DIGITAL TELEVISION: FIRST GENERATION

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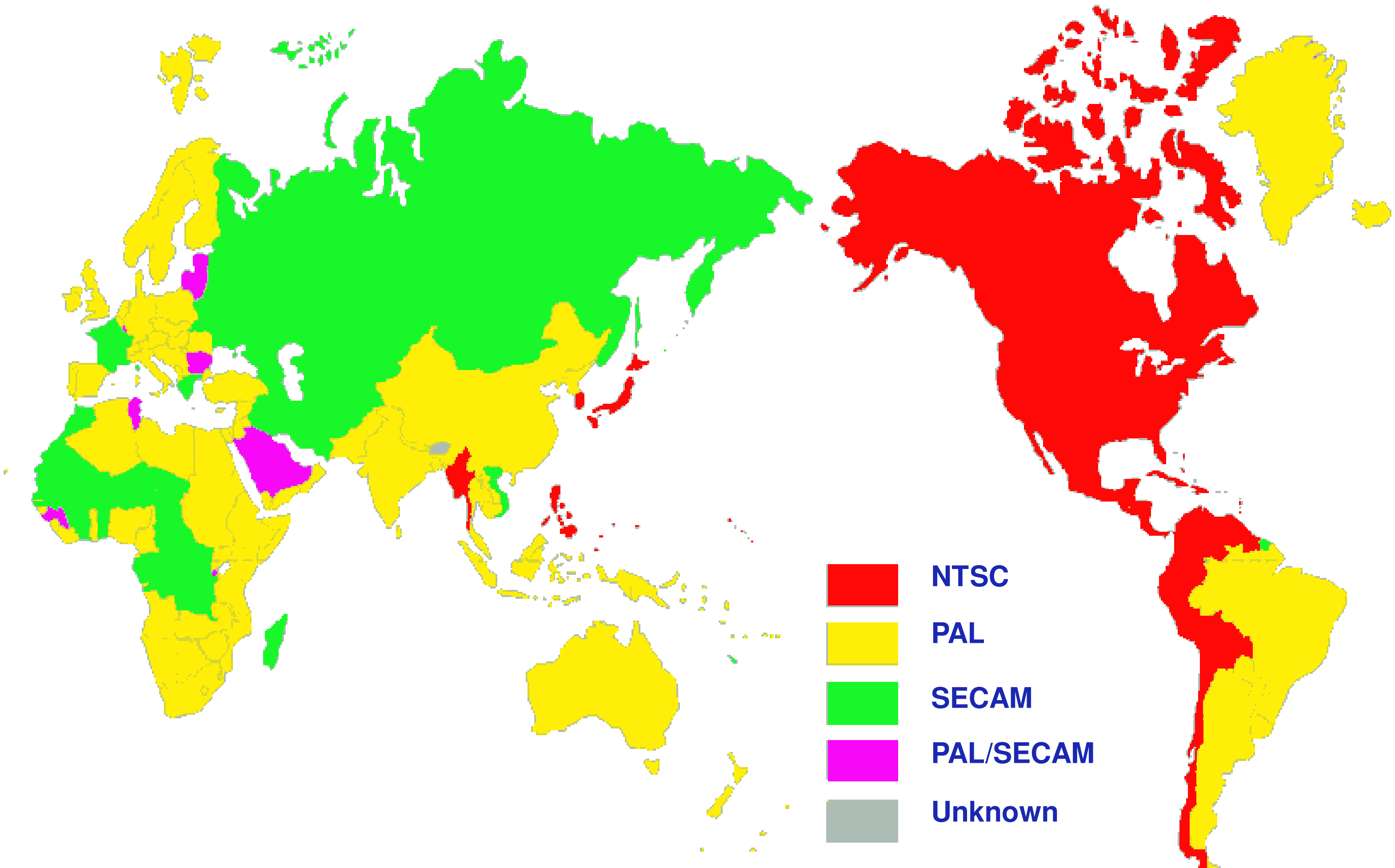
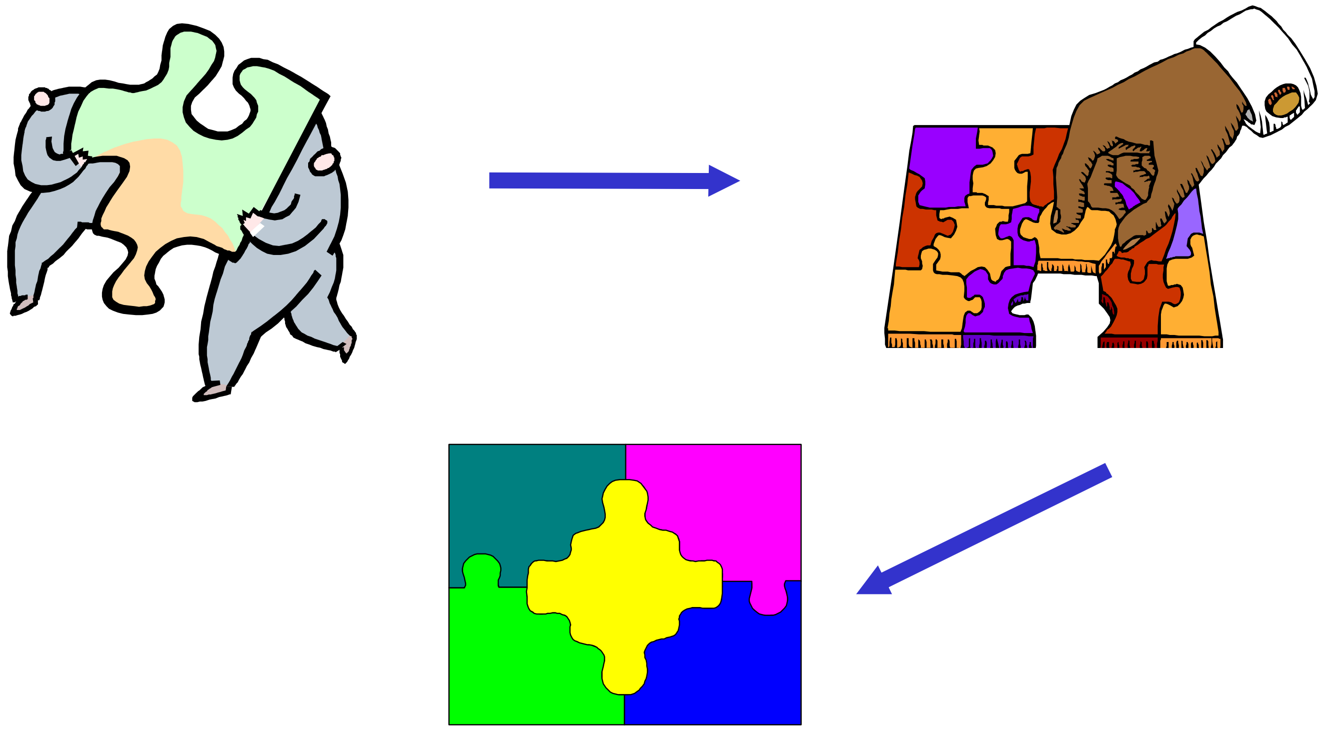
The Analogue TV World



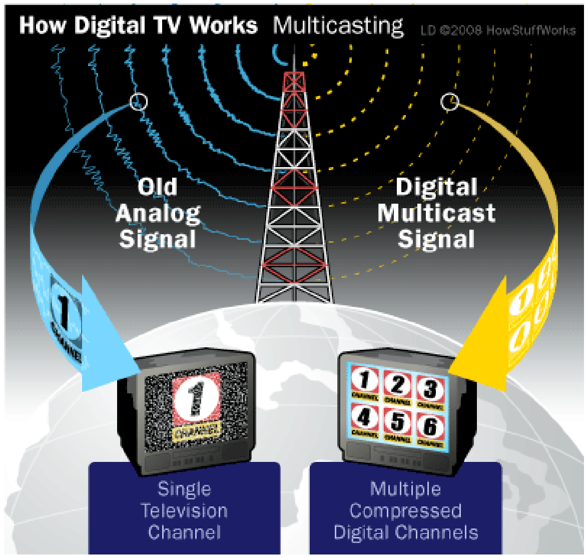
TV Digital: What is it Really ?



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**



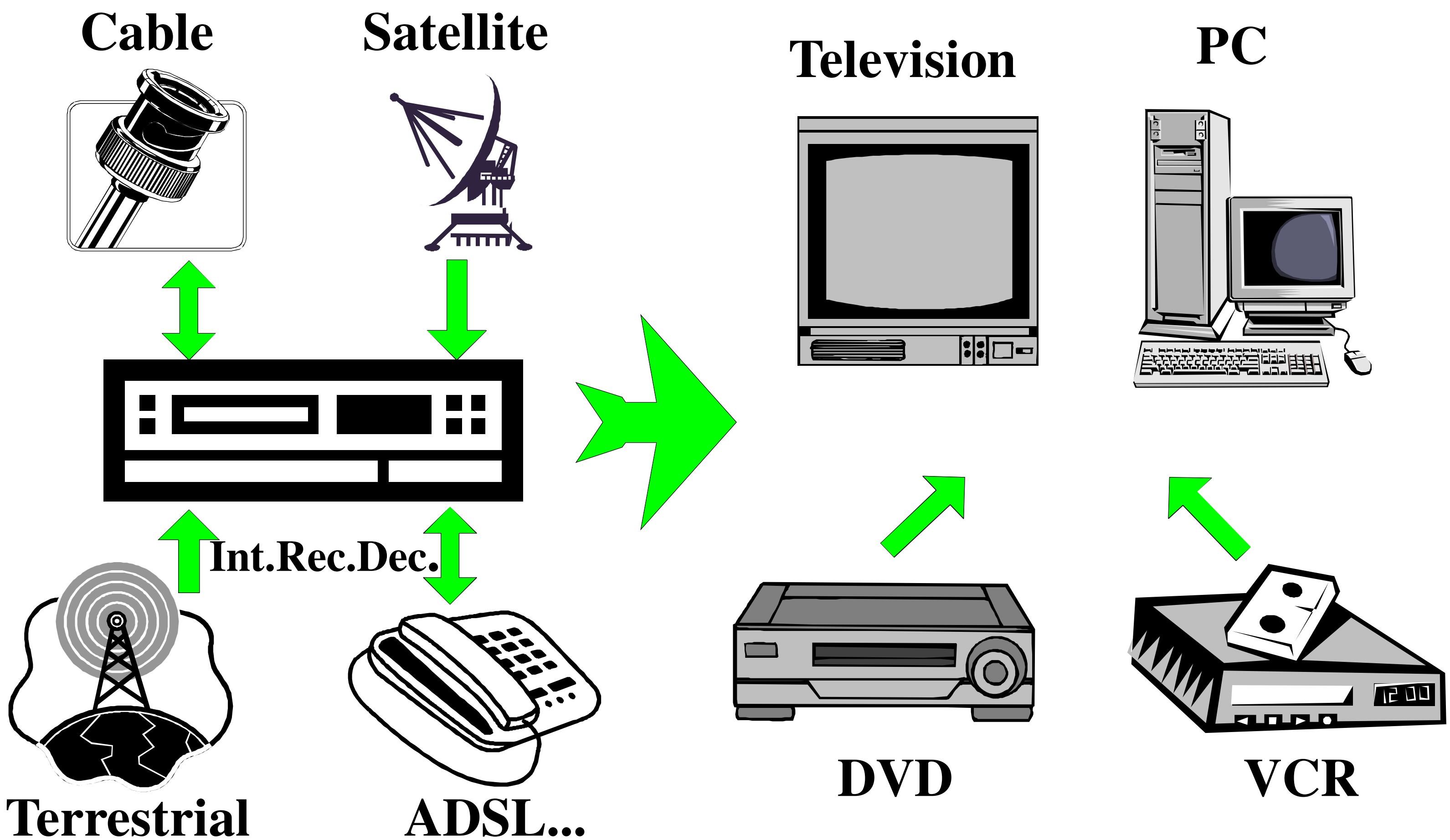




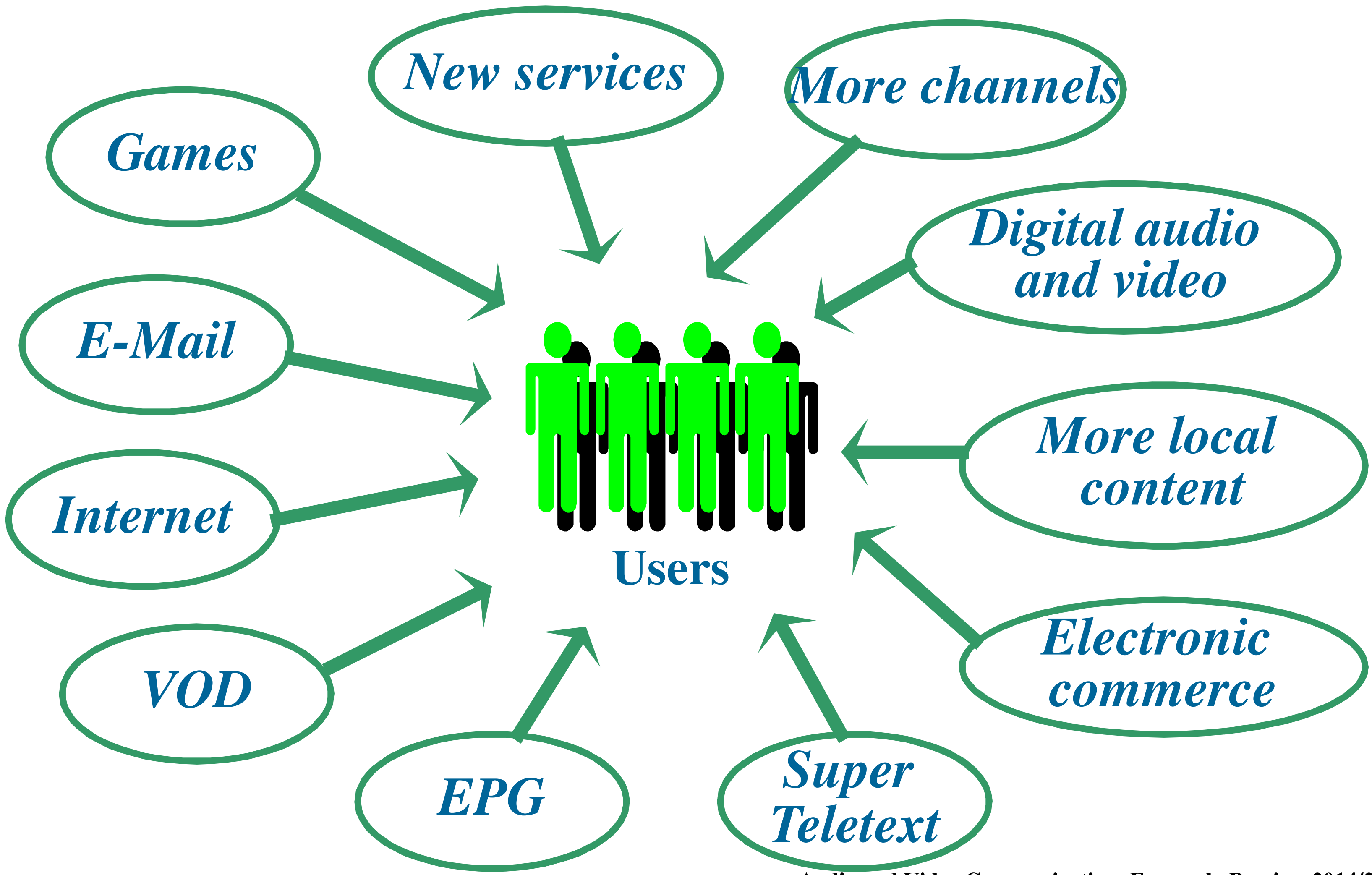




The Digital Domestic Scenario



Digital TV: Content or Terminal ?



Which Arguments Convince the Users ?

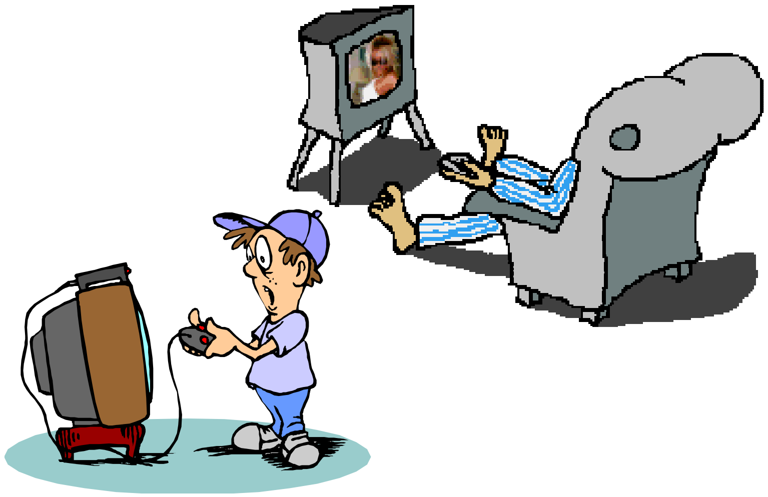
- **Satisfaction of important needs / added value / functionalities**
- **Interoperability at the application level –** ***users don’t care much about the specific technical solution***
- **Quality and reliability**
- **Facility of usage**
- **Low cost of usage and equipment**
- **Variety and quality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

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

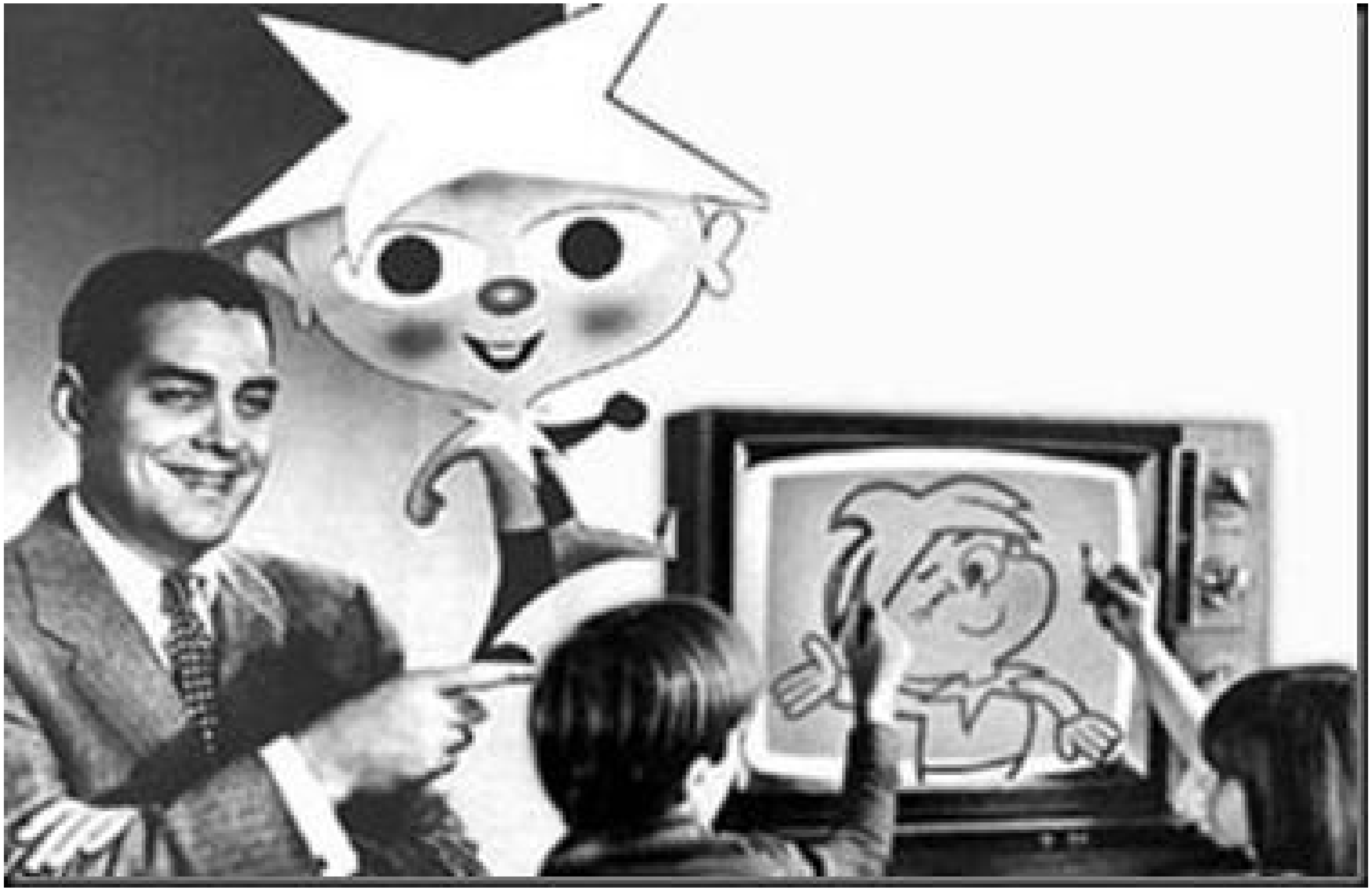
Interactivity

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:

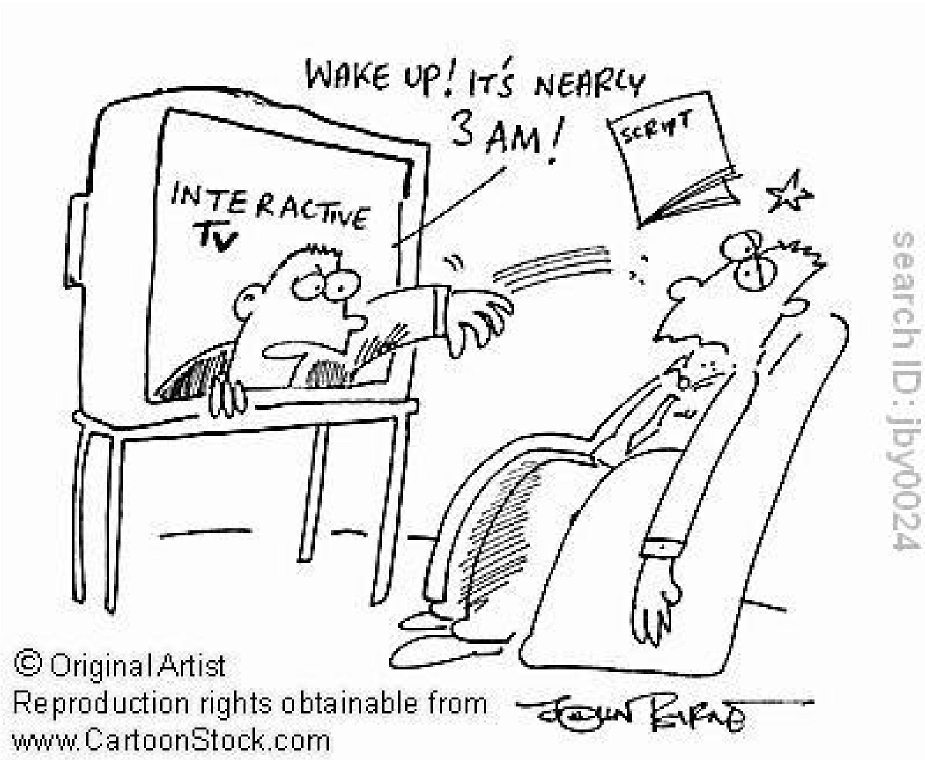
- **Access to thematic information**
- **Access to complementary information**
- **Control of the visualization sequence**
- **Select the visualization angle**
- **Express opinions, vote**
- **Use various services, e.g. tele-shopping, tele-banking**
- **...**



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



Types of Interactivity

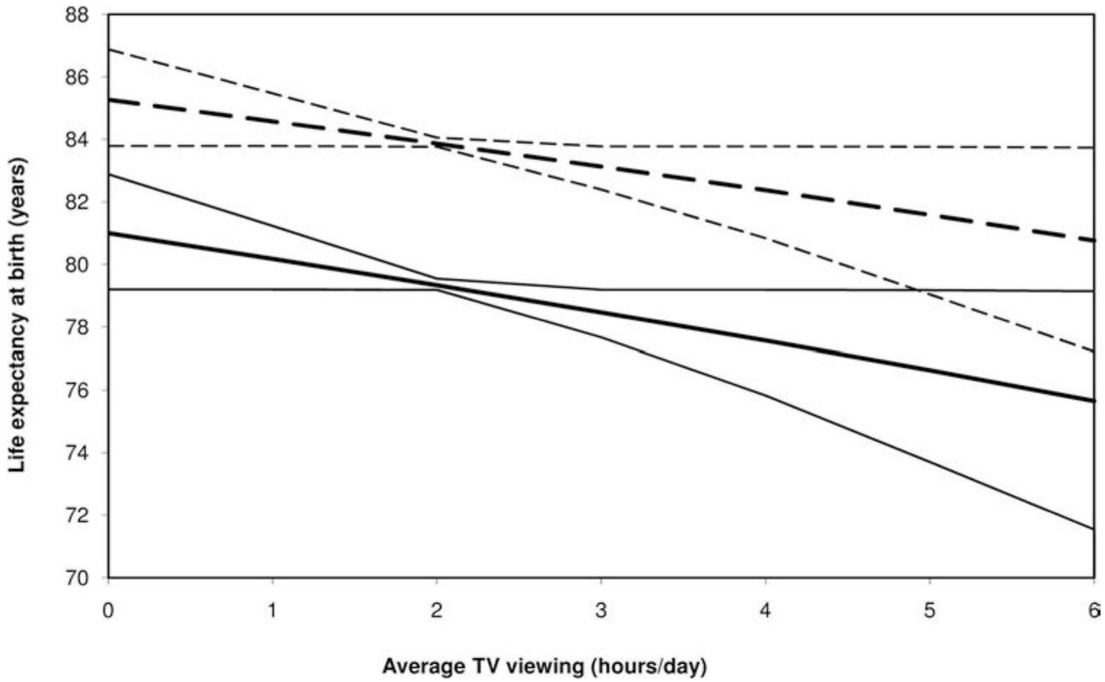


- **Low Interactivity – Z**apping, audio control
- **Medium Interactivity –** Defines the program but does not change it, e.g.VOD, teletext
- **High Interactivity –** Changes the program, e.g. program personalization, selection of the preferred end, mix with Internet

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

TV Viewing May Kill …

DANGER



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 is it Changing ?

Analogue	Digital
Broadcast	*Monocast*
Fixed schedules	Programs on demand, box storage
Monthly subscription	*Pay per view*
Passivity	Interactivity
Zappers	EPGs, personalization
Teletext	*World Wide Web*

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Digital TV Technologies

Main Digital TV Systems

The main digital TV systems are:

- **Digital Video Broadcasting (DVB) –** Driven by Europe
- **Advanced Television Systems Committee (ATSC) –** Driven by USA
- **Integrated Services Digital Broadcasting (ISDB) –** Driven by Japan (large similarities with DVB)
- **Digital (Terrestrial) Multimedia Broadcasting (DTMB) –** Driven by China
- **Sistema Brasileiro de TV Digital (SBTVD) –** Driven by Brazil (large similarities with ISDB)

What is DVB ?

