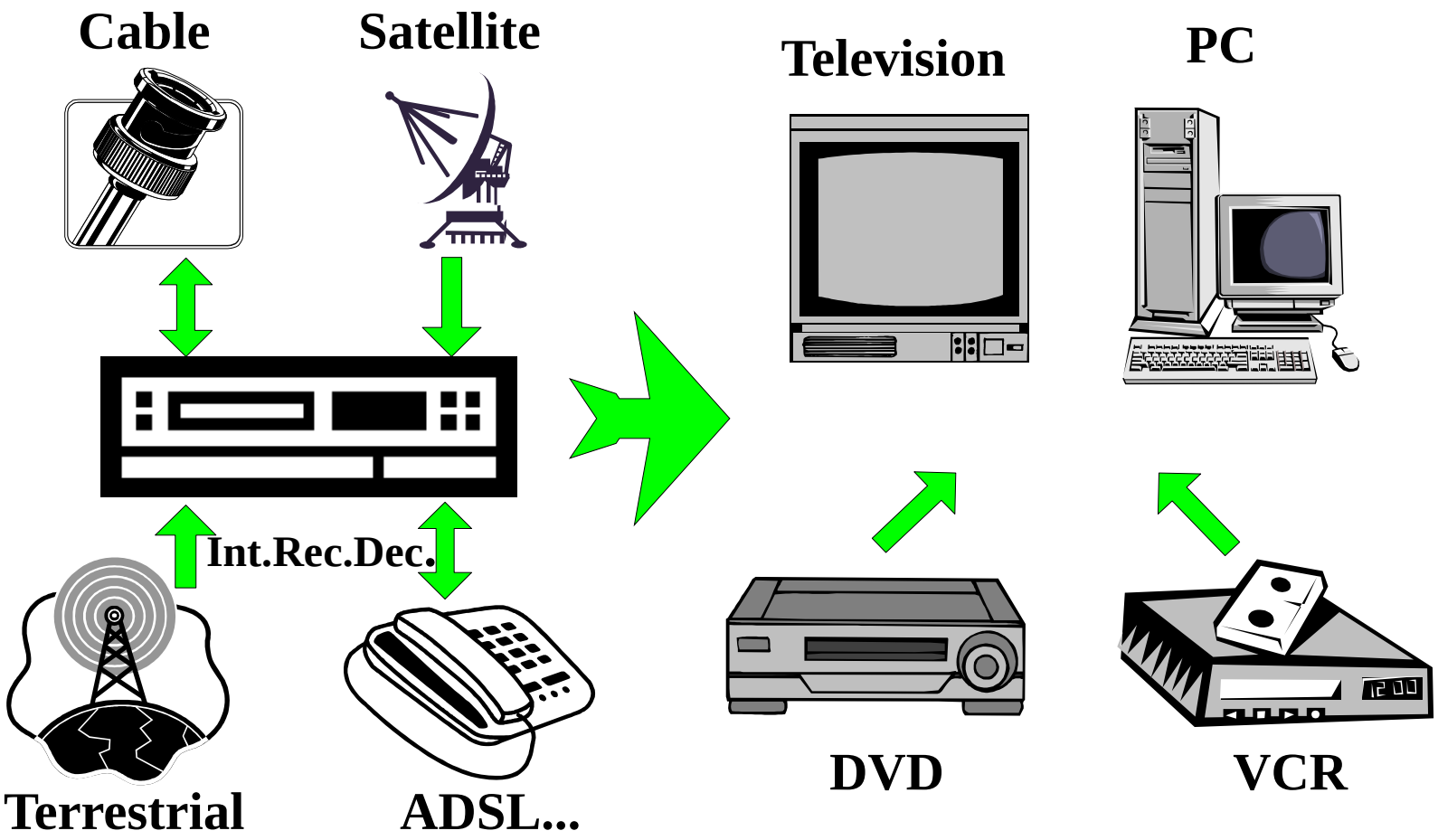
- More efficient spectrum usage
- More channels and services
- Interactivity
- Personalization
- Error robustness
- Audio and video quality control
- Easier processing
- Better relation with the computer world
- Easier multiplexing and encryption
- Possibility of information regeneration
- ...

In summary, easier management and processing of the information !

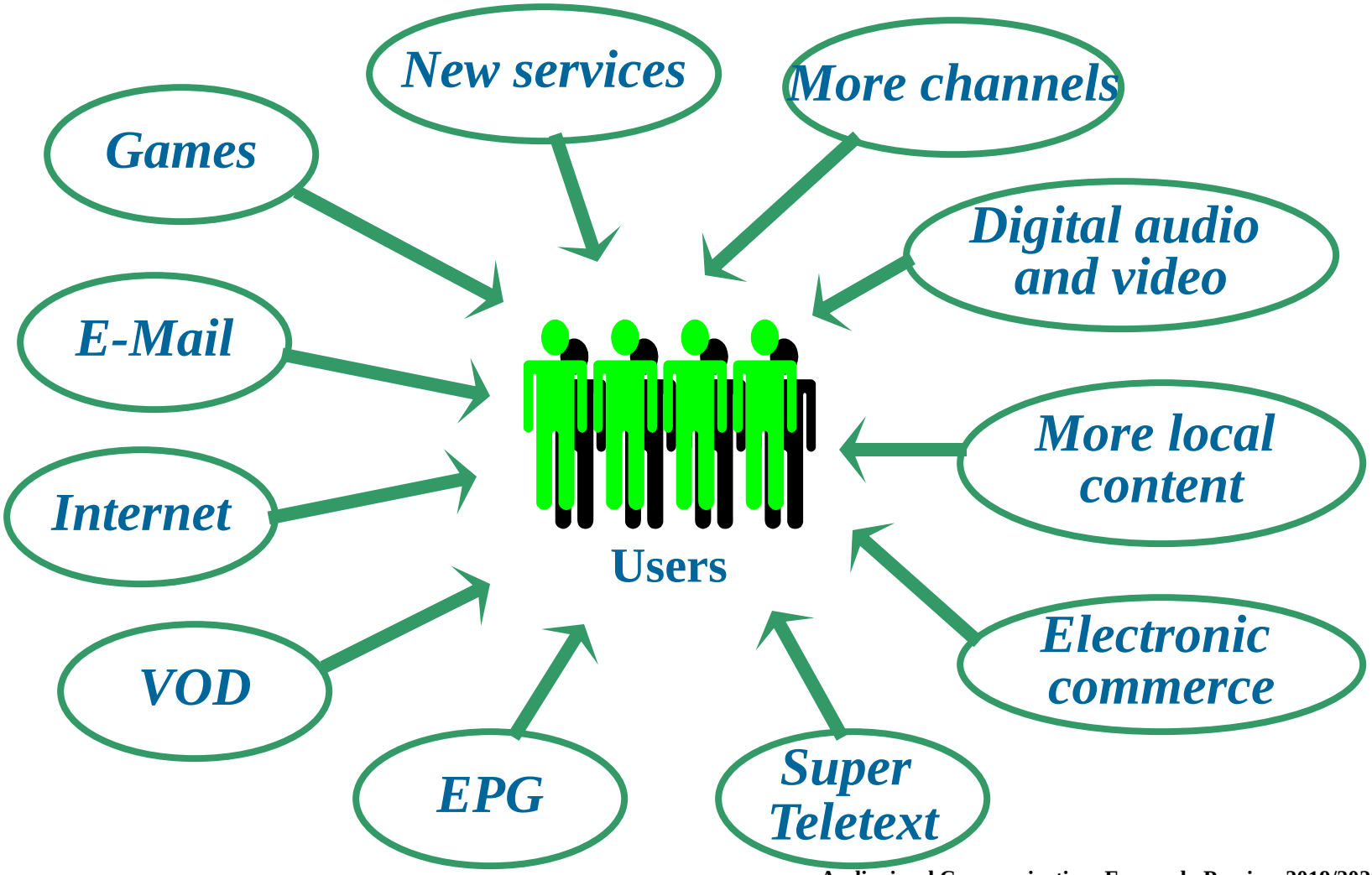
TV Everywhere ...

- **Set-top box + TV analogue**
- **Digital TV**
- ***PC Card***
- ***Mobile device***
- **Any type of digital receiver**

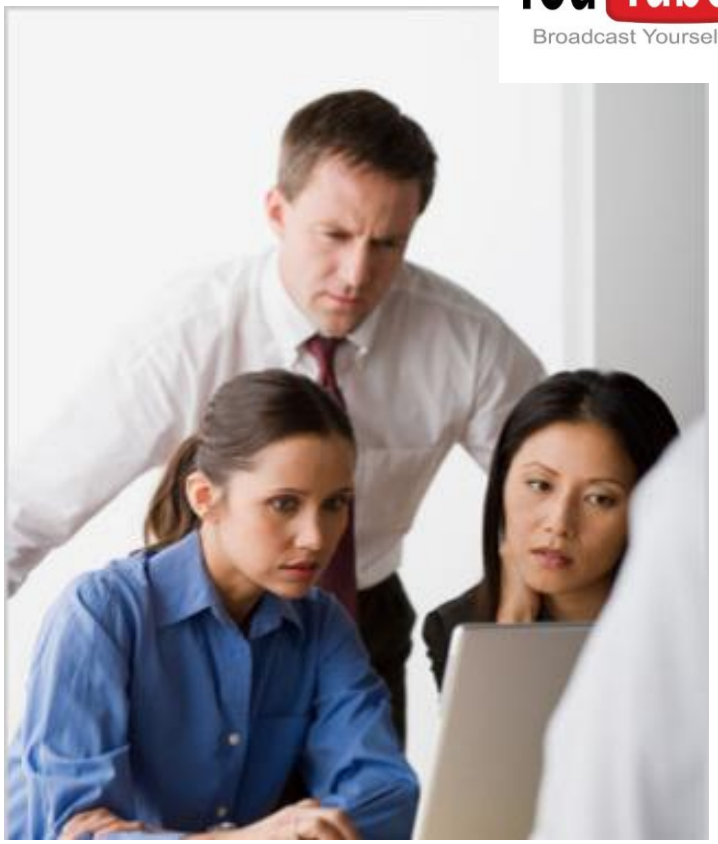
The Digital Domestic Scenario



Digital TV: Content or Terminal ?



Lean Backward versus Lean Forward



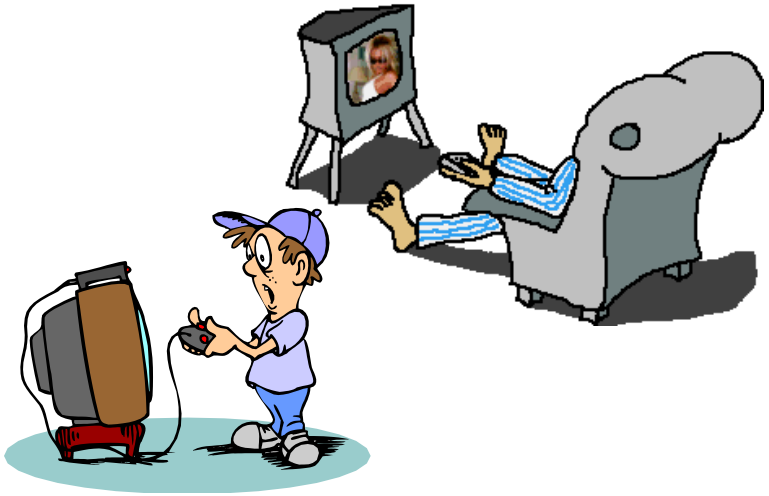
Which Arguments Convince the Users ?

- **Satisfaction of important needs / added value / functionalities**
- **Interoperability at the application level – *users don't care much about the specific technical solution***
- **Quality and reliability**
- **Facility of usage**
- **Low cost of usage and equipment**
- **Variety and quality of content**
- **Interactivity**

Technology is important but content (and rights) may be even more important !

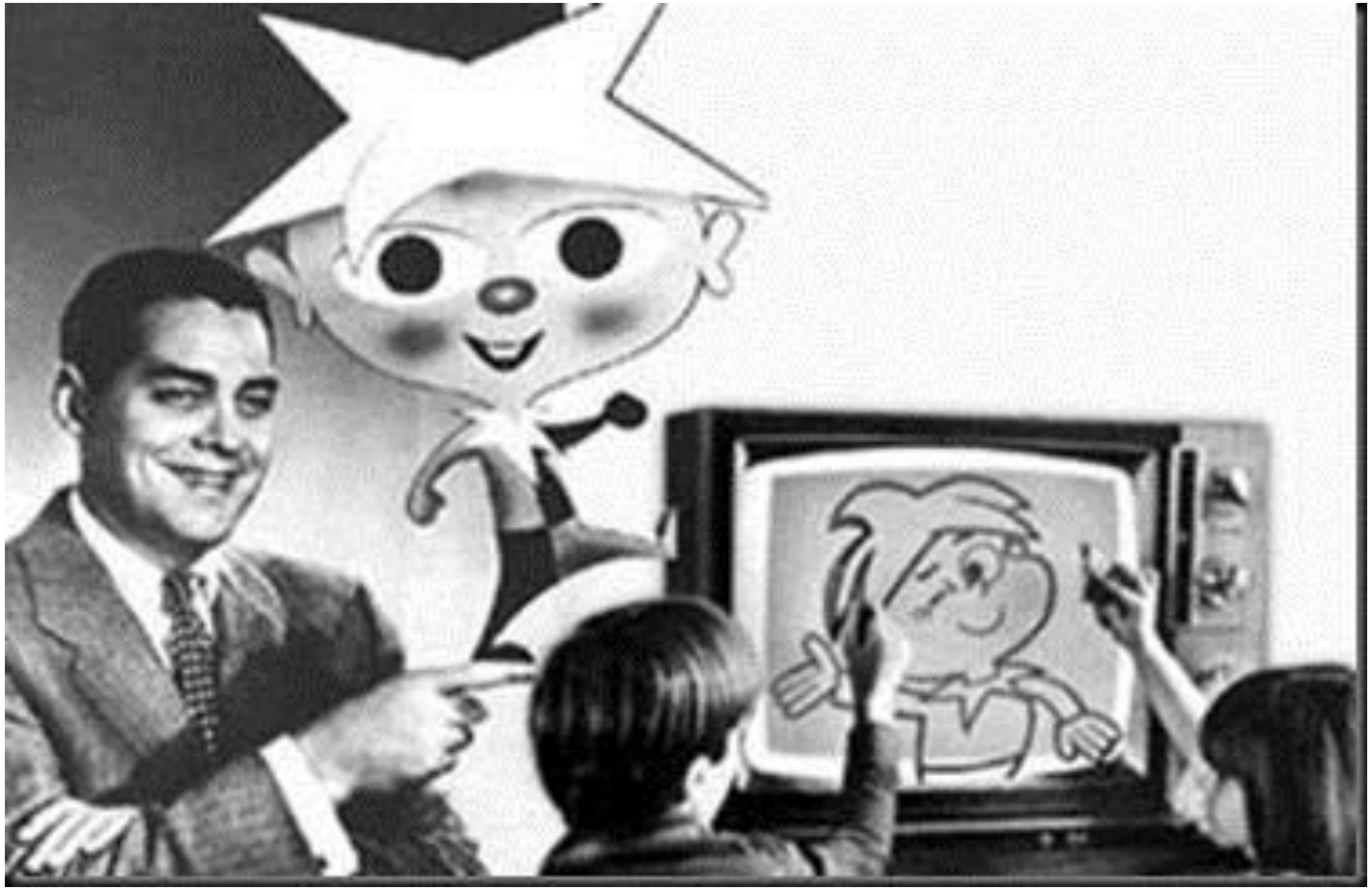
Interactivity

The digital representation of information facilitates the explosion of interactive capabilities – *user capability to select or change something, thus personalizing the TV experience* - associated to television and the capability of the users to:



- **Access to thematic information**
- **Access to complementary information**
- **Control the visualization sequence**
- **Select the visualization angle**
- **Express opinions, vote**
- **Use various services, e.g. tele-shopping, tele-banking**
- **...**

Early Interactions: Winky Dink and You (1953-57, CBS, USA)…

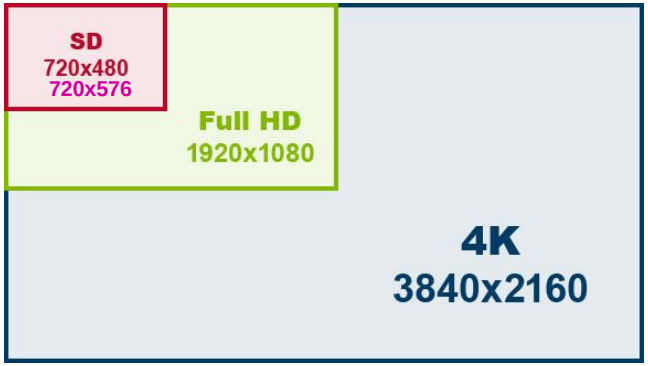


Types of Interactivity

- **Low Interactivity –** Zapping, audio control
- **Medium Interactivity –** Defines the program but does not change it, e.g.VOD, teletext
- **High Interactivity –** Changes the program, e.g. program personalization, selection of the preferred end, mix with Internet

Moreover, interactivity does not always require to use a feedback channel …

From SDTV to HDTV … And 4/3 to 16/9 …



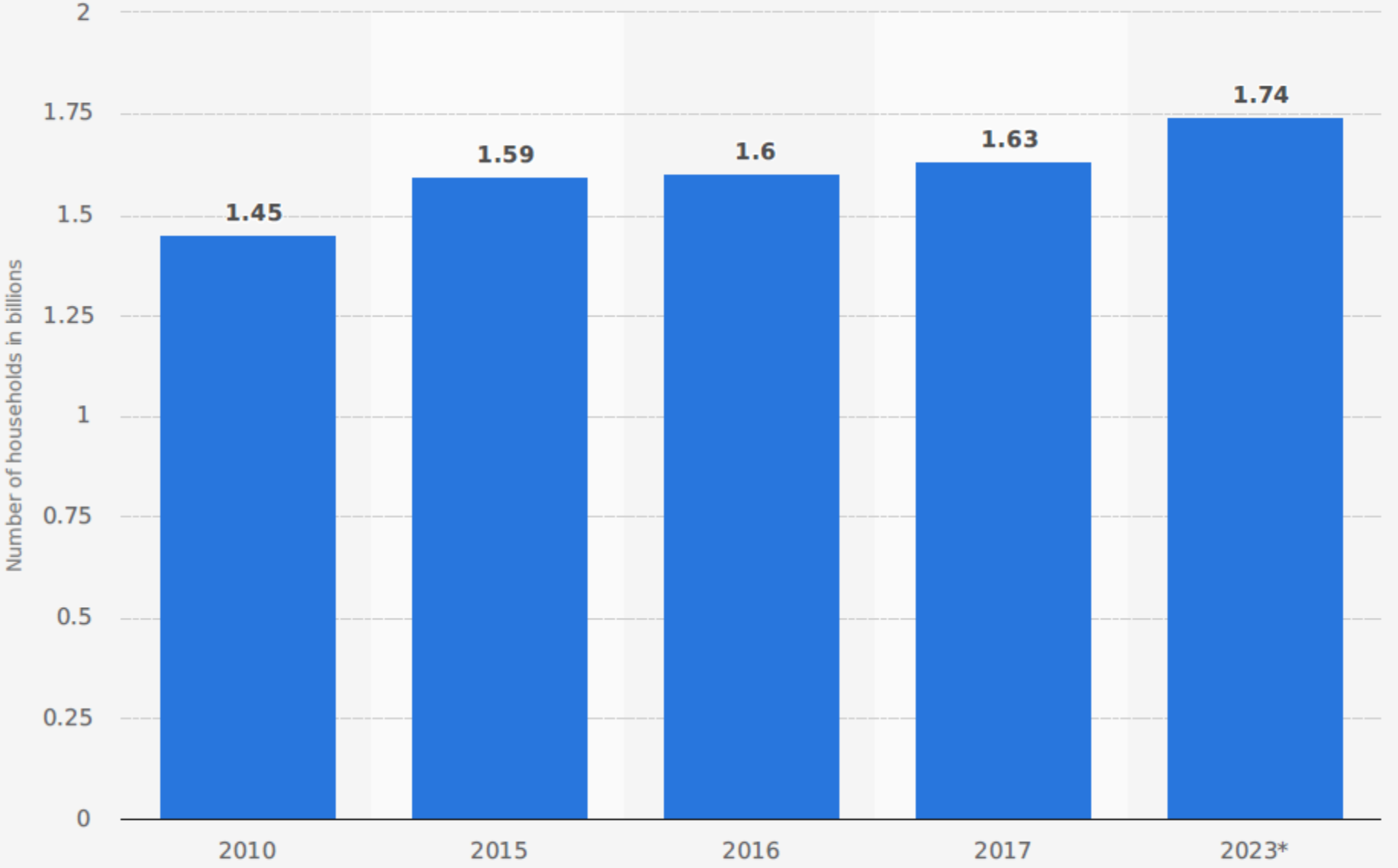
SDTV
STANDARD DEFINITION TELEVISION

HDTV
HIGH-DEFINITION TELEVISION

Displays: from Big and Heavy to Slim and Light

TV: Big and Small Both Rocking ...

Number of TV households worldwide from 2010 to 2023 (in billions)

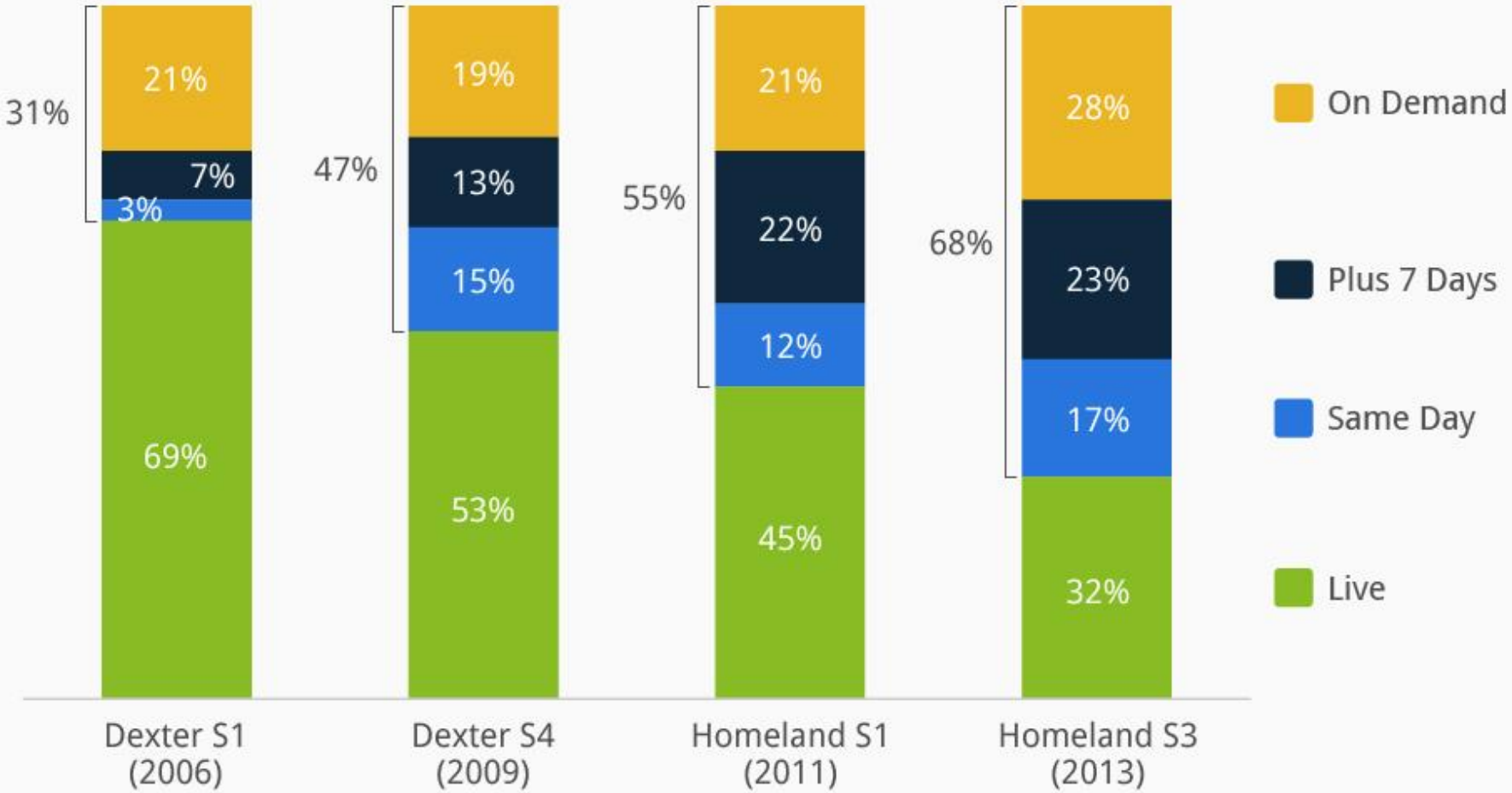


Source
Digital TV Research

Additional Information:
Worldwide; 2010, 2015, 2016 and 2017

How TV Watching Has Evolved Over The Past 8 Years

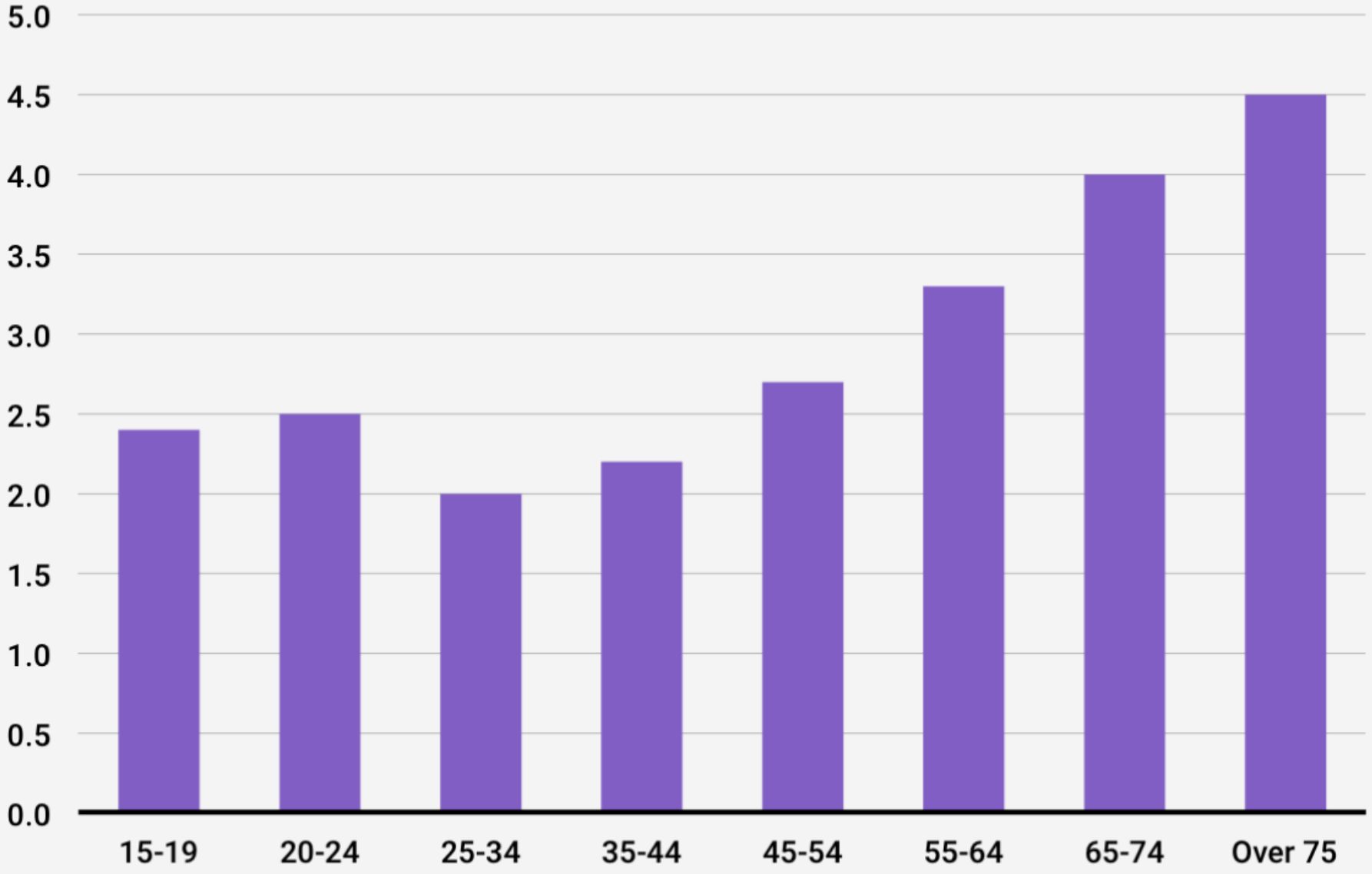
Average weekly viewing of Showtime TV programs (live vs. time-shifted)