- **Consortium with 220 members from 30 countries (at the beginning mainly European), formed in September 1993:**
  - **Content producers**
  - **Equipment manufacturers**
  - **Telecom operators**
  - **Regulation organizations**

with the objective to define standards for digital television broadcasting over several transmission channels.

- **Joint Technical Committee of ETSI / CENELEC / EBU**

DVB: Initial Objectives

- High quality digital video delivery (up to HDTV)
- Delivery with good quality of TV programs using narrow bandwidth channels and increase the number of programs in current channels
- Reception in pocket terminals equipped with small reception antennas (portable reception)
- Mobile reception with good quality of TV programs
- Possibility of easy transmission over various telecom networks and integration with the PC world

From SDTV to HDTV

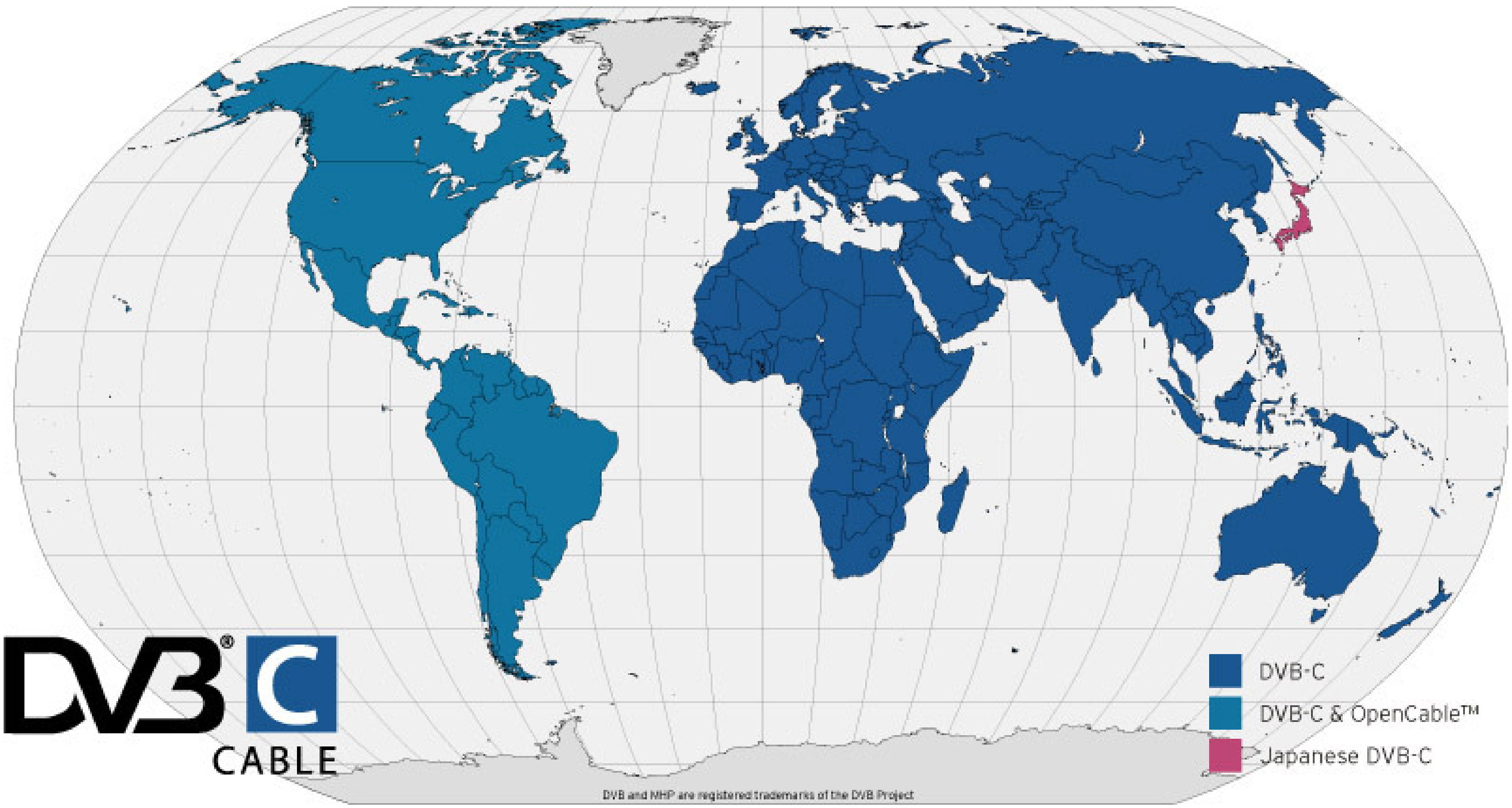
SDTV
STANDARD DEFINITION TELEVISION

HDTV
HIGH-DEFINITION TELEVISION

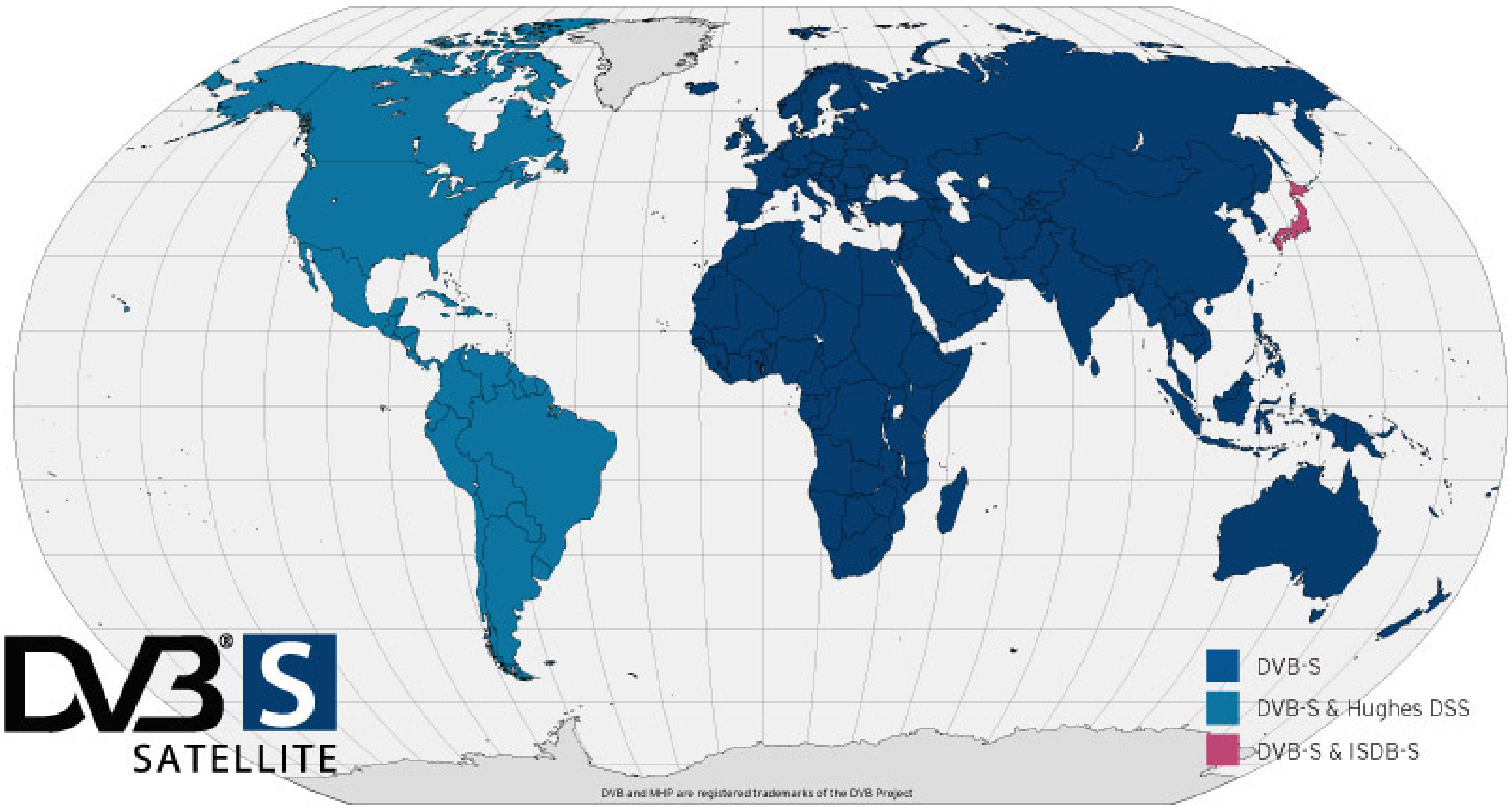
The DVB Scenarios and Standards

- **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)**
- **...**

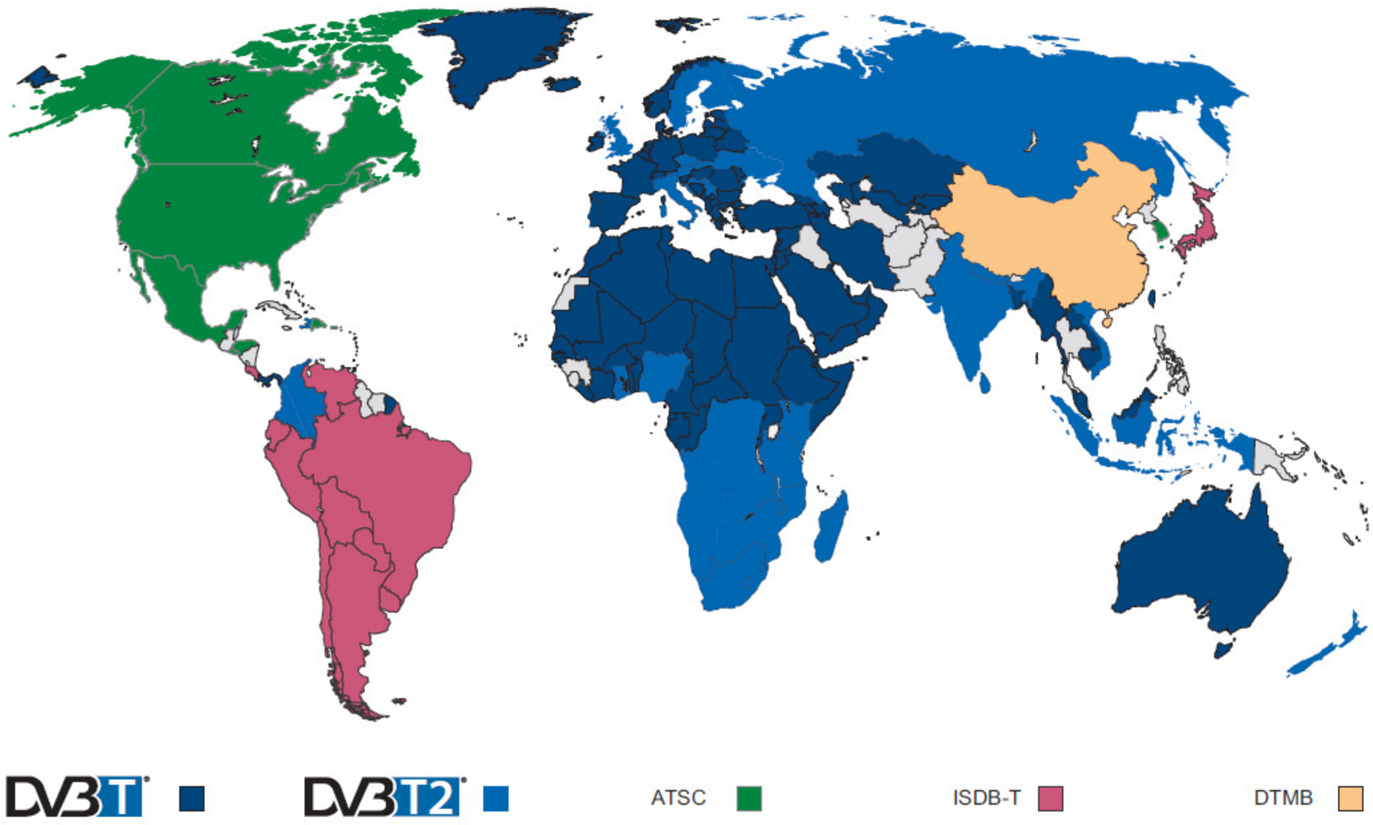
DVB-C: Adoption …



DVB-S: Adoption …



DVB-T: Adoption …



DVB Technologies

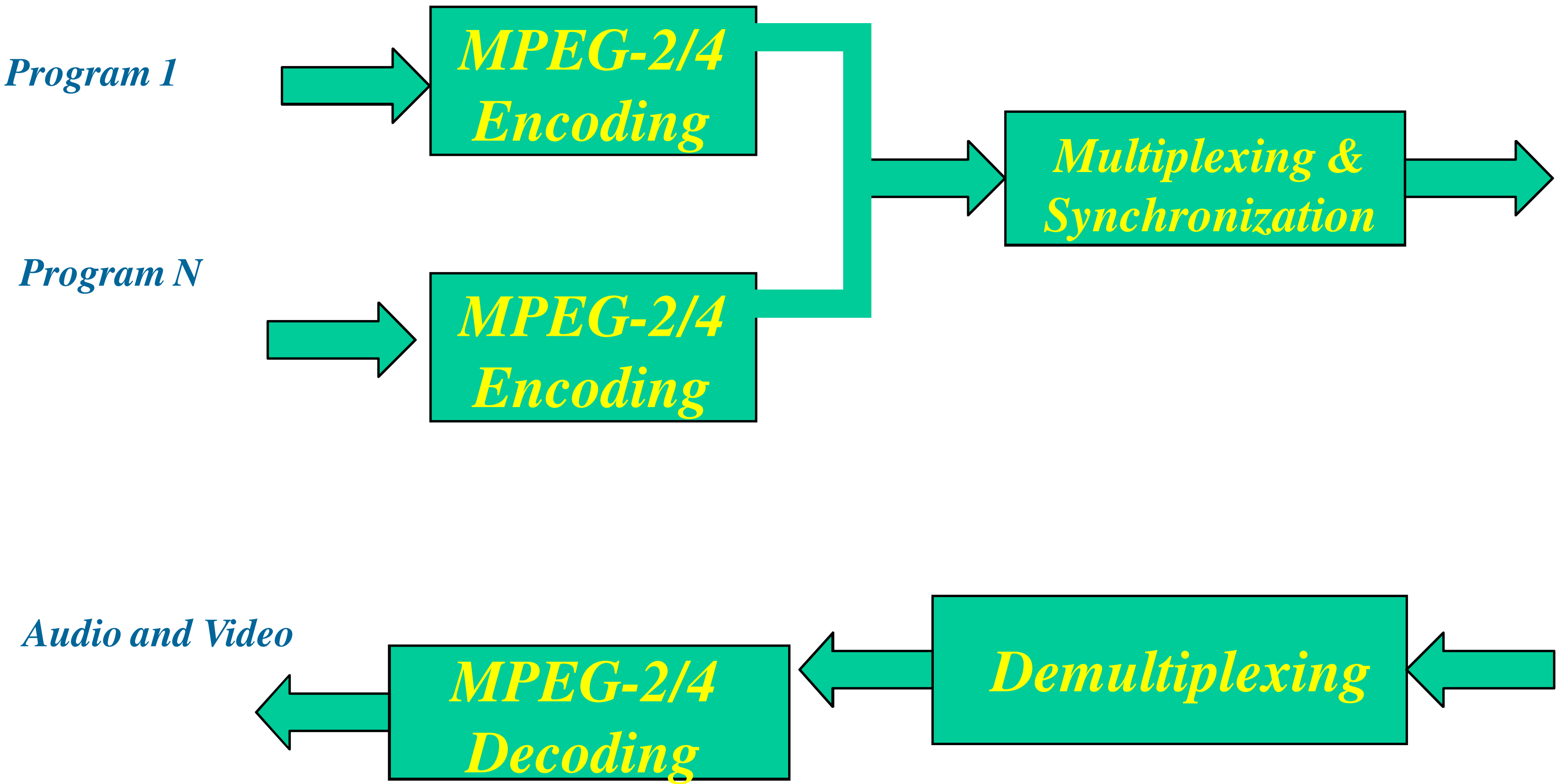
The DVB Specifications

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

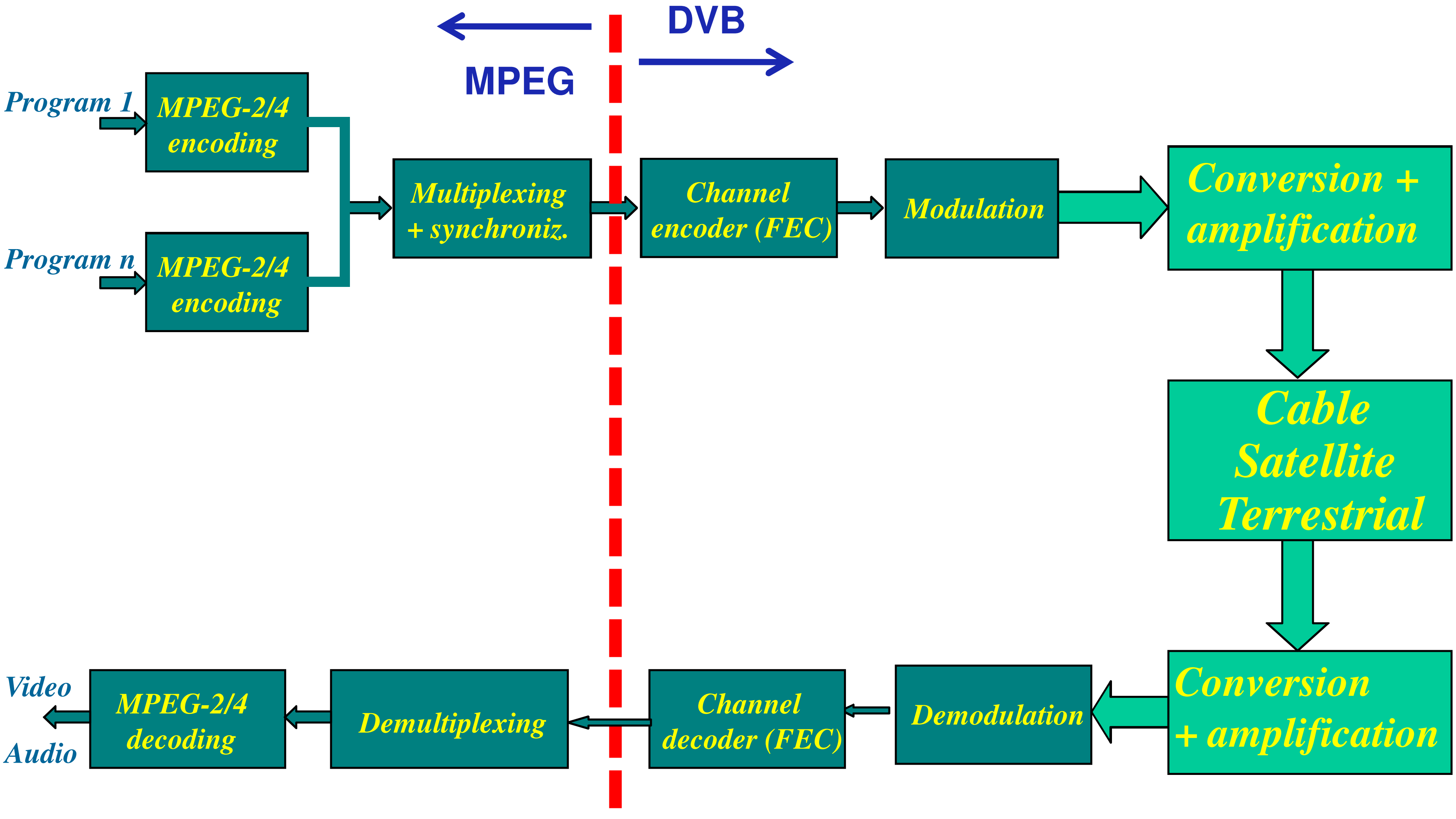
The main modules specified are:

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

Source Representation: Starting with MPEG-2 ...



The Channel ... After the Source …



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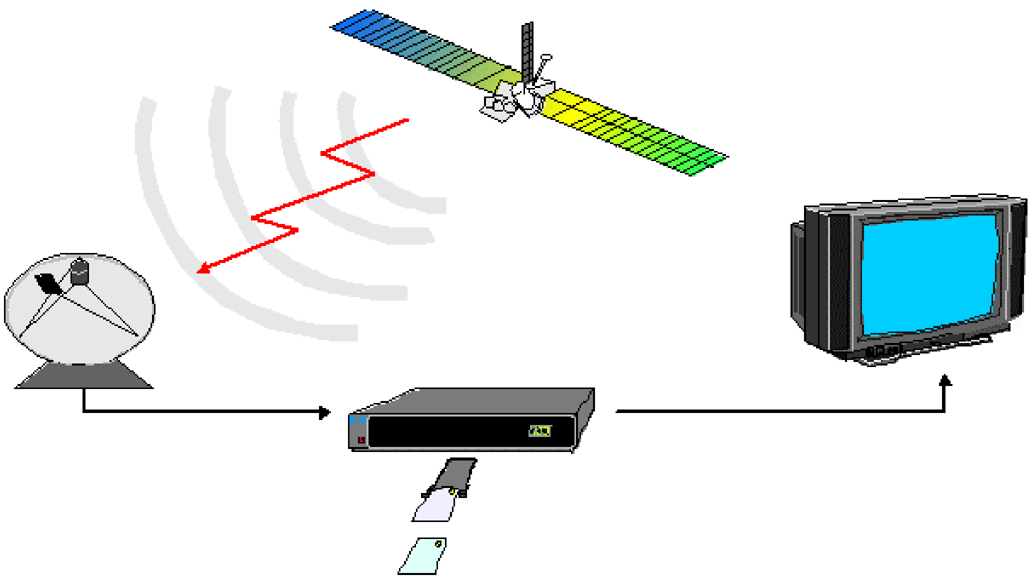
MPEG-2 Standard



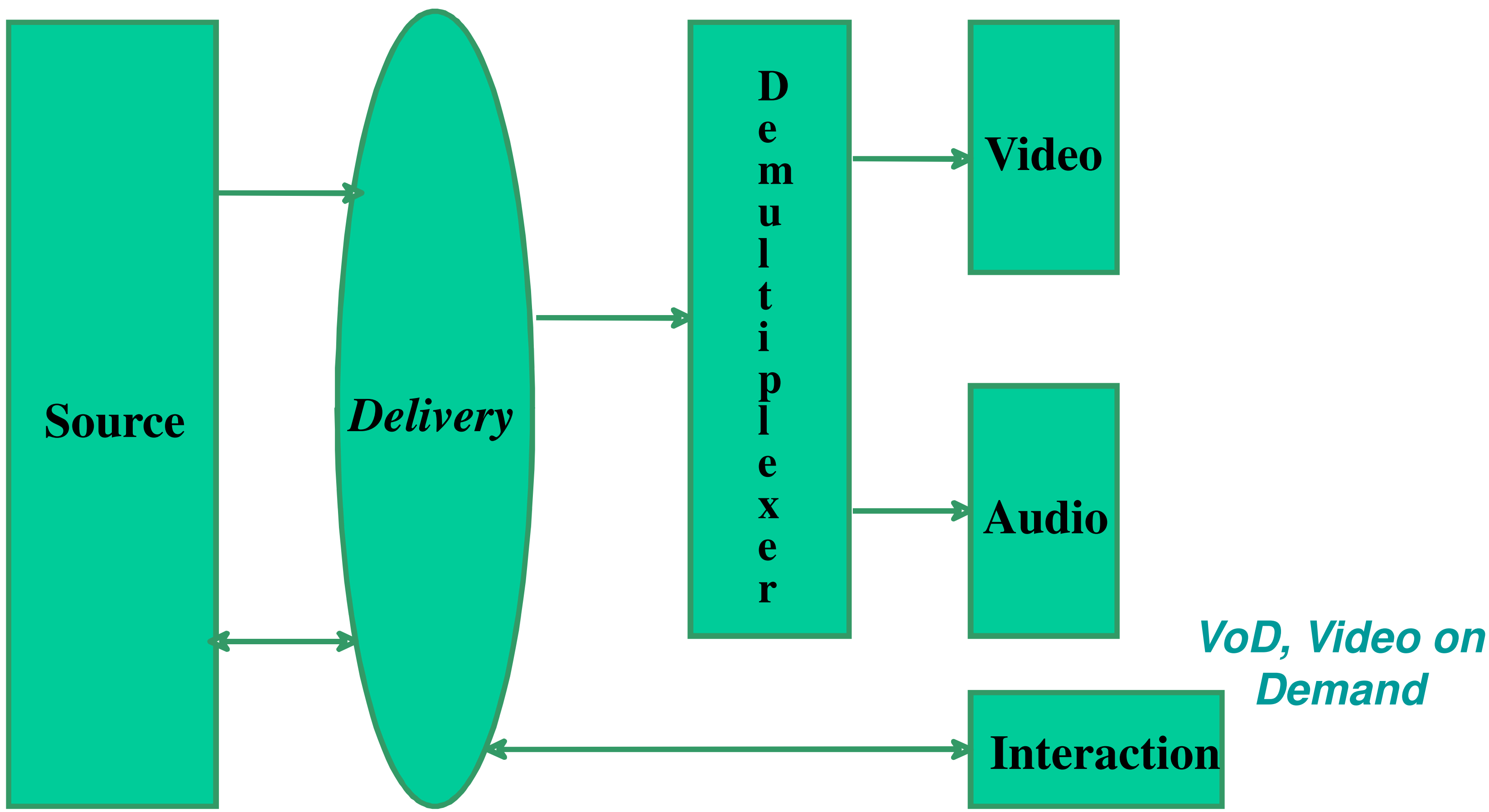
MPEG-2: Objectivos

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



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: What Advantages ?

- Offers more channels, e.g. thematic channels, regional channels
- Offers various angles of visualization, e.g. in the transmission of music or sports
- Introduction of high definition television
- Introduction of stereoscopic television
- Offers a large variety of television related services, e.g. VOD
- Releases bandwidth allocated to terrestrial TV, notably for the expansion of mobile networks
- ...

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.**

MPEG-2 Standard

Part 1: Systems

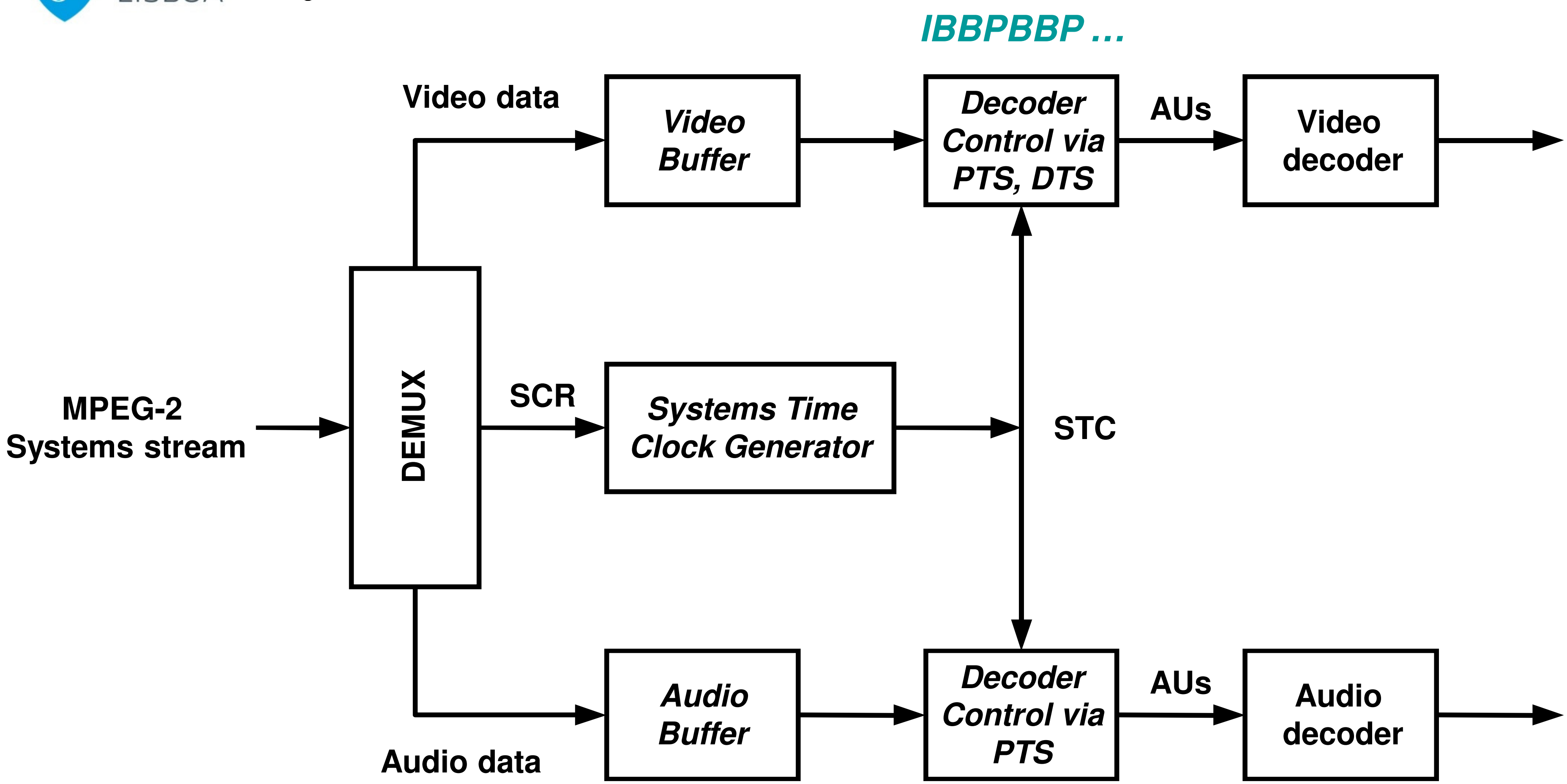
MPEG-2 Systems: Objective

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



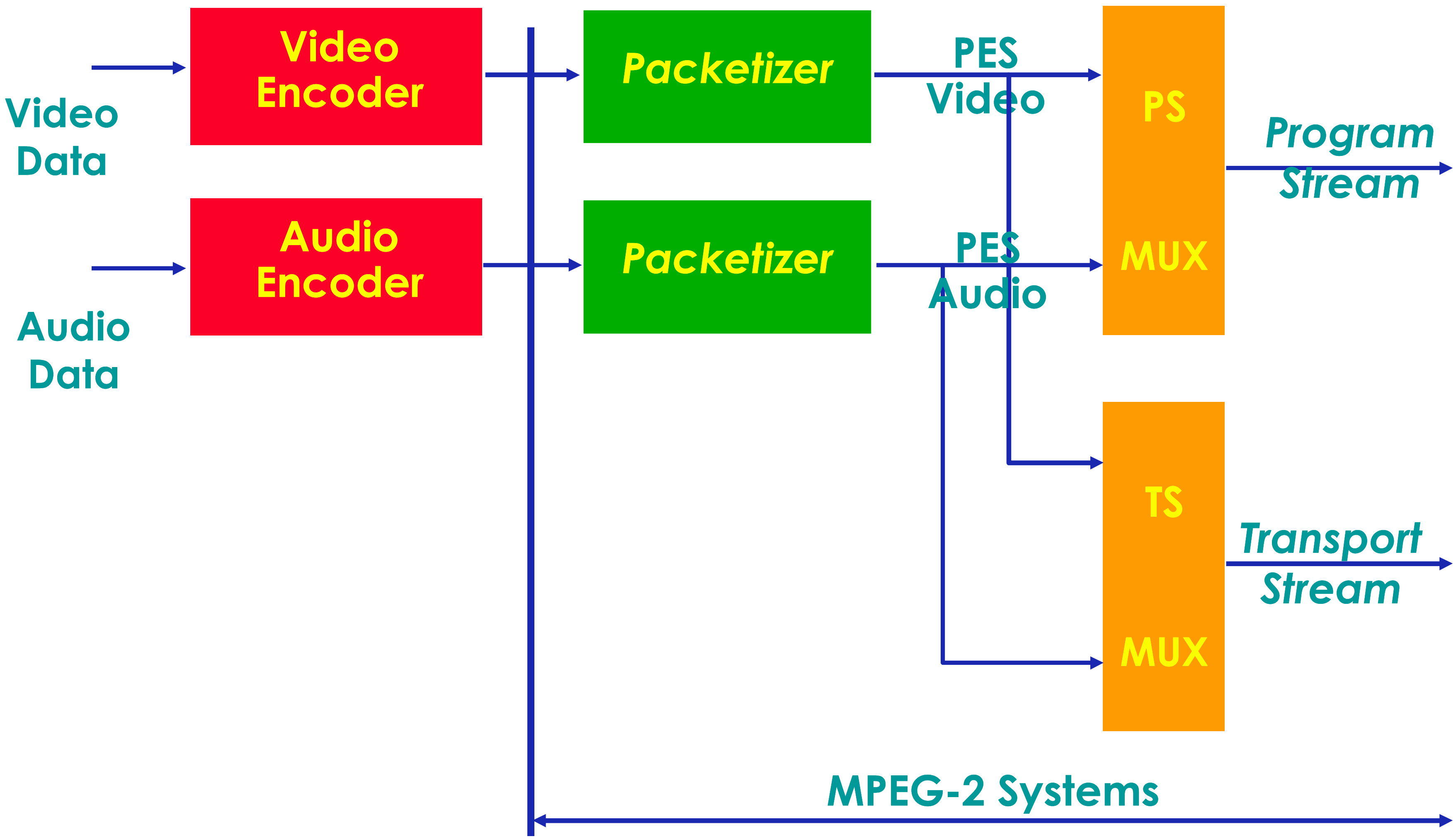
DTS - Decoding Time Stamp

SCR - System Clock Reference (SCR)

PTS - Presentation Time Stamp

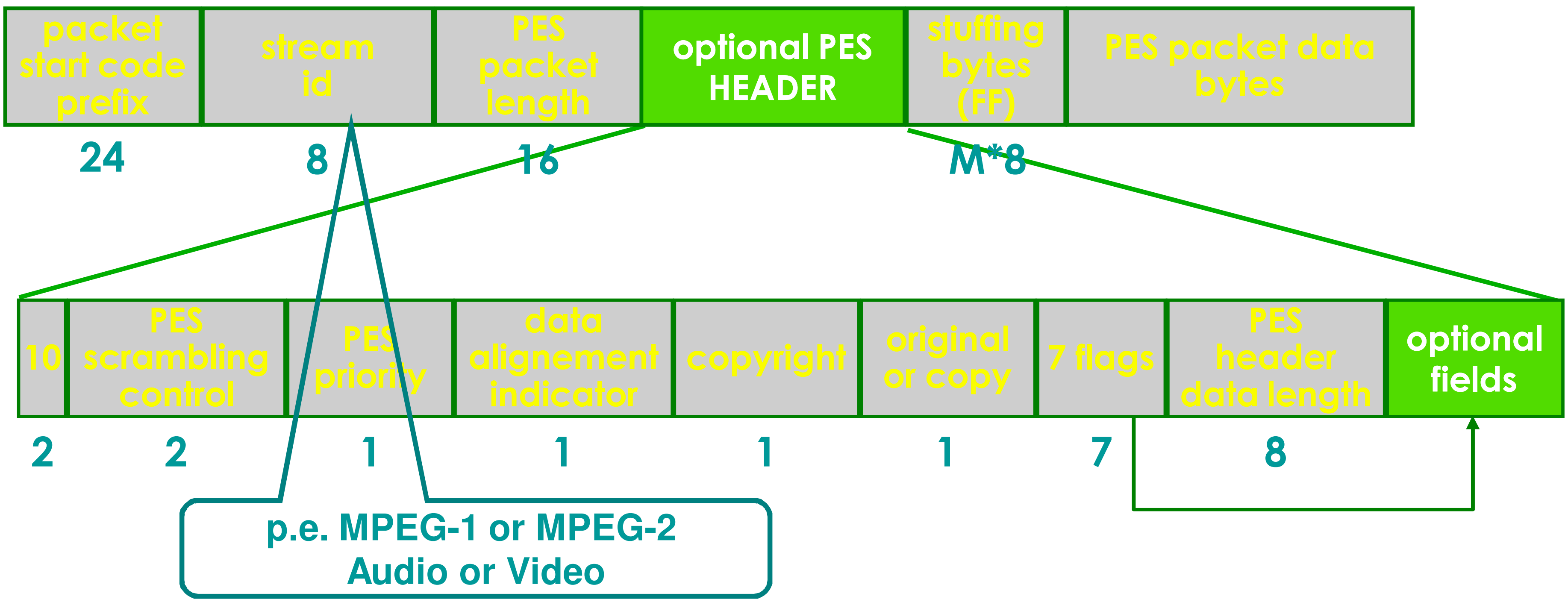
STC – System Time Clock

MPEG-2 Systems: Basic Architecture



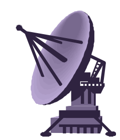
Packetized Elementary Streams (PESs) & Packet Syntax

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.



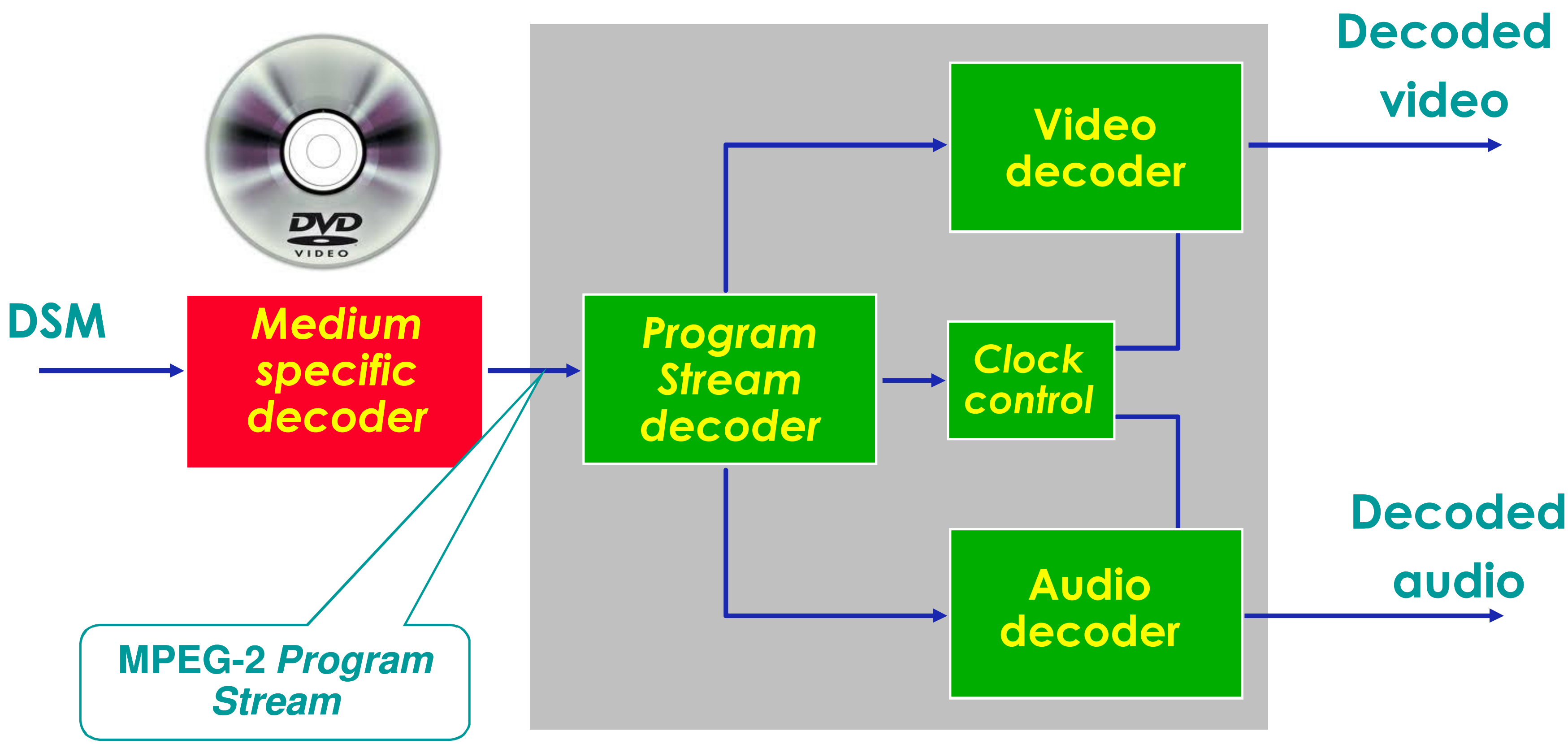
Program Stream and Transport Stream

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

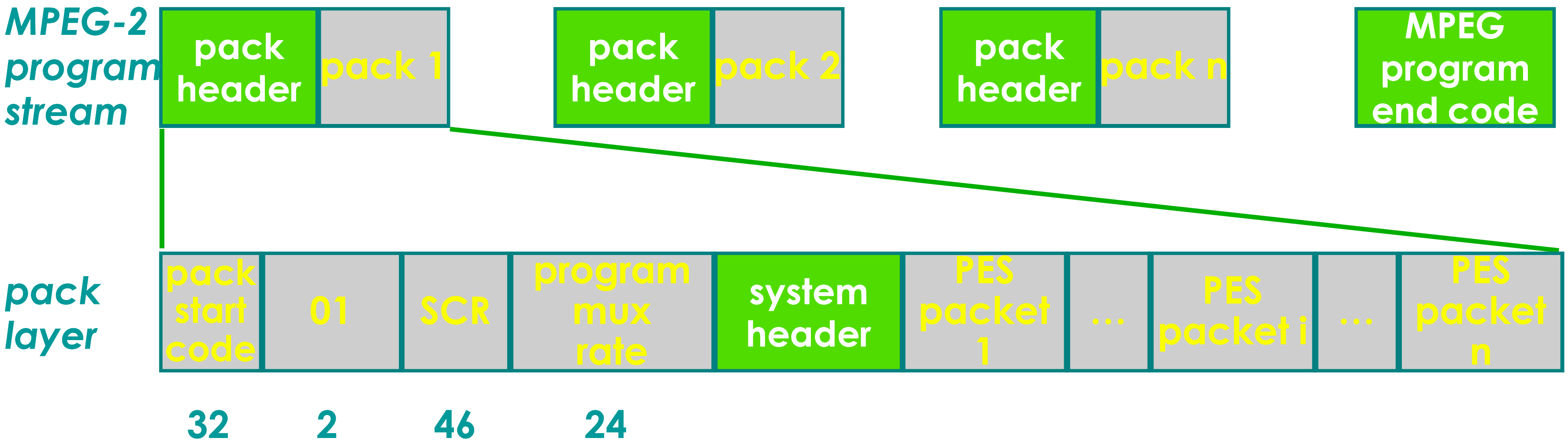


- **Transport Stream:**
  - **Stream may include several time bases to combine programs with different time bases; however, each PES has a single time base**
  - **Adequate for transmission in error prone channels (BER > 10^{-4}), e.g.. broadcasting**
  - **Packets with <u>a fixed length of 188 bytes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

Decoding Program Streams …



Program Stream Syntax



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

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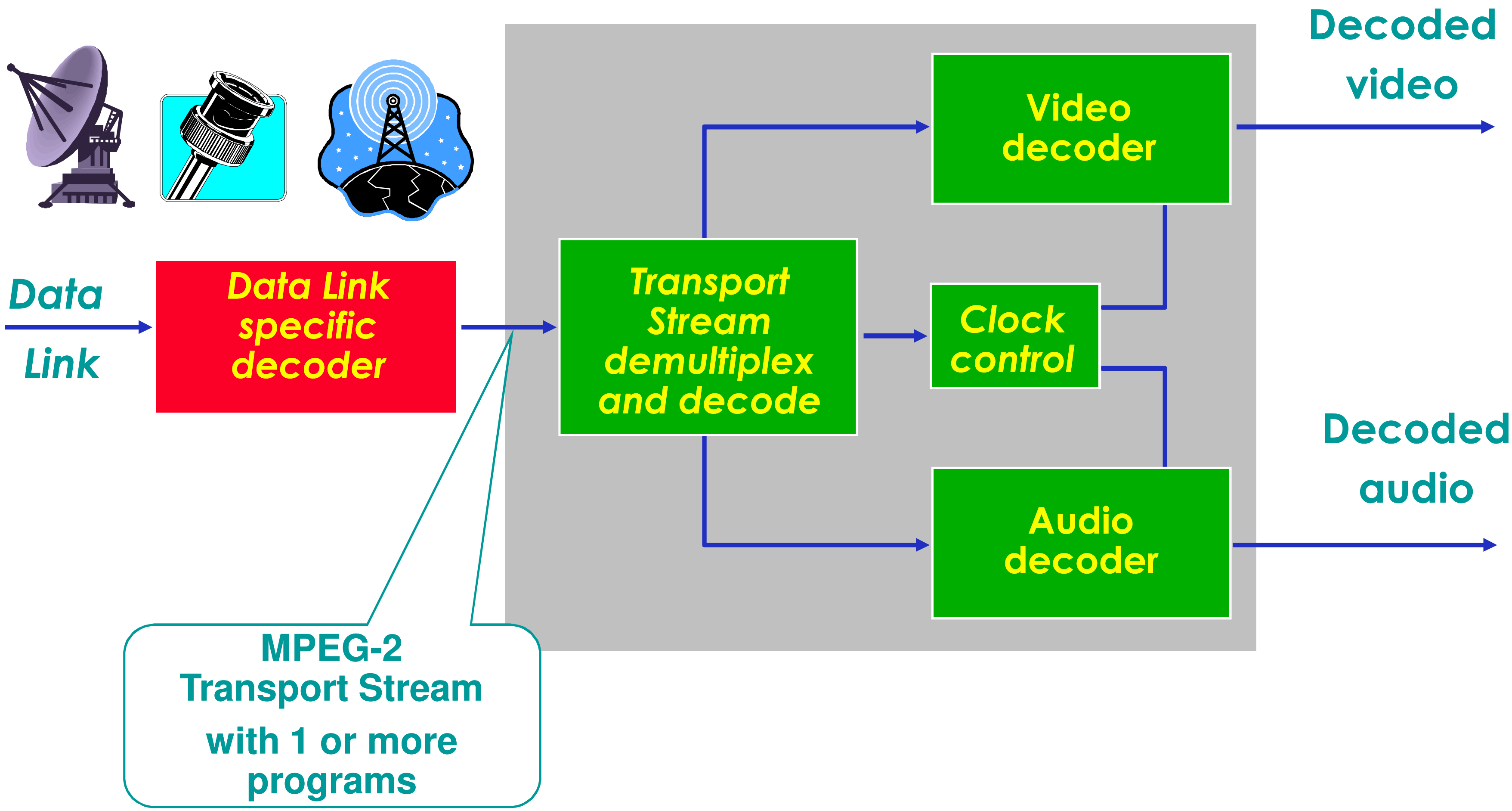
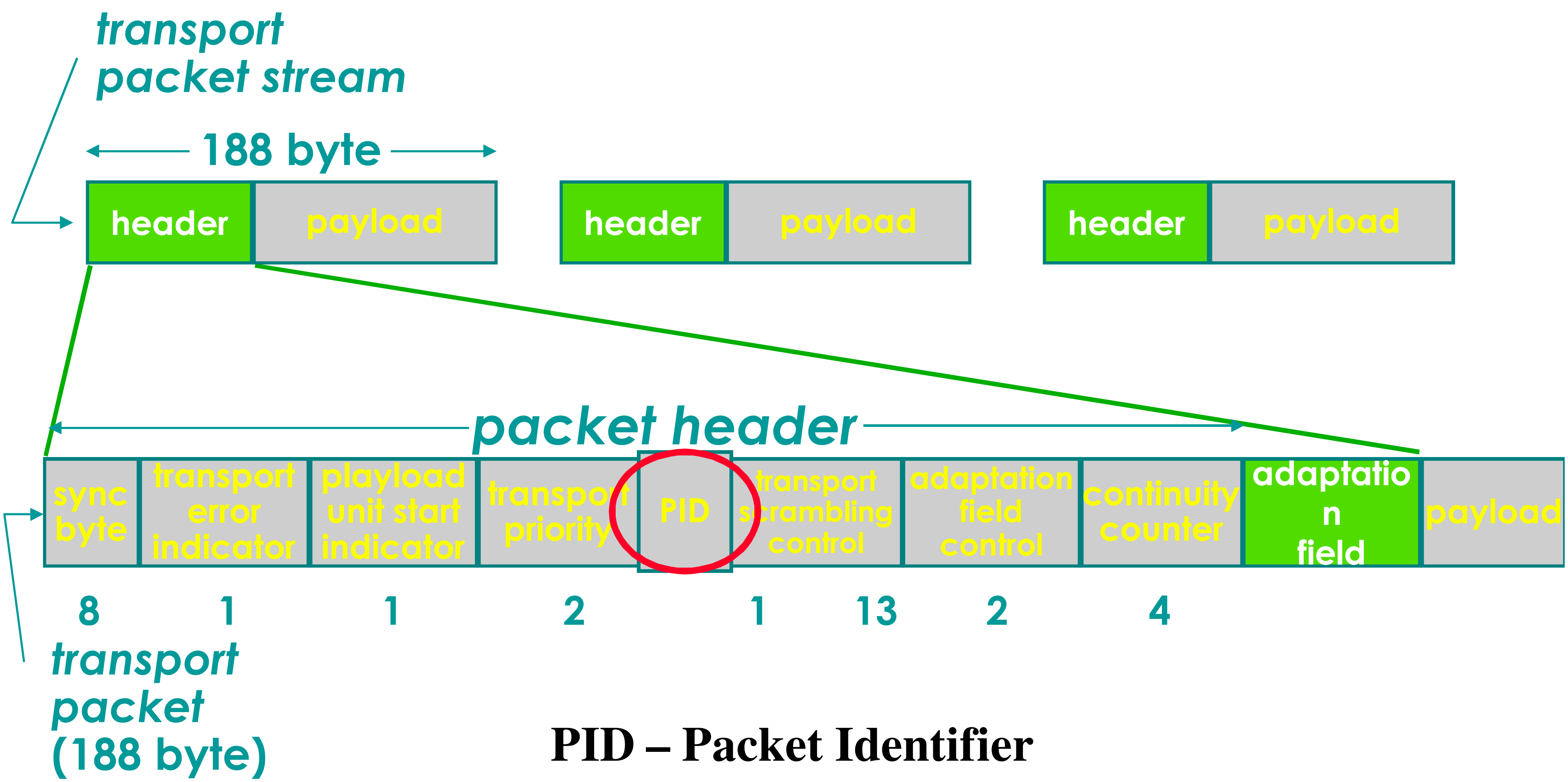
Decoding Transport Streams …

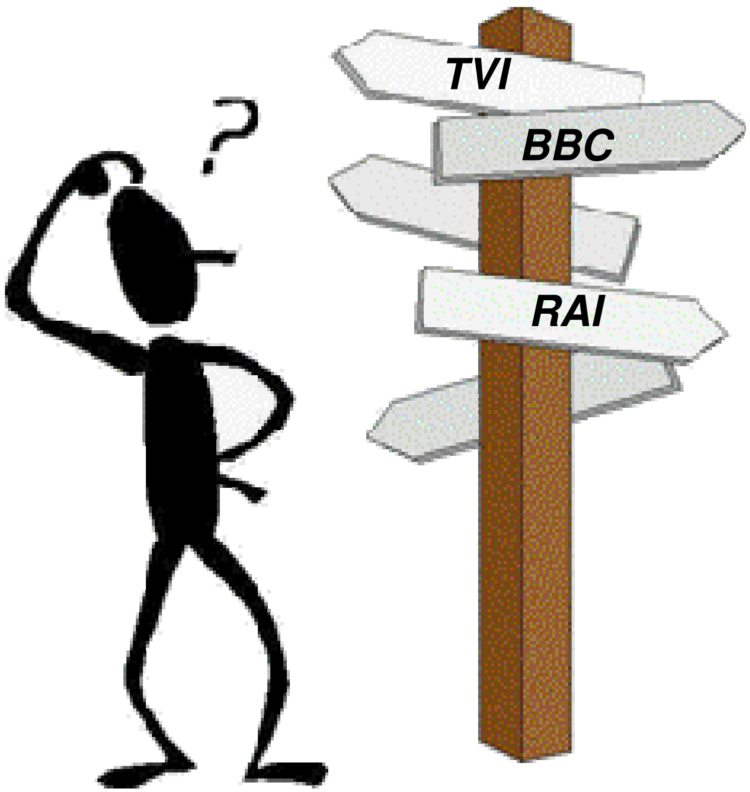


Transport Stream Syntax



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**

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- ***Program Association Table* (PAT) – Corresponds to PID 0x00 and it 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 <u>for each program</u>; it is always *on the clear* even if the programs are encrypted.**
- ***Conditional Access Table* (CAT) – Corresponds to PID 0x01 and it 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).**