 Sources: Showtime, Nielsen, Rentrak

statista

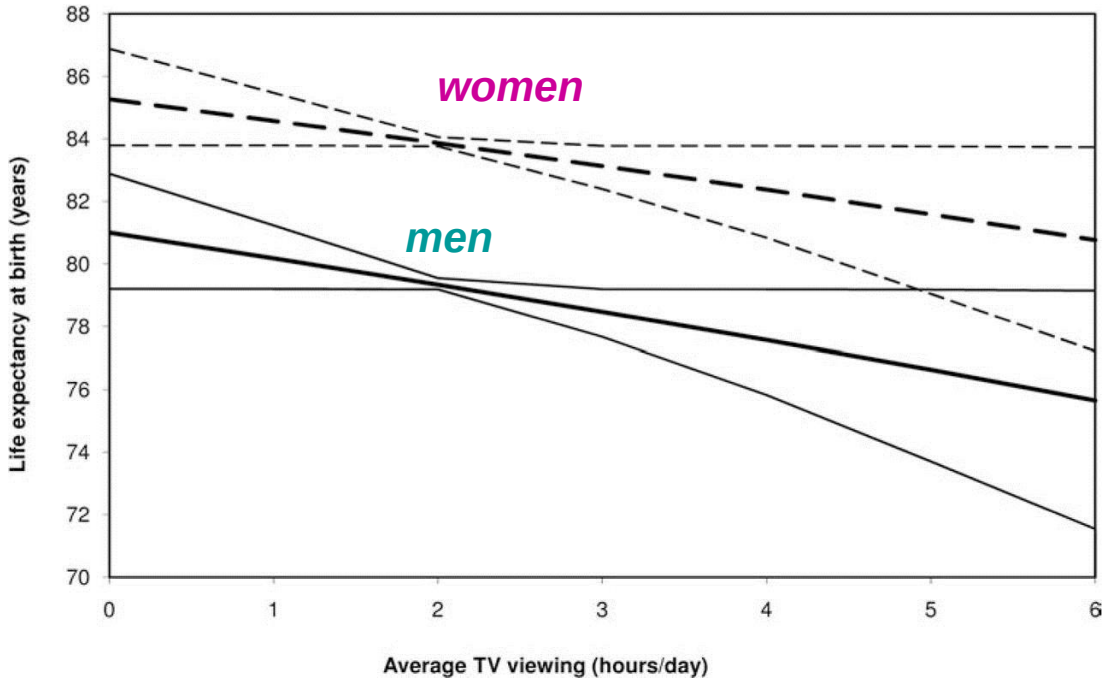
AVERAGE HOURS SPENT WATCHING TV



SOURCE: Bureau of Labor Statistics, 2014 American Time Use Survey

BUSINESS INSIDER

TV Viewing May Kill …

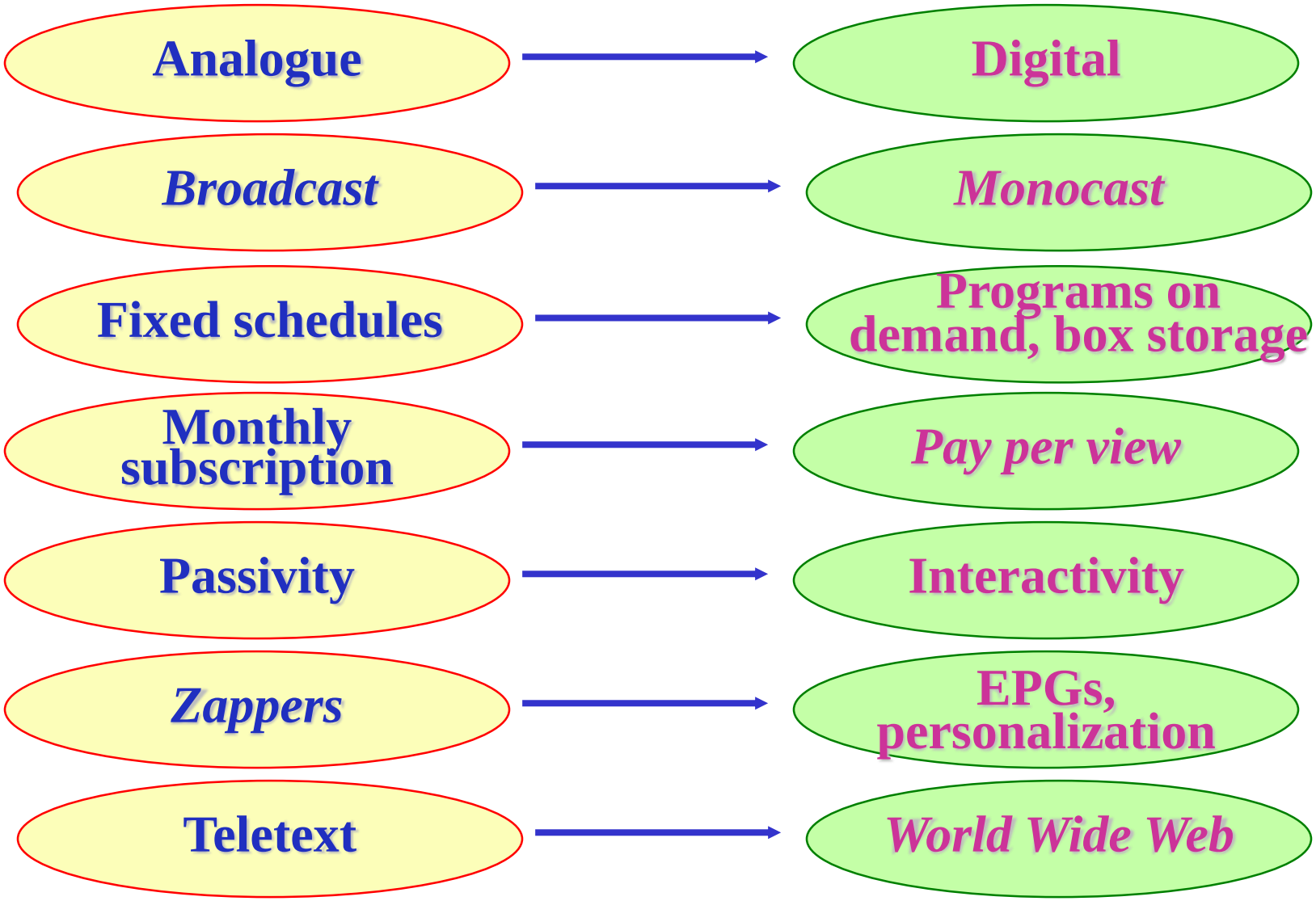


Life expectancy at birth by average daily amount of TV viewing time.

Men in continuous lines and women in dashed lines; means (bold) and 95% uncertainty intervals. Data from Australia in 2008.

From "Television viewing time and reduced life expectancy: a life table analysis", British Journal of Sports Medicine, 2012

Television: How has it been Changing …



TÉCNICO LISBOA

Digital TV Solutions

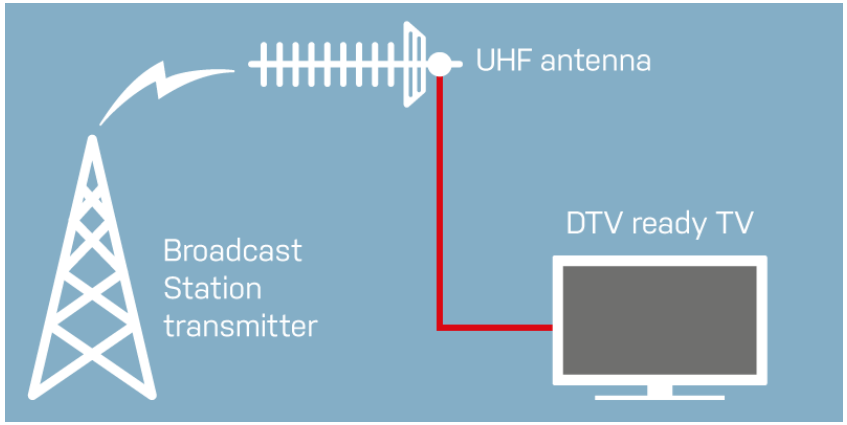
Digital TV Classification Dimensions

- **Type of representation:** analogue versus digital
- **Type of channel:** terrestrial, satellite, coaxial cable, fiber
- **QoS management:** managed versus Over-the-Top (OTT)
- **Mobility:** wireless (moving) versus fixed user consumption
- **Technology:** IP and non-IP based cable services
- …

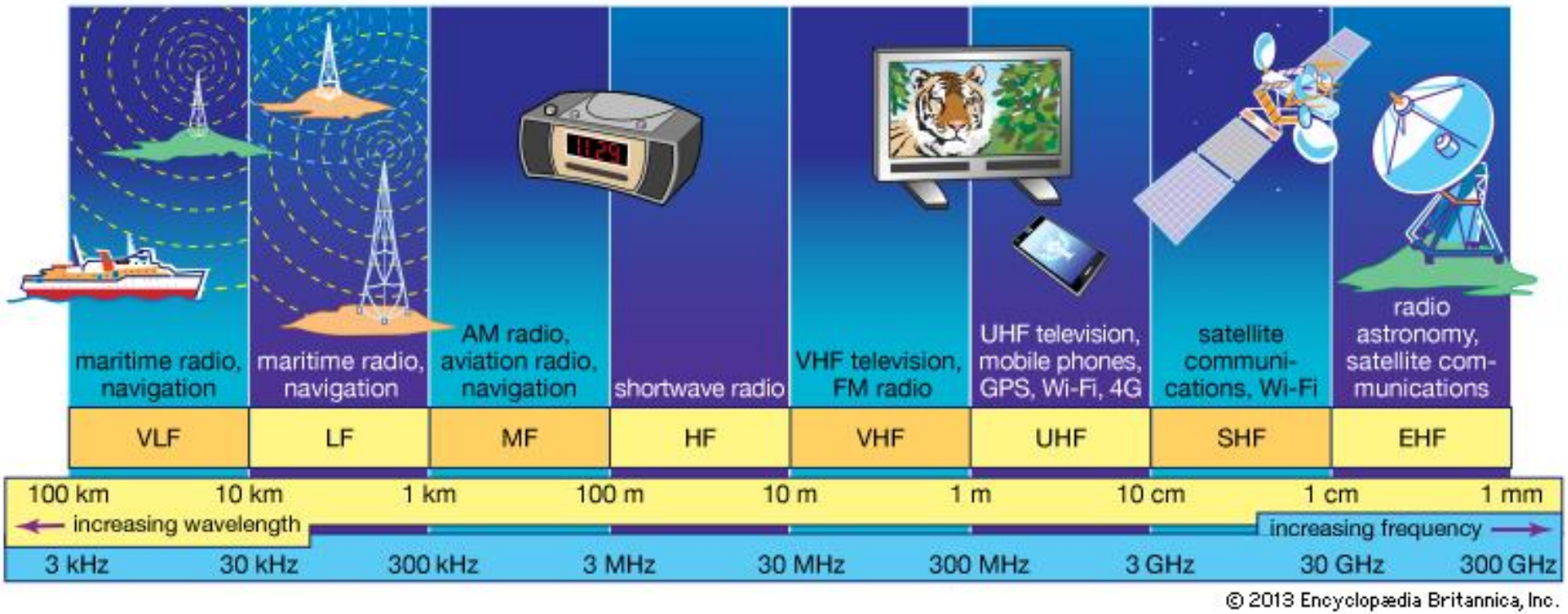
Broadcasting happens from a central point.

TÉCNICO LISBOA

Terrestrial Broadcasting

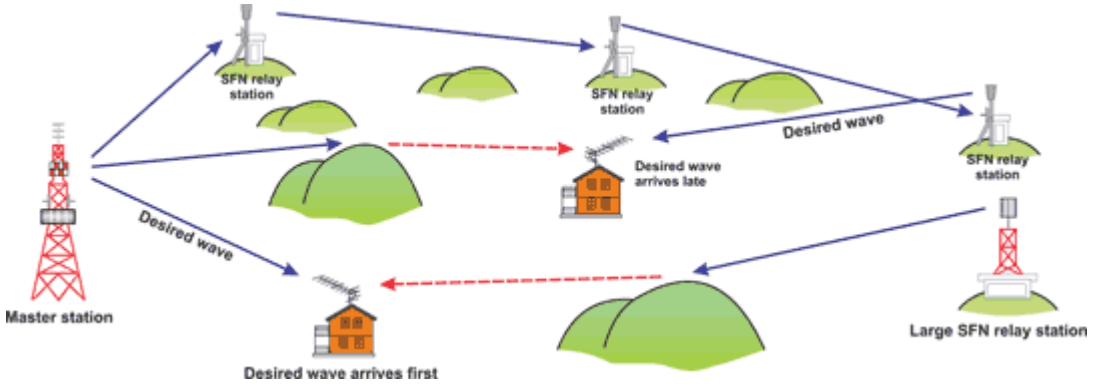


Communications Spectrum

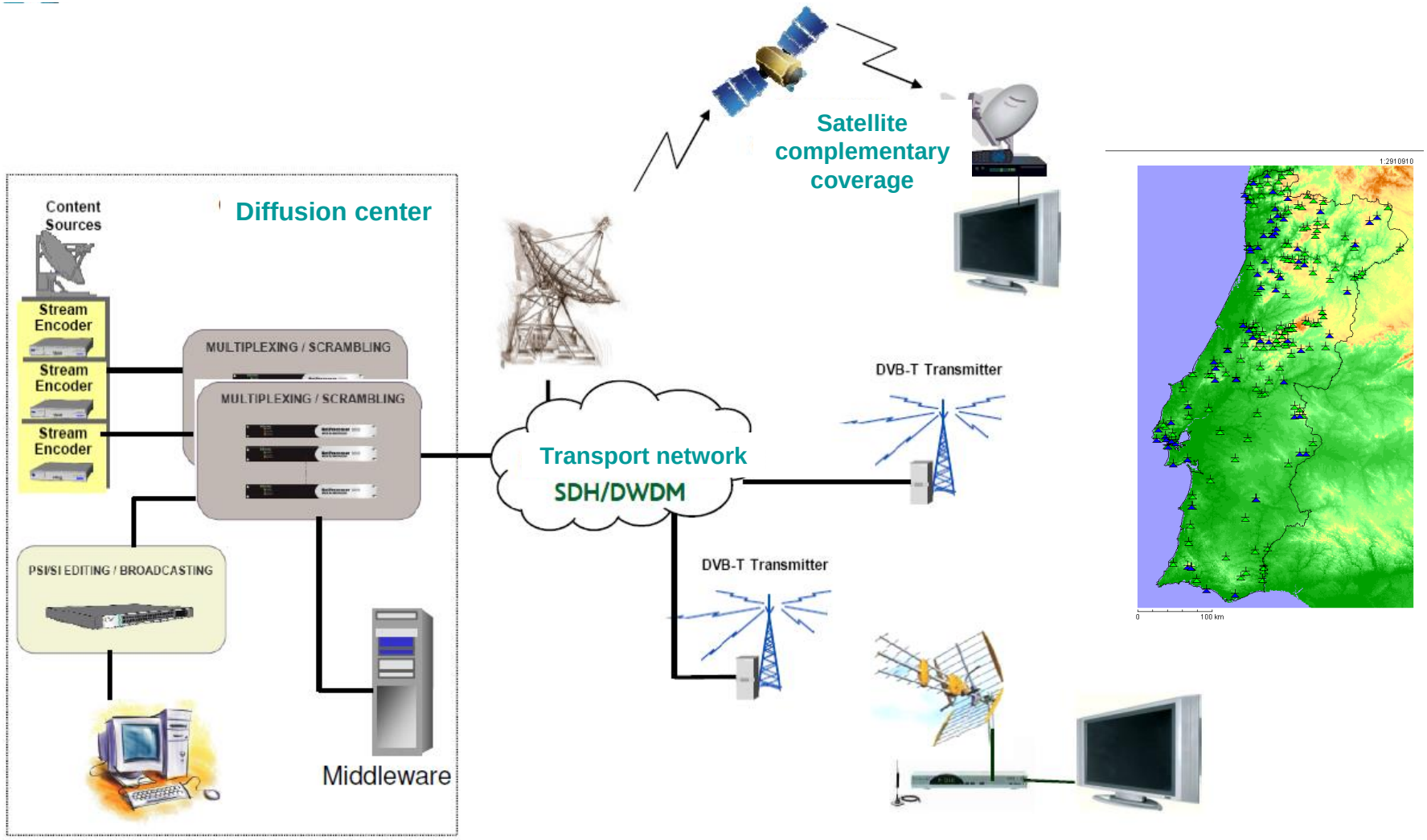


Terrestrial Broadcasting

- **Terrestrial television is a type of television broadcasting in which the television signal is transmitted by radio waves from the terrestrial (Earth based) transmitter of a television station/operator to a TV receiver having an antenna.**
- **Terrestrial television was the first technology used for television broadcasting.**
- **Analogue TV was mostly terrestrial, with significant bandwitdh consumption as frequencies cannot be reused within a limited area.**
- **Terrestrial TV suffers from multi-path effects, which may signficantly impact the reception quality.**



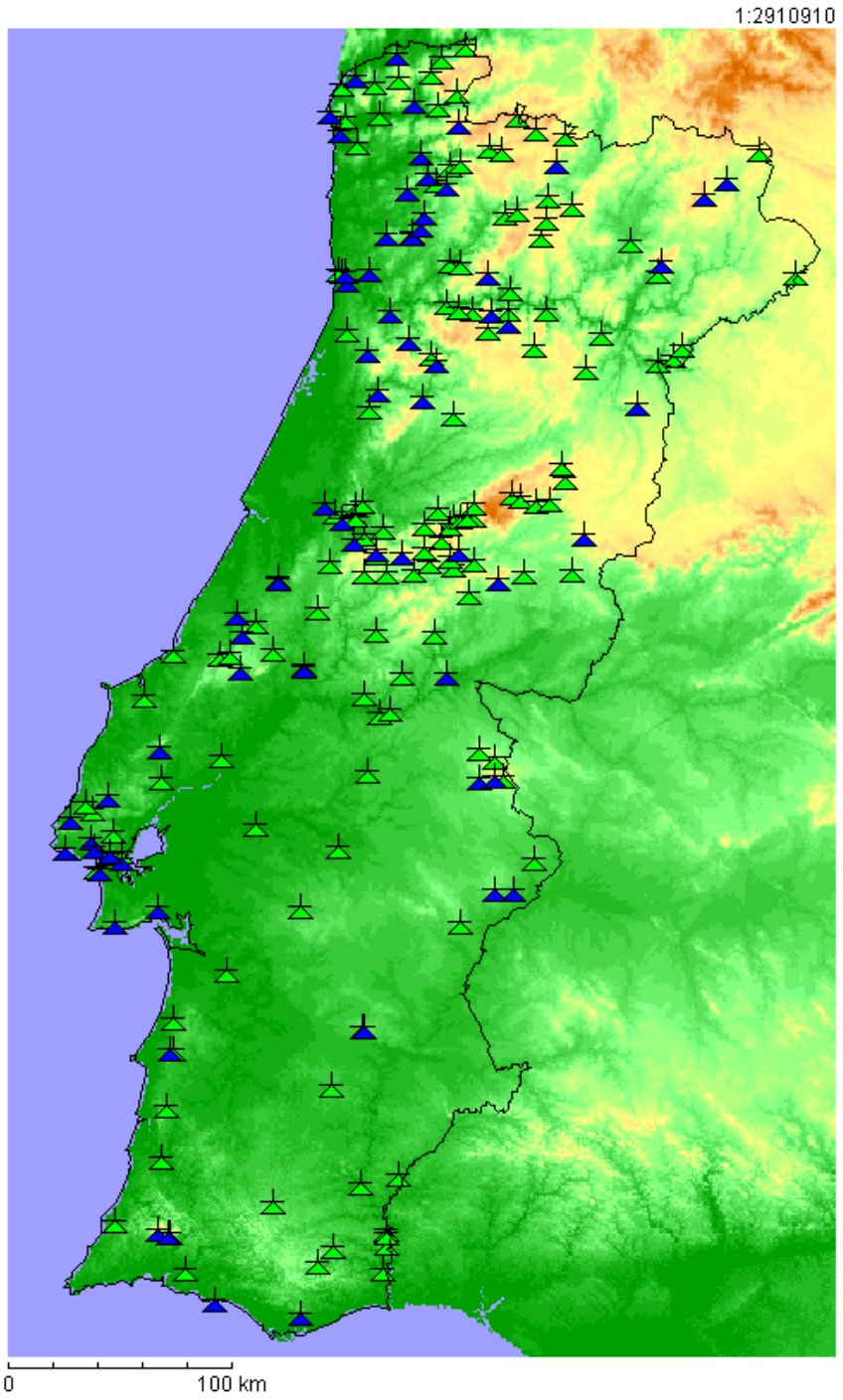
Terrestrial Digital TV Network: Generic Architecture



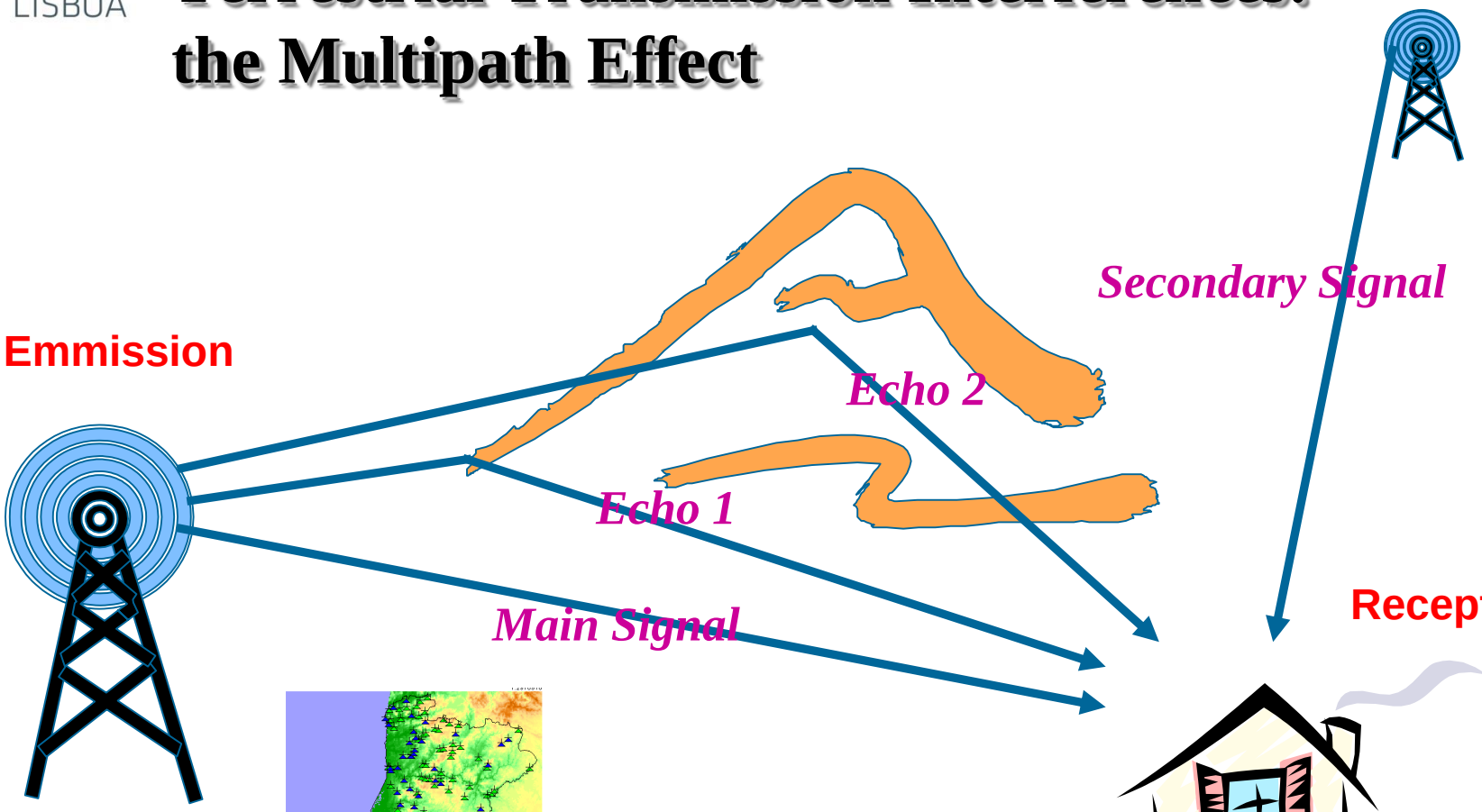
Portugal: Terrestrial Transmission

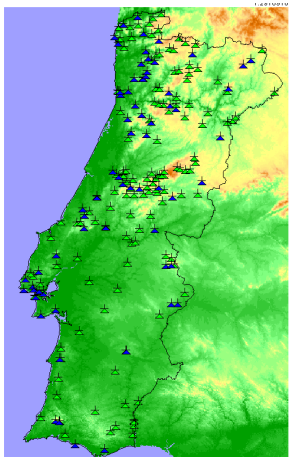
Until 2008, there were two terrestrial broadcasting networks in Portugal:

- PT Comunicações (green in the map) network which included the network that was initially from RTP and TDP
- RETI, Rede Teledifusora Independente, (blue in the map) network, which developed from the radio network from Rádio Renascença; this network was bought by PT in 2008 and fused with the other network



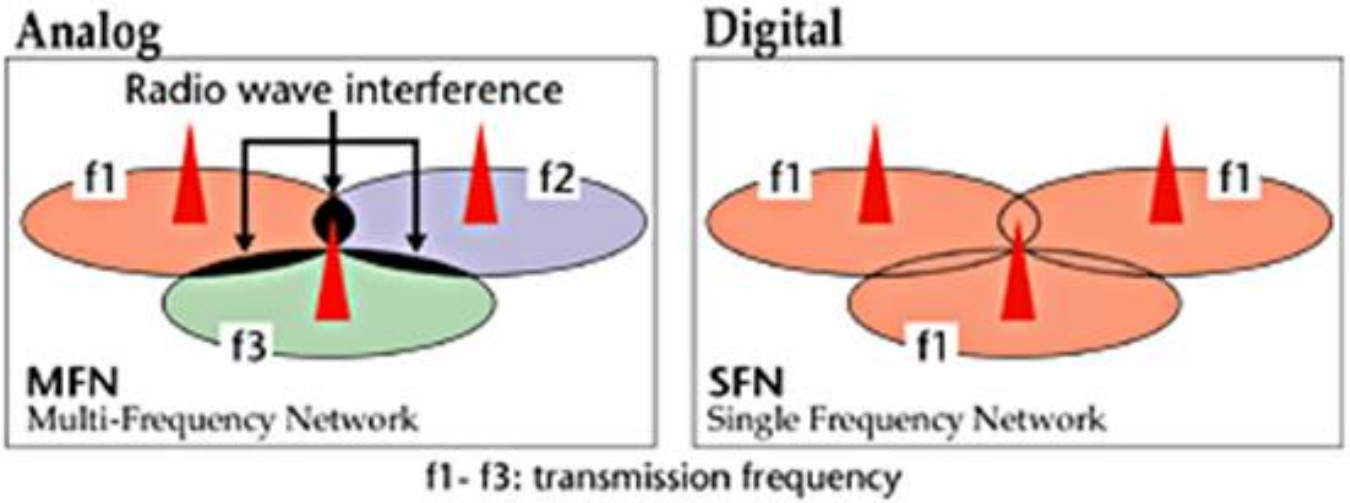
Terrestrial Transmission Interferences: the Multipath Effect





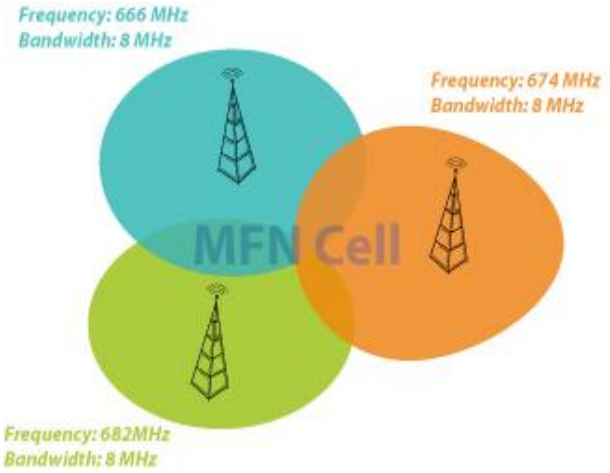
Replicas are received with different delays !

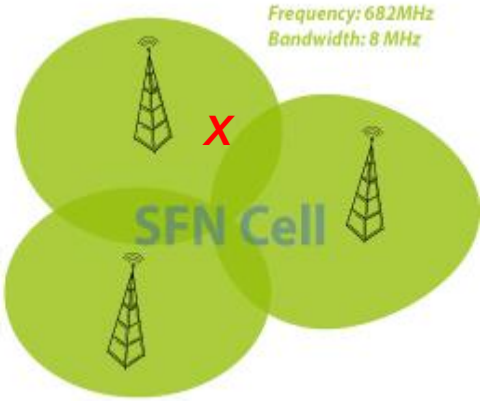
Multiple versus Single Frequency Networks

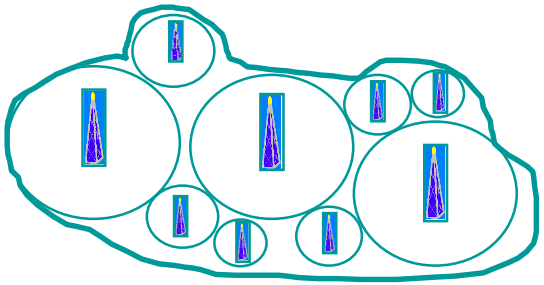


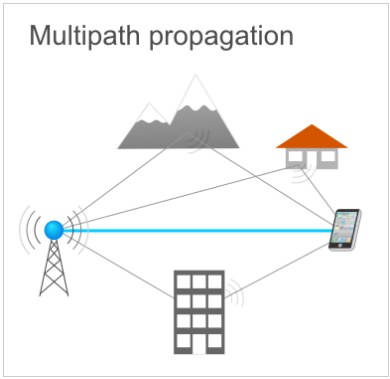
- **In analogue reception, the user tunes the best 'behaving' frequency for a certain TV channel (from different emitters); this also involves orienting the antenna in the right direction.**
- **Due to the interference areas, it is not possible to use the same frequency for all cells in analogue TV as this could much degrade the reception quality.**
- **In digital Single Frequency Networks (SFN), all transmitters within some area can transmit the same TV channel on the same frequency.**

Digital Multiple and Single Frequency Networks





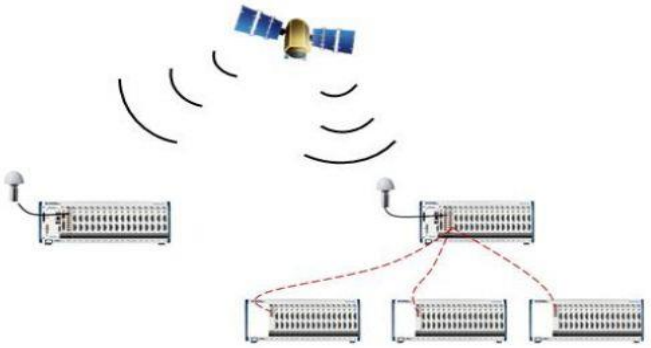




- **In SFN, it is not only important to 'filter' the signals from the other transmitters using an well oriented antenna with an adequate radiation diagram but it is also essential to deal with the associated multipath delays.**
- **While the SFN operation significantly contributes to the efficient use of the radio frequency spectrum, it requires addressing the multipath interferences.**

Single Frequency Networks Synchronization

- **Symbol Synchronization -** To operate within a Single Frequency Network, transmitters must transmit the same data and must be synchronized to transmit the same symbol at any time. The later is achieved by inserting synchronization packets into the MPEG-2 Transport Stream. This allows each transmitter to wait until the indicated time to start broadcasting a particular packet.

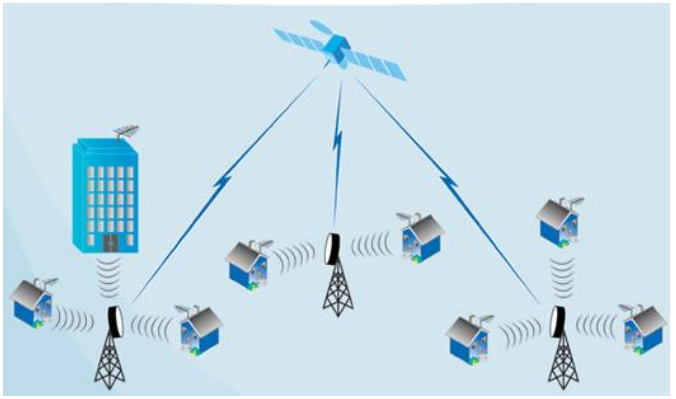


- **SFN Synchronization -** The frequency and timing of transmitters operating in SFN network must also be synchronized. Usually, this is done with a GPS frequency and time reference. This allows the network to reach the accuracy and stability needed for SFN synchronization - *better than 1 Hz in the frequency domain and 1 microsecond in the time domain*.

TÉCNICO LISBOA

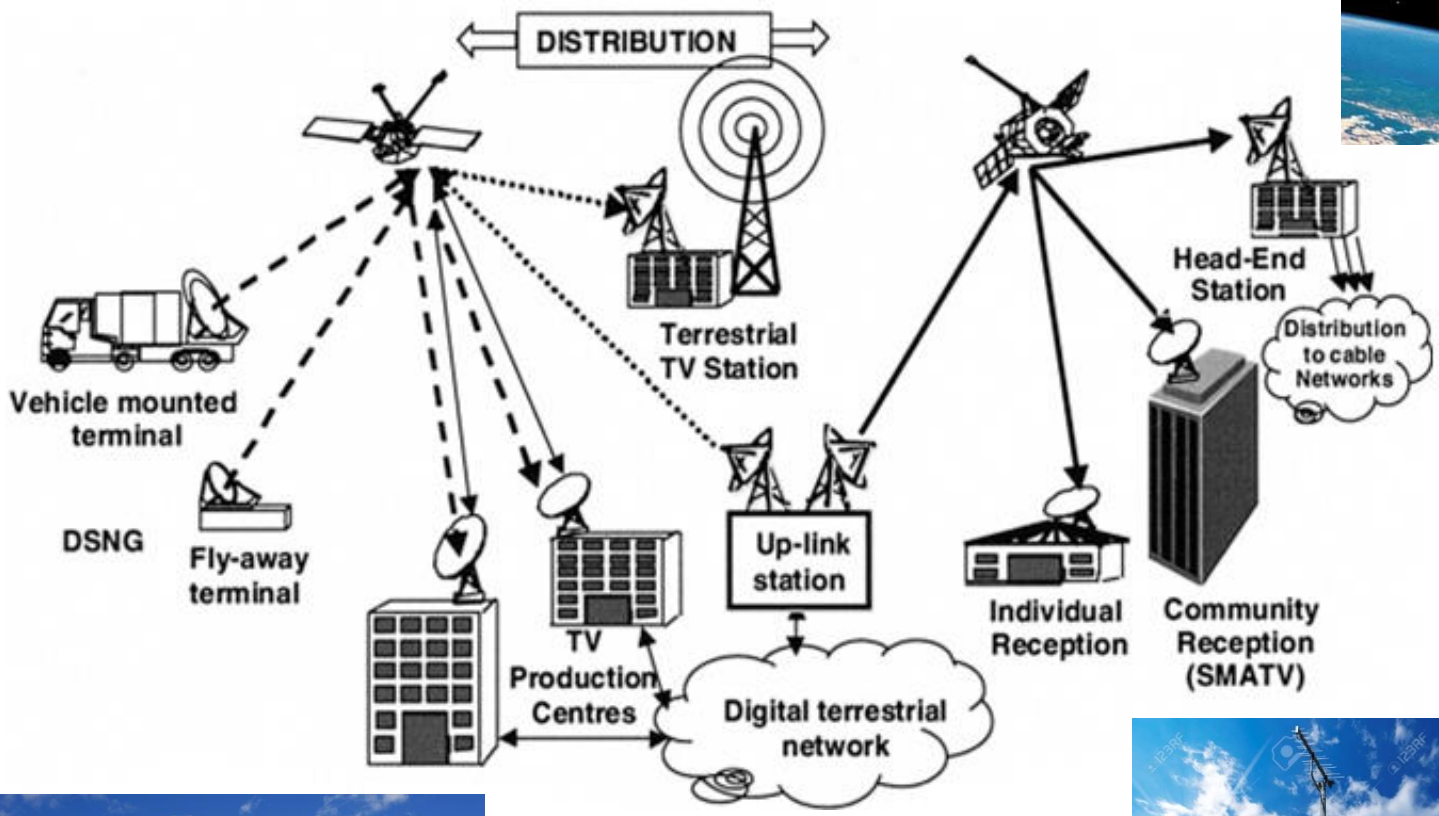
Satellite Broadcasting

Satellite Broadcasting



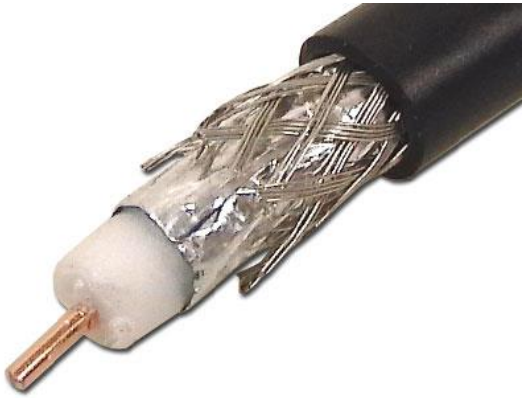
- **Satellite broadcasting is the distribution of multimedia content or broadcast signals over or through a satellite network.**
- **The broadcast signals usually originate from a station such as a TV or radio station and then are sent via a satellite uplink (uploaded) to a geo-stationary artificial satellite for redistribution or retransmission to other predetermined geographic locations through an open or a secure channel.**
- **Downlinks are then received by base stations such as small home satellite dishes or by base stations owned by the local cable network for redistribution to their customers.**
- **Satellite broadcasting involves long distances, and thus high signal attenuation and delay.**

TÉCNICO LISBOA



TÉCNICO LISBOA

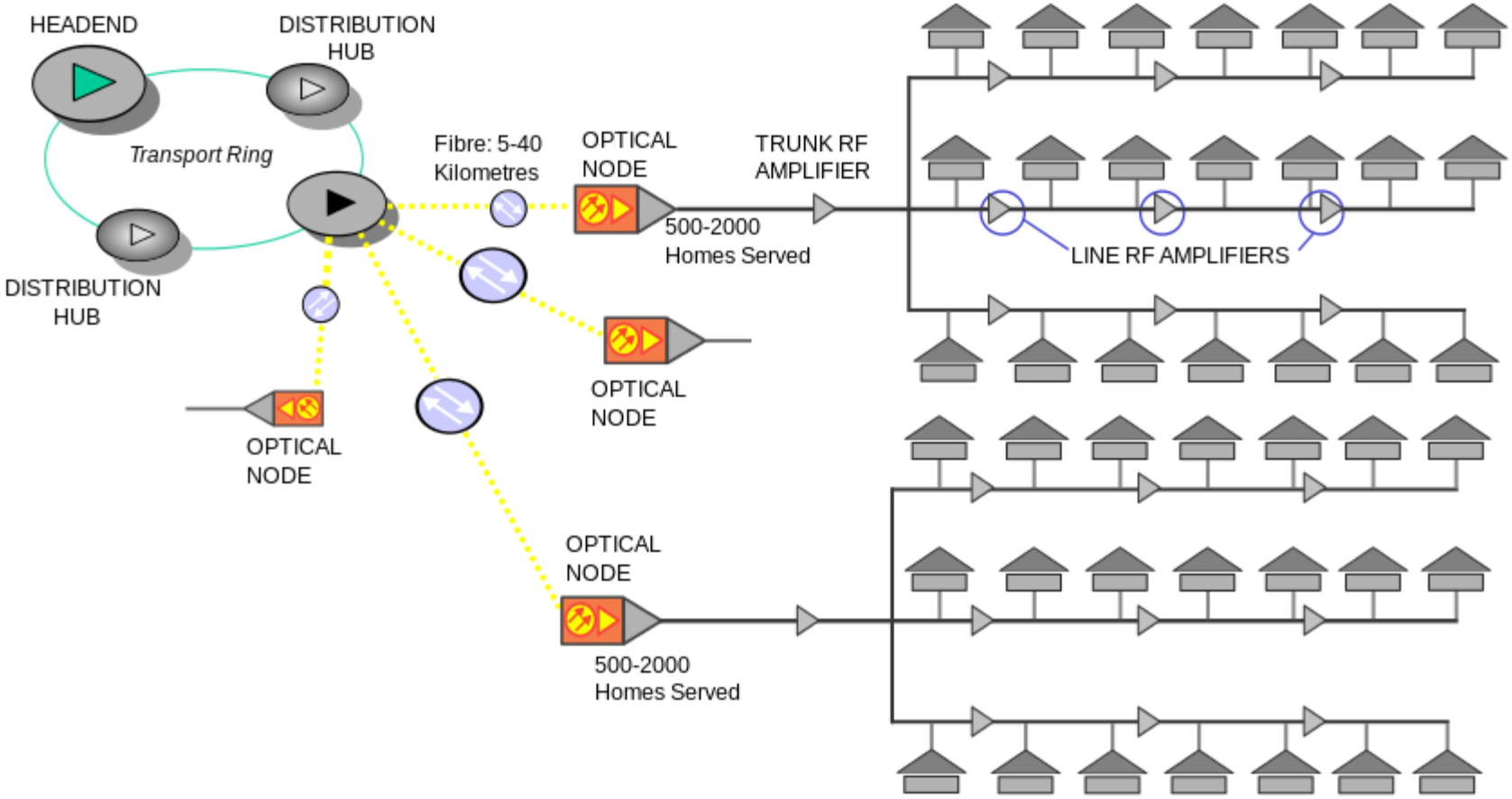
Cable Broadcasting



Cable Broadcasting

- **Cable television is a system of delivering television programming, usually to paying subscribers, via radio frequency (RF) signals transmitted through coaxial cables, or in more recent systems, light pulses through fiber-optic cables.**
- **Coaxial cables are capable of bi-directional carriage of signals as well as the transmission of large amounts of data.**
- **Analog cable television was standard in the 20th century, but since the 2000s, cable systems have been upgraded to digital cable operation.**
- **Traditional cable television providers and traditional telecommunication companies increasingly compete in providing voice, video and data services to residences. The combination of television, telephone and Internet access is commonly called "*triple play*".**

Hybrid Fiber-Coaxial Cable TV System

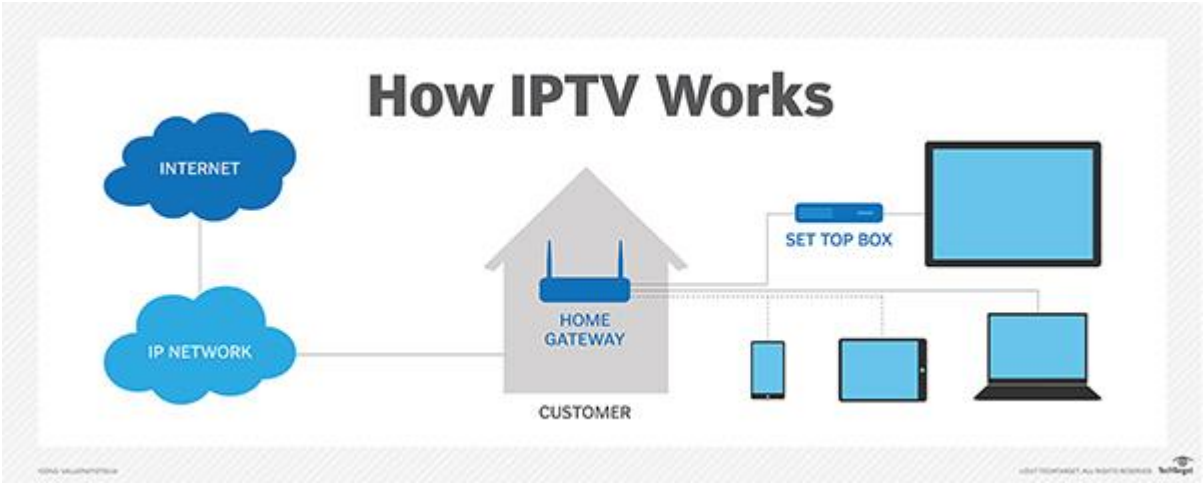


Data Over Cable Service Interface Specification (DOCSIS)

- **Data Over Cable Service Interface Specification is an international telecommunications standard that permits the addition of high-bandwidth data transfer to an existing cable TV (CATV) system.**
- **It is employed by many cable television operators to provide Internet access (see cable Internet) over their existing hybrid fiber-coaxial (HFC) infrastructure.**
- **DOCSIS divides the fiber and cable bandwidth into multiple 6-MHz wide channels. These channels were a perfect fit for the original analog TV; over time, they have been used to carry digital TV.**
- **DOCSIS 3.0 uses 256 QAM and bonds four 6-MHz channels together, so maximum speed is 152 Mbits/s downstream and 108 Mbits/s upstream.**
- **When you switch channels, what you're actually doing is "tuning in" to the various frequencies included in your cable plan.**

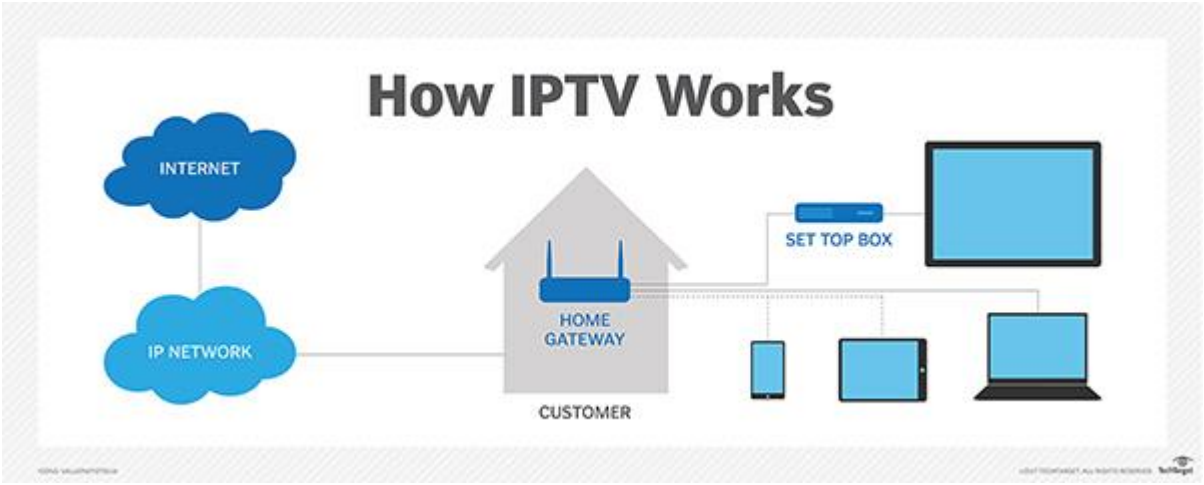
TÉCNICO LISBOA

Managed Networks: IPTV



TÉCNICO LISBOA

Managed Networks: IPTV



IPTV …

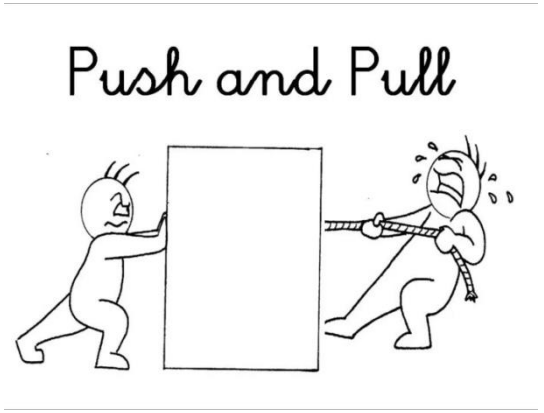
- **IPTV is a service provided by some carriers in a business model similar to that used by the cable TV industry.**
- **IPTV content is often delivered over a managed or dedicated network.**
- **Compared to the public Internet, a private network gives network operators more control over the video traffic and, by extension, the ability to ensure quality of service (QoS), uptime and reliability.**
- **IPTV primarily uses IP multicasting with Internet Group Management Protocol (IGMP) for live television broadcasts and Real-Time Streaming Protocol (RTSP) for on-demand programs.**
- **Because IPTV uses a packet-based delivery system, it can be bundled with other IP-based services, such as voice over IP (VoIP) and high-speed internet.**

Cable Broadcasting versus IPTV

- **Cable networks were originally one-way networks deployed on purposes while IPTV used the incumbent two-way telecommunications network.**

- **In cable networks, all programming is broadcast simultaneously; the program signals flow downstream, and the viewer selects a program by changing the channel (*push approach*). An IPTV service, sends only one program at a time. Content remains on the service provider's network, and only the program the customer selects is sent to the residence (*pull approach*).**

- **In cable networks, typically broadband signal, QAM modulated is used. In IPTV, a lower bandwidth, baseband, DSL signal is used.**



TÉCNICO LISBOA

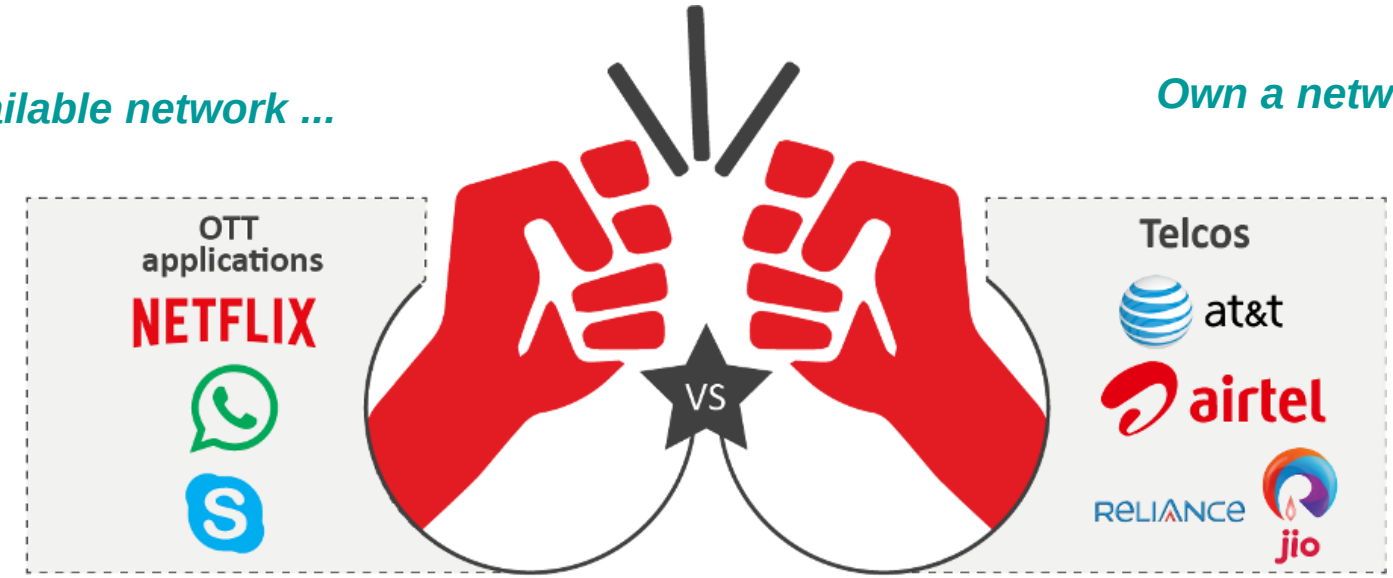
Unmanaged Networks: Internet/OTT TV

Managed versus Unmanaged: A Modern War

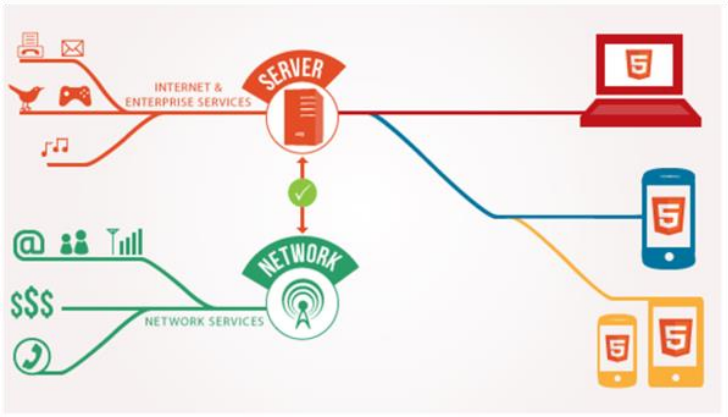
A Modern War …

Use an available network ...