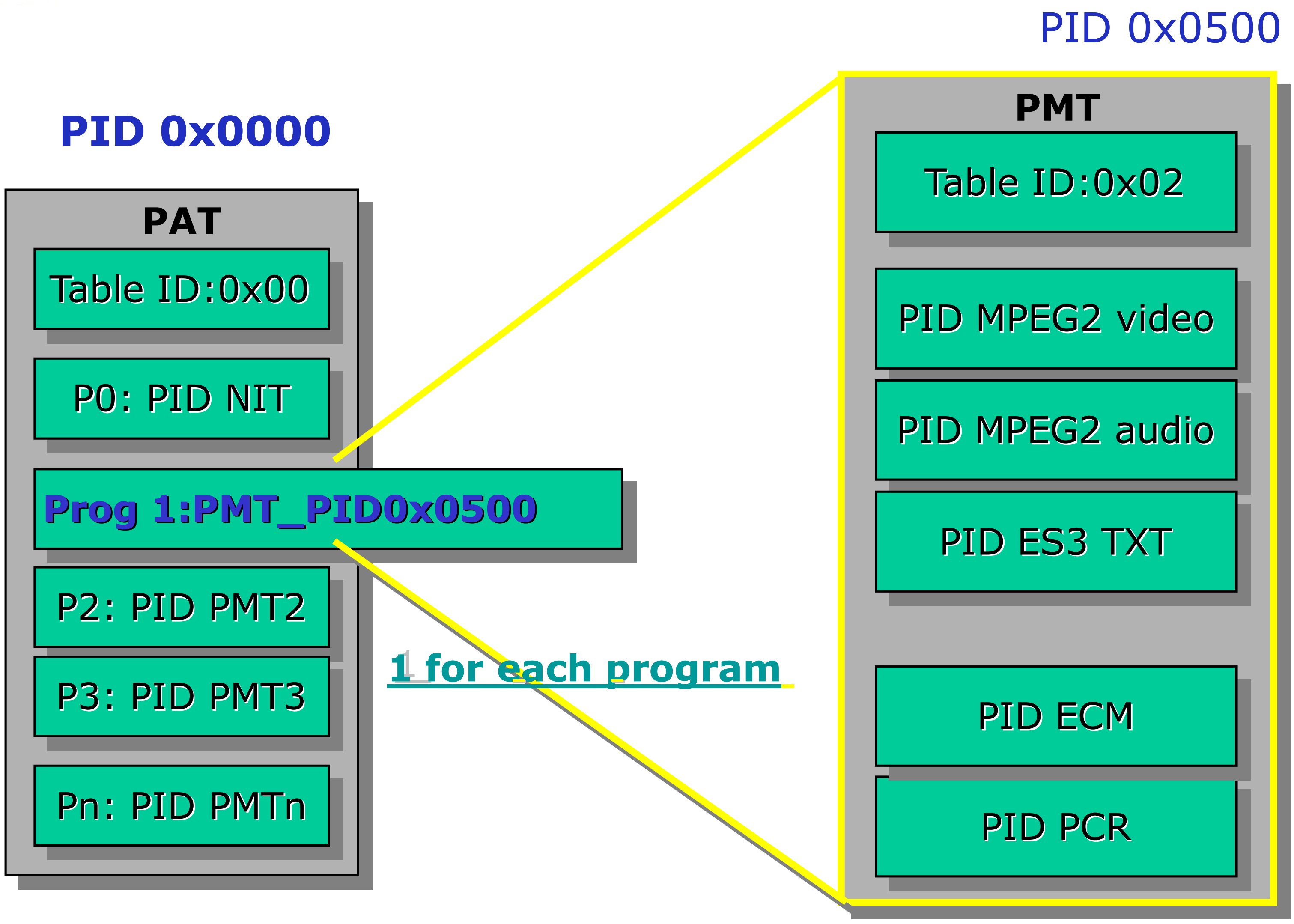
Program Association Table (PAT): the Main Entrance Door

- Mandatory table for each transport stream
- Delivered in the packets with PID = 0
- Indicates for all programs present in this transport stream, the relation between the program number (0 - 65535) and the PID of the packets transporting the map of that program, this means the Program Map Table
- The PAT is always sent without protection even if all programs in the transport stream are protected

Program Map Table (PMT)

- **Provides detailed information about a specific program**
- **Identifies the packets (PIDs) transporting the audio and video elementary streams associated to the program it refers**
- **Identifies the PID for the packets transporting the temporal references associated to the relevant program clock (SCRs)**
- **May be enhanced with a set of descriptors (standard or user specified), e.g.**
  - Video coding parameters
  - Audio coding parameters
  - Language identification
  - Conditional access information

Relation between PAT and PMT



Network Information Table (NIT)

- Optional table with private content, i.e. its content is defined by the user and is not standardized by MPEG

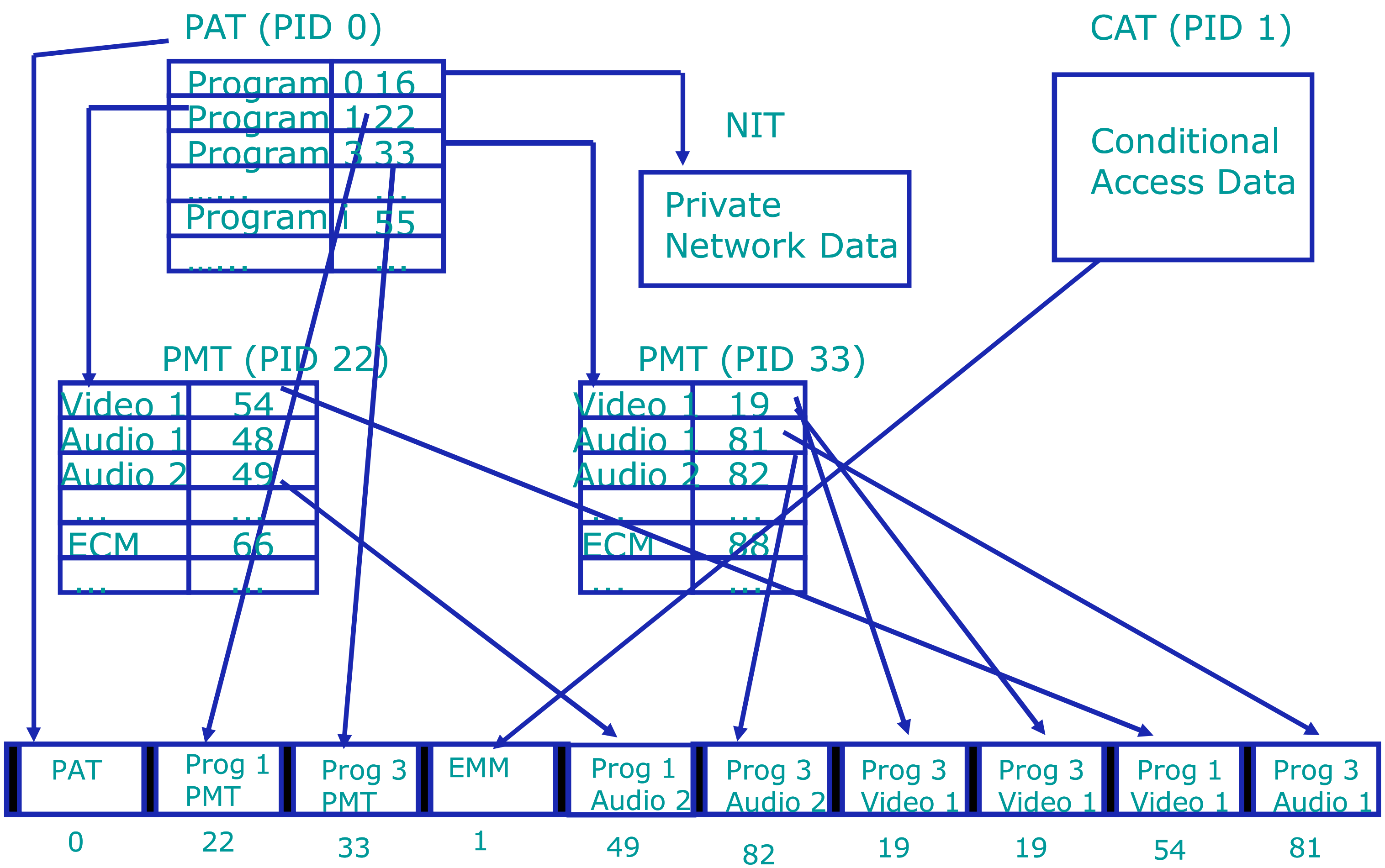
- Should provide information about the physical network, e.g.
  - Channel frequencies
  - Satellite details
  - Modulation characteristics
  - Service provider
  - Alternative available networks

- When present, the PID for the NIT is contained in the PAT program 0

Conditional Access Table (CAT)

- **Mandatory whenever there is, at least, one elementary stream in the transport stream which is protected**
- **Provides information about the <u>used protection system</u> (scrambling)**
- **Identifies the PIDs for the packets transporting the conditional access management and authorization information**
- **Its format is not specified by the MPEG-2 standard since it depends on the used protection mechanism which is typically operator dependent**

Relation between PSI Tables ...



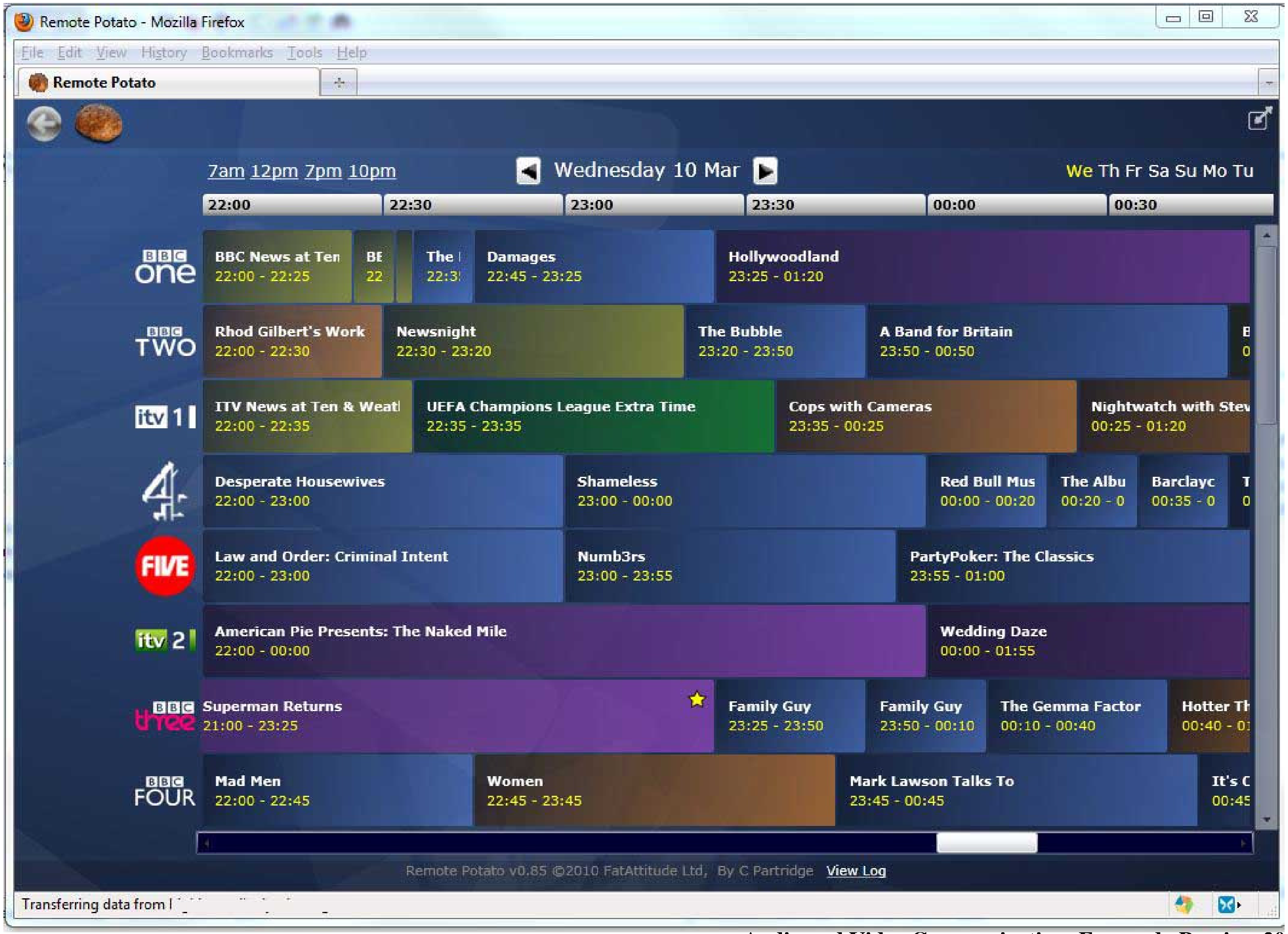
DVB Service Information (SI) Tables

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 and depend on 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

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MPEG-2 Standard

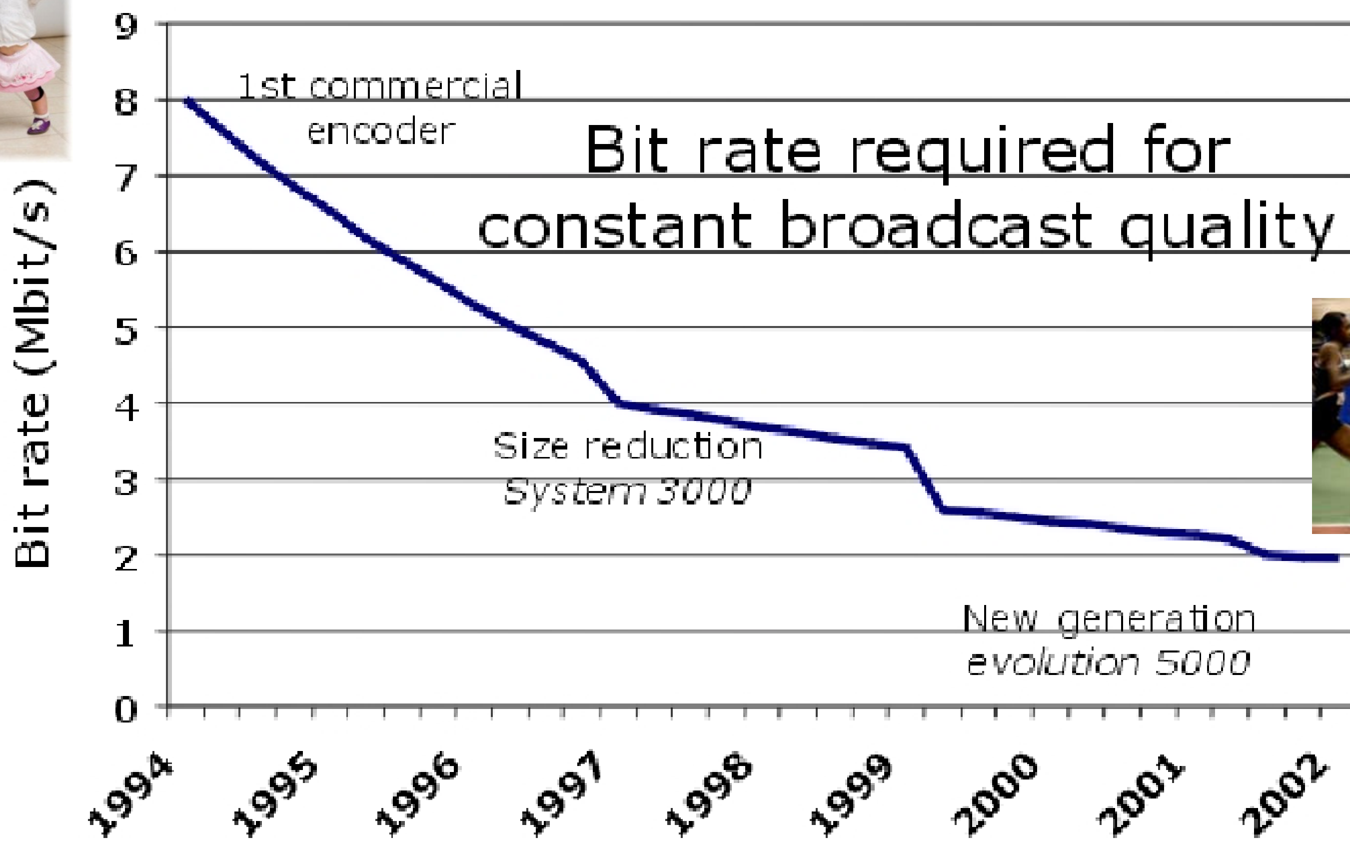
Part 2: Video

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).

Better Encoders for the Same Decoders ...



MPEG-2 Video

Reproduced with the kind permission of TANDBERG Television

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)**

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

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

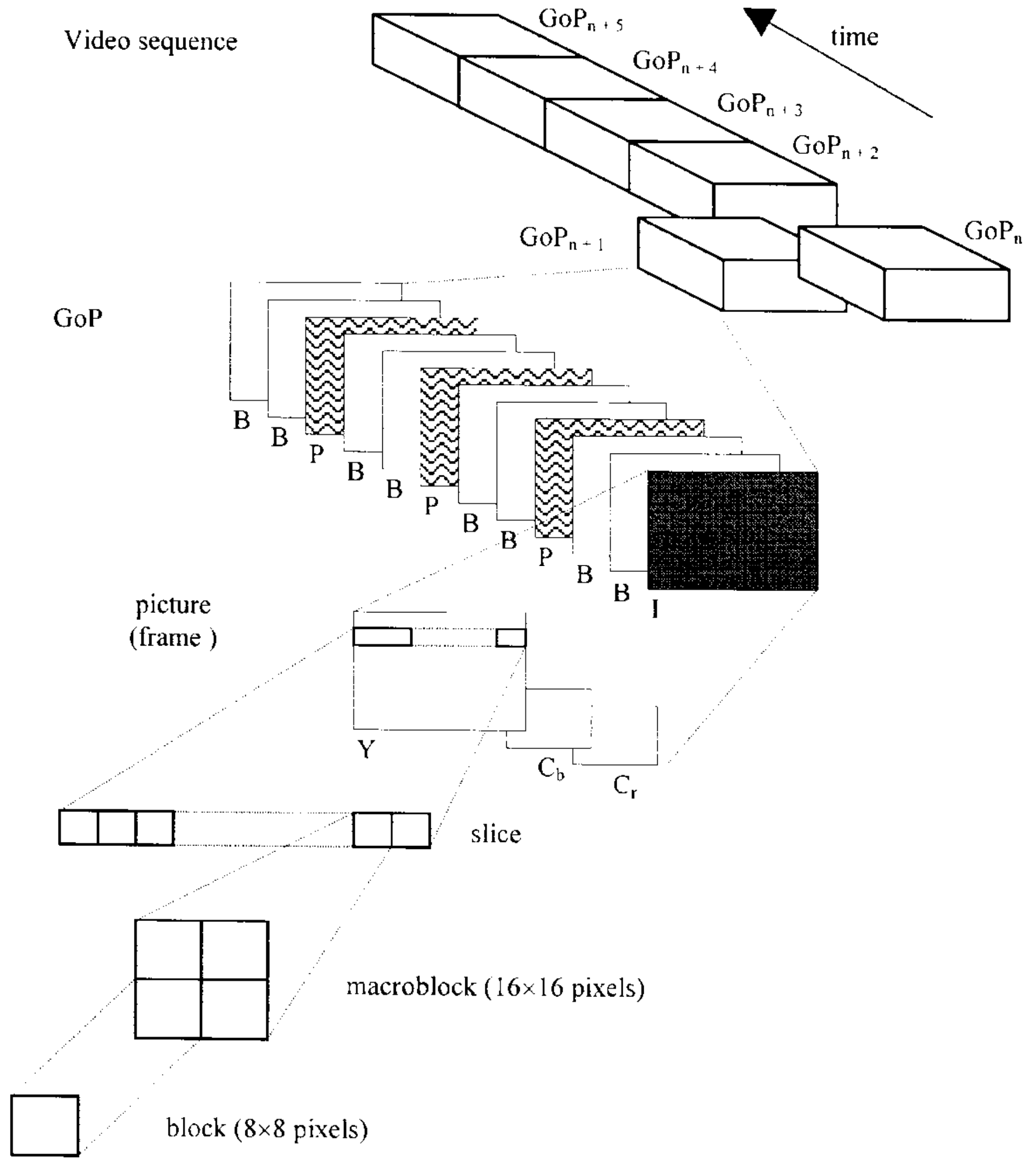
- **Symmetric Applications – For the *one to one* type of applications, both the encoders and decoder should have a reasonable (low) complexity.**

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.

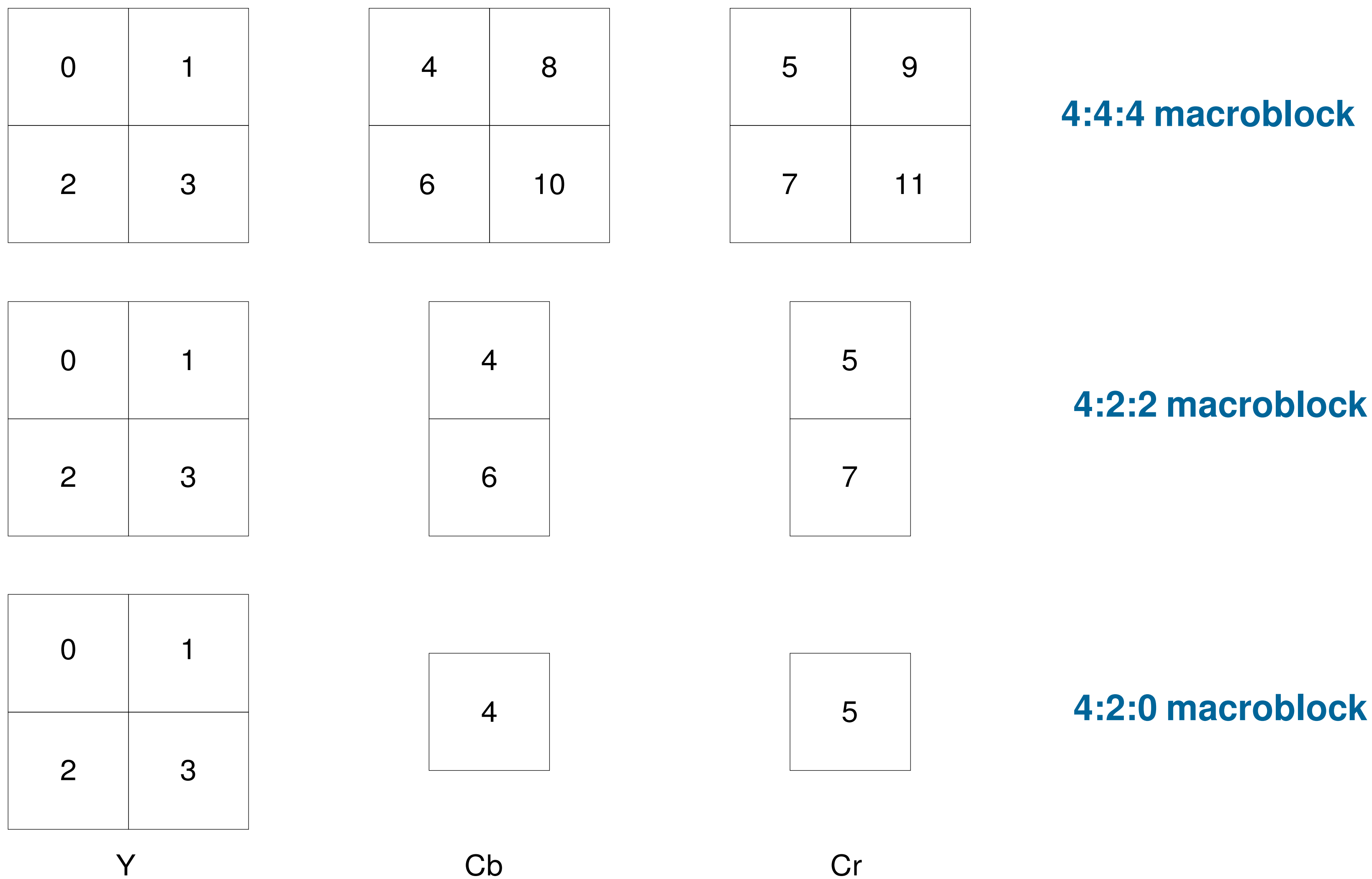
Video Structure

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

Lossless :-)