Own a network ...



OTT vs. Telcos



Internet/OTT Television

- **Internet television is the digital distribution of television content via the public Internet (which also carries other types of data).**
- **Internet television is a type of over-the-top (OTT) content which is the delivery of audio, video, and other media over the Internet without the involvement of an operator in the control or distribution of the content.**
- **Quality control mechanisms are critical …**
- **The receiver must have an Internet connection and could be:**
  - A web browser running on a personal computer or mobile device
  - A mobile app running on a smartphone or tablet computer
  - A SmartTV which has Internet capability and built-in software accessed with the remote control
  - A Video Game Console connected to the internet
  - A DVD player or Blu-ray disc player with Internet capabilities
  - A set-top box or digital video recorder (DVR) provided by the cable or satellite company, which has Internet capabilities

Cable versus OTT TV

	Pay-TV	Netflix
Linear Content	✓	✗
Live Sports Content	✓	✗
Live Content	✓	✗
PVOD Content	✓	✗
VOD Content (Free On-Demand Movies)	✓	✓
Episodic On-Demand Content	✓	✓*
Pay-Per-View Content	✓	✗
Premium Channels/Packages	✓	✗

*While Netflix has episodic on-demand content, and with the exception of Netflix's own original content, the episodic content typically is a season or two behind.

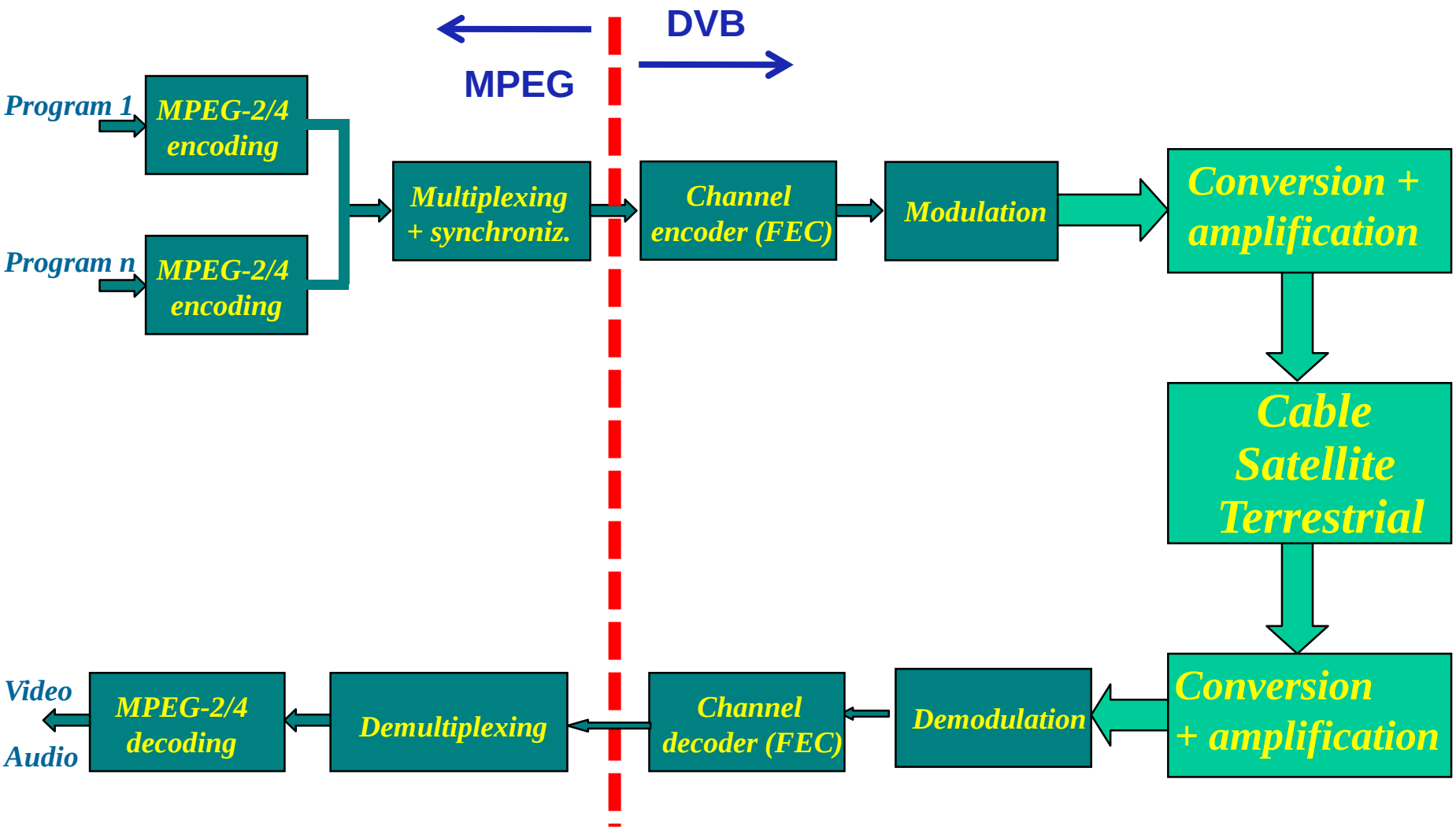
TÉCNICO LISBOA

Mobile TV

Mobile Television …

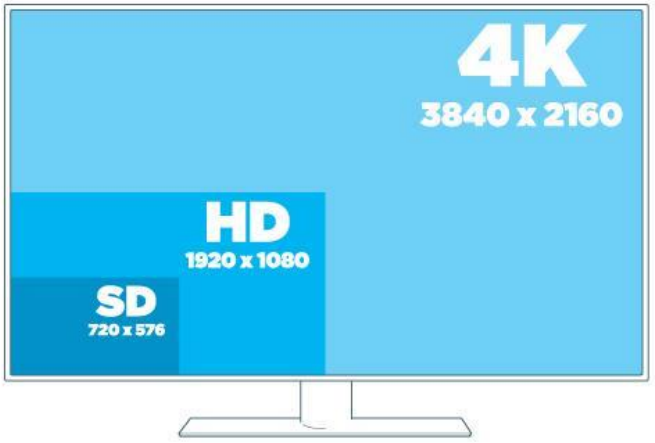
- **Mobile television is television watched on a small handheld or mobile device.**
- **Mobile TV (free and pay TV) may happen through**
  - **Terrestrial television broadcasting networks, DVB-T and DVB-H**
  - **Mobile communication networks**
- **Regular broadcast standards or special mobile TV transmission formats can be used, notably due to bandwidth constraints.**
- **Additional features include downloading TV programs and podcasts from the Internet and storing programming for later viewing.**
- **Battery consumption is always a problem …**

The Digital TV Chain ...

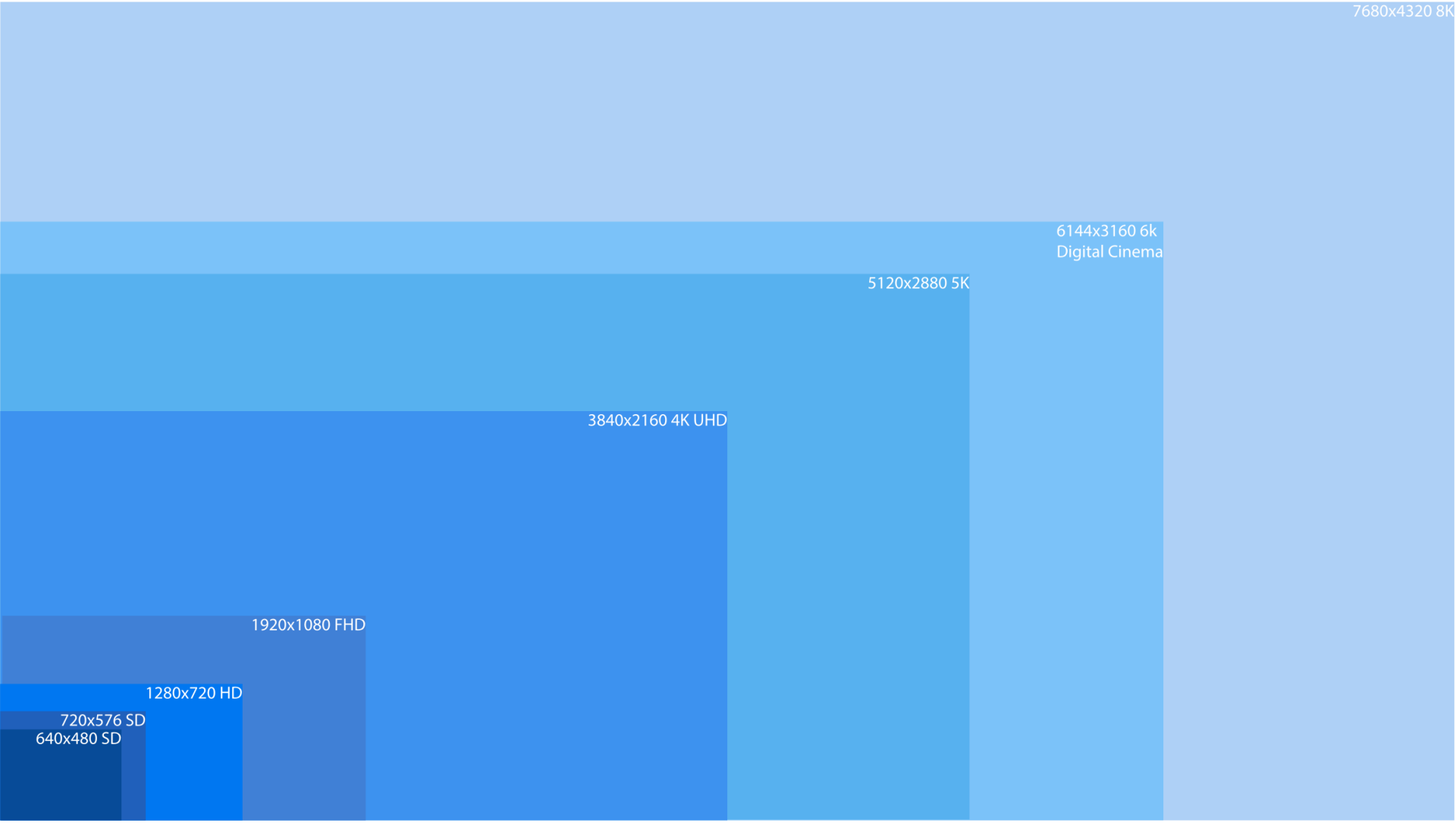


Digital TV Generations

- 1st Generation (past)
  - Standard definition (SD)
  - MPEG-2 Video coding
- 2nd Generation (present)
  - High definition (HD)
  - H.264/AVC (MPEG-4 Part 10) coding
- 3rd Generation (future)
  - Ultra high definition, 4K (UHD)
  - HEVC coding



TÉCNICO LISBOA



The DVB Specifications

The DVB specifications – which are also *ETSI standards* – define all the modules in the TV delivery chain needing a normative specification; this is made both by using available standards defined by other standardization bodies and developing new (DVB) specifications.

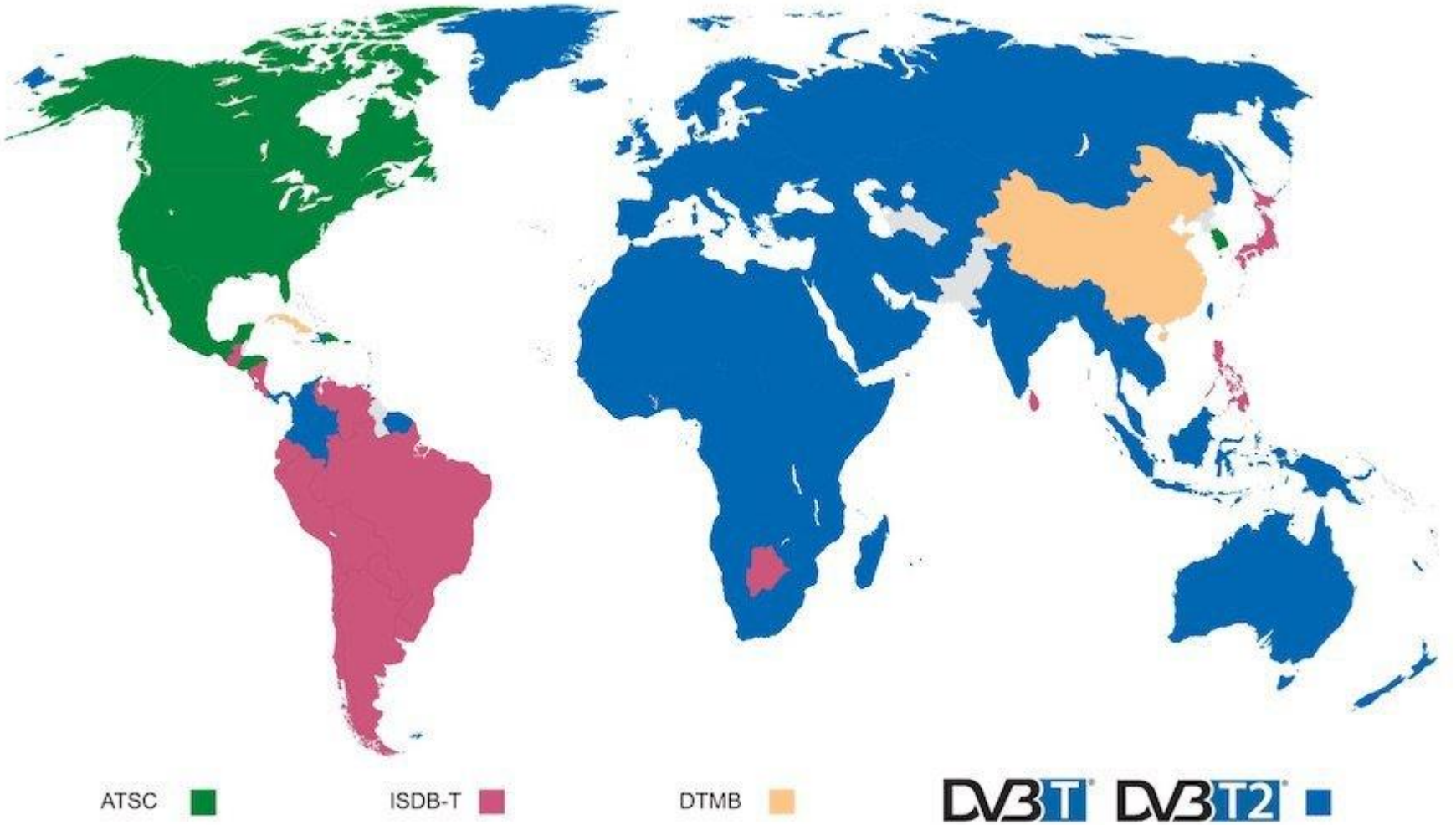
The main modules specified are:

- **Audio and Video Source Coding -** MPEG-2 Audio and MPEG-2 Video are adopted; later also H.264/AVC and HEVC have been adopted
- **Synchronization and Multiplexing -** MPEG-2 Systems is adopted
- **Channel Coding**
- **Modulation**
- **Conditional Access (partly)**

The Digital Video Broadcasting Scenarios and Standards

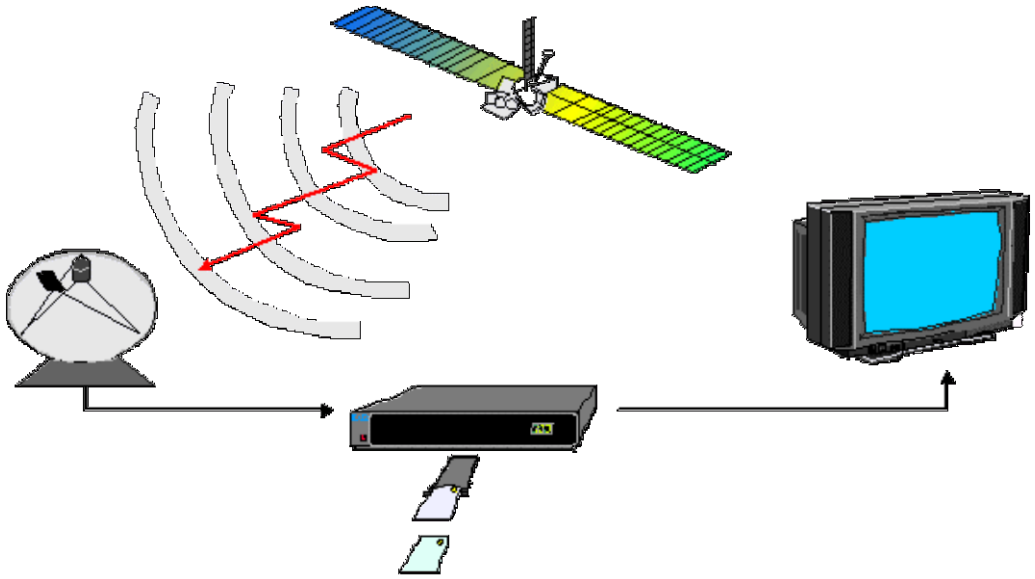
- **Cable: DVB-C (1994), DVB-C2 (2008)**
- **Satellite: DVB-S (1997), DVB-S2 (2005)**
- **Terrestrial: DVB-T (1997), DVB-T2 (2008)**
- **DVB-MHP (Multimedia Home Platform, 2000) –** middleware tools allowing to use a single set-top box for all services and applications (hardware abstraction)
- **Portable: DVB-H (2004)**
- **...**

DVB-T: Adoption …



TÉCNICO LISBOA

MPEG-2 Standard



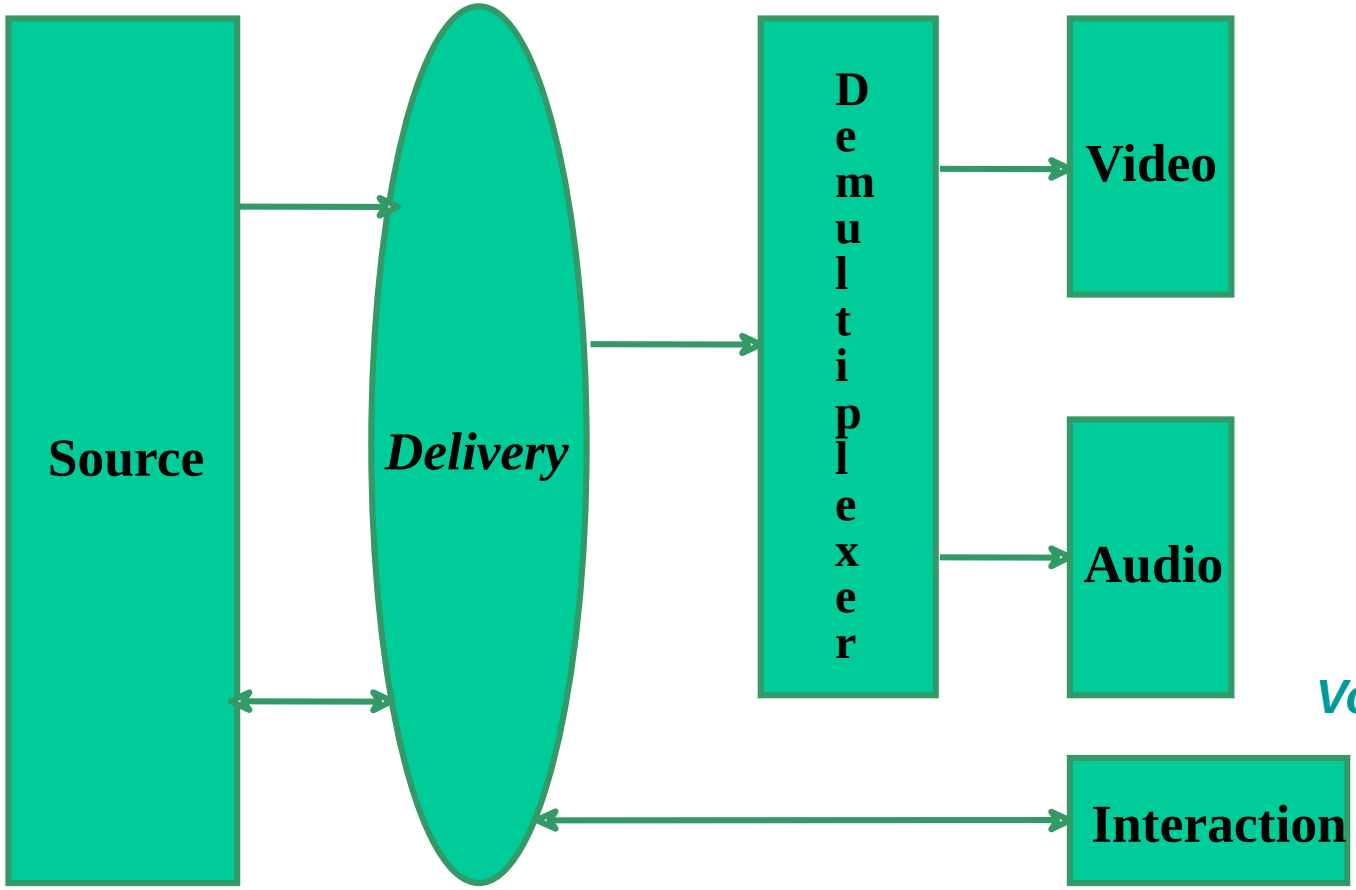
MPEG-2: Objectivos

Generic Coding of Moving Pictures and Associated Audio

Audio and video coding for high quality transmission and storage, e.g. high and medium definition television.

- **The ISO/IEC MPEG-2 Video standard is a joint development with ITU-T where it is designated as Recommendation H.262.**
- **The MPEG-2 standard should have covered audiovisual coding up to 10 Mbit/s, leaving to MPEG-3 the higher rates and definitions. However, since the MPEG-2 standard addressed well the HDTV space, MPEG-3 was never defined and MPEG-2 lost its upper bitrate limit.**

MPEG-2: The Service Model



VoD, Video on Demand

MPEG-2: Applications

- **More channels due to the more efficient usage of the available bandwidth (mainly determined by coding and modulation)**
- **Cable, satellite, terrestrial digital TV**
- **HDTV, Stereoscopic TV**
- ***Pay per view, Video on demand, Tele-shopping***
- **Games**
- **Storage, p.e. DVD**
- **…**
- **High quality personal communications**

MPEG-2 Standard: Organization

- **Part 1 - SYSTEMS** – Specified the multiplexing, synchronization and protection of coded elementary bitstreams (audio, video and data).
- **Part 2 - VIDEO** – Specifies the coded representation of video signals.
- **Part 3 - AUDIO** - Specifies the coded representation of audio signals.
- **Part 4 – CONFORMANCE TESTING** – Specifies compliance tests for decoders and streams.
- **Part 5 – REFERENCE SOFTWARE** – Includes software implementing the technical specification parts.
- **Part 6 - DSM-CC (Digital Storage Media – Command Control)** - Specifies user management and control protocols; they constitute and extension of the Systems parts.

TÉCNICO LISBOA

MPEG-2 Standard

Part 1: Systems

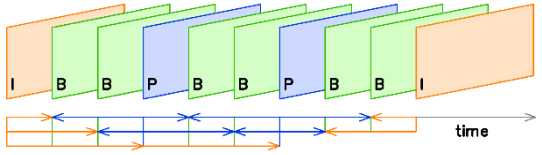
MPEG-2 Systems: Objective

MPEG-2 Systems has the basic objective to combine and synchronize one or more coded audio and video bitstreams in a single multiplexed bitstream.

The main objectives of this standards regard:

- **Multiplexing of various streams, e.g. audio and video from one program or several programs together**
- **Synchronization between streams, e.g. audio and video from one program or several programs**

Synchronization



IBBPBBP …

IPBBPBBP …

Video data

Video Buffer

Decoder Control via PTS, DTS

AUs

Video decoder

MPEG-2 Systems stream

DEMUX

SCR

Systems Time Clock Generator

STC

A frame X may have a PTS after frame Y but its DTS is before Y … e.g. P frames when B frames are used

Audio Buffer

Decoder Control via PTS

AUs

Audio decoder

Audio data

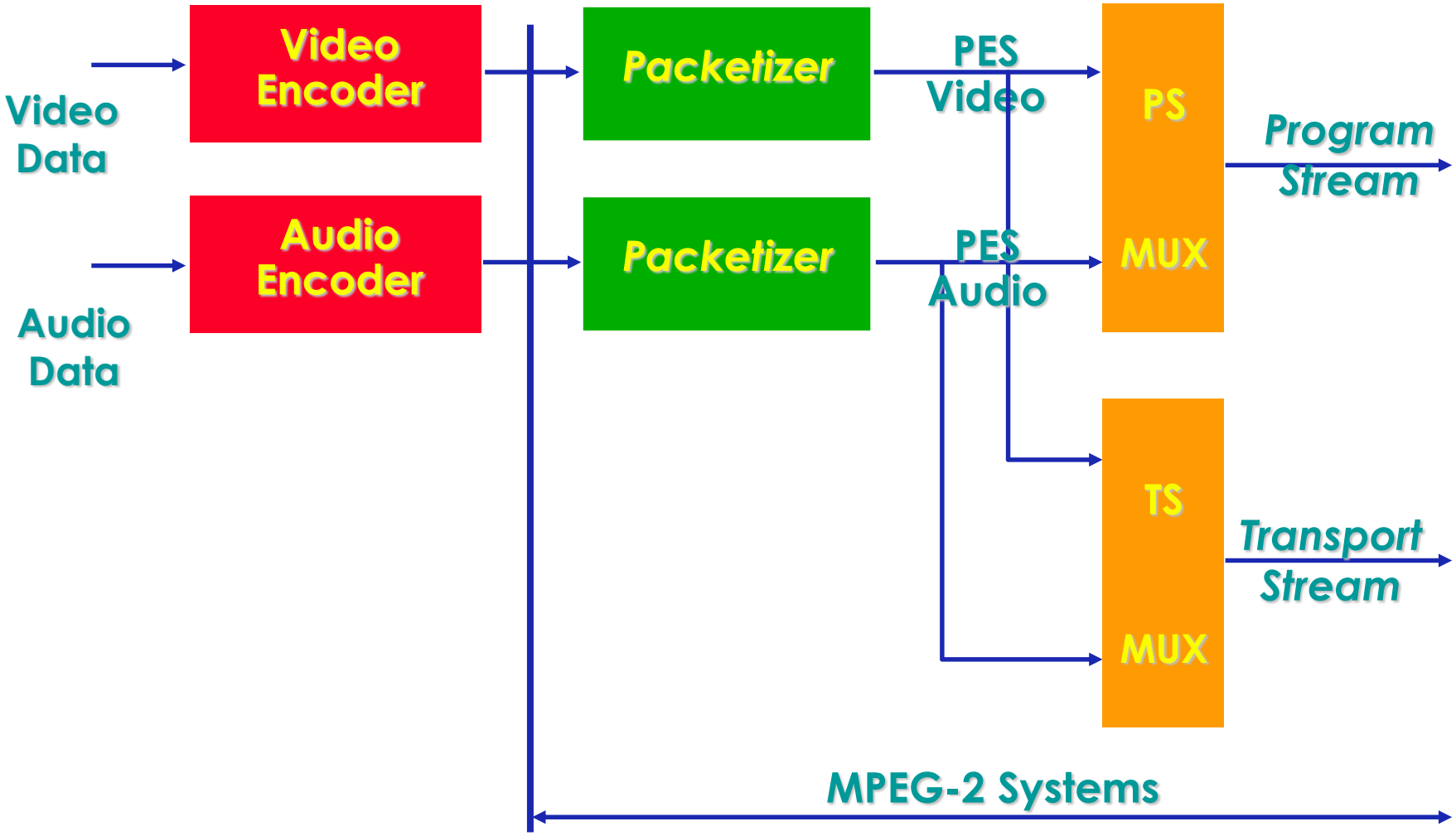
DTS - Decoding Time Stamp

SCR - System Clock Reference (SCR)

PTS - Presentation Time Stamp

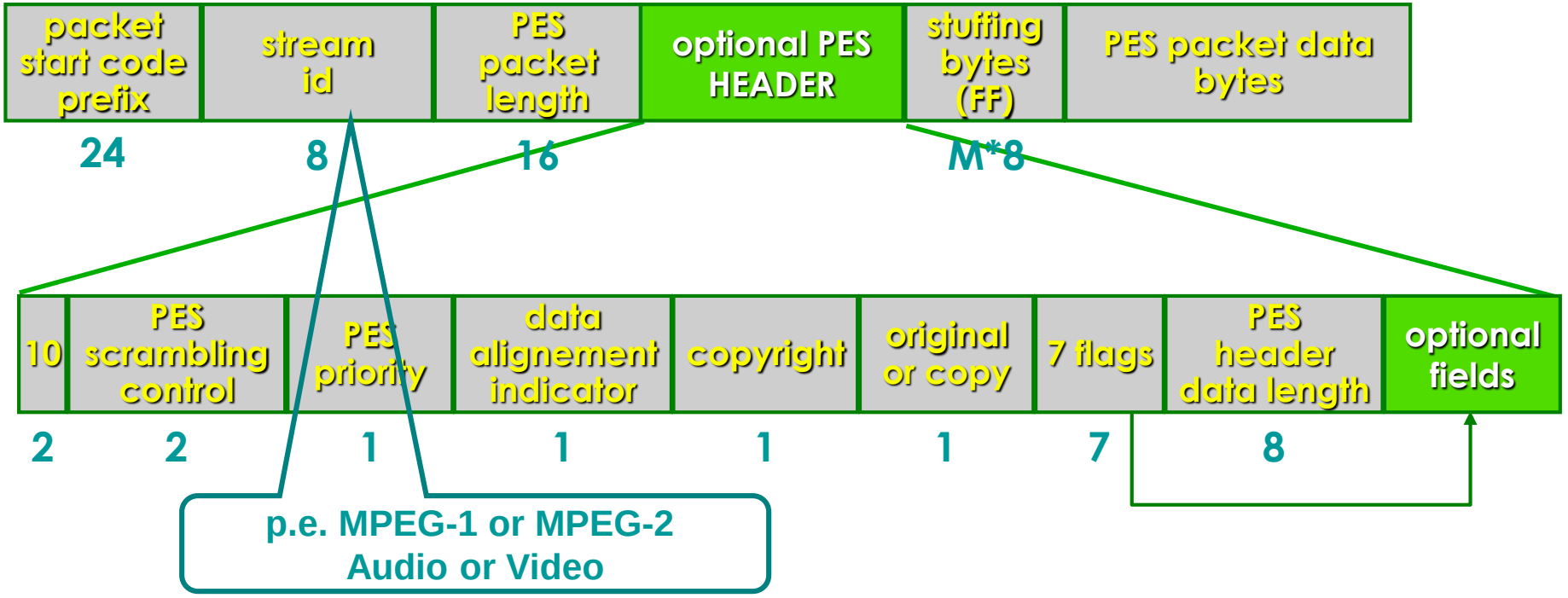
STC – System Time Clock

MPEG-2 Systems: Basic Architecture



Packetized Elementary Streams (PESs) & Packet Syntax

The audio and video coded elementary streams are divided into variable length packets - *the packets* – creating the so-called *Packetized Elementary Streams* (PESs), as for MPEG-1 Systems.

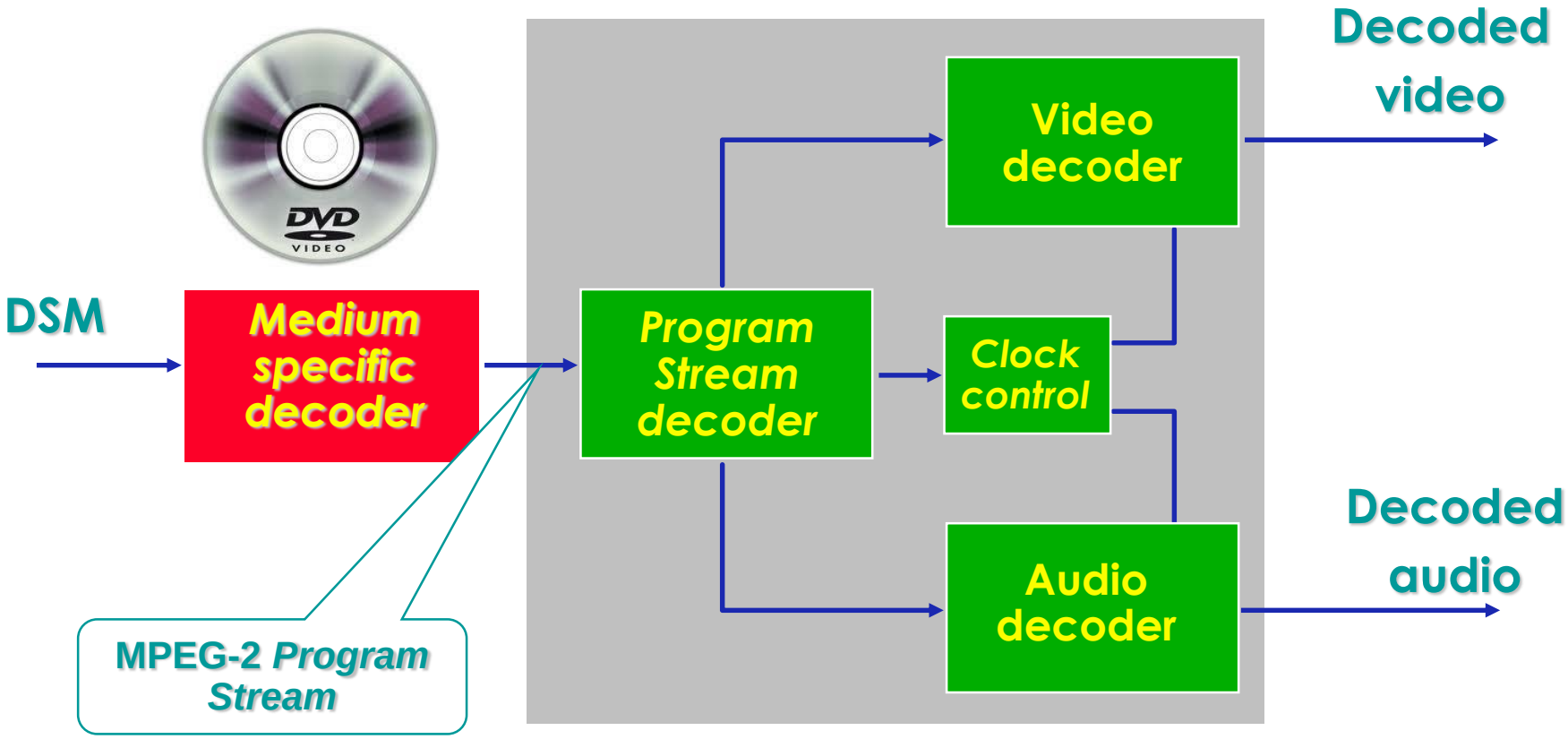


Program Stream and Transport Stream

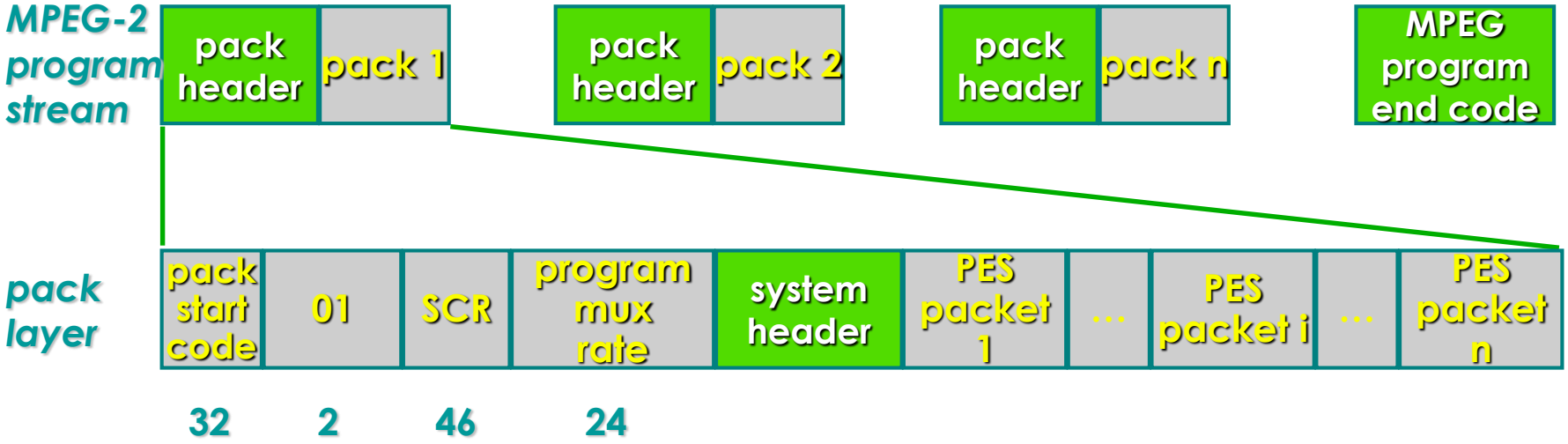
- **Program Stream:**
  - Stream with a single time base for all multiplexed streams
  - Variable length packets as for MPEG-1 Systems
  - Adequate for transmission and storage in channels virtually without errors (BER < 10^{-10}), e.g. CD-ROM, DVD, hard disks

- **Transport Stream:**
  - Stream may include several time bases to combine programs with different time bases; however, each PES has a single time base
  - Packets with a fixed length of 188 bytes
  - Adequate for transmission in error prone channels (BER > 10^{-4}), e.g.. broadcasting

Decoding Program Streams …

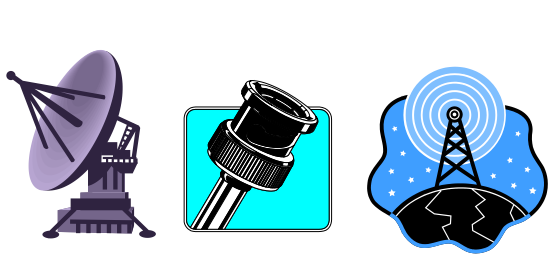


Program Stream Syntax



MPEG-2 Program Streams are similar to MPEG-1 Systems streams.

Decoding Transport Streams …



Data Link

Data Link specific decoder

Transport Stream demultiplex and decode

Video decoder

Clock control

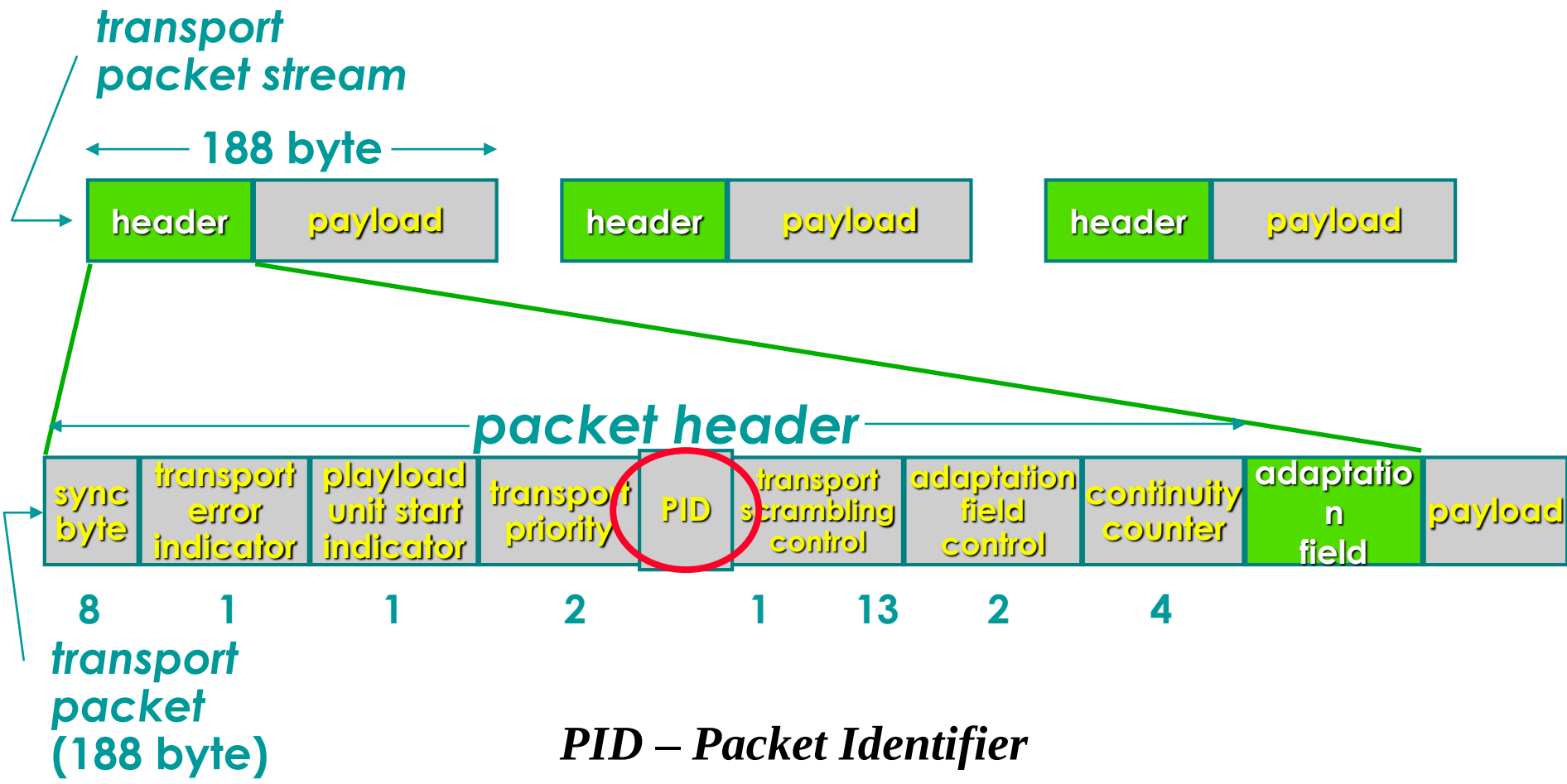
Audio decoder

Decoded video

Decoded audio

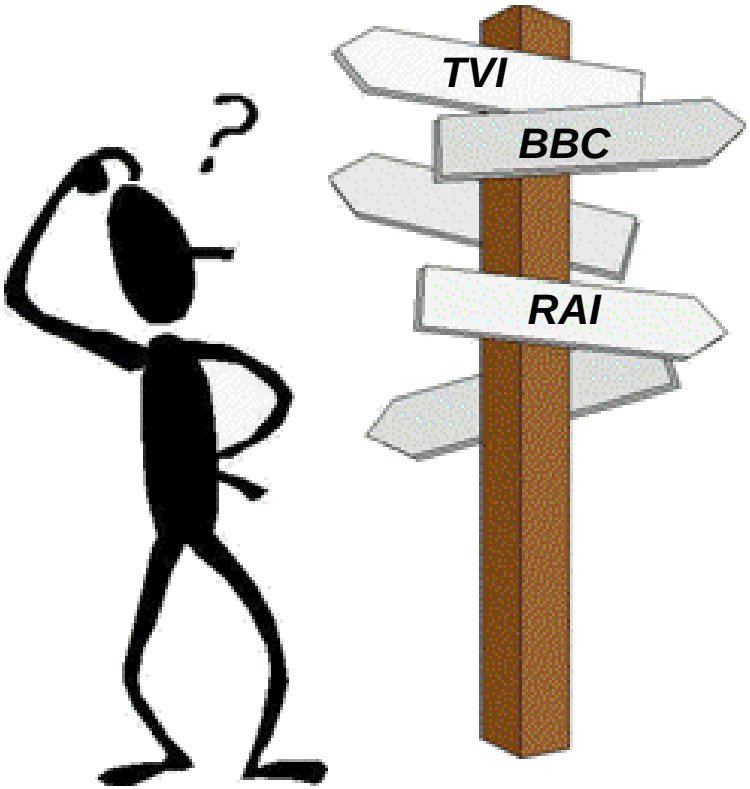
MPEG-2 Transport Stream with 1 or more programs

Transport Stream Syntax



PID – Packet Identifier

‘Surviving in the Labyrinth’ …



For a user to find the elementary streams he/she needs in a MPEG-2 Transport Stream, e.g. audio and video for RTP 2 or SIC, some help, this means some auxiliary data, is needed !

Program Specific Information (PSI)

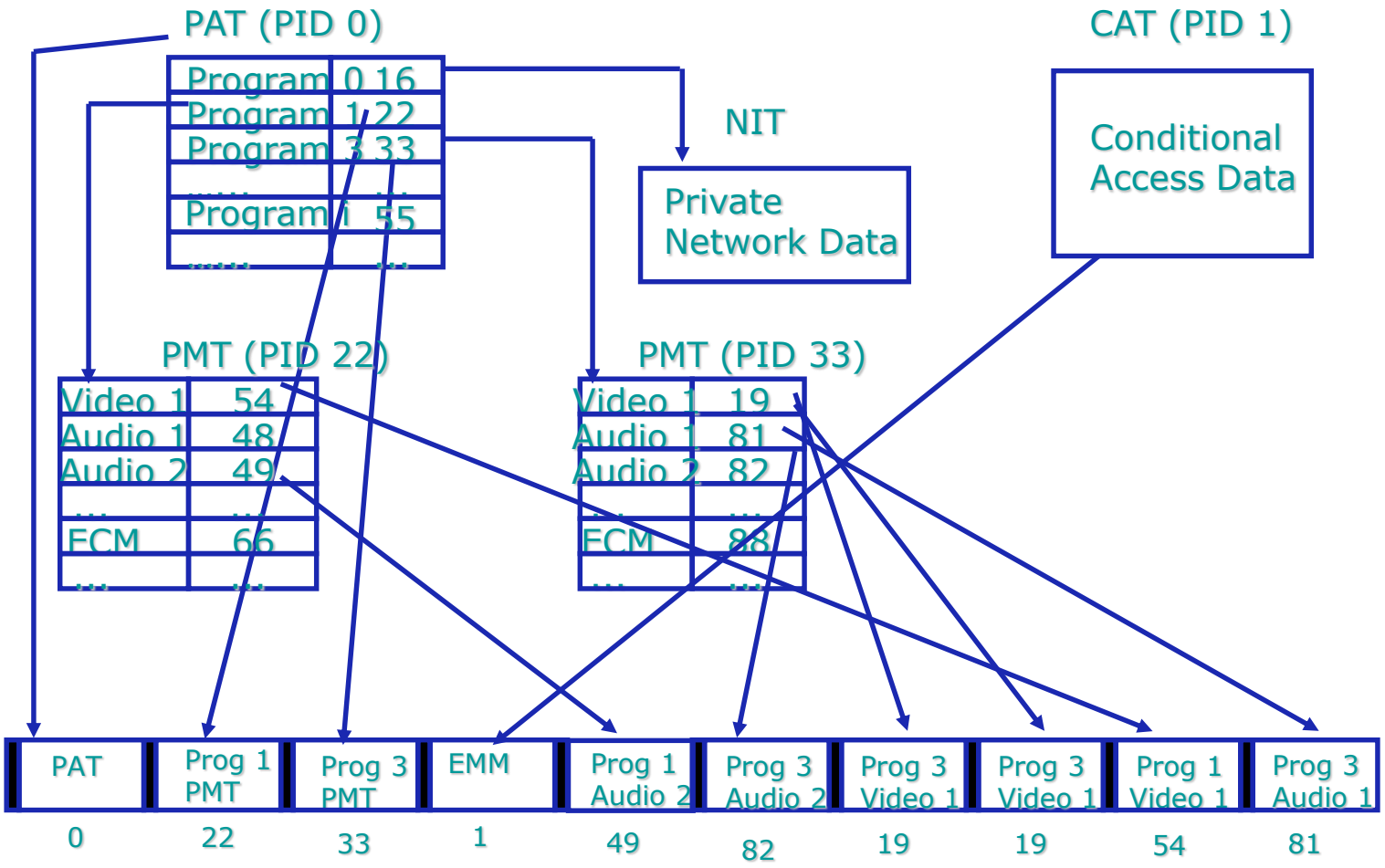
***Program Specific Information* (PSI) is delivered in the *transport stream* 'showing the path in the labyrinth'.**

- **PSI is carried using 4 tables (corresponding to a small bitrate budget)**
- **Each table is repeated many times (in a *carroussel*), e.g. 10-50/s, and corresponds to a different PID**
- **Tables are only applicable to Transport Streams (not Program Streams)**
- **A common syntax is defined to segment and carry the tables in Transport Packets (with 188 bytes)**
- **The syntax allows a clean and backward compatible strategy to possibly extend the current standard with new tables, both standardized or privately (e.g. DVB) defined**

Transport Stream PSI Tables

- ***Program Association Table* (PAT) – Corresponds to PID 0x00 and is mandatory; it contains the PIDs for the PMTs corresponding to each program in each transport stream; it also contains the PID for the NIT.**
- ***Program Map Table* (PMT) – Each PMT indicates the PIDs corresponding to the elementary streams for each program; it is always *on the clear* even if the programs are encrypted.**
- ***Conditional Access Table* (CAT) – Corresponds to PID 0x01 and contains the PIDs for the packets with conditional access data, e.g. corresponding to the DVB tables with the access keys for the encrypted programs.**
- ***Network Information Table* (NIT) – Information about the network, e.g. the frequency for each RF channel (only the syntax is defined in MPEG-2).**

Relation between PSI Tables ...