- **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

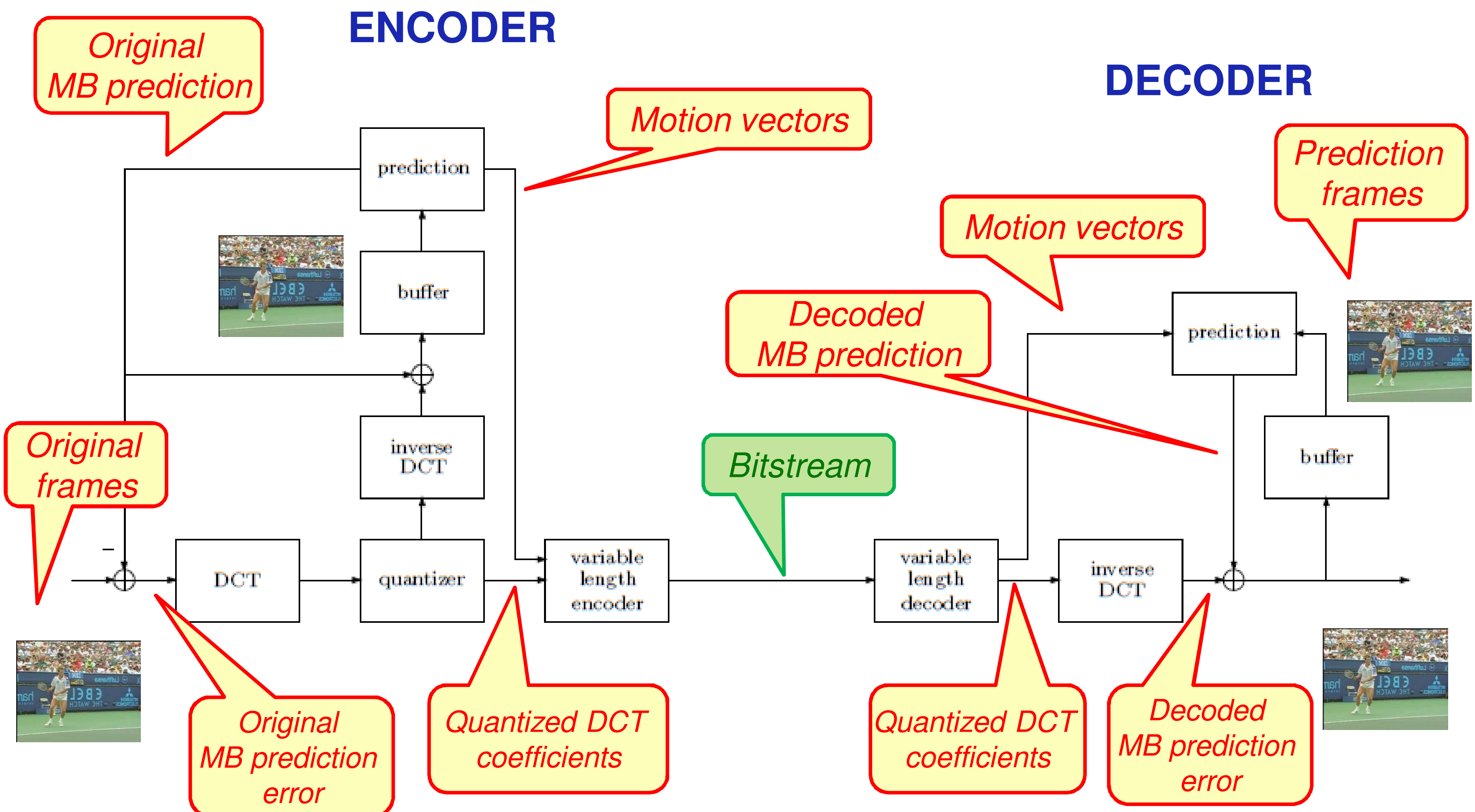
- **Irrelevancy**

Lossy :-(

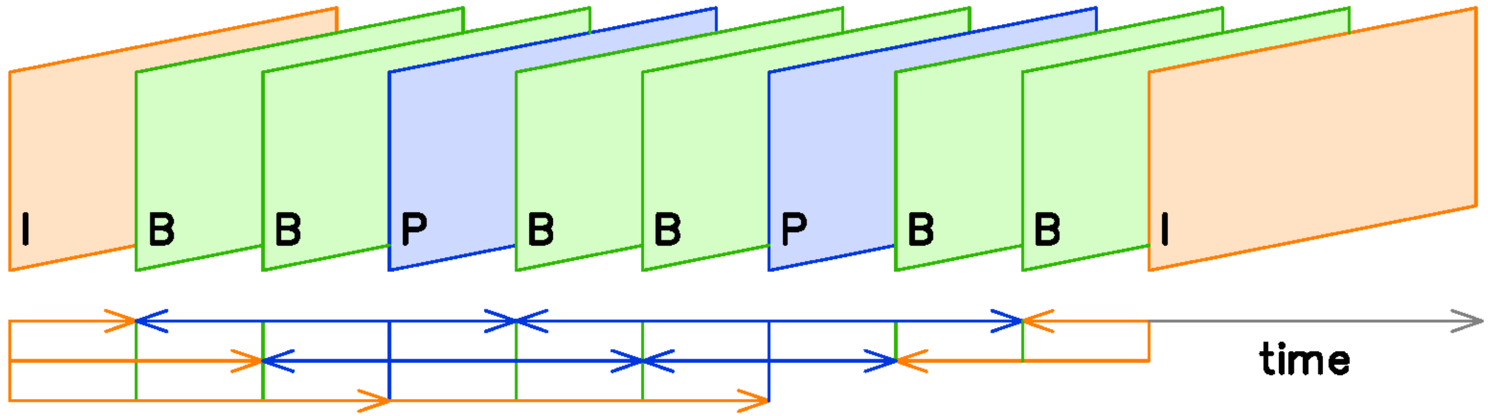
DCT coefficients quantization

Starting with the same Architecture …

Buying Quality with Computation, Memory and Delay …



Temporal Prediction Structure



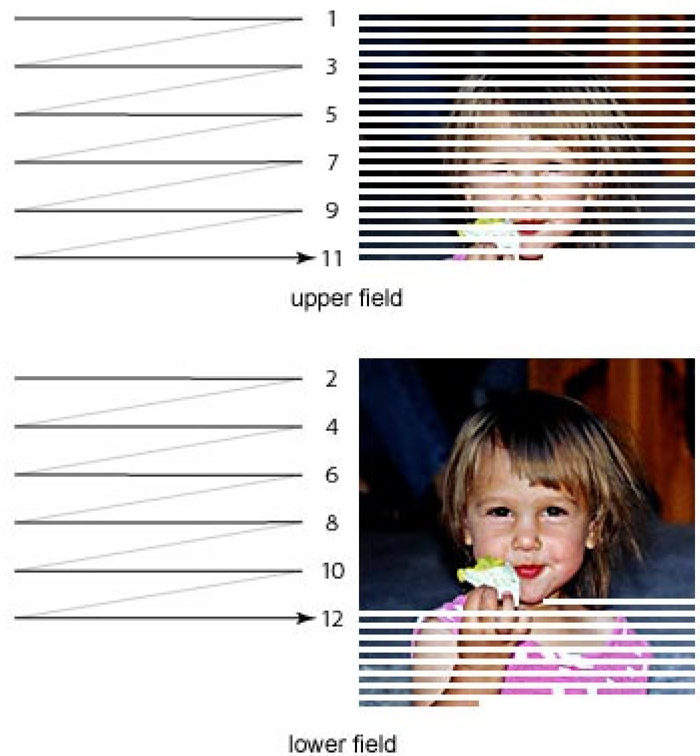
The "conflict" between compression efficiency and random access led to the definition of 3 frame types depending on the used coding tools:

- 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**

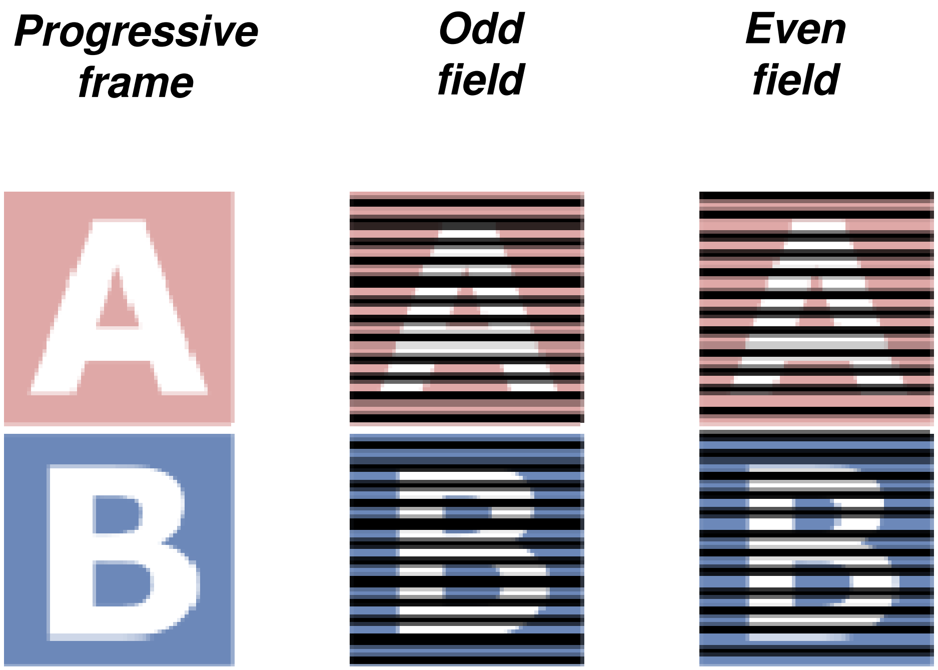


TÉCNICO LISBOA

MPEG-2 Video

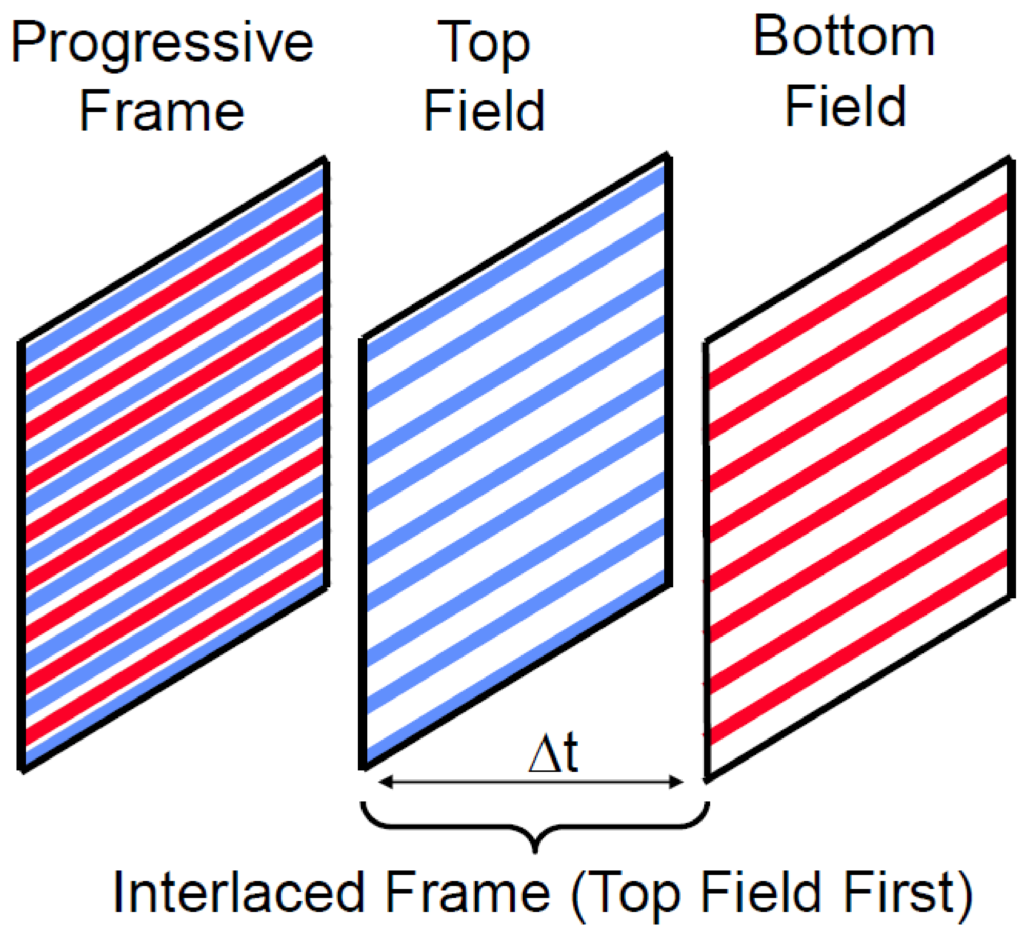
Interlaced Coding

TV World: Interlaced versus Progressive



Coding directly the ‘deinterlaced’ frame as a progressive frame may imply coding many (fake) high frequencies which is also expensive !

Progressive and Interlaced-Scan Video Signal

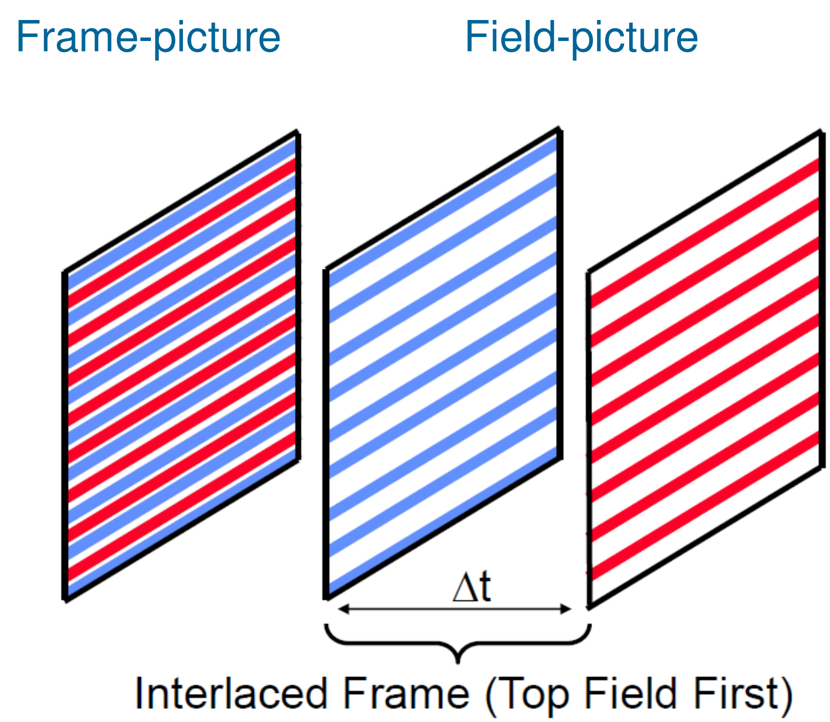


- Progressive and interlaced frames can be coded as one single unit
- Progressive vs. interlaced frame is signaled but has no impact on the decoding tools
- In interlaced content, each field can be coded separately
- The encoder can switch between frame and field coding on a picture-by-pictures basis

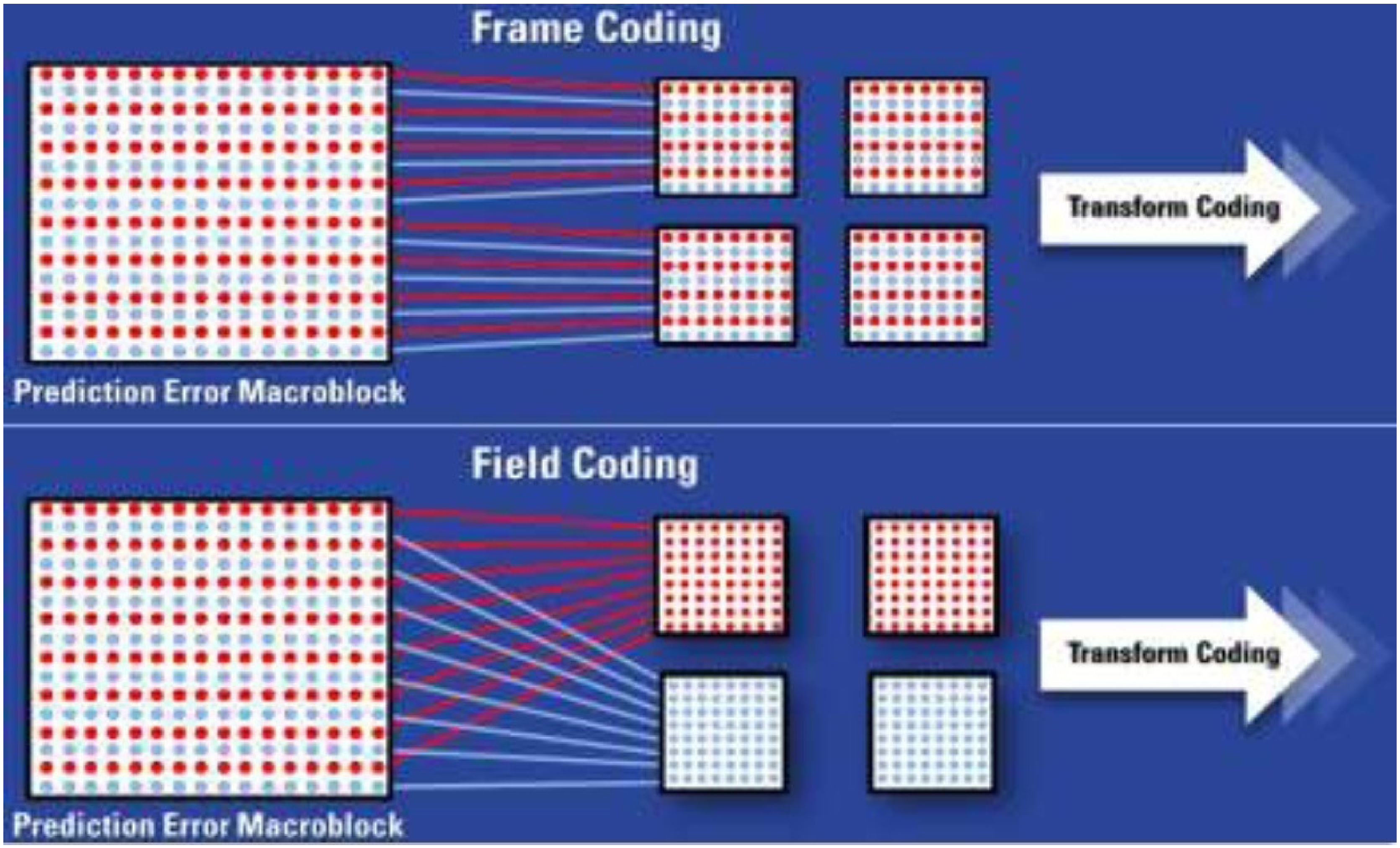
Interlaced Content Coding

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



Adaptive Frame/Field Transform



Main Prediction Modes

1) Frame-Pictures

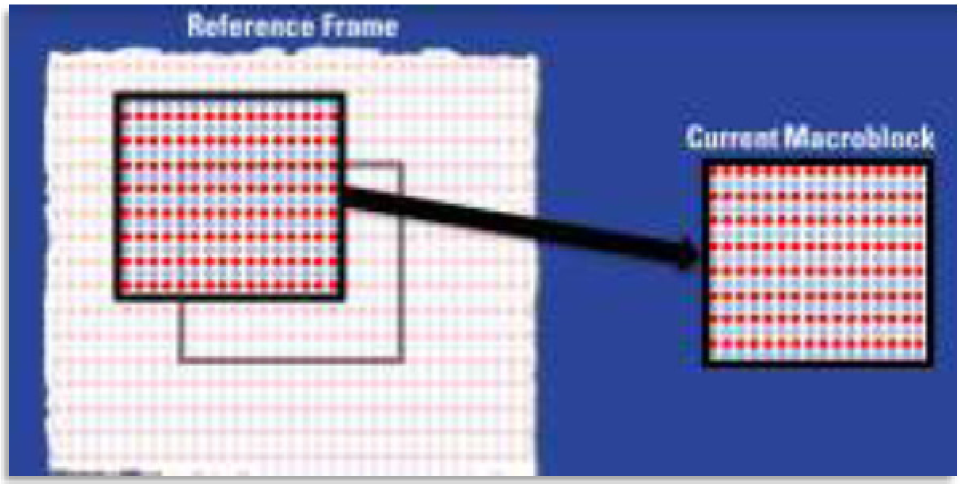
- **Frame Mode for Frame-Pictures –** Similar to MPEG-1 Video, frames are coded as I, P or B frames with current and prediction MBs defined in the frames; gives good results for content with low or moderate motion or pannings over detailed backgrounds.
- **Field Mode for Frame-Pictures –** Each MB in 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

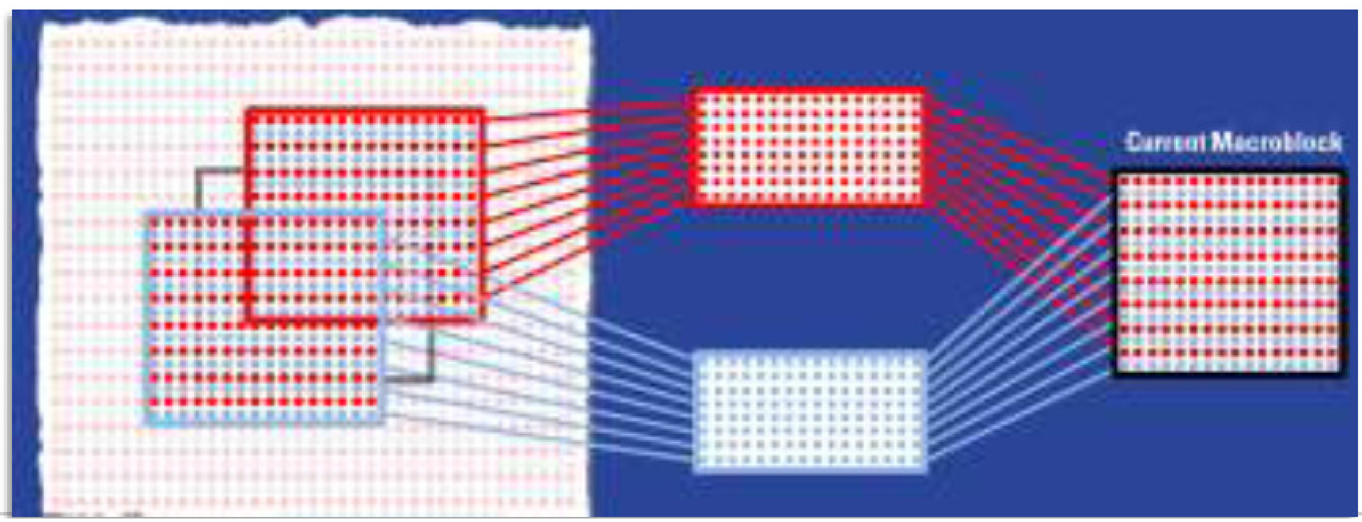
- **Field Mode for Field-Pictures –** Conceptually similar to the previous mode but now with the MBs defined within each field and the predictions also coming from a single field, top or bottom (not necessarily with the same parity).
- **16×8 Blocks for Field-Pictures –** A motion vector is allocated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

Adaptive Frame/Field Motion Prediction

Frame Mode for Frame-Pictures

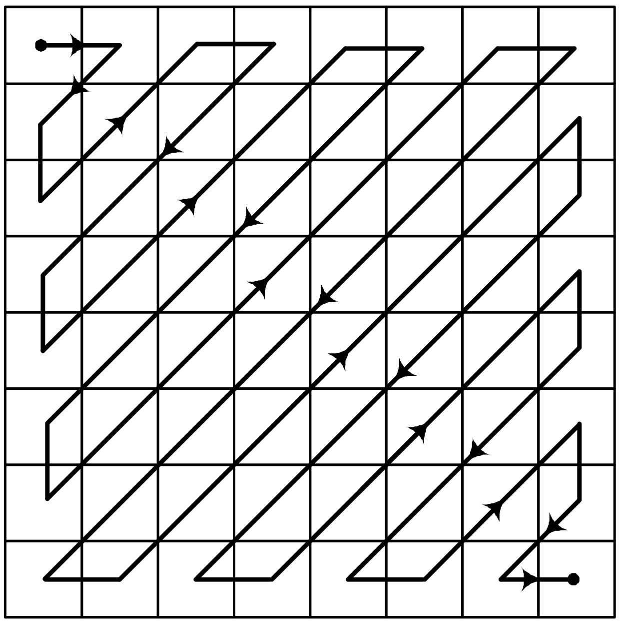


Field Mode for Frame-Pictures

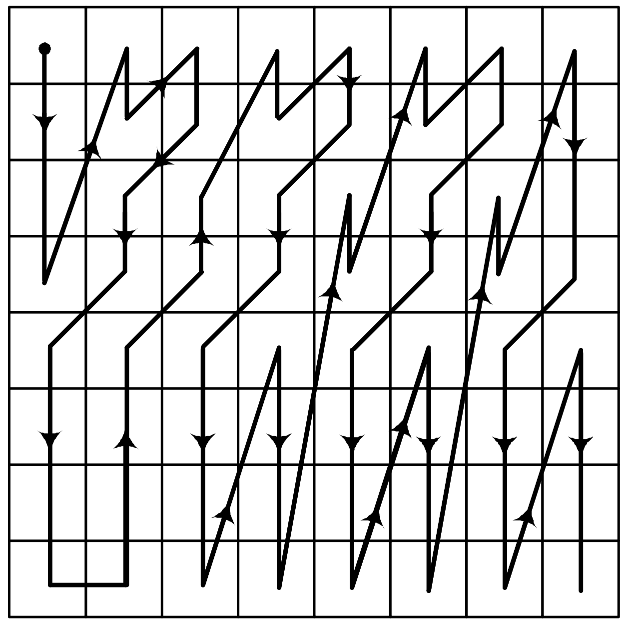


Alternate Scanning Order for Frame Pictures …

Zig-zag order



Alternate order



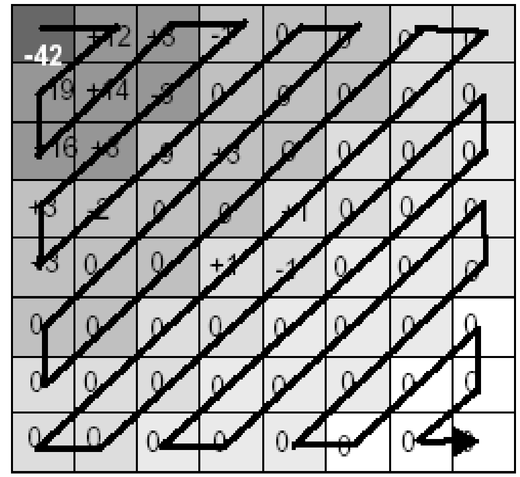
For frame-pictures, the correlation between lines may be reduced for the pictures with more motion. Thus, it is possible to use another scanning order – ALTERNATE order – where the DCT coefficients corresponding to the vertical transitions (meaning horizontal edges) are privileged in terms of scanning order.