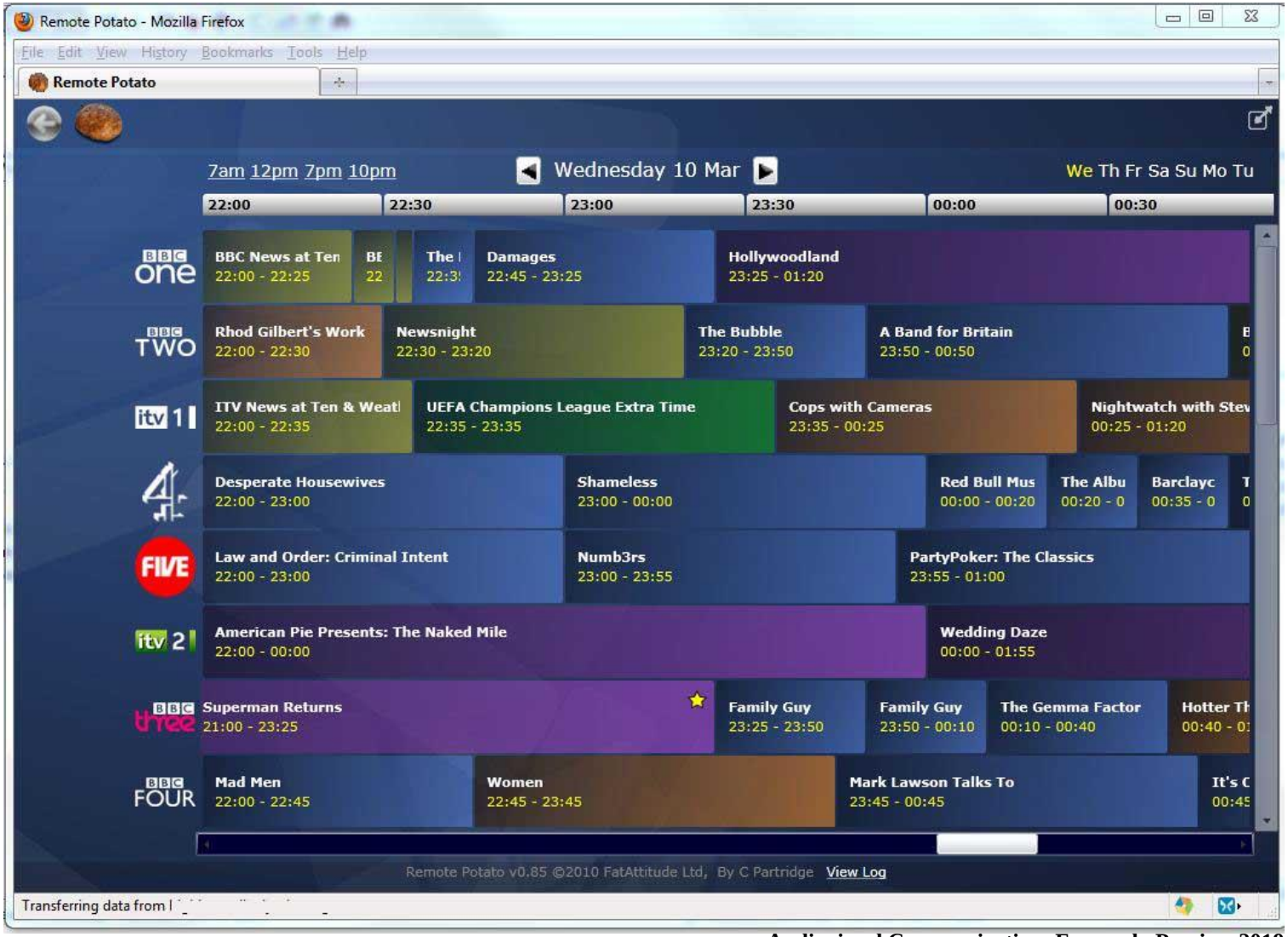
DVB Service Information (SI) Tables

DVB specifies additional tables which, among other things, allow the receiver to automatically configure itself and the user to navigate using an electronic program guide (EPG).

- **Service Description Table (SDT)** – Includes the names and parameters for the services in the multiplexed stream.
- **Event Information Table (EIT)** – Includes information related to events (current and future) in the same stream or in other multiplexed streams.
- **Time and Date Table (TDT)** – Allows to update the internal clock of the set-top box.
- **Bouquet Association Table (BAT)** – Allows to group services in bouquets; one program may be part of one or more bouquets.
- **Running Status Table (RST)** – Serves to update the situation of some events.
- **Stuffing Table (ST)** - Serves to substitute tables that became invalid.

EPG: Program Timelining

Interfaces are free (non-normative) and depend on the set-top box manufacturers !



DVB-SI Content Descriptor excerpt

Description
undefined content
Movie/Drama:
movie/drama (general)
detective/thriller
adventure/western/war
science fiction/fantasy/horror
comedy
soap/melodrama/folkloric
romance
serious/classical/religious/historical movie/drama
adult movie/drama
reserved for future use
user defined
News/Current affairs:
news/current affairs (general)
news/weather report
news magazine
documentary
discussion/interview/debate
reserved for future use
user defined
Show/Game show:
show/game show (general)
game show/quiz/contest
variety show
talk show
reserved for future use
user defined

Description
Sports:
sports (general)
special events (Olympic Games, World Cup etc.)
sports magazines
football/soccer
tennis/squash
team sports (excluding football)
athletics
motor sport
water sport
winter sports
equestrian
martial sports
reserved for future use
user defined
Children's/Youth programmes:
children's/youth programmes (general)
pre-school children's programmes
entertainment programmes for 6 to14
entertainment programmes for 10 to 16
informational/educational/school programmes
cartoons/puppets
reserved for future use
user defined
Music/Ballet/Dance:
music/ballet/dance (general)
rock/pop
serious music/classical music
folk/traditional music
jazz
musical/opera
ballet
reserved for future use
user defined

TÉCNICO LISBOA

MPEG-2 Standard

Part 2: Video

MPEG-2 Video (also H.262): Quality Objectives

The following quality objectives (for standard resolution) have been initially defined:

- **Secondary distribution – For broadcasting to the users, the signal quality at 3-5 Mbit/s must be better, or at least similar, to the quality of available analogue systems, i.e. PAL, SECAM and NTSC.**

- **Primary distribution – For contribution, e.g. transmission between studios, the signal quality at 8-10 Mbit/s must be similar to the quality of Recommendation ITU-R 601 (using PCM).**

MPEG-2 Video: the Quality

- **The quality requirements depend on the application (thus type of content, e.g. TV and videotelephony are different) and are strongly related to**
  - Resolution (in space and time) of the video signal
  - Bitrate available (and thus compression factor)
- **Screen size, form factor and viewing distance are also important for the final quality of experience.**
- **Other important requirements related to quality:**
  - Quality robustness of the coding scheme to sudden changes of the signal statistics, e.g. scene changes
  - Quality robustness to cascading this means successive coding and decoding processes

MPEG-2 Video: Requirements

- **FORMAT - Both progressive and interlaced (for legacy) formats**
- **RESOLUTION - Large range of spatial and temporal resolutions**
- **CROMA SUBSAMPLING - Several chrominance subsampling formats, e.g. 4:4:4, 4:2:2 and 4:2:0**
- **SPECIAL MODES - Random access for edition and channel hoping, fast modes, conditional access, and easy transcoding to MPEG-1 Video, H.261 and JPEG**
- **RATE VARIABILITY - Flexibility in terms of bitrates, constant or variable**
- **ADAPTABILITY - Flexibility in adapting to different transmission and storage channels, e.g. in terms of synchronization and error resilience**

MPEG-2 Video: the Complexity

The complexity assessment of the encoders and decoders is essential for the adaptation to the technological constraints and adoption by the market.

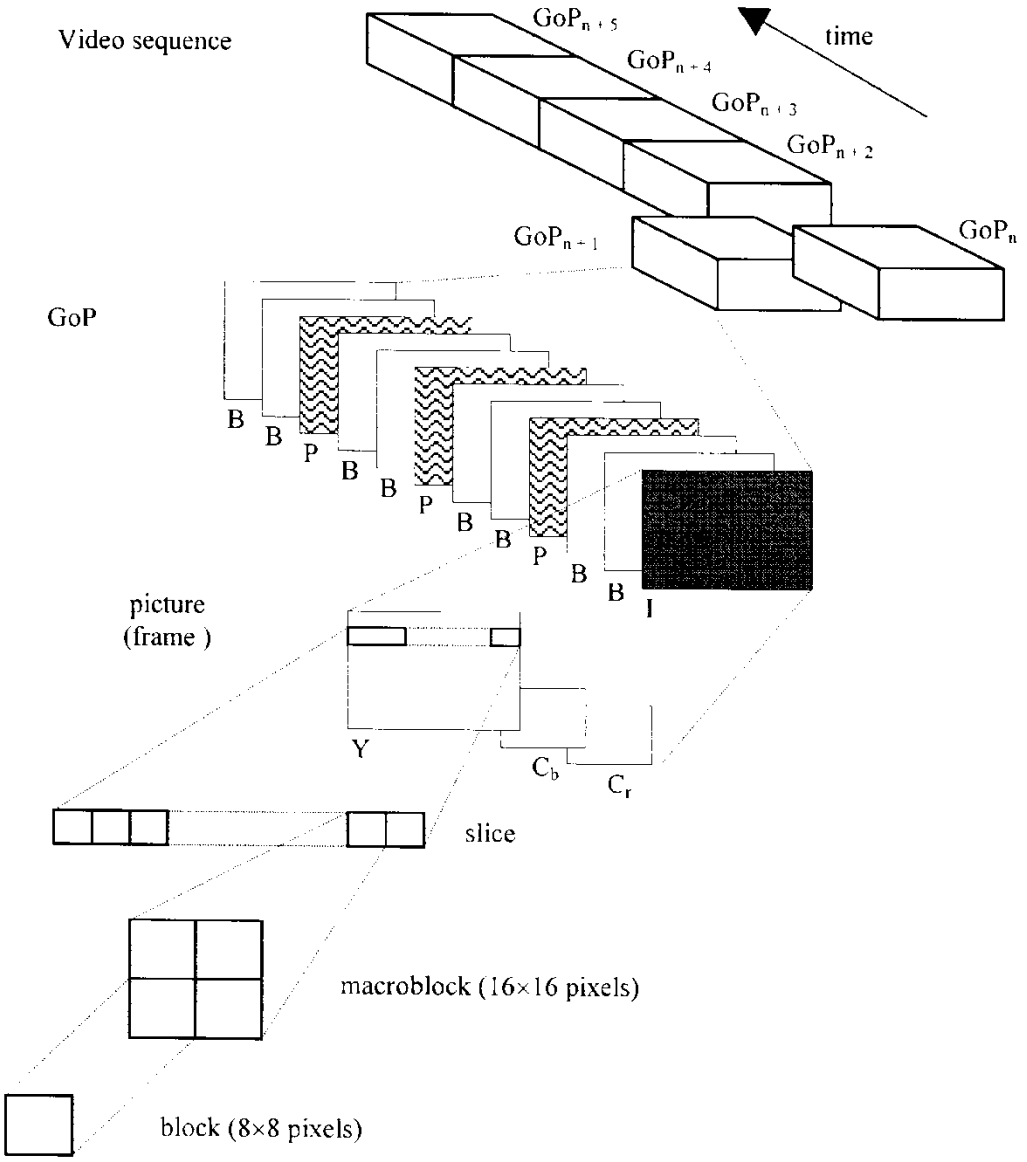
- **Assymmetric Applications** – **For the *one encoder, many decoders* type of applications, it is possible to develop high quality encoders even if at the cost of additional (encoder) complexity since the overall system cost is mainly related to the decoders which should have a reduced complexity (and cost).**
- **Symmetric Applications** – **For the *one to one* type of applications, both the encoders and decoder should have a reasonable (low) complexity.**

The complexity of a codec is assessed based on parameters such as memory size to contain the reference images, required access to memory speed, number of operations per second, size of coding tables and number of coding table accesses per second.

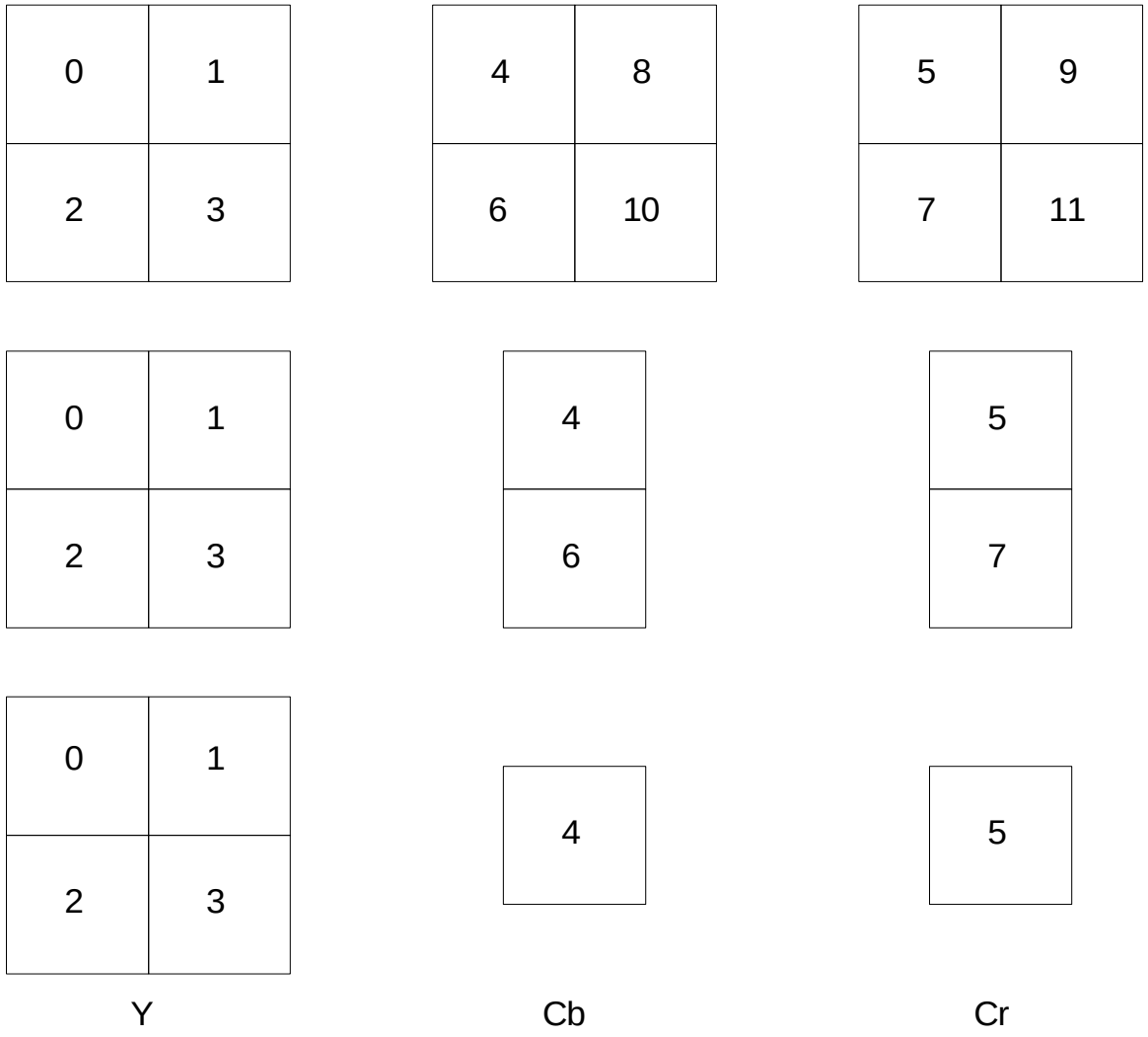
Video Structure

The video data is organized in a structure with 5 hierarchical layers (as for MPEG-1 Video):

- **Sequence**
- **Group of Pictures (GOP)**
- **Picture**
- **Slice**
- **Macroblock (MB)**
- **Block**



Macroblocks in Various Subsampling Formats



MPEG-2 Video: the Core Coding Tools

- **Temporal Redundancy**

Predictive coding: temporal differences and motion compensation (uni and bidirectional; ½ pixel accuracy)

- **Spatial Redundancy**

Transform coding (DCT)

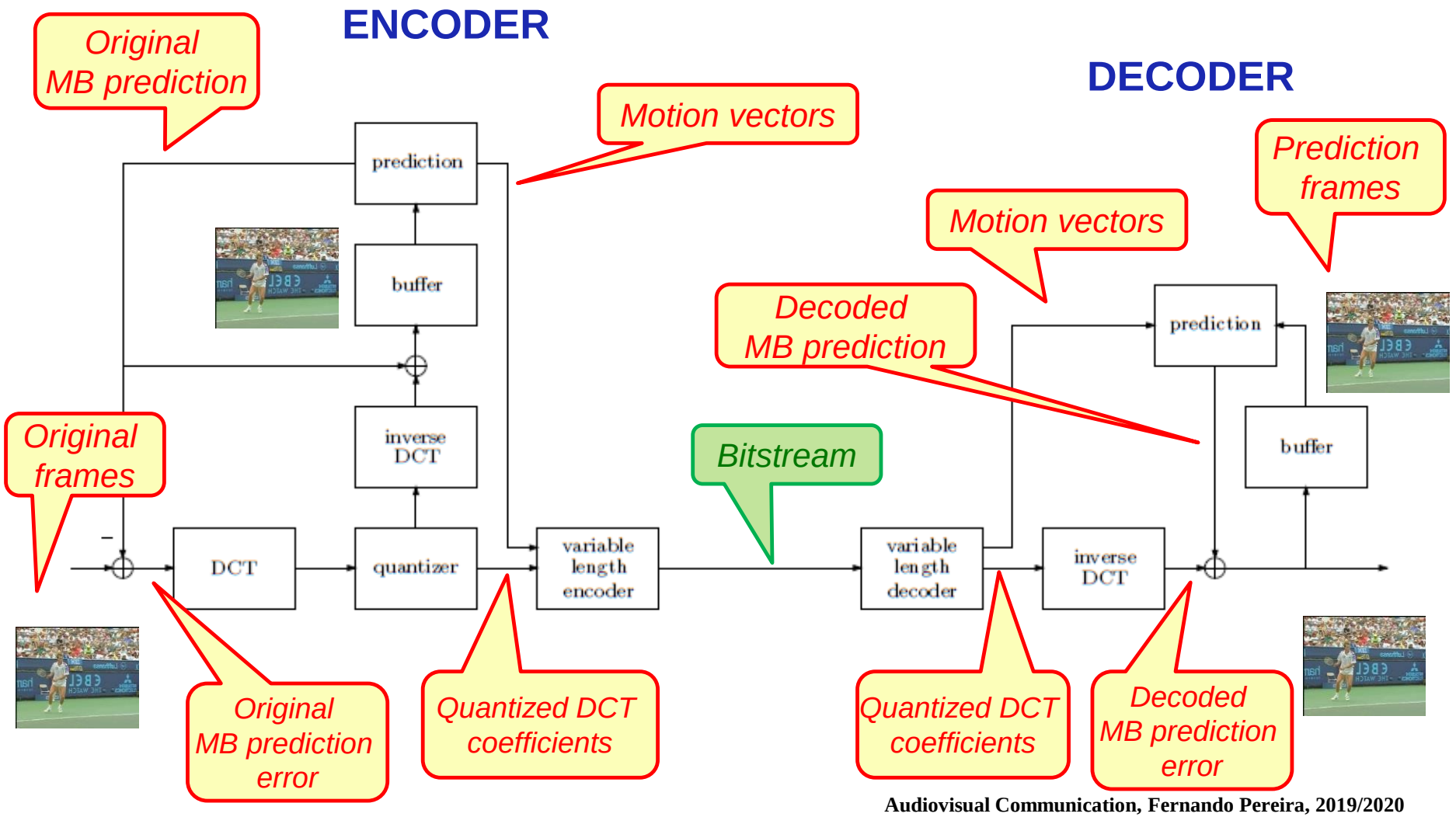
- **Statistical Redundancy**

Huffman entropy coding

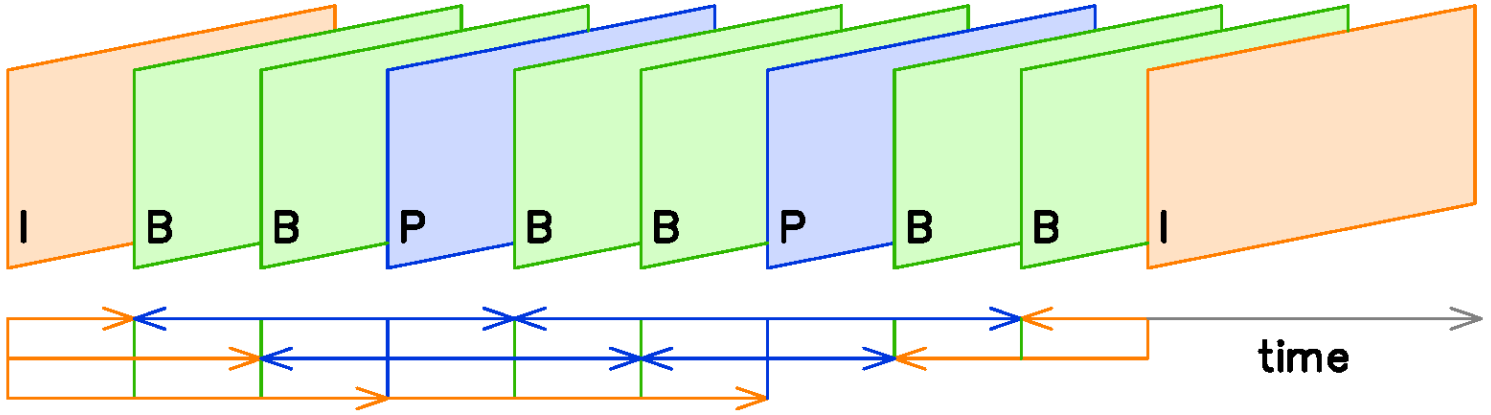
- **Irrelevancy**

DCT coefficients quantization

Starting with the same Architecture …
Buying Quality with Computation, Memory and Delay …



Temporal Prediction Structure



The "conflict" between compression efficiency and random access led to the definition of 3 frame types depending on the used coding tools:

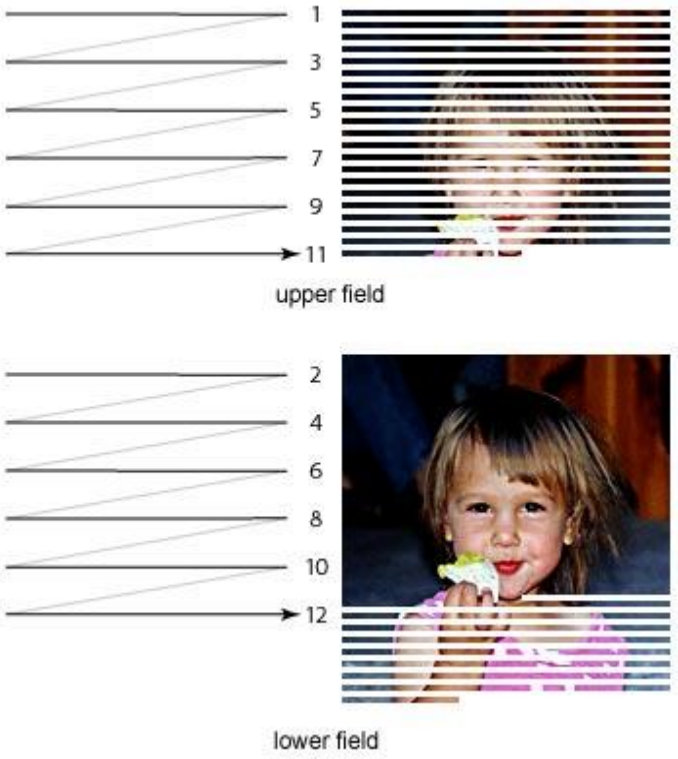
- **Random access: Intra frames (I) – Don't use temporal prediction tools**
- **Compression efficiency:**
  - **Predicted frames (P) – May only use *forward* prediction from previous I/P frame (no algorithmic delay)**
  - **Bidirectionally predicted frames (B) – May use both forward and backward prediction from first previous and first future I/P frame (algorithmic delay)**

MPEG-2 Video versus MPEG-1 Video

The main additions in MPEG-2 Video regarding MPEG-1 Video are:

- **INTERLACING - Coding of interlaced video content; this need is related to the analogue TV legacy (largely used)**

- **SCALABILITY - Scalable coding in (rarely used)**
- **Improved coding efficiency - Different quantization, VLC tables, and additional coefficient scan patterns (largely used)**

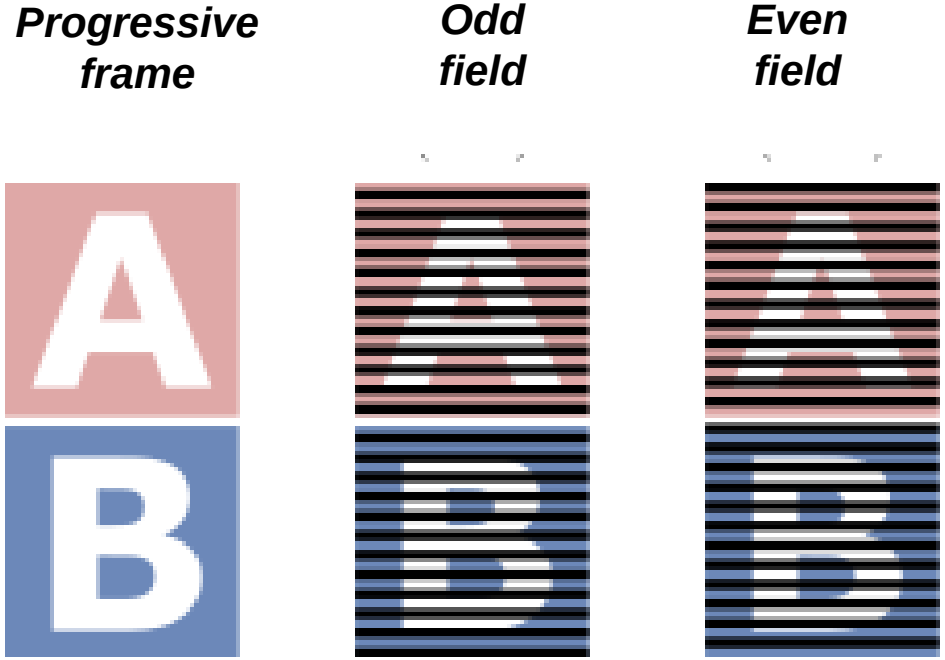


TÉCNICO LISBOA

MPEG-2 Video

Interlaced Coding

TV World: Interlaced versus Progressive

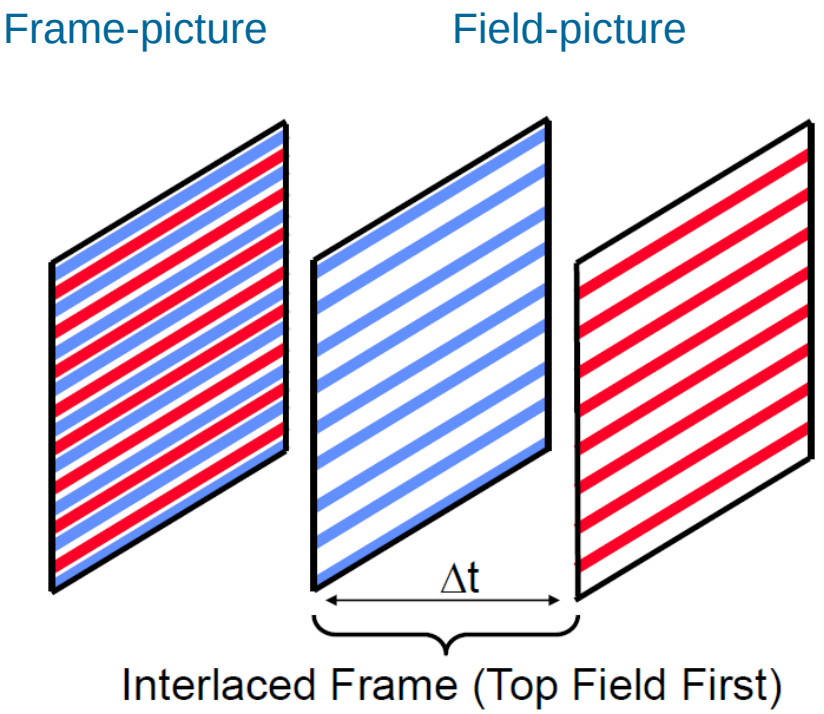


Coding directly the 'deinterlaced' frame as a progressive frame may imply coding many (fake) high frequencies which is very rate expensive !

Interlaced Content Coding

To more efficiently code interlaced content, MPEG-2 Video classifies each coded picture as:

- **Frame-Picture - The MBs to code are defined in the frame resulting from the combination of the 2 fields (top and bottom)**
- **Field-Pictures - The MBs to code are defined within each of the fields (top or bottom) which are independently processed**



Main Prediction Modes

1) Frame-Pictures

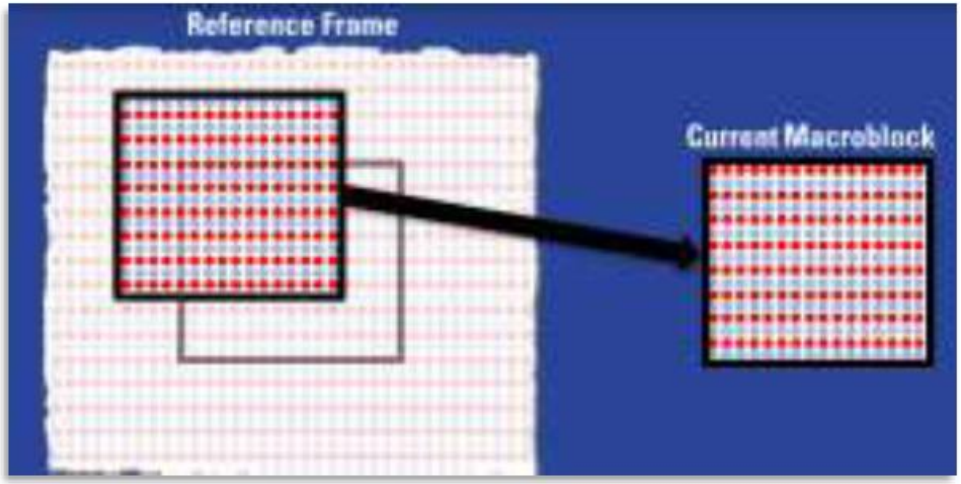
- **Frame Mode for Frame-Pictures** – Similar to MPEG-1 Video, frames are coded as I, P or B frames with current and prediction MBs defined in the frames; gives good results for content with low or moderate motion or pannings over detailed backgrounds.
- **Field Mode for Frame-Pictures** – Each MB in the frame-picture is divided in the pixels corresponding to the top and bottom fields with the predictions coming from 16×8 matrices from one of the fields of the reference pictures.

2) Field Pictures

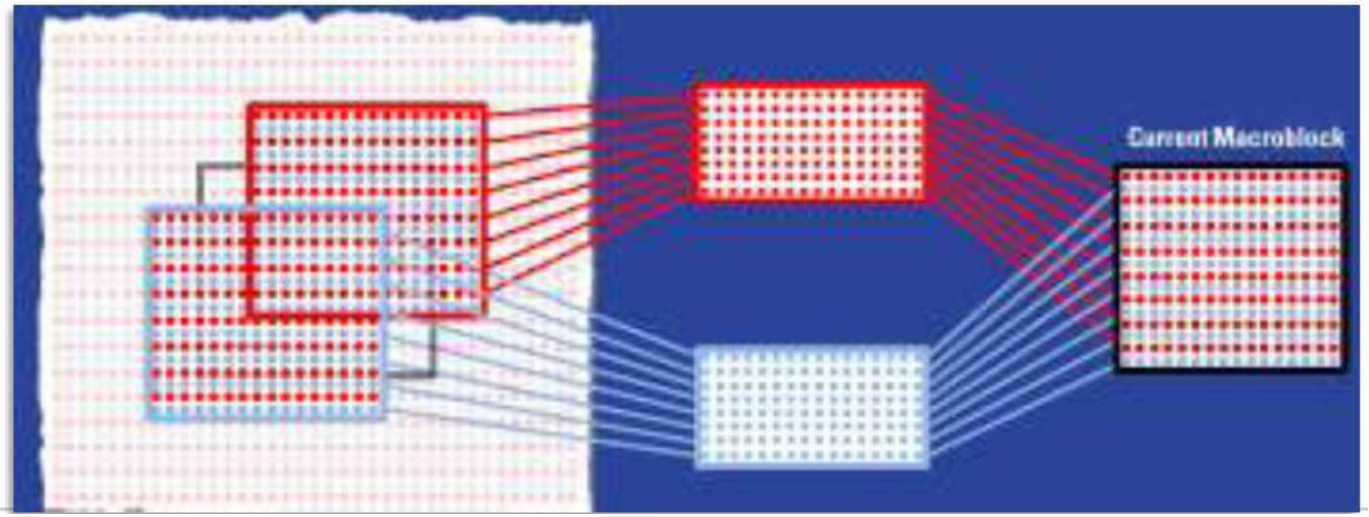
- **Field Mode for Field-Pictures** – Conceptually similar to the previous mode but now with the MBs defined within each field and the predictions also coming from a single field, top or bottom (not necessarily with the same parity).
- **16×8 Blocks for Field-Pictures** – A motion vector is allocated to each half of each MB for each field.

Adaptive Frame/Field Motion Prediction

Frame Mode for Frame-Pictures

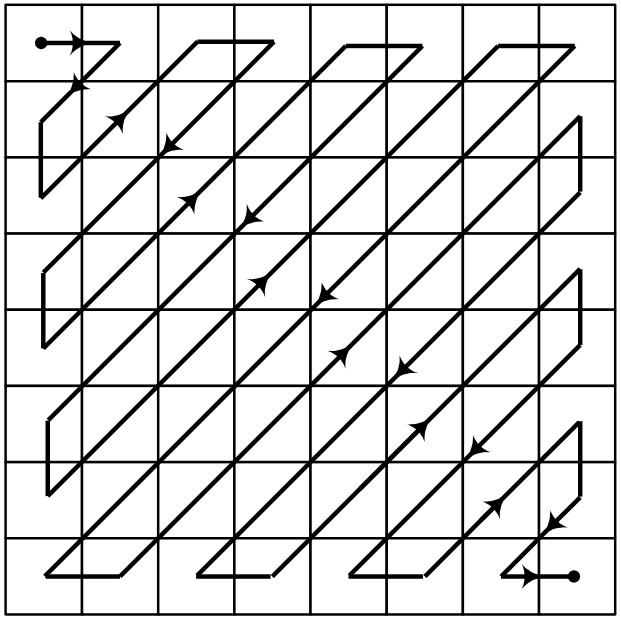


Field Mode for Frame-Pictures

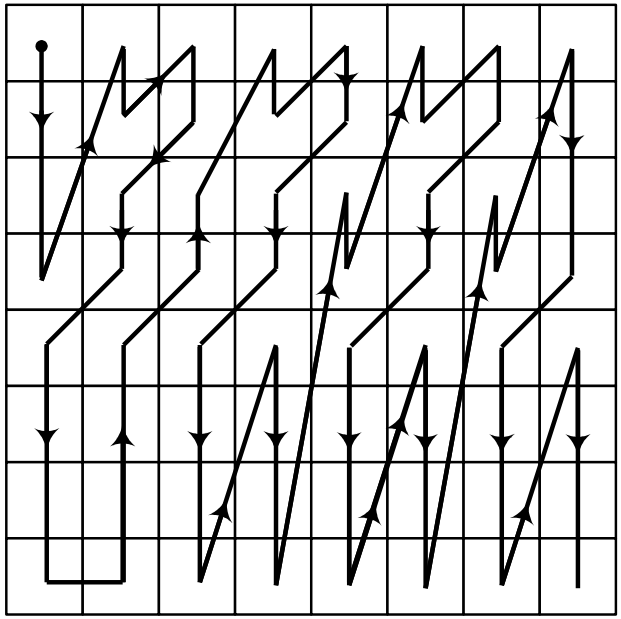


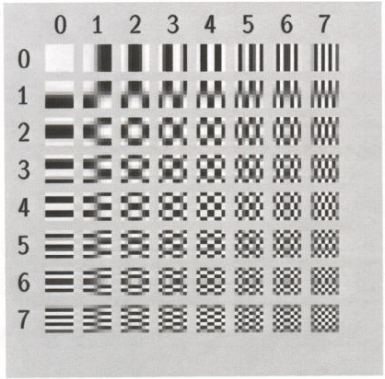
Alternate Scanning Order for Frame Pictures …

Zig-zag order



Alternate order





For frame-pictures, the correlation between lines may be reduced for the pictures with more motion, notably if the frame mode is used (where the 2 fields are mixed).

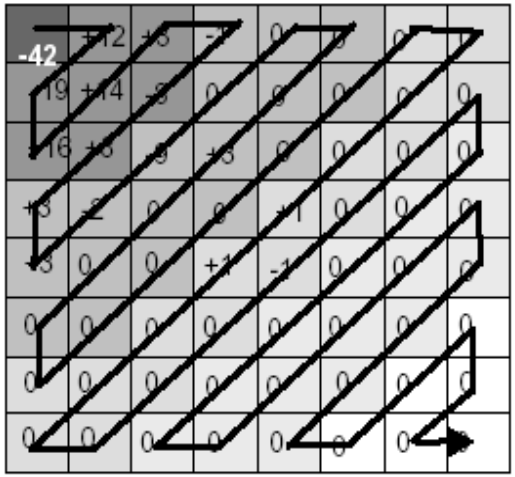
To improve efficiency, it is possible to use an ALTERNATE scanning order where the DCT coefficients corresponding to the vertical transitions (meaning horizontal edges) are privileged in terms of scanning order.

Zig-zag versus Alternate Scanning Orders

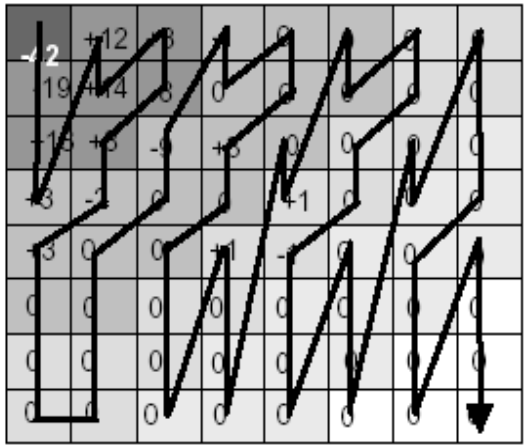
-42	+12	+3	-1	0	0	0	0
-19	+14	-8	0	0	0	0	0
+16	+8	-9	+3	0	0	0	0
+3	-2	0	0	+1	0	0	0
+3	0	0	+1	-1	0	0	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0

Increasing vertical frequency

Increasing horizontal frequency



Zigzag Scan



Vertical Scan

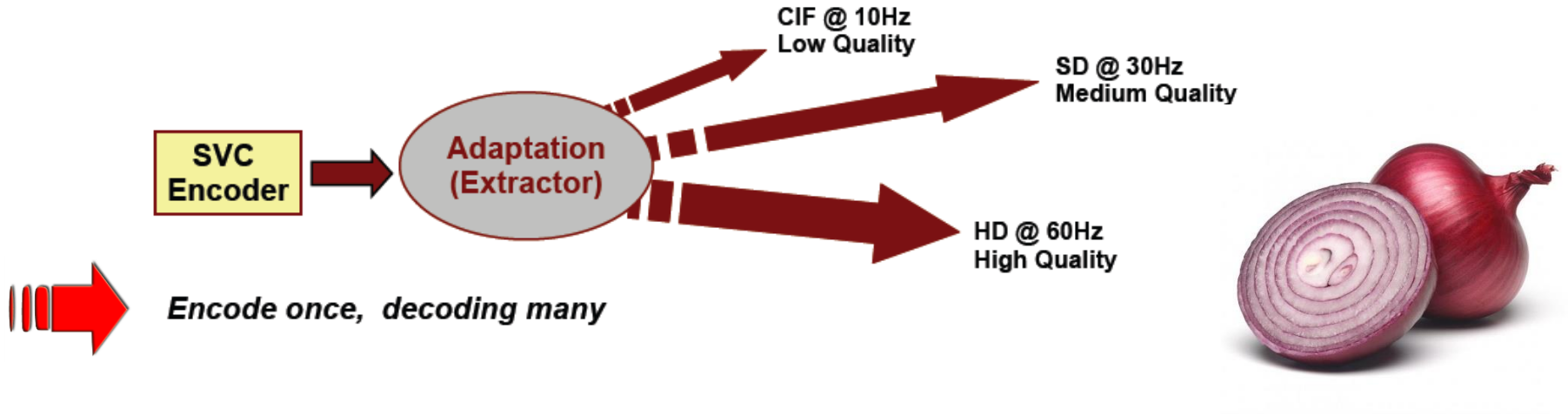
TÉCNICO LISBOA

MPEG-2 Video

Scalable Coding

Scalability or the Swiss Army Knife Approach

Scalable Coding: the Definition

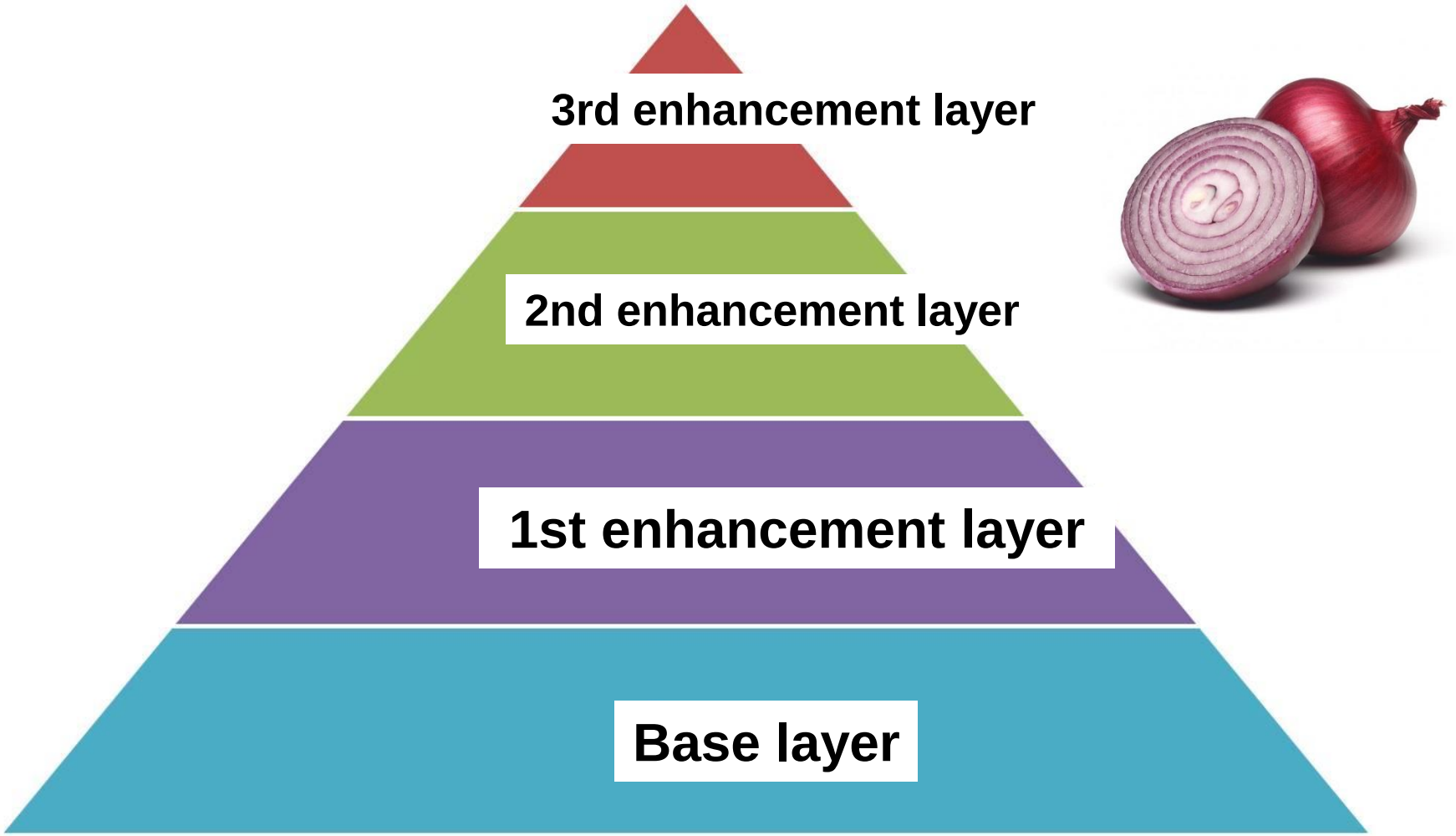


Scalability is a functionality regarding the <u>useful decoding of parts</u> of a coded bitstream, ideally

i) **while achieving an RD performance at any supported spatial, temporal, or SNR resolution that is comparable to single-layer (non-scalable) coding at that particular resolution, and**

ii) **without significantly increasing the decoding complexity**

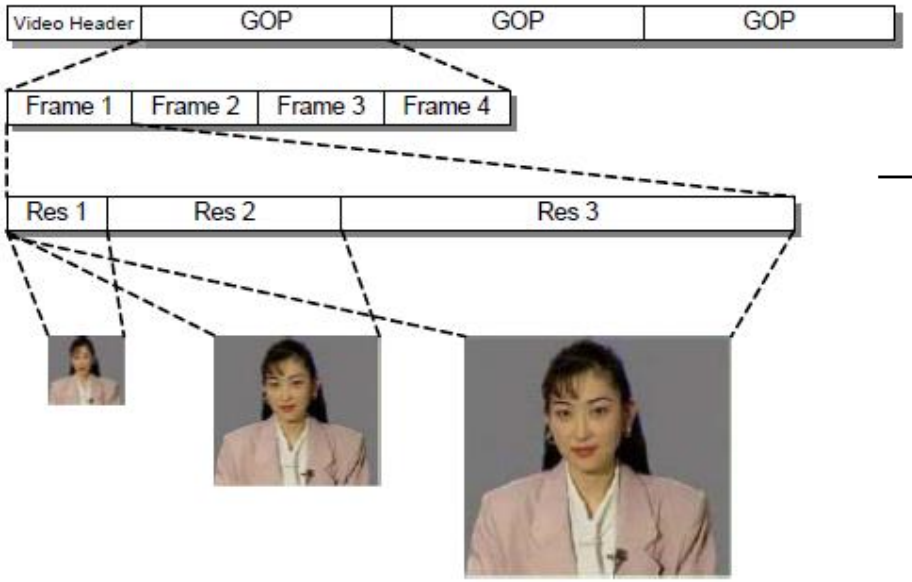
Scalable Hierarchical Coding

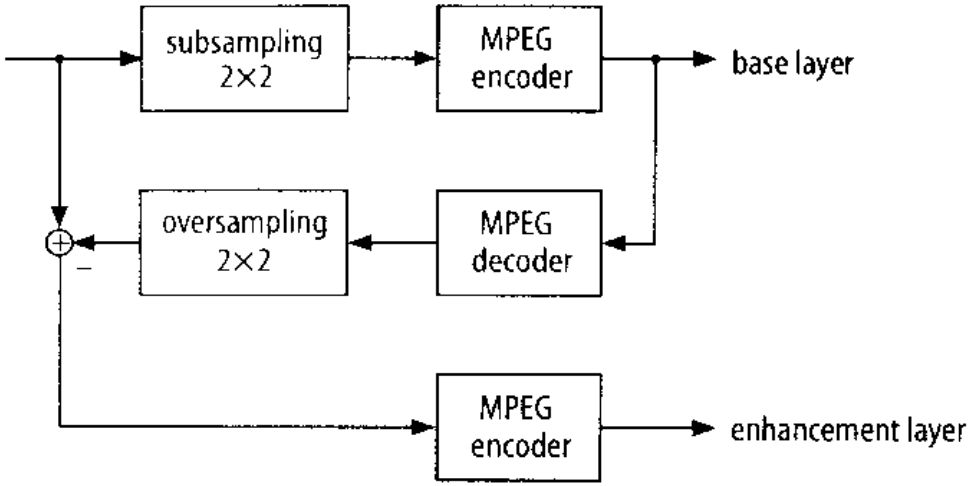


Scalable Coding Types: Spatial Scalability

- **SPATIAL SCALABILITY – The original video signal is scalable coded with several spatial resolution layers.**

Can accomodate SDTV and HDTV in 1 single stream ! In opposition to 2 independent, non-scalable streams !





Spatial scalability in MPEG-2

Non-scalable versus Scalable HD Broadcasting

Non-Scalable

SD	
HD	
SD & HD	*Independent SD* / *Independent HD*

Scalable

SD & HD	*Independent SD* / *Hierarchical HD*

MPEG-2 Video Scalability: Weaknesses

MPEG-2 Video scalability was not successful/adopted mainly due to:

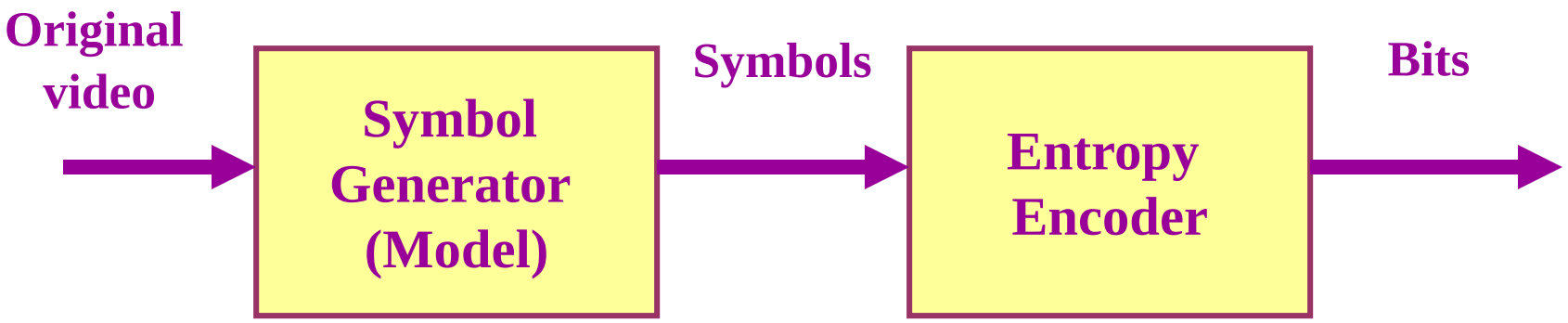
- **Characteristics of traditional video transmission systems where a fixed bandwidth was guaranteed and, thus, no dynamic variations or heterogeneous consumptions had to be accommodated**

- **HDTV did not explode as flat displays did not emerge and thus standard definition was still the single solution**
- **Significant penalty in compression efficiency regarding non-scalable coding solutions, meaning much larger bitrate for the same maximum quality/resolution**
- **Large increase in decoder complexity regarding non-scalable coding solutions as all layers up to the target layer have to be decoded and accumulated**

TÉCNICO LISBOA

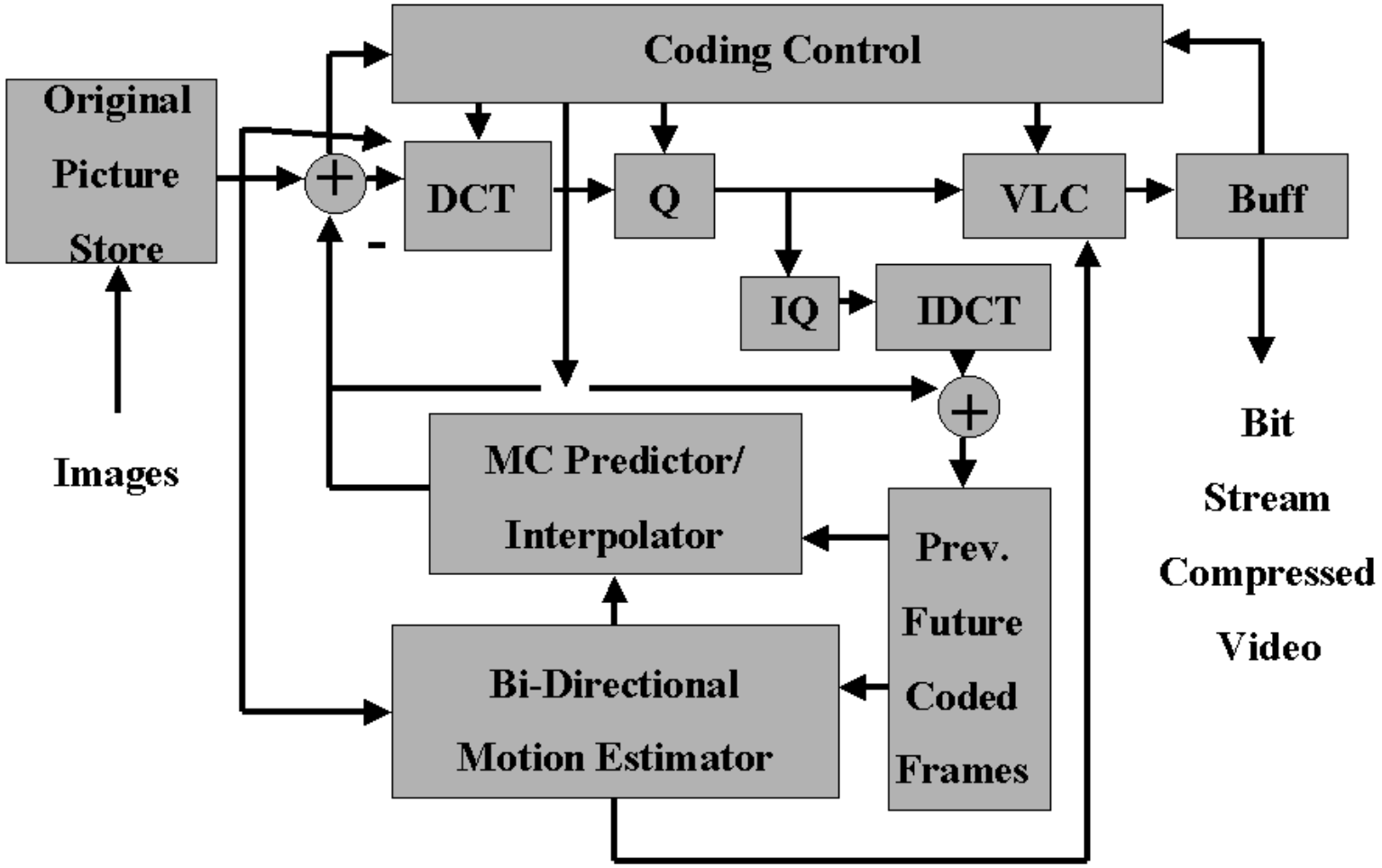
Combining the Coding Tools ...