Zig-zag versus Alternate Scanning Orders

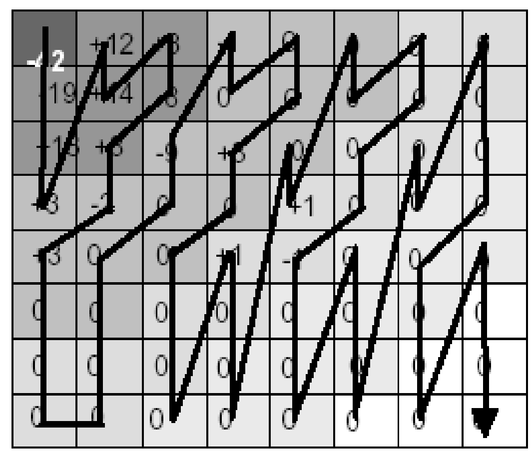
-42	+12	+3	-1	0	0	0	0
-19	+14	-8	0	0	0	0	0
+16	+8	-9	+3	0	0	0	0
+3	-2	0	0	+1	0	0	0
+3	0	0	+1	-1	0	0	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0

Increasing vertical frequency

Increasing horizontal frequency



Zigzag Scan



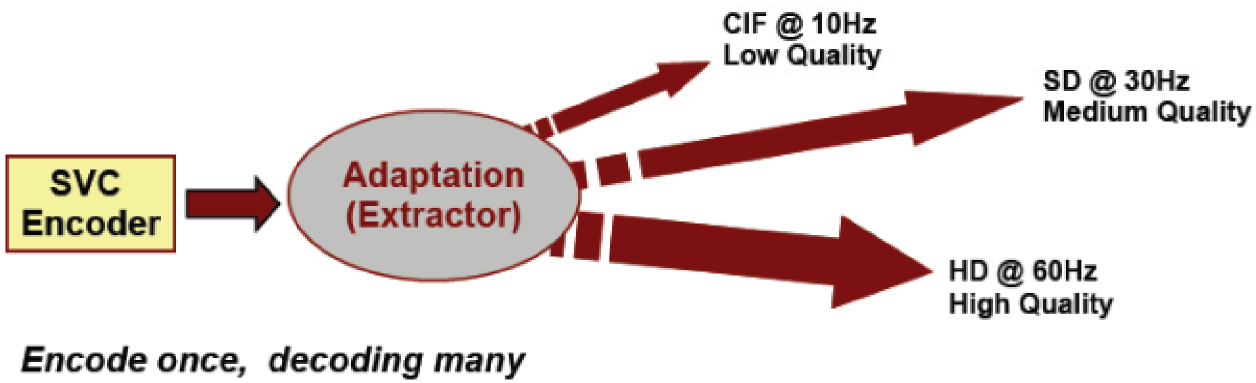
Vertical Scan

MPEG-2 Video

Scalable Coding

Scalability or the Swiss Army Knife Approach

Scalable Coding: the Definition

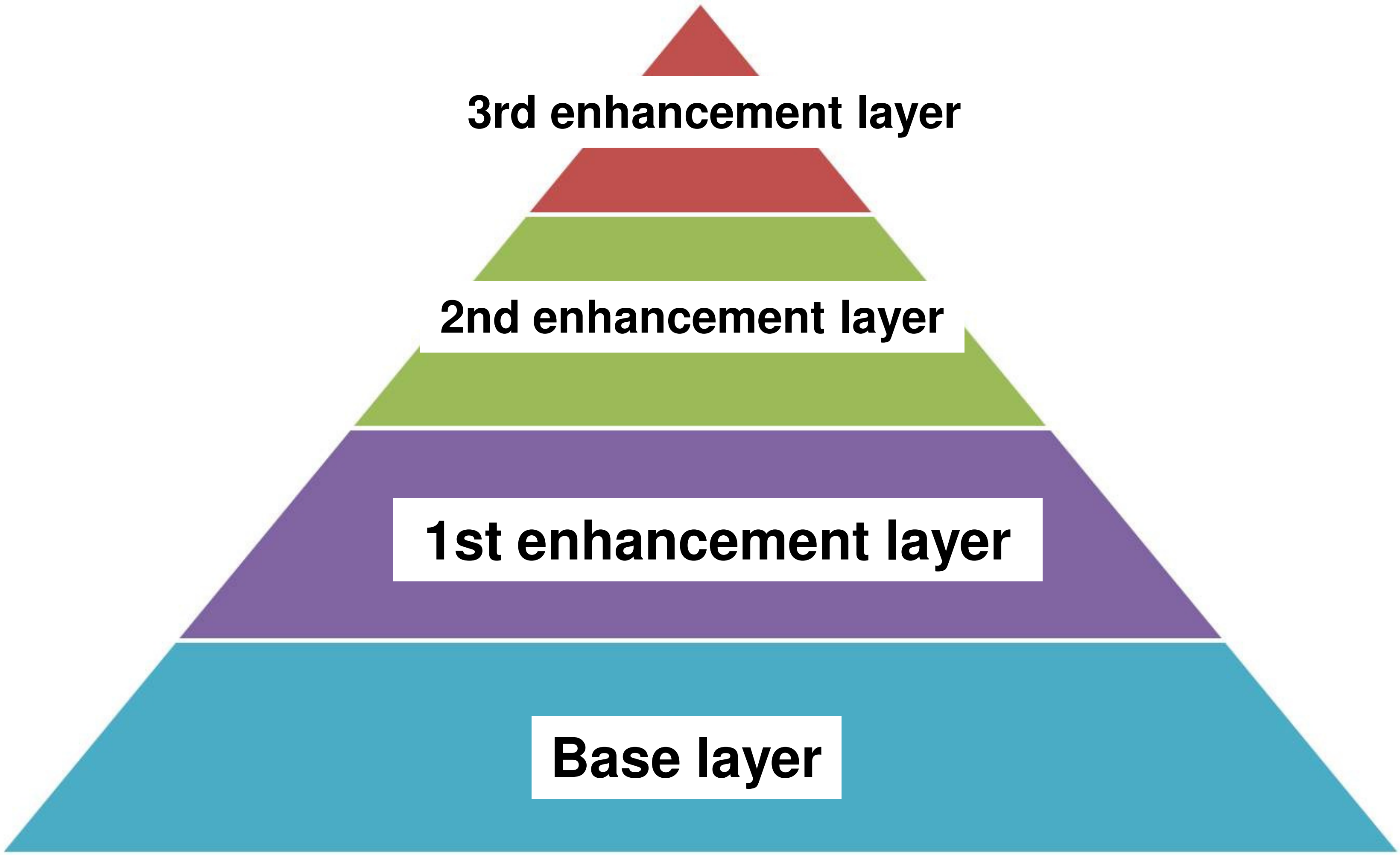


Scalability is a functionality regarding the <u>useful decoding of parts</u> of a coded bitstream, ideally

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**

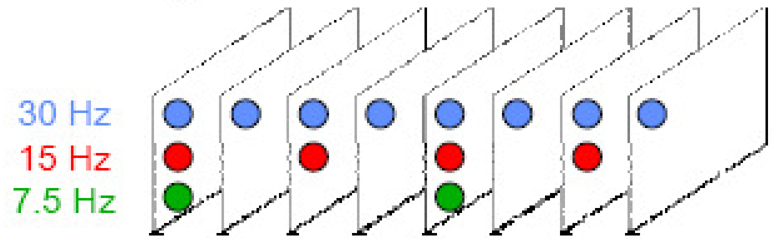
ii) **without significantly increasing the decoding complexity.**

Scalable Hierarchical Coding



Scalability Types

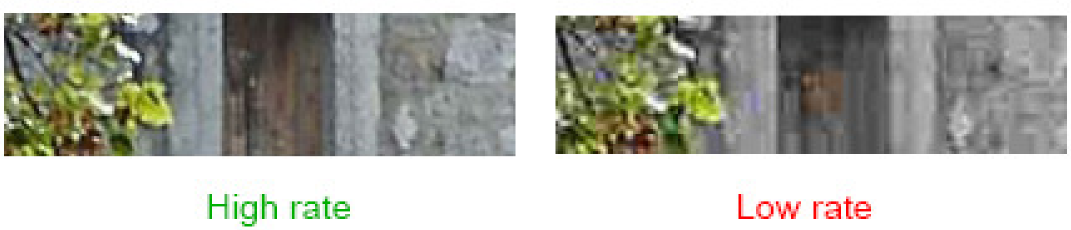
- **Temporal**: change of frame rate



- **Spatial**: change of frame size

HDTV

- **Fidelity**: change of quality (a.k.a. SNR)



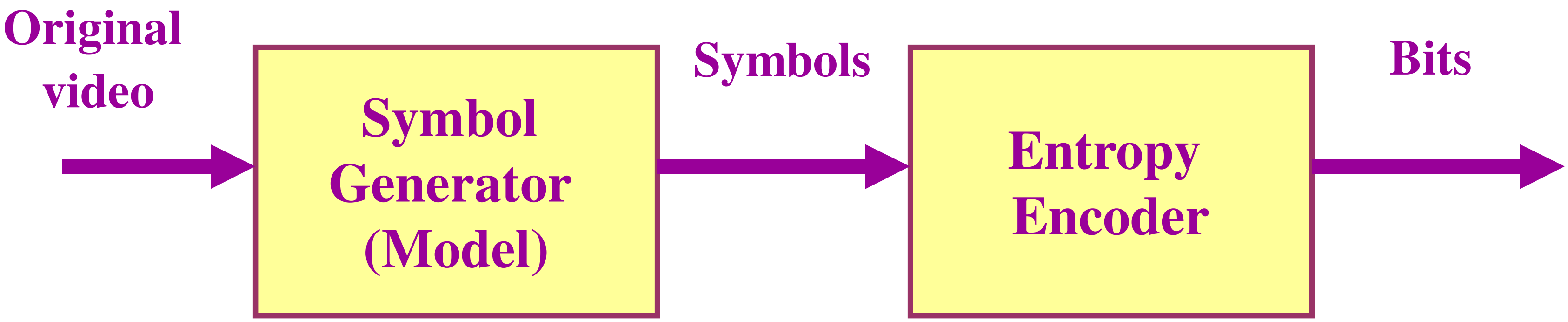
MPEG-2 Video Scalability: Weaknesses

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

- **<u>Characteristics of traditional video transmission systems</u> where a fixed bandwidth was guaranteed and thus no dynamic variations or heterogeneous consumptions had to be accommodated**
- **<u>HDTV did not explode</u> as flat displays did not emerge and thus standard definition was still the single solution**
- **<u>Significant penalty in compression efficiency</u> regarding non-scalable coding solutions, meaning much larger bitrate for the same maximum quality/resolution**
- **<u>Large increase in decoder complexity</u> regarding non-scalable coding solutions as all layers up to the target layer have to be decoded and accumulated**

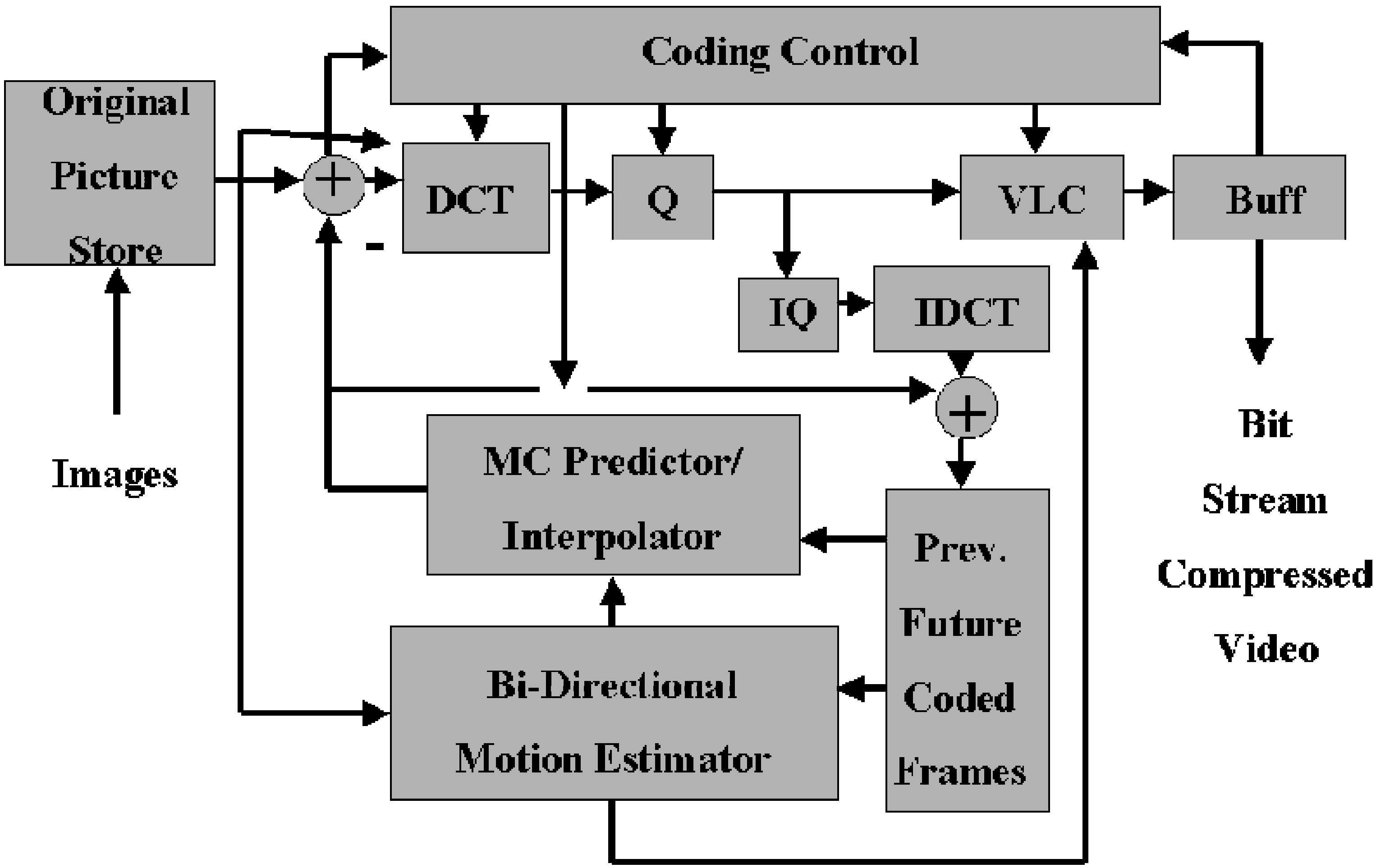
Combining the Coding Tools …

The MPEG-2 Video Symbolic Model

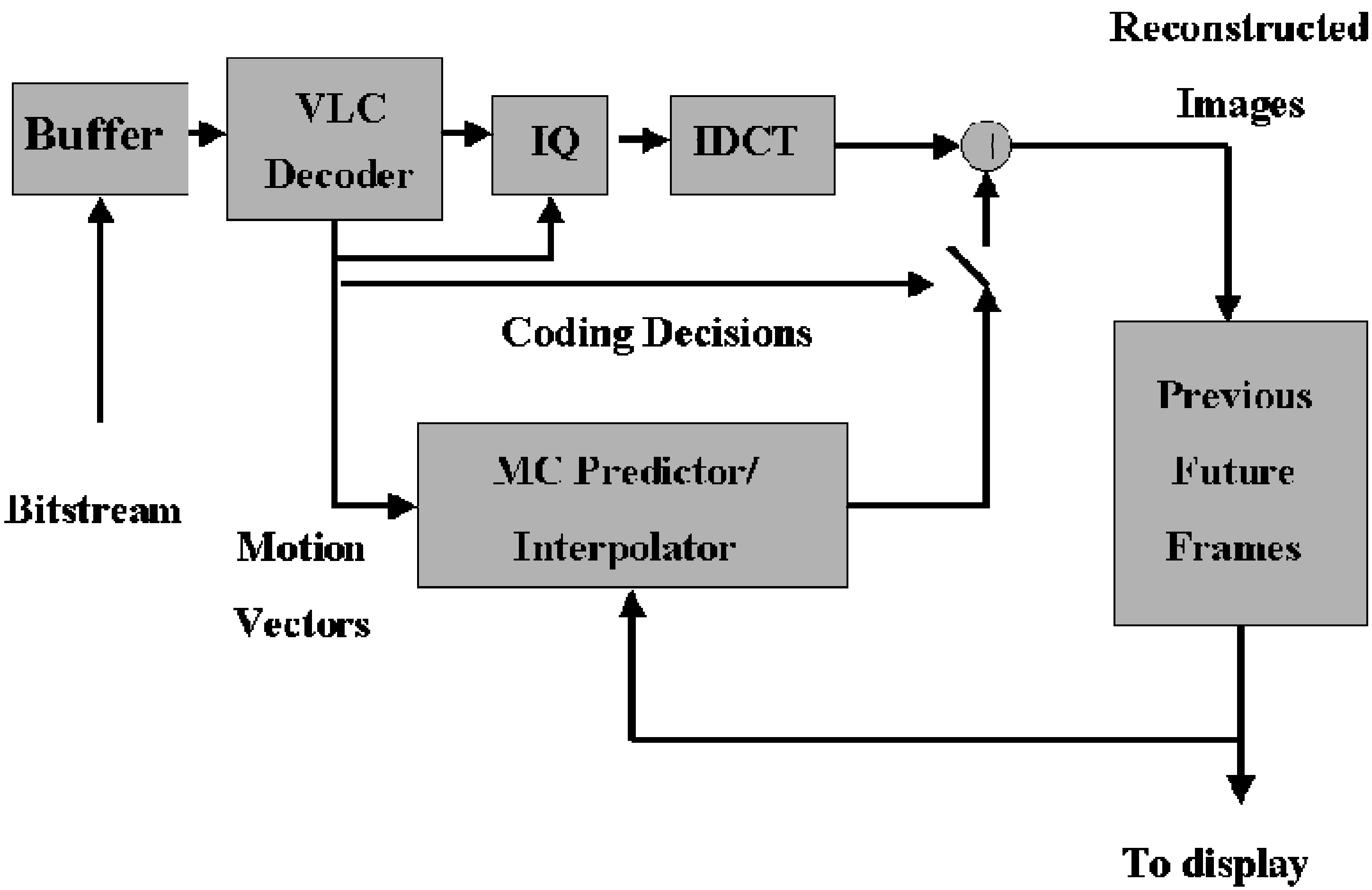


A video sequence (interlaced or progressive) is represented, in a scalable way or not, as a succession of GOPs including pictures coded as frames or fields and classified as I, P or B, structured in macroblocks, each of them represented using motion vectors and/or DCT quantized coefficients, following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

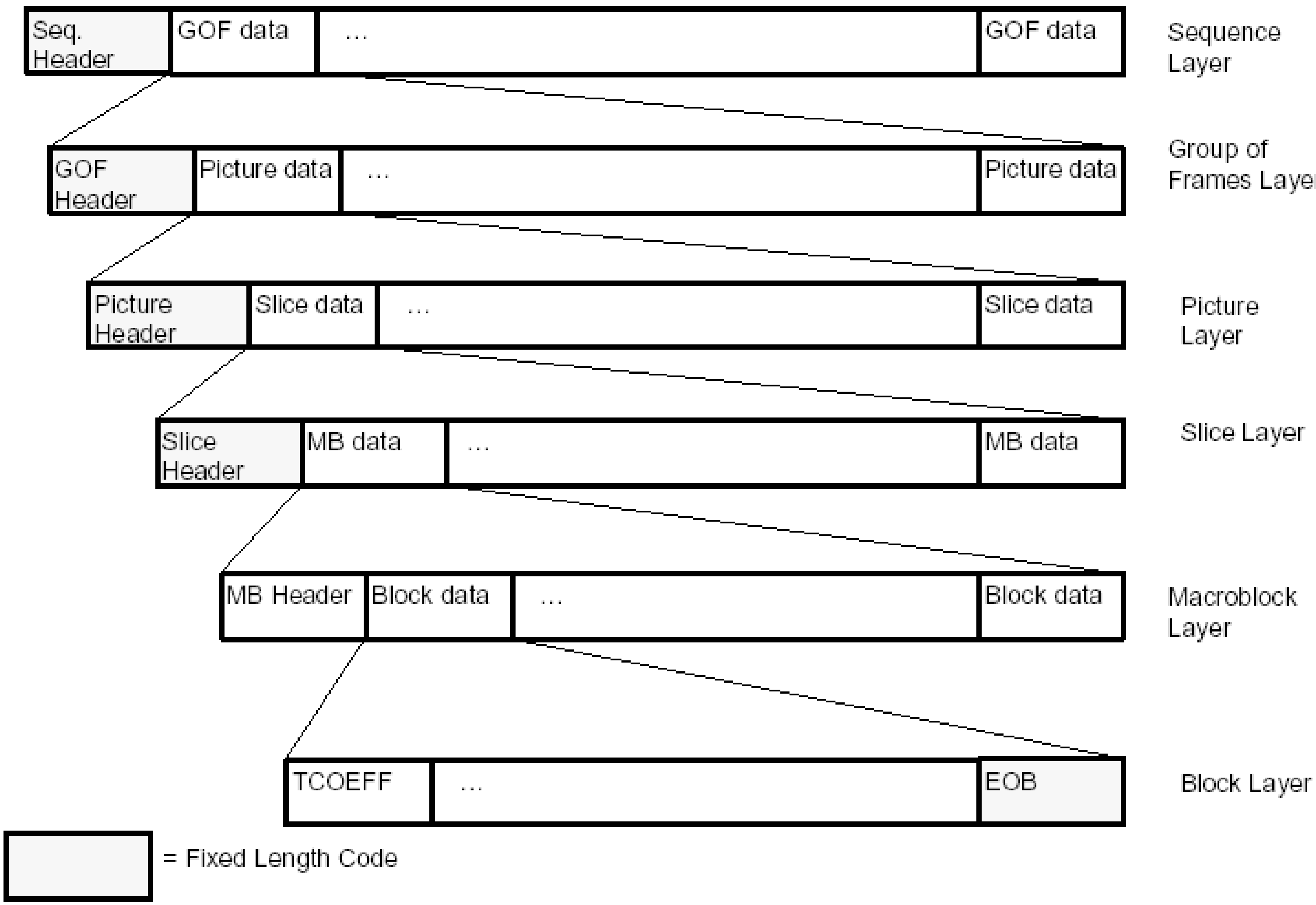
MPEG-2 Video: Encoder



MPEG-2 Video: Decoder



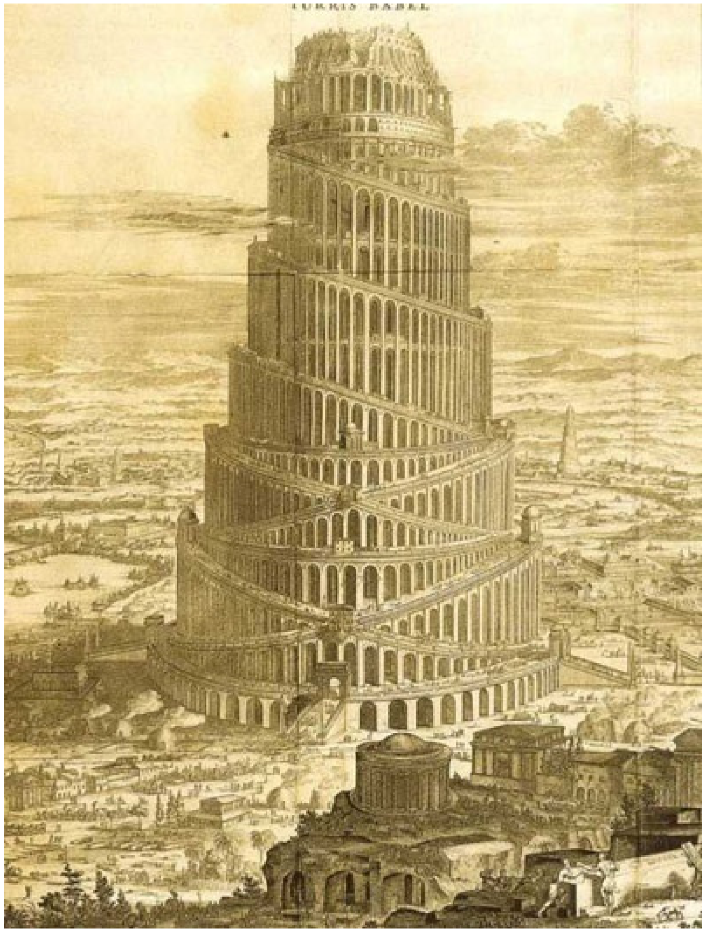
MPEG-2 Video Syntax



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

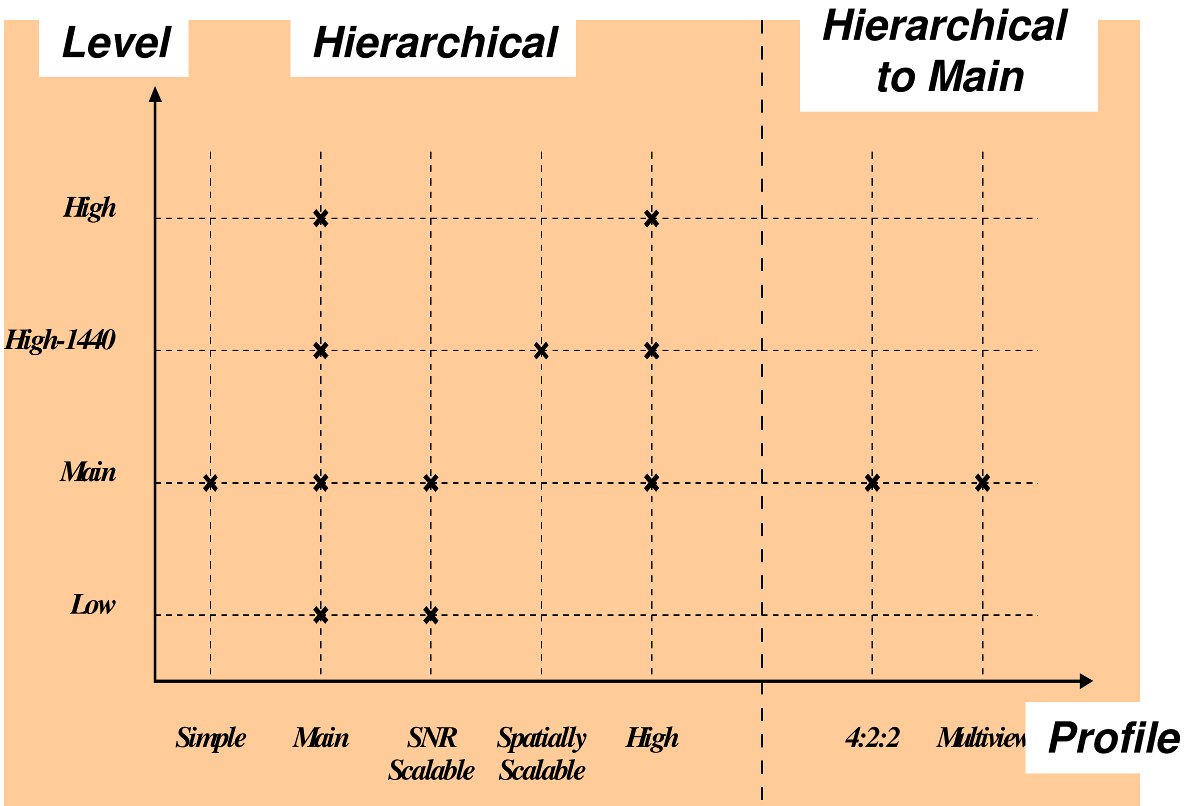
while guaranteeing the necessary compression efficiency capability required by the class of applications in question and limiting the codec complexity and associated costs.

- **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: the Profile and Level Hierarchies



There are 7 profiles although only Main has been largely used.

Some profiles are syntactically hierarchical this means one profile is syntactically a superset of another and so on.

For a profile, the syntactic elements do not vary with the level, just the parametric constraints.

Also the levels may be hierarchical meaning that the constraints become less strict for higher levels, e.g. bitrate increases.

Compliance points for decoder and bitstreams correspond to a profile@level combination.

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

MPEG-2 Standard

Part 3: Audio

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 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).**

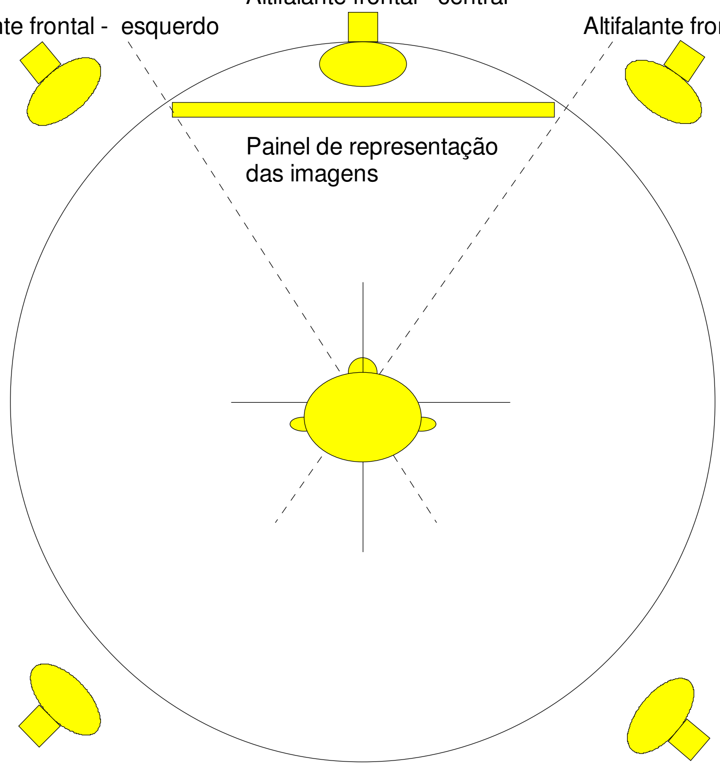
MPEG-2 Audio (Part 3): What's New ?

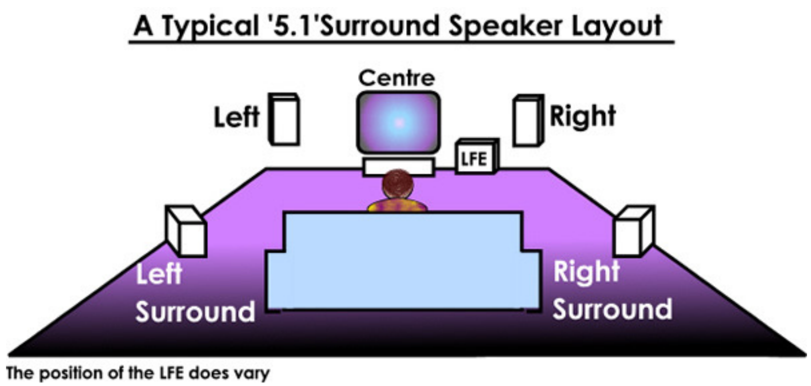
There are two main technical innovations in MPEG-2 Audio (BC or Part 3) regarding MPEG-1 Audio:

- **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 bandwidth
- **Multichannel coding**
  - Motivated by the need to increase the user experience, notably with HDTV.

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

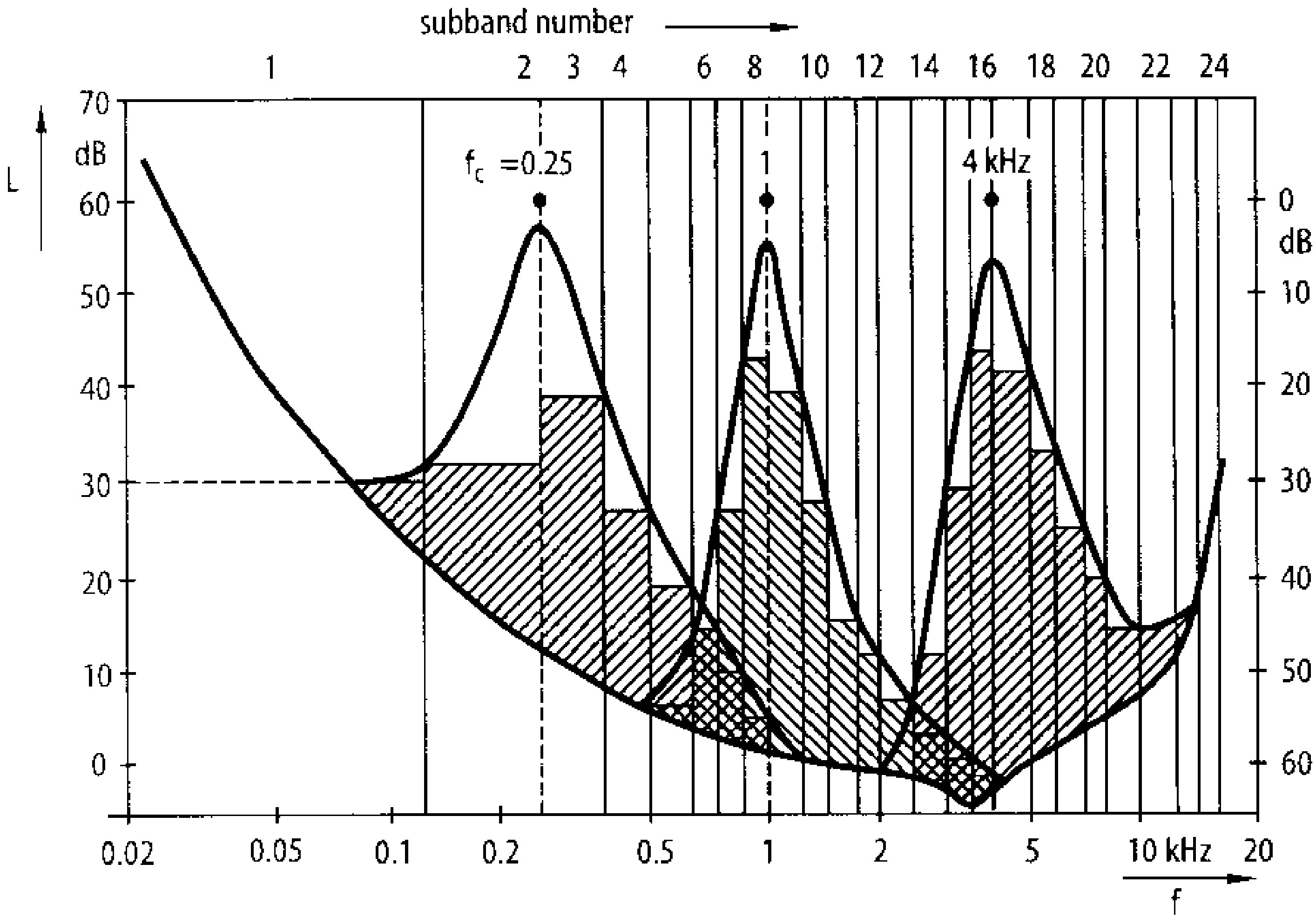
MPEG-2 Audio: Multichannel Configuration



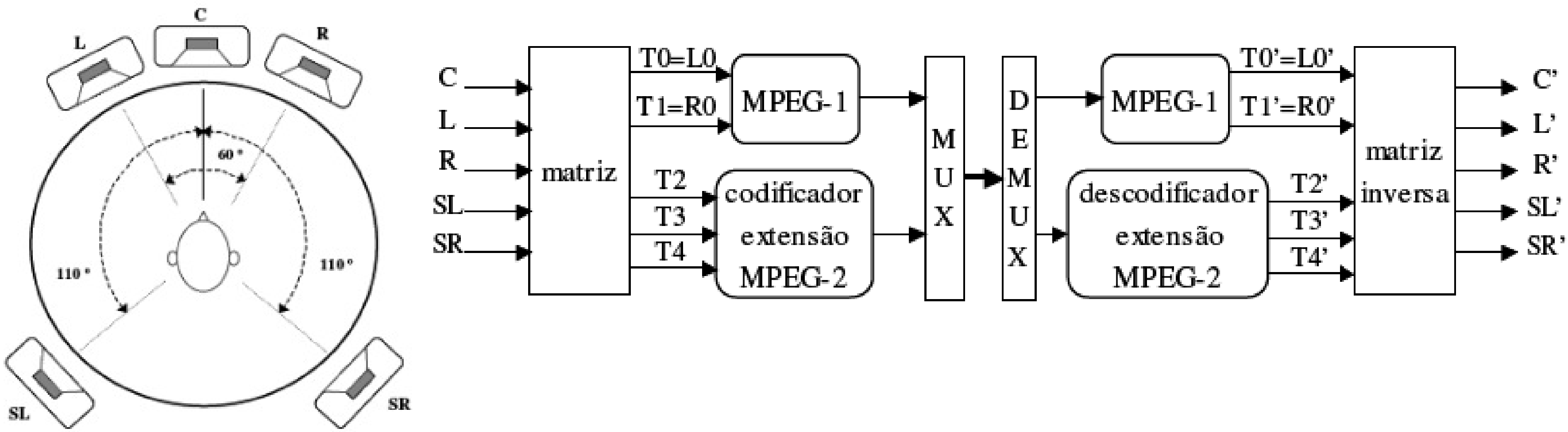


The 5.1 multichannel configuration includes 5 full bandwidth channels and a low frequency enhancement (LFE) channel covering frequencies below 200 Hz (less than 10% of the full bandwidth).

MPEG-2 Audio: the Secret !



MPEG-2 and MPEG-1 Audio Compatibility



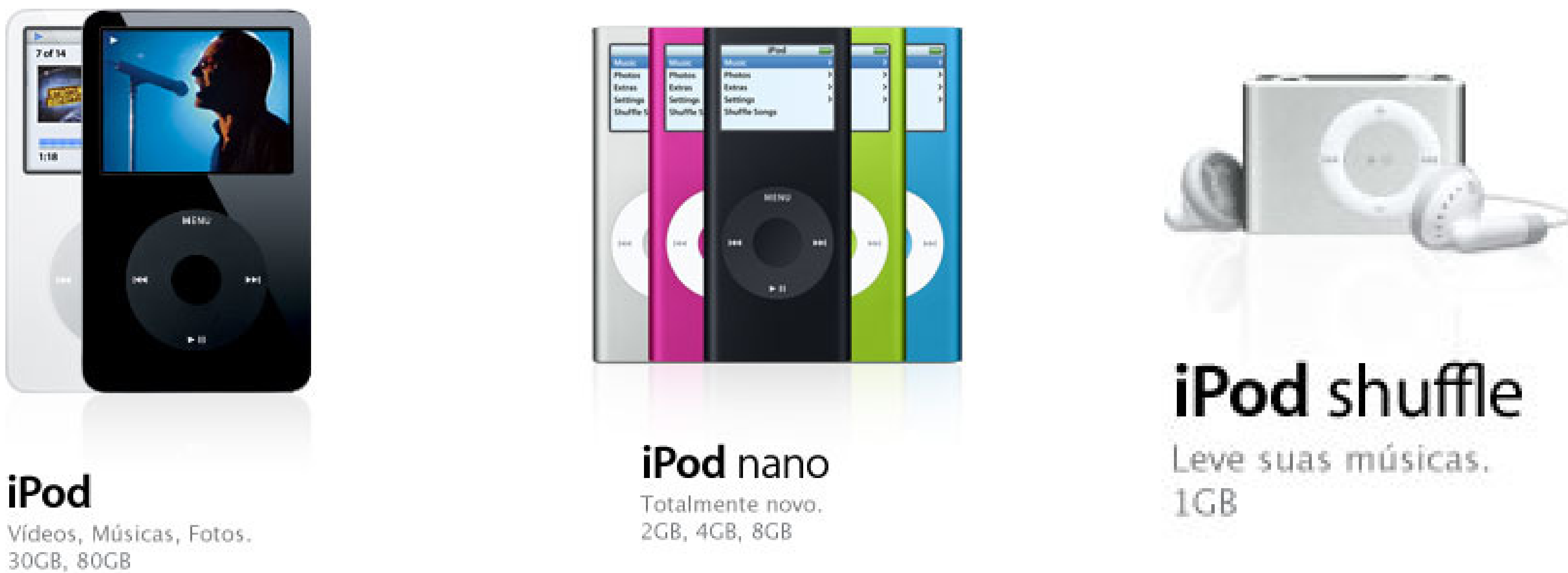
MPEG-2 Audio backward compatibility is provided by designing MPEG-2 Audio as a MPEG-1 Audio compliant stereo pair and additional MPEG-2 Audio compliant data for the other channels.

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.

New Systems and … Business Models …



iPod is able to play the following audio formats: MP3, WAV, AAC, Protected AAC, AIFF and Apple Lossless.

Technologies Developed by DVB

DVB-x:

The First Generation

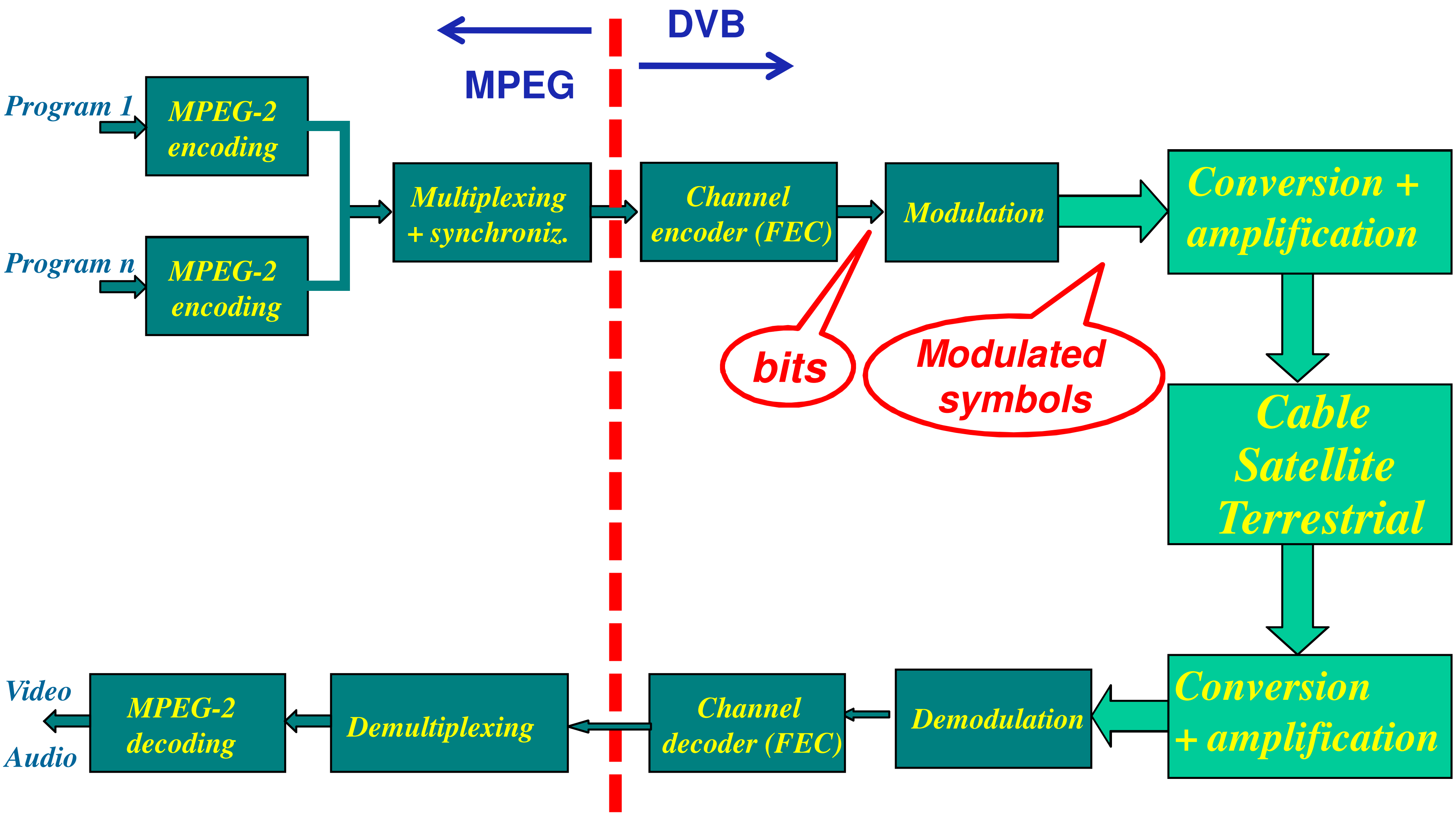
CABLE
1994

SATELLITE
1997

TERRESTRIAL
1997

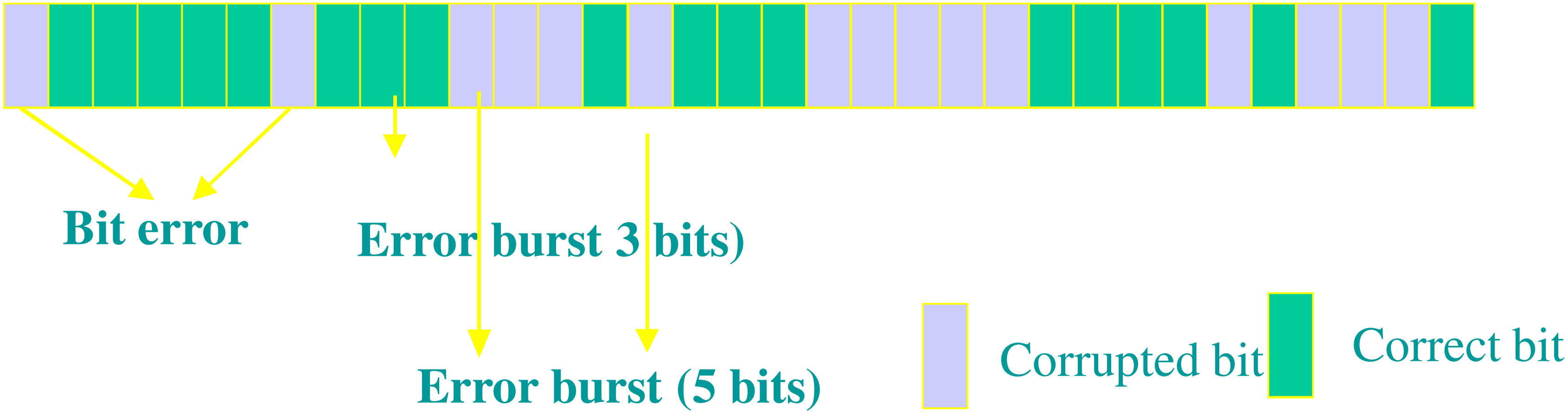
DVB-x Channel Coding

The Channel .. After the Source !

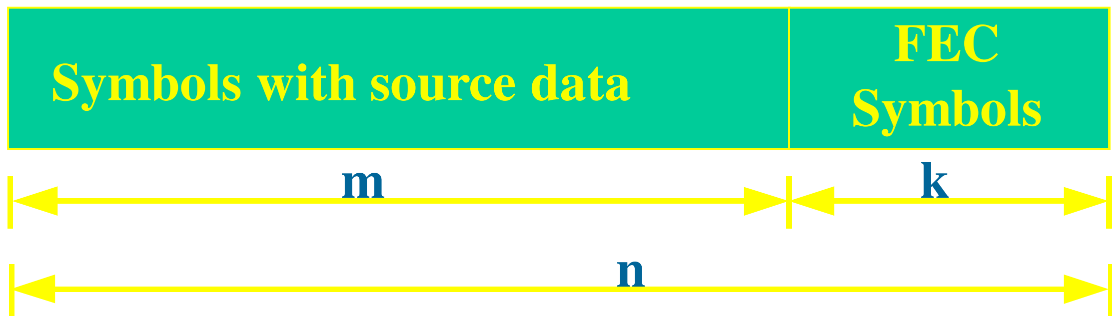


Channel Coding

- At sender, additional redundancy is included in the compressed signal to allow the channel decoder the detection and correction of channel errors.
- The introduction of added redundancy results in a bitrate increase. The channel coding selection must consider the channel characteristics and the modulation.
- The compressed signal needs a channel with a small amount of (RESIDUAL) errors, e.g. BER of 10^{-10}- 10^{-12} which means 0.1-1 erred bits per hour for a rate of 30 Mbit/s.



DVC Channel Coding Tools

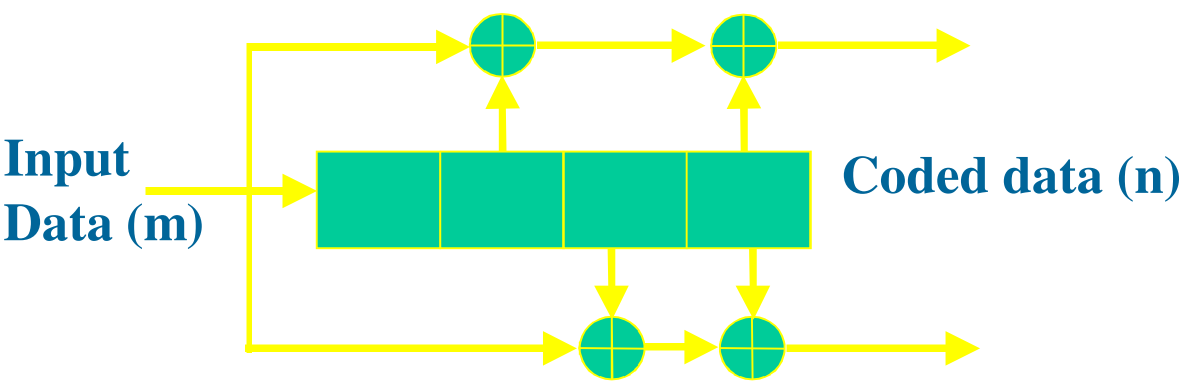


Block codes

FEC – Forward Error Correction

R = m/n = 1 – k/n

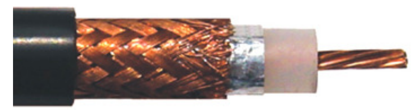
A coding rate of ½ means that the output rate is the double of the input rate.



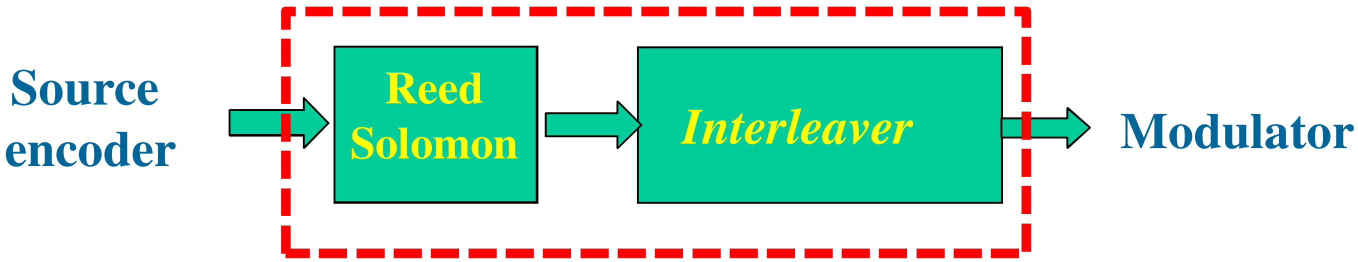
Convolutional codes

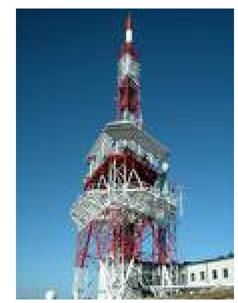
R = m/n – Coding rate, e.g. ½, 2/3, 9/10 …

DVB-C, S and T Channel Coding Solutions

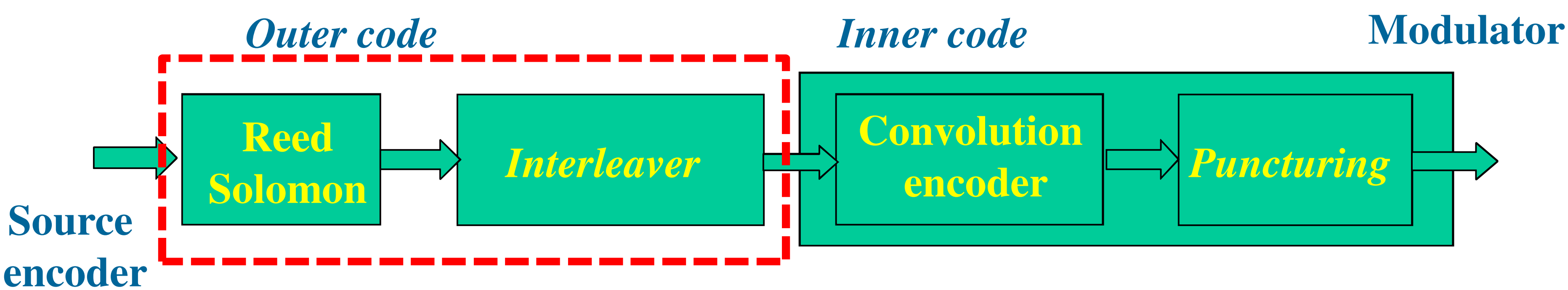


DVB-C Channel Coding

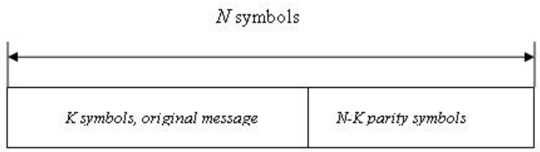




DVB-S and DVB-T Channel Coding



DVB-C/S/T: Reed-Solomon Coding



- **The Reed-Solomon (RS) code is a block code:**
  - **Allowing the <u>detection</u> of corrupted symbols (up to a certain limit)**
  - **Allowing the <u>correction</u> of corrupted symbols (up to a certain limit)**

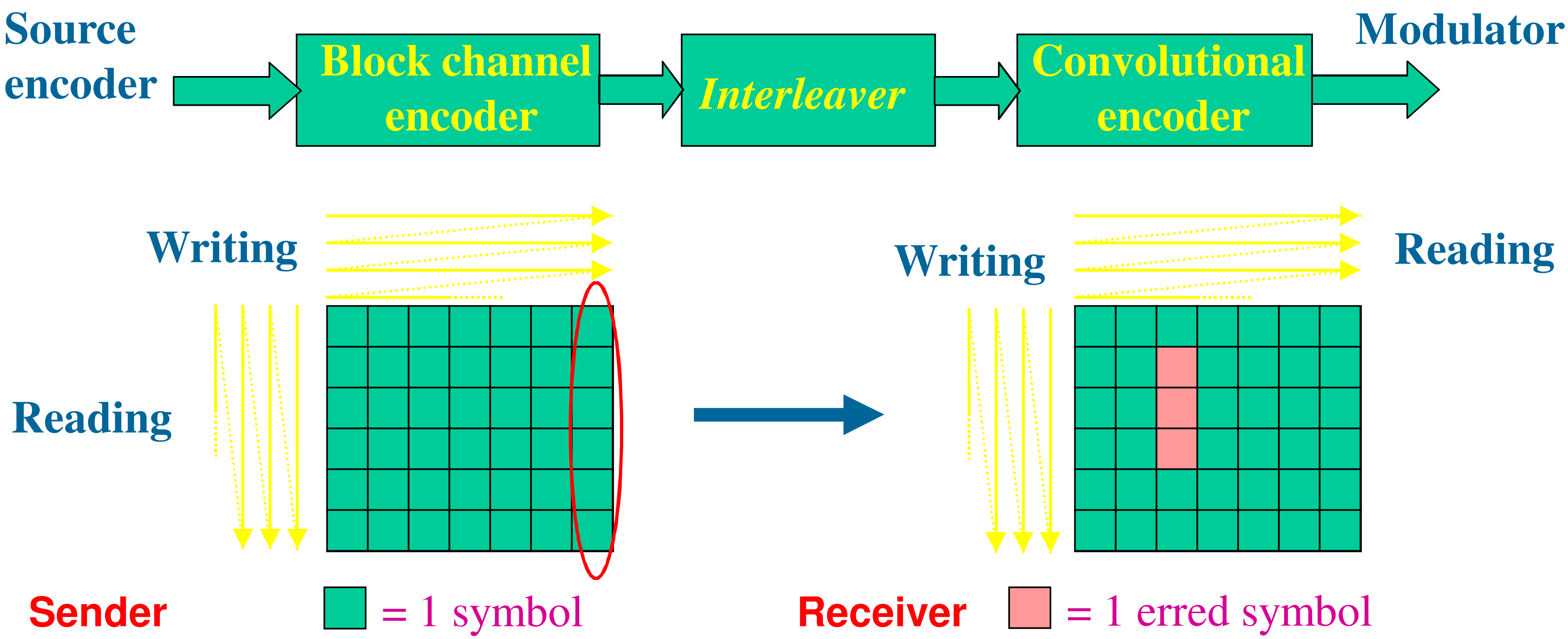
- **Good performance for burst errors … naturally, in combination with the interleaver.**

- **The RS code used in DVB is <u>RS(204,188)</u>, this means 188 source bytes in each full block of 204 bytes; this implies a 16/188 = 8 % overhead.**

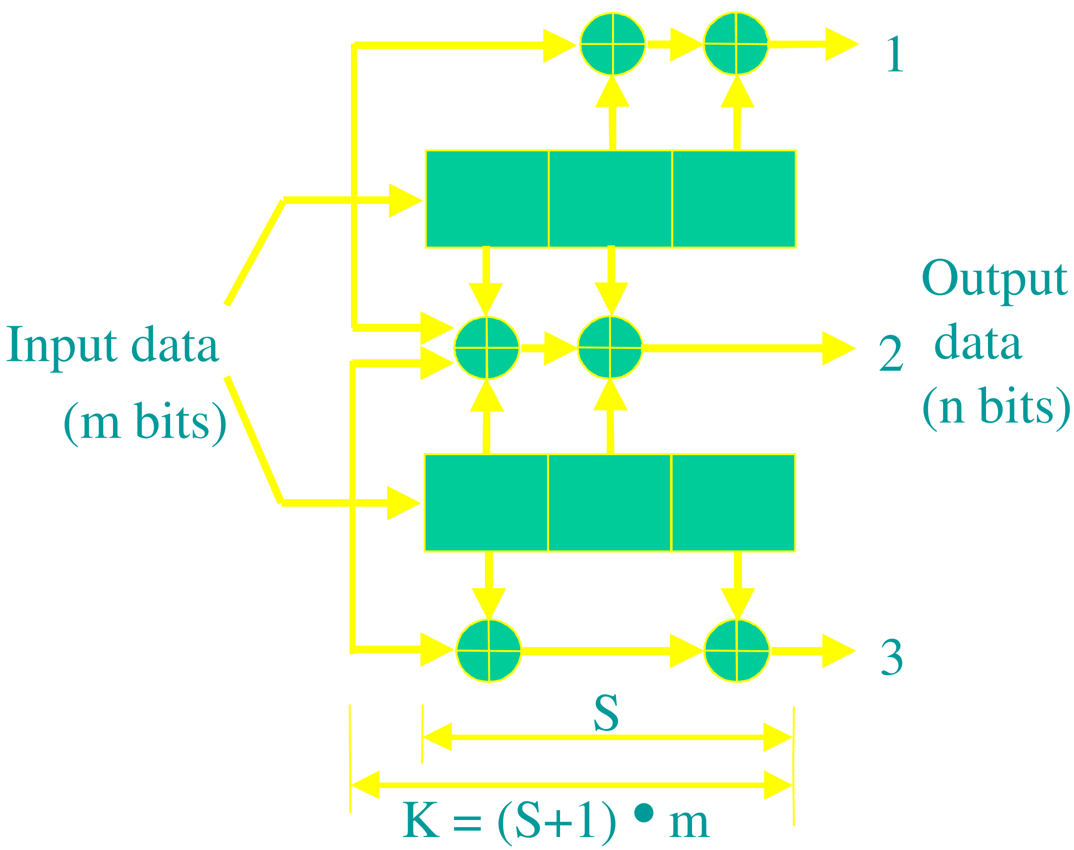
- **The RS(204,188) code has the capacity to correct 8 bytes in each block; if there are more than 8 bytes corrupted in a RS block, the channel decoder signals the lack of capability to correct the errors in the block.**

Interleaving

The interleaver does not provide error correction capabilities by itself; it rather reorganizes the symbols to have burst and bit errors more efficiently corrected when also using a channel code, e.g. a RS code, at the cost of delay, memory and complexity.