The MPEG-2 Video Symbolic Model

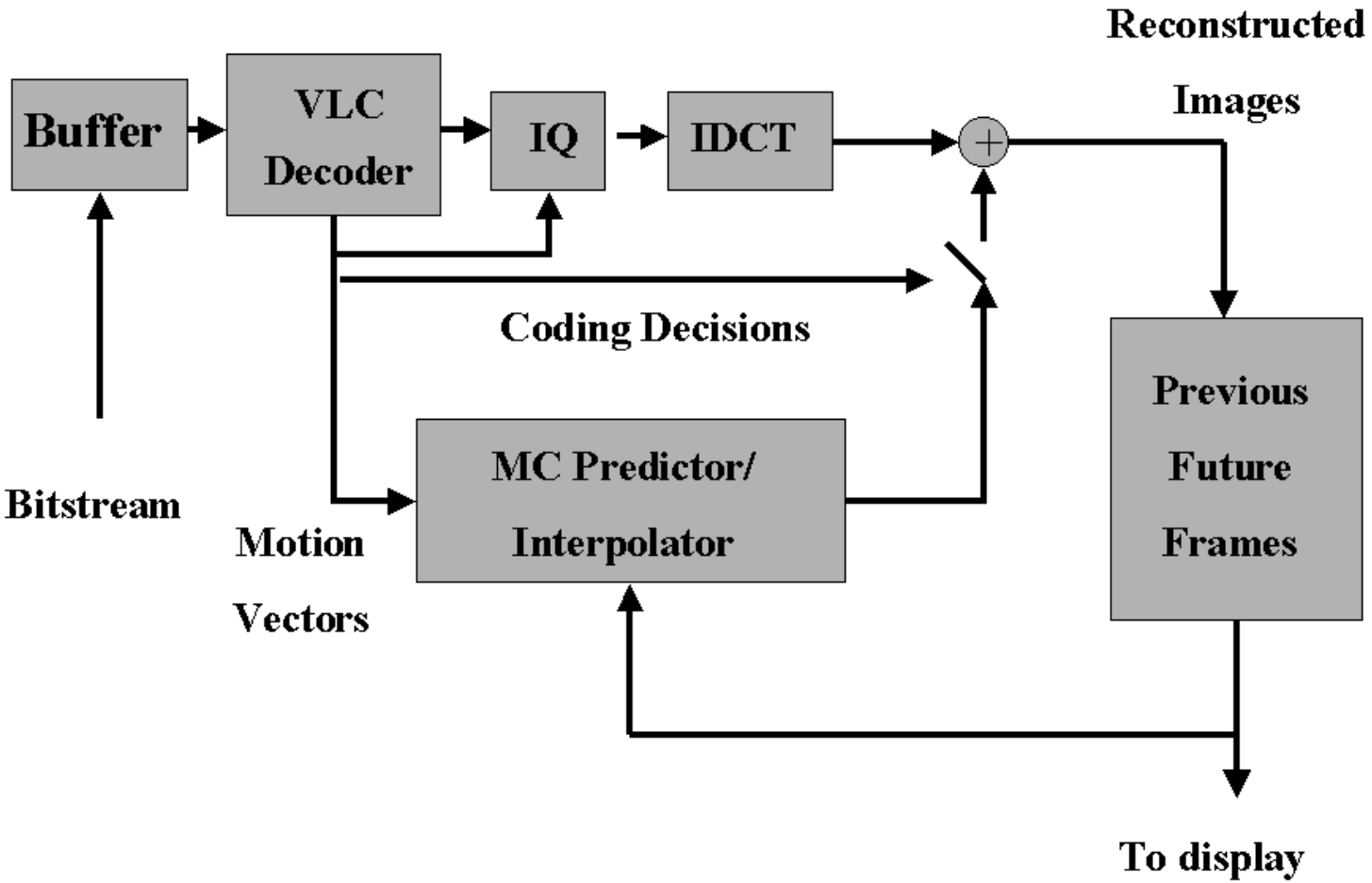


A video sequence (interlaced or progressive) is represented, in a scalable way or not, as a succession of GOPs including pictures coded as frames or fields and classified as I, P or B, structured in macroblocks, each of them represented using motion vectors and/or DCT quantized coefficients, following the constraints imposed by the picture coding type.

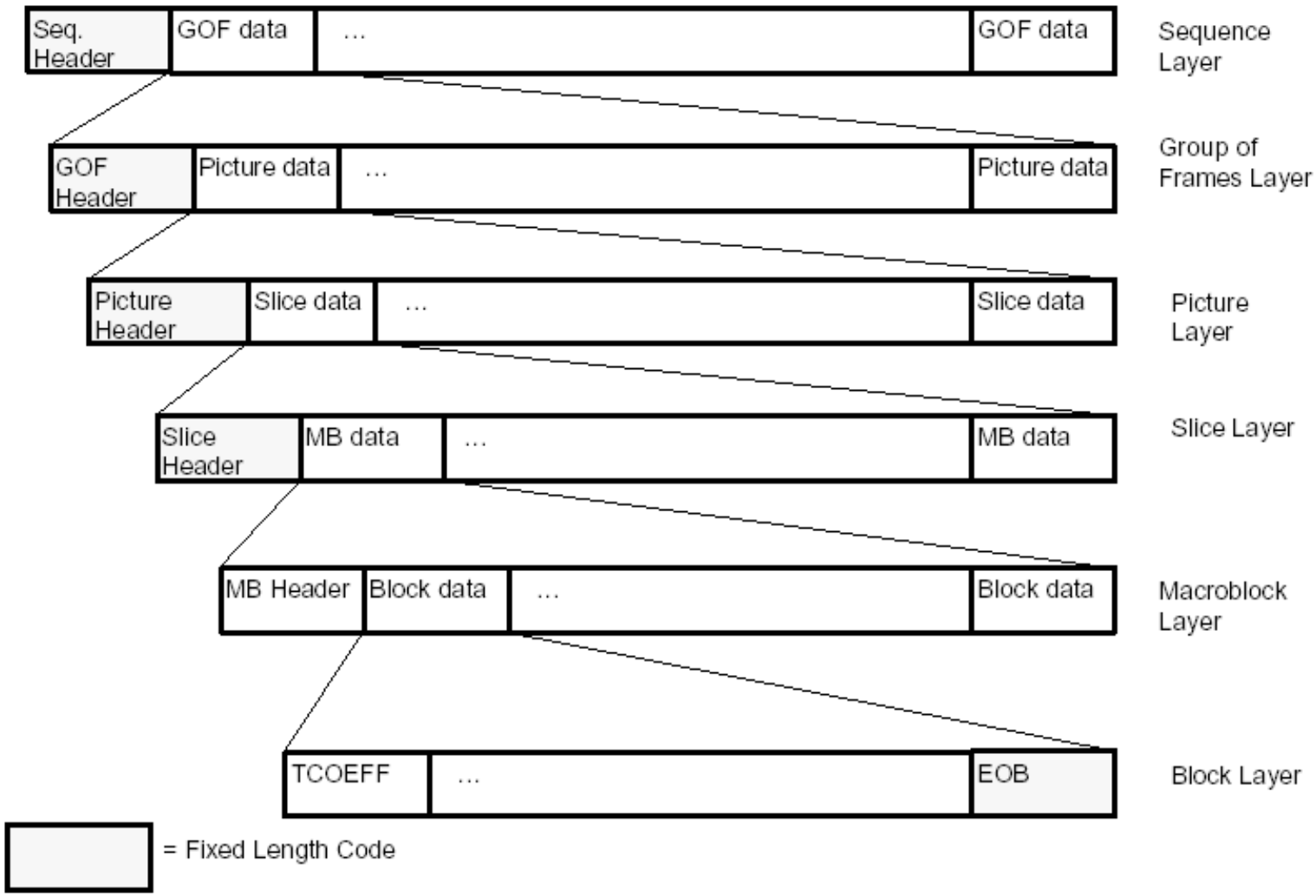
MPEG-2 Video: Encoder



MPEG-2 Video: Decoder



MPEG-2 Video Syntax

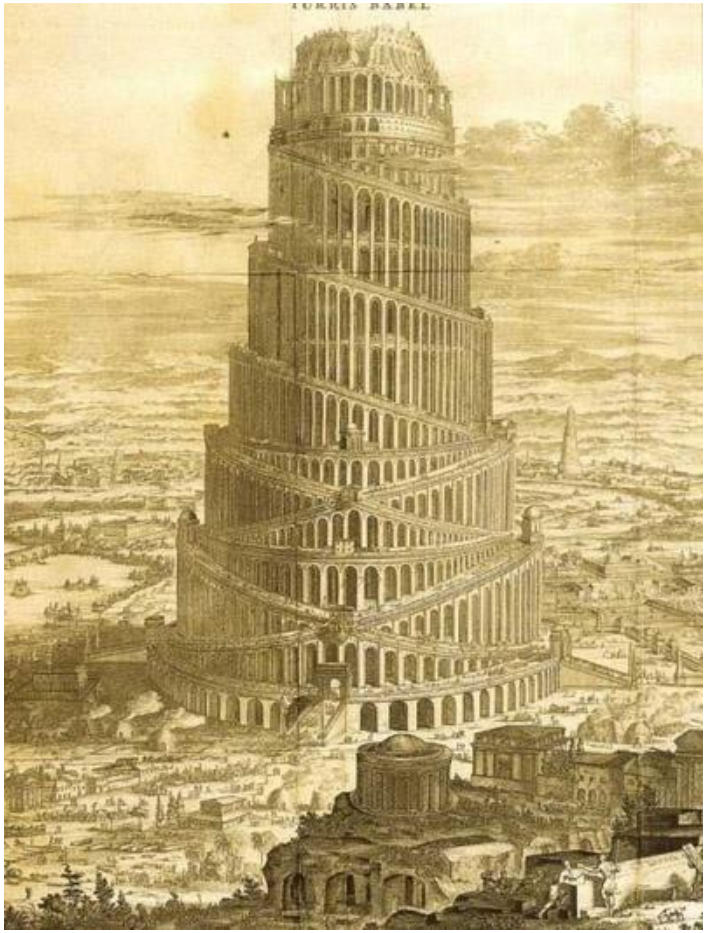


TÉCNICO LISBOA

MPEG-2 Video

Profiles and Levels

MPEG-2 Video: Very Big or Just Enough ?



- **MPEG-2 Video is already a ‘big’ standard !**
- **The MPEG-2 Video tools address many requirements from several application domains.**
- **Some tools are very likely useless in certain application domains.**

It is essential to define adequate subsets of tools in terms of functionalities and complexity !

Profiles and Levels: Why ?

The profile and level concepts were first adopted by the MPEG-2 Video standard and they provide a trade-off between:

- **Implementation complexity for a certain class of applications**
- **Interoperability between applications**

while guaranteeing the necessary compression efficiency capability required by the class of applications in question and limiting the codec complexity and associated costs.

- **PROFILE – Subset of coding tools corresponding to the requirements of a certain class of applications**
- **LEVEL – Establishes for each profile constraints on relevant coding parameters, e.g. bitrate and memory**

Some MPEG-2 Video Profiles and Levels

levels \ profiles	simple profile	main profile	SNR scalable profile	spatial scalable profile	high profile
high level		1920×1152 pixels 80 Mbit/s			1920×1152 pixels (960×576) 100(80.25) Mbit/s
high-1440 level		1440×1152 pixels 60 Mbit/s		1440×1152 pixels (720×576) 60(40.15) Mbit/s	1440×1152 pixels (720×576) 80(60.20) Mbit/s
main level	720×576 pixels 15 Mbit/s	720×576 pixels 15 Mbit/s	720×576 pixels 15(10) Mbit/s		720×576 pixels (352×288) 20(15.4) Mbit/s
low level		352×288 pixels 4 Mbit/s	352×288 pixels 4(3) Mbit/s		
	(main profile, without B-pictures)	(4 : 2 : 0, no scalabilty)	(main profile, + SNR scalability)	(SNR profile, + spat. scalability)	(spatial profile, + 4 : 2 : 2 coding)

MPEG-2 Video in DVB

- **Standard Definition TV (SDTV) uses MP@ML (*Main Profile at Main Level*)**
  - Frame rate - 25 or 30 Hz
  - Aspect ratio - 4:3, 16:9 or 2.21:1
  - Spatial resolution - (720, 576, 480) × 576 or 352 × (576, 288) or (720, 640, 544, 480, 352) × 480 or 352 × 540
  - Chrominance subsampling - 4:2:2 or 4:2:0
- **HDTV uses MP@HL (*Main Profile at High Level*)**
  - Frame rate - 25, 50 or 30 e 60 Hz
  - Aspect ratio - 16:9 or 2.21:1
  - Spatial resolution - 1152 rows per frame at most and 1920 luminance samples per row at most
  - Complexity: 62 688 800 luminance samples per second at most

TÉCNICO LISBOA

MPEG-2 Standard

Part 3: Audio

The Compatibility Challenge

Audio in MPEG-2: Objective

Efficient high quality audio coding targeting the broadcasting and storage of TV or TV like signals.

There are two parts in the MPEG-2 standard specifying audio codecs:

- **Audio (Part 3), 1993** – Codes up to 5 (full) channels + 1 low frequency channel with high quality, at 384 kbit/s or less per channel, using the following additional sampling rates: 16, 22.05 and 24 kHz; MPEG-2 Audio Part 3 offers backward compatibility with MPEG-1 Audio, thus the name of ***MPEG-2 Audio Backward Compatible*** **(BC).**

- **Advanced Audio Coding (Part 7), 1997** – Gives up on any compatibility with MPEG-1 Audio, improving its RD (rate-distortion) performance, thus reaching higher quality for the same rate; codes 1 to 48 canais, with sampling rates from 8 to 96 kHz; it was initially designated as ***MPEG-2 Audio Non-Backward Compatible*** **(NBC), now *Advanced Audio Coding* (AAC).**

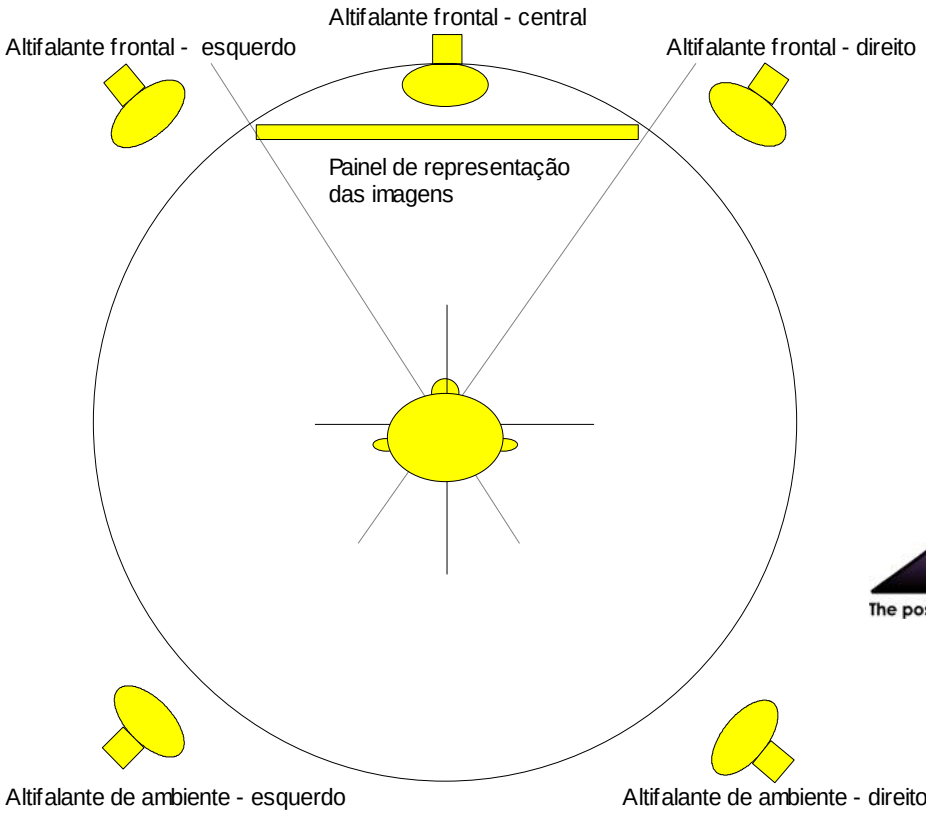
MPEG-2 Audio (Part 3): What's New ?

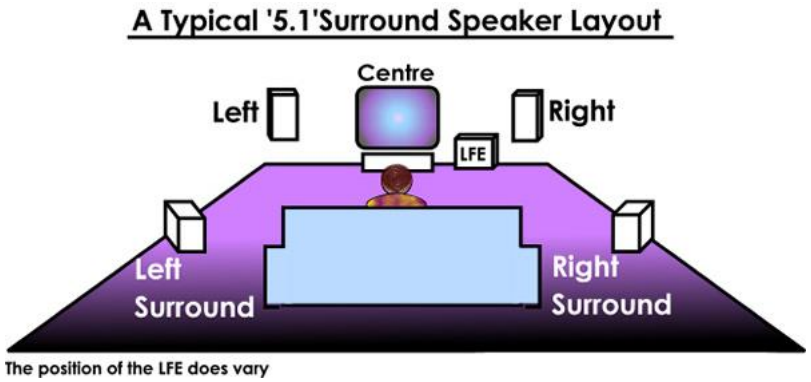
There are two main technical innovations in MPEG-2 Audio (BC or Part 3) regarding MPEG-1 Audio:

- **Lower Sampling Frequencies (MPEG-2 Audio LSF): adding 16, 22.05 and 24 kHz to 32, 44.1 and 48 kHz**
  - Motivated by the increase of low data rate applications over the Internet, it has the main goal to achieve MPEG-1 Audio or better audio quality at lower data rates at the cost of a lower audio bandwidth (and thus sampling rate)
- **Multichannel coding**
  - Motivated by the need to increase the user experience, notably with HDTV

The three MPEG-1 Audio layers with different complexity-compression performance tradeoffs are again defined in MPEG-2 Audio Part 3.

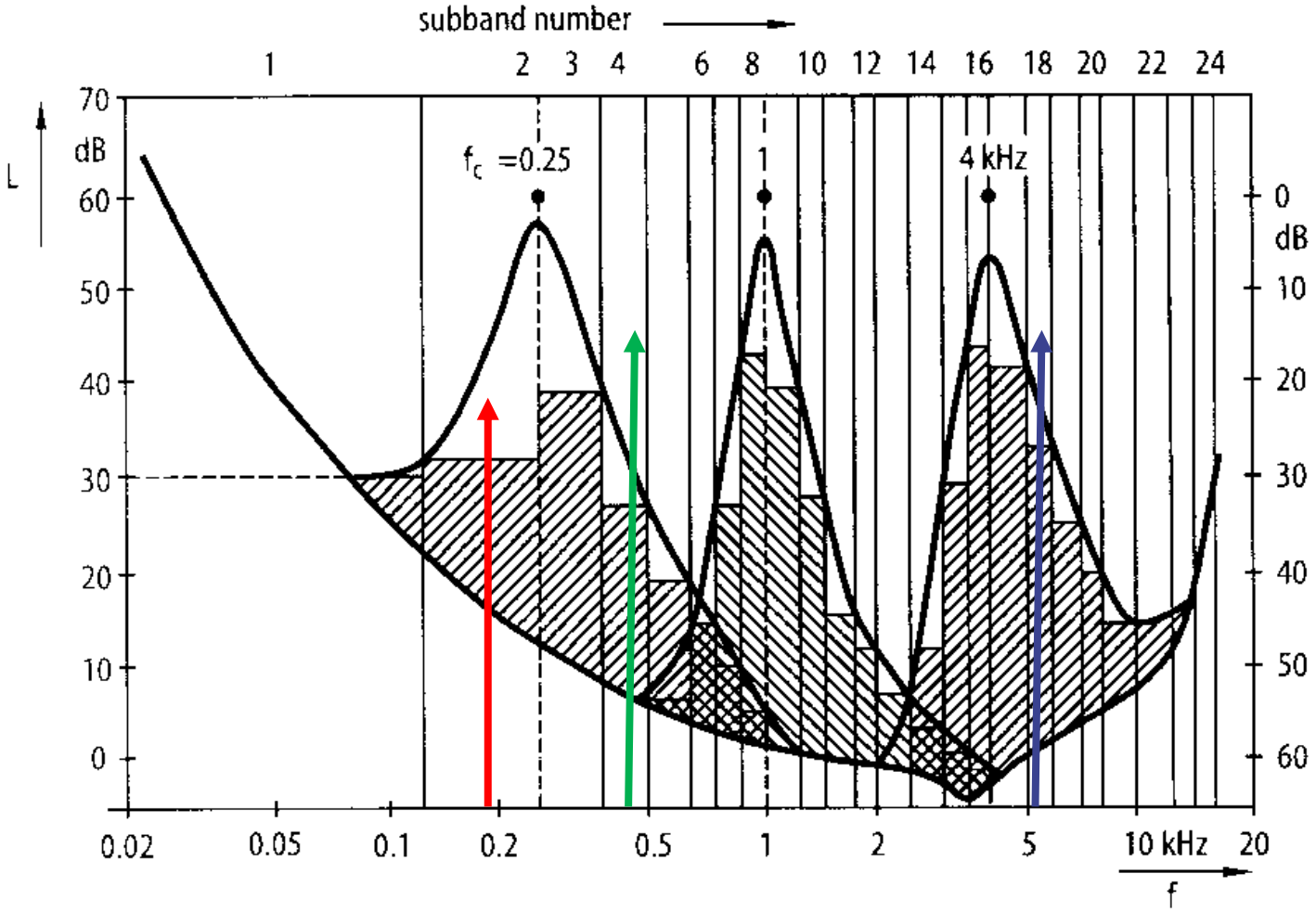
MPEG-2 Audio: Multichannel Configuration



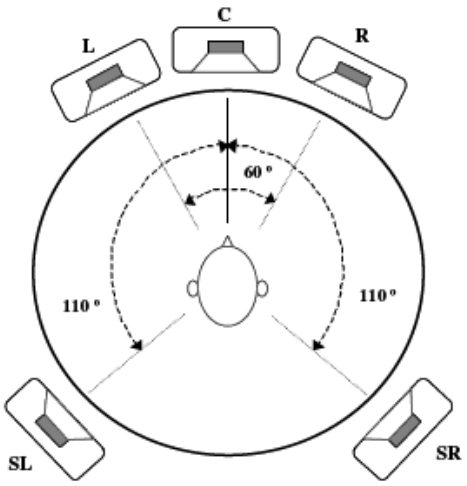


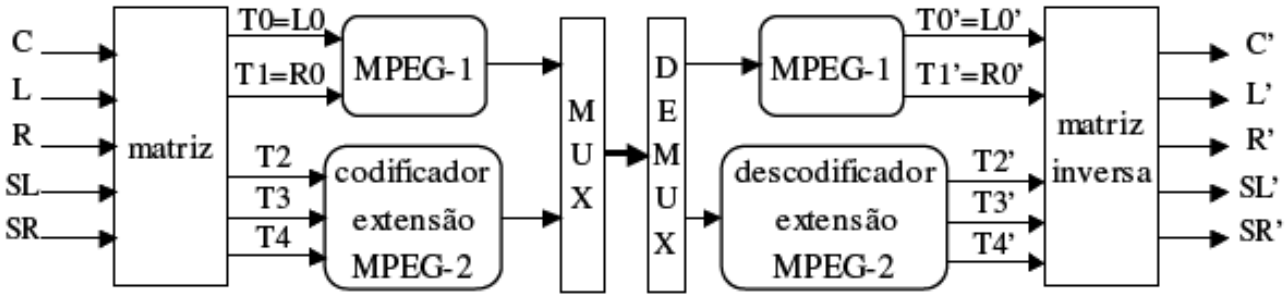
The 5.1 multichannel configuration includes 5 full bandwidth channels and a low frequency enhancement (LFE) channel covering frequencies below 200 Hz (less than 10% of the full bandwidth).

MPEG-2 Audio: the Secret !



MPEG-2 and MPEG-1 Audio Compatibility





MPEG-2 Audio backward compatibility is provided by designing MPEG-2 Audio as a MPEG-1 Audio compliant stereo pair and additional MPEG-2 Audio compliant data for the other channels.

This also implies MPEG-2 forward compatibility as a MPEG-2 Audio decoder may decode the MPEG-1 stereo pair.

MPEG-1/2 Audio in DVB

- **All DVB audio decoders use MPEG-1 Audio, Layers 1 and 2, or MPEG-2 Audio Part 3 (BC), Layers 1 and 2.**
- **For MPEG-1 Audio, it is recommended to use Layer 2.**
- **It is possible to recover, with a MPEG-1 Audio decoder, a stereo pair from a multichannel MPEG-2 Audio BC coded bitstream.**
- **It is also possible to recover a stereo pair through downmixing where all channels contributed to create the stereo pair.**
- **Sampling frequencies: 32, 44.1 and 48 kHz.**

Final Remarks

- **There are many hundreds of millions of MPEG-2 (and now also H.264/AVC) set-top boxes sold, especially in USA and Europe.**
- **Both Europe (DVB) and USA (ATSC) decided to use the MPEG-2 Systems and MPEG-2 Video standards (unfortunately with small differences). While DVB also uses MPEG-2 Audio, ATSC uses Dolby AC-3, another audio coding format.**
- ***Digital Video Disc* (DVD) has adopted MPEG-2 standards.**

Most deployed digital TV is not anymore MPEG-2 based …

Another, more efficient, video coding solution quickly took over after around 2005: H.264/AVC (see next episode)!

Bibliography

- **H. Benoit, *Digital Television: MPEG-1, MPEG-2 and principles of the DVB system*, Arnold, 1997**
- **U. Reimers, *Digital Video Broadcasting*, Springer Verlag, 2001**
- **B.Haskell, A. Puri, A. Netravali, *Digital Video: an Introduction to MPEG-2*, Chapman & Hall, 1997**
- **R. de Bruin, J. Smits, *Digital Video Broadcasting*, Artech House, 1998**