DVB-S/T: Convolutional Coding



- **Convolutional channel coding is introduced as a complement to Reed Solomon coding.**
- **For every *m* input bits, there are *n* output bits, typically with a m/n = ½ coding rate which means that the source rate is half the total rate.**
- **The channel coding rate (m/n) is the ratio of the source rate to the total rate (1 when there is no channel coding)**
- **To raise the coding rate (to make it higher than 1/2), puncturing is used which means that some bits at the convolutional encoder output are not transmitted, reducing the overall rate.**

Puncturing for Coding Rate Flexibility

- *Puncturing* is the process of removing some of the parity bits after encoding with an error-correction code. This has the same effect as encoding with an error-correction code with a higher channel coding rate, or less redundancy.
- However, with puncturing, the same decoder can be used regardless of how many bits have been punctured; thus, puncturing considerably increases the flexibility of the system without significantly increasing its complexity.
- In some cases, a *pre-defined pattern of puncturing* is used in an encoder. Then, the inverse operation, known as *depuncturing*, is implemented by the decoder.
- DVB-S/T – In the convolutional encoder, the output rate doubles the input rate; to reduce this high redundancy, at least in part, the output data is punctured, i.e. defined bits of the output data are deleted to reduce the output data rate.

Puncturing Example

- **Input coded data:**

1 0 1 1 0 0 0

- **Channel coded data, ½ coding rate:**

11 10 00 01 01 11 00

- ***Puncturing with rate* ¾ (regarding the input data to the channel encoder: ¾ = ½ × 3/2); when *puncturing,* 4 bits in each 6 are transmitted with a YYNYYN pattern:**

11 (1)0 0(0) 01 (0)1 1(1) 00

- **Transmitted data (with lower protection rate):**

11 00 01 11 00

- **Reconstruction/depuncturing for decoding:**

11 X0 0X 01 X1 1X 00 **X – unknown bits**

DVB-x Modulation

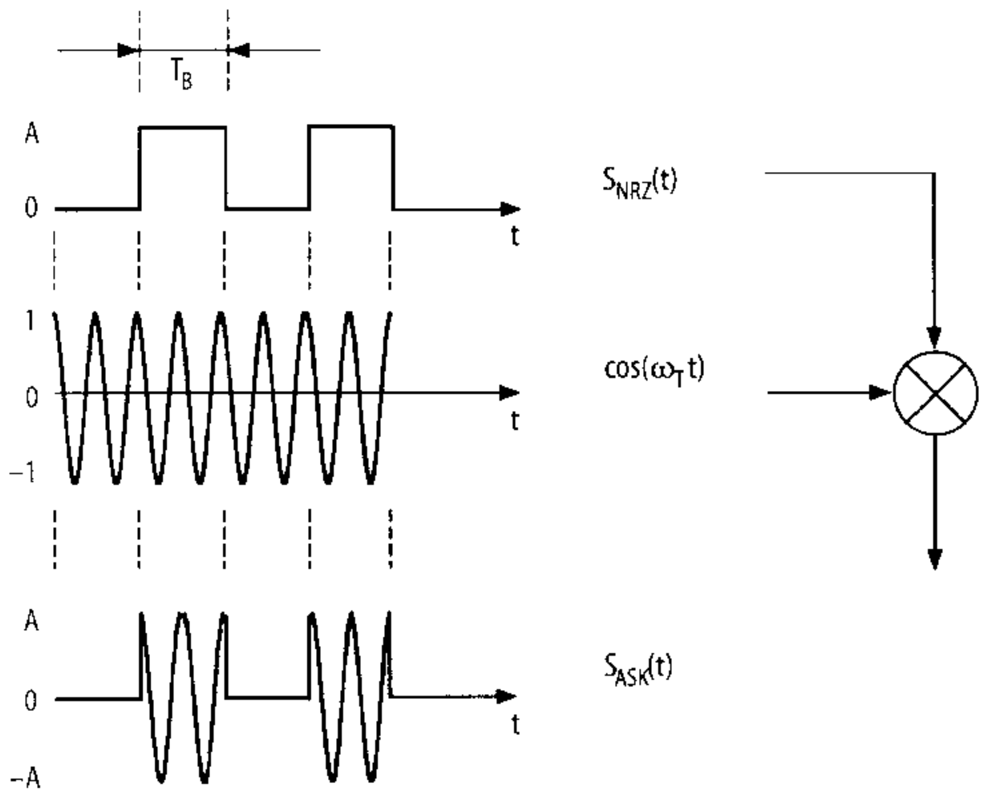
About Modulation …

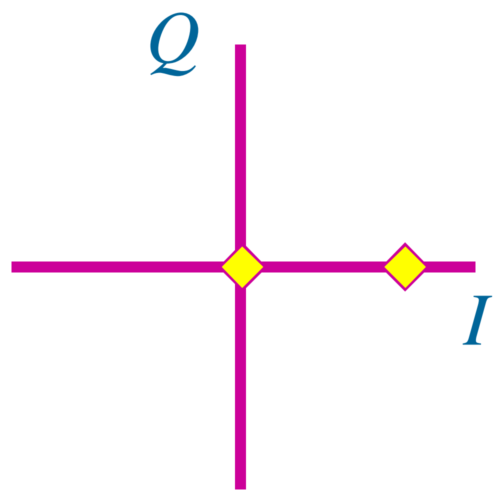
- **Factors to consider when selecting a modulation:**
  - Channel characteristics
  - Spectral efficiency, i.e. how many bits are transmitted per Hertz
  - Robustness to channel distortion
  - Tolerance to transmitter and receiver imperfections
  - Minimization of requirements for interference protection

- **Main basic digital modulation techniques:**
  - Amplitude modulation (ASK)
  - Frequency modulation (FSK)
  - Phase modulation (PSK)
  - Combined amplitude and phase modulation (QAM)

Amplitude Modulation: ASK

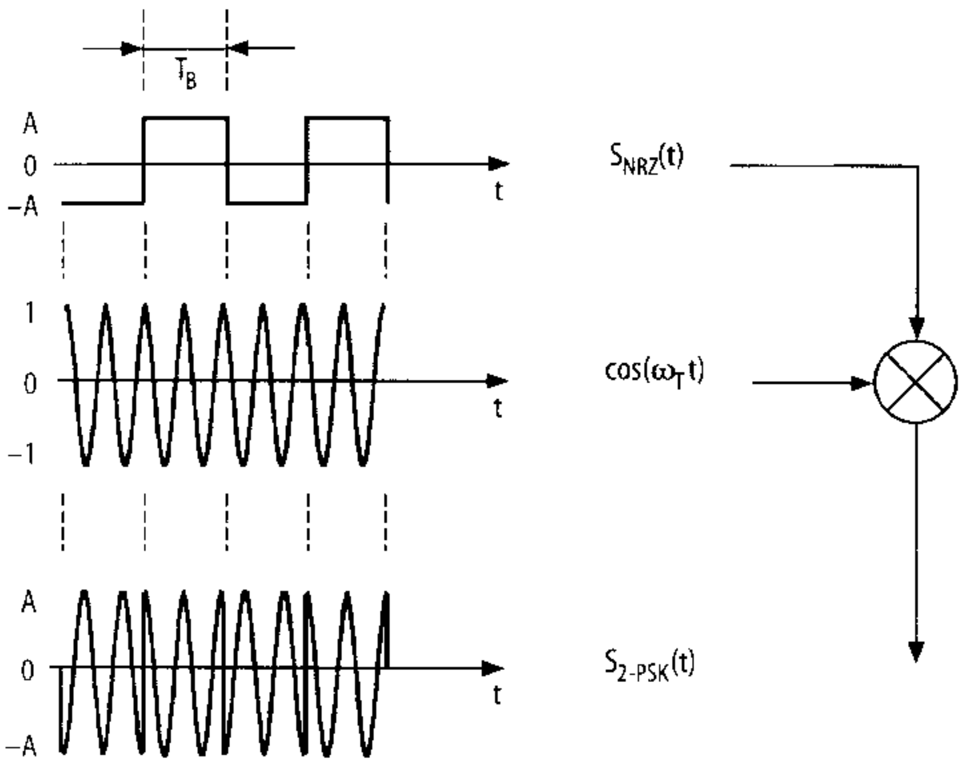
The information is transmitted in the signal amplitude !

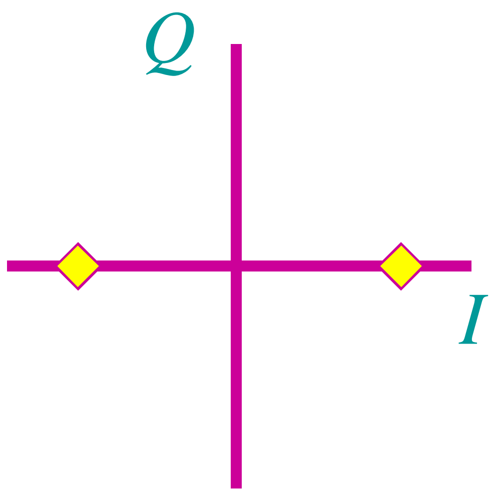




Phase Modulation: PSK

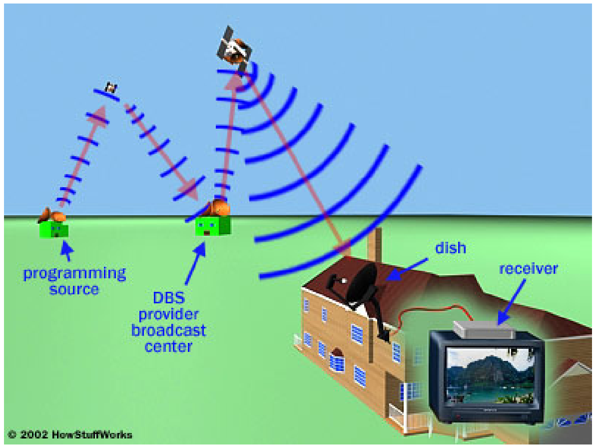
The information is transmitted in the signal phase !

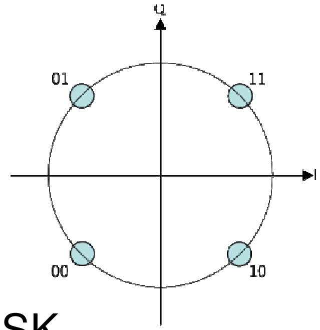




DVB-S Modulation

- **DVB-S uses QPSK (4-PSK) due to the typical very low SNR**
- **Any amplitude modulation is difficult due to the high attenuation resulting from the long distances (may come to tens of thousands of km)**

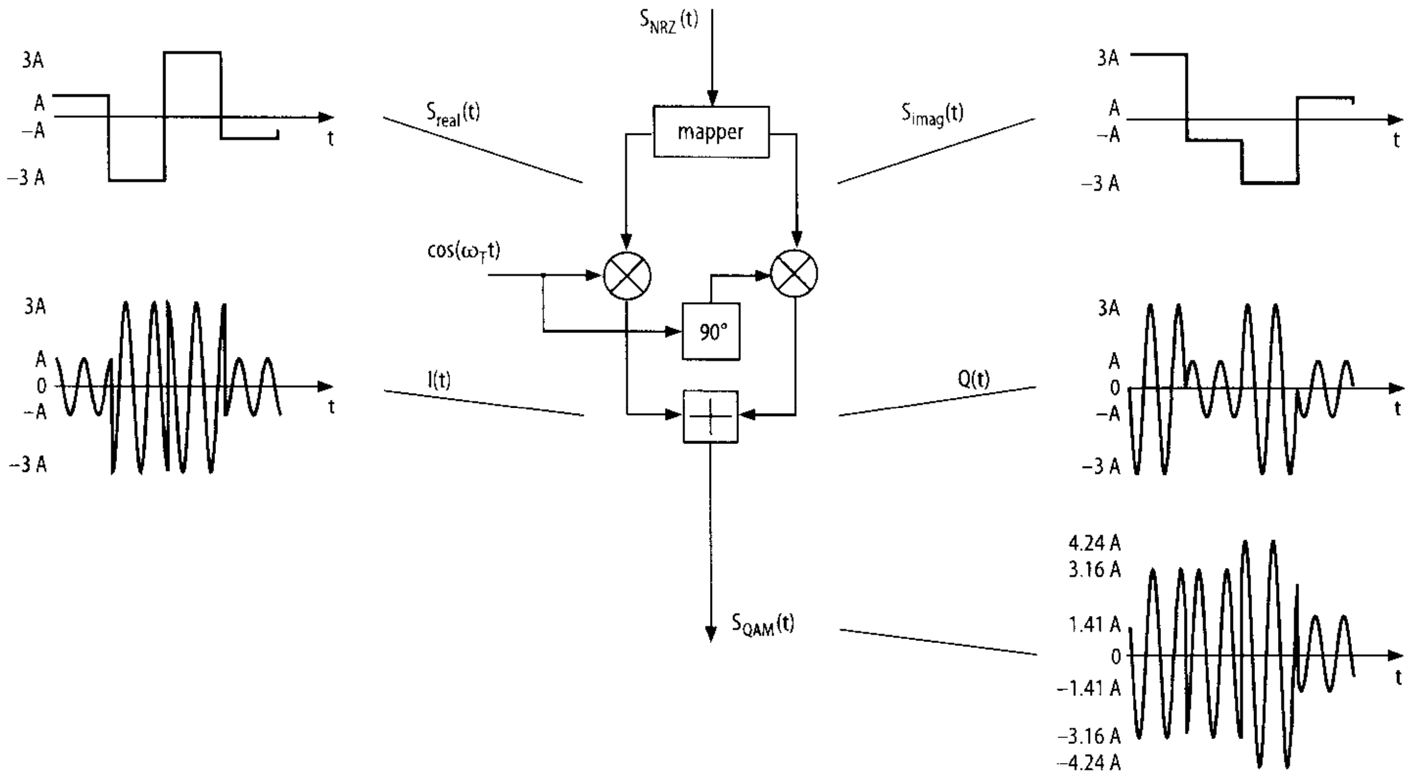




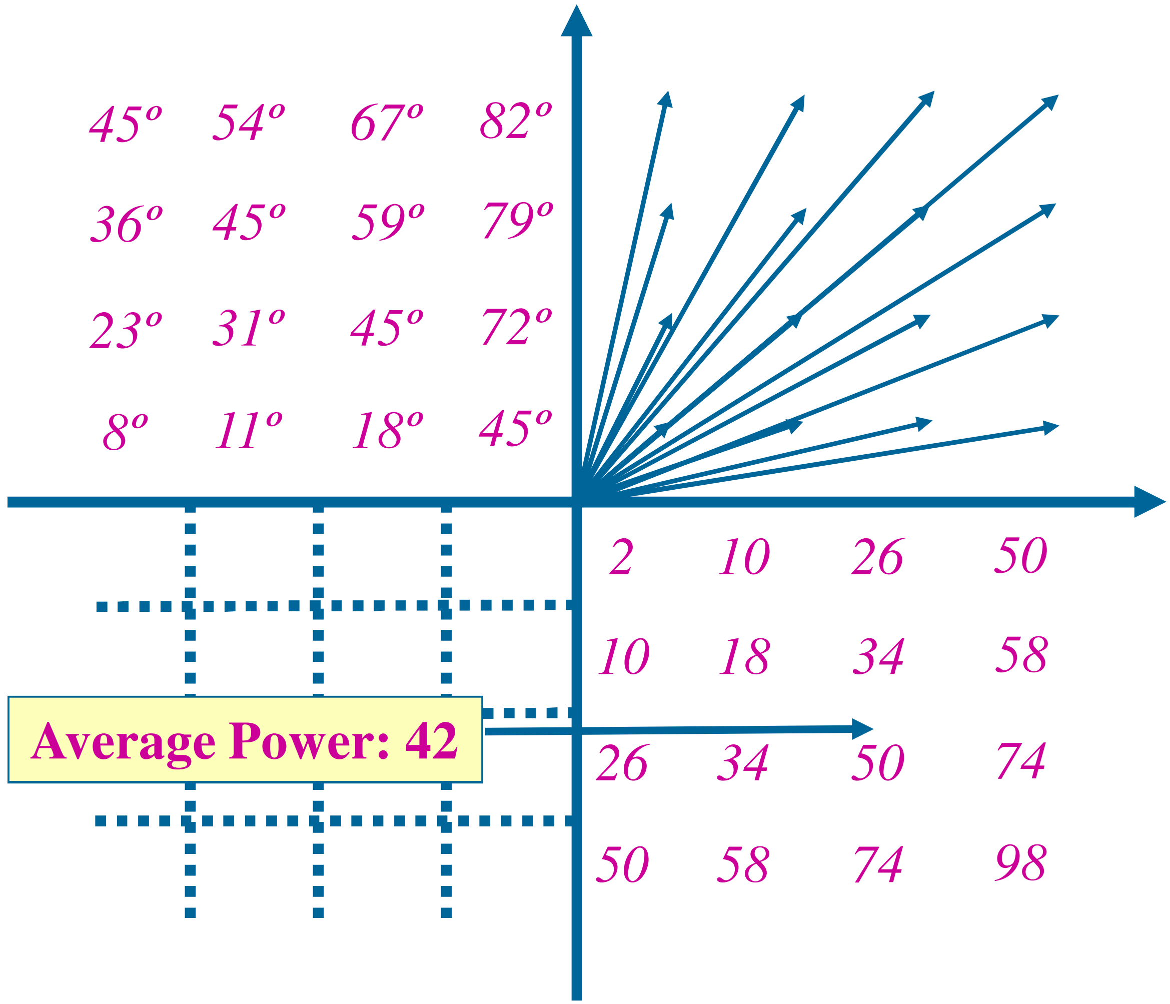
QPSK

QAM Modulation

The digital signal is decomposed into 2 multilevel components corresponding to two carriers I and Q (in quadrature); the information is transmitted in the signal amplitude and phase, simultaneously.



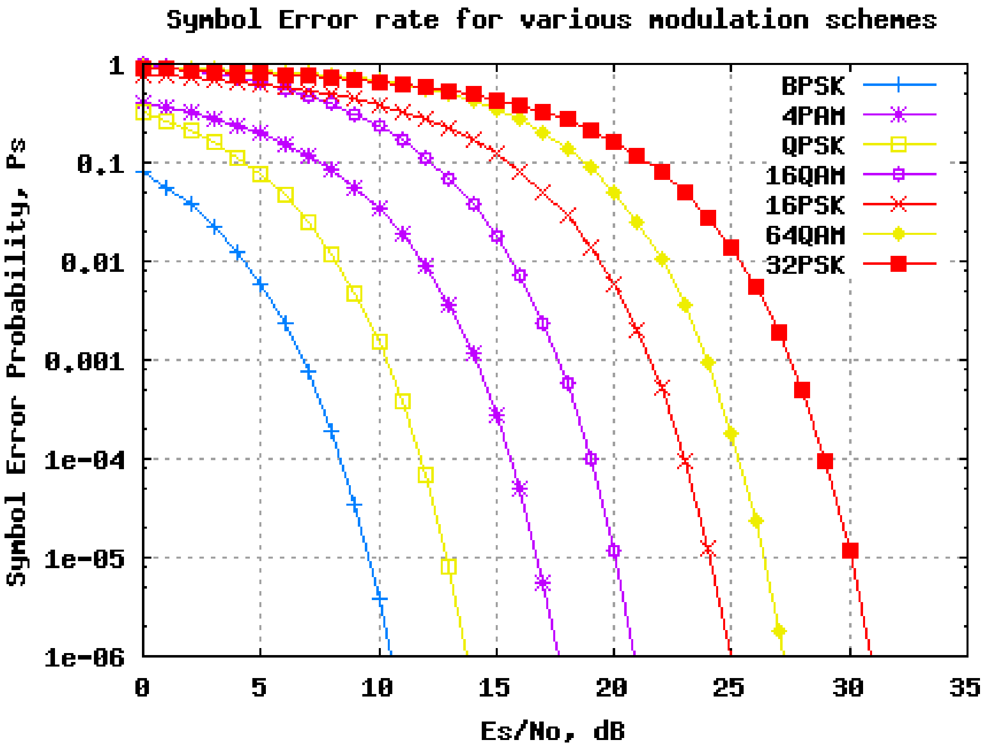
64-QAM Modulation Constellation …



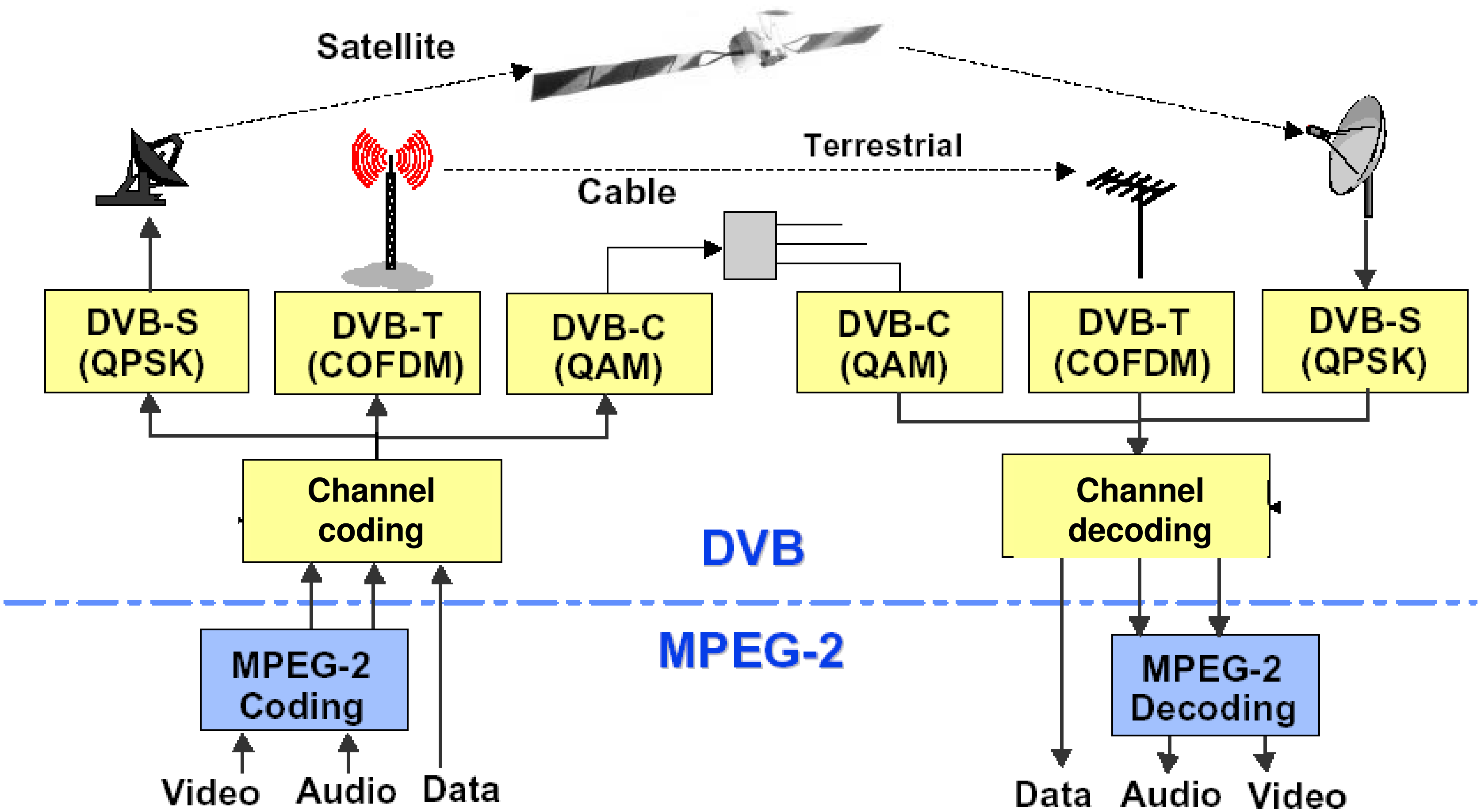
DVB-C Modulation

- **DVB-C uses 16 to 256-QAM, typically 64-QAM.**

- E_b/N_0 (the energy per bit to noise power spectral density ratio) is an important parameter in digital communication or data transmission.
- E_b/N_0 is a normalized signal-to-noise ratio (SNR) measure, also known as the "SNR per bit".
- E_b/N_0 is especially useful when comparing the bit error rate (BER) performance of different digital modulation schemes without taking bandwidth into account.



DVB Systems Architecture



TÉCNICO LISBOA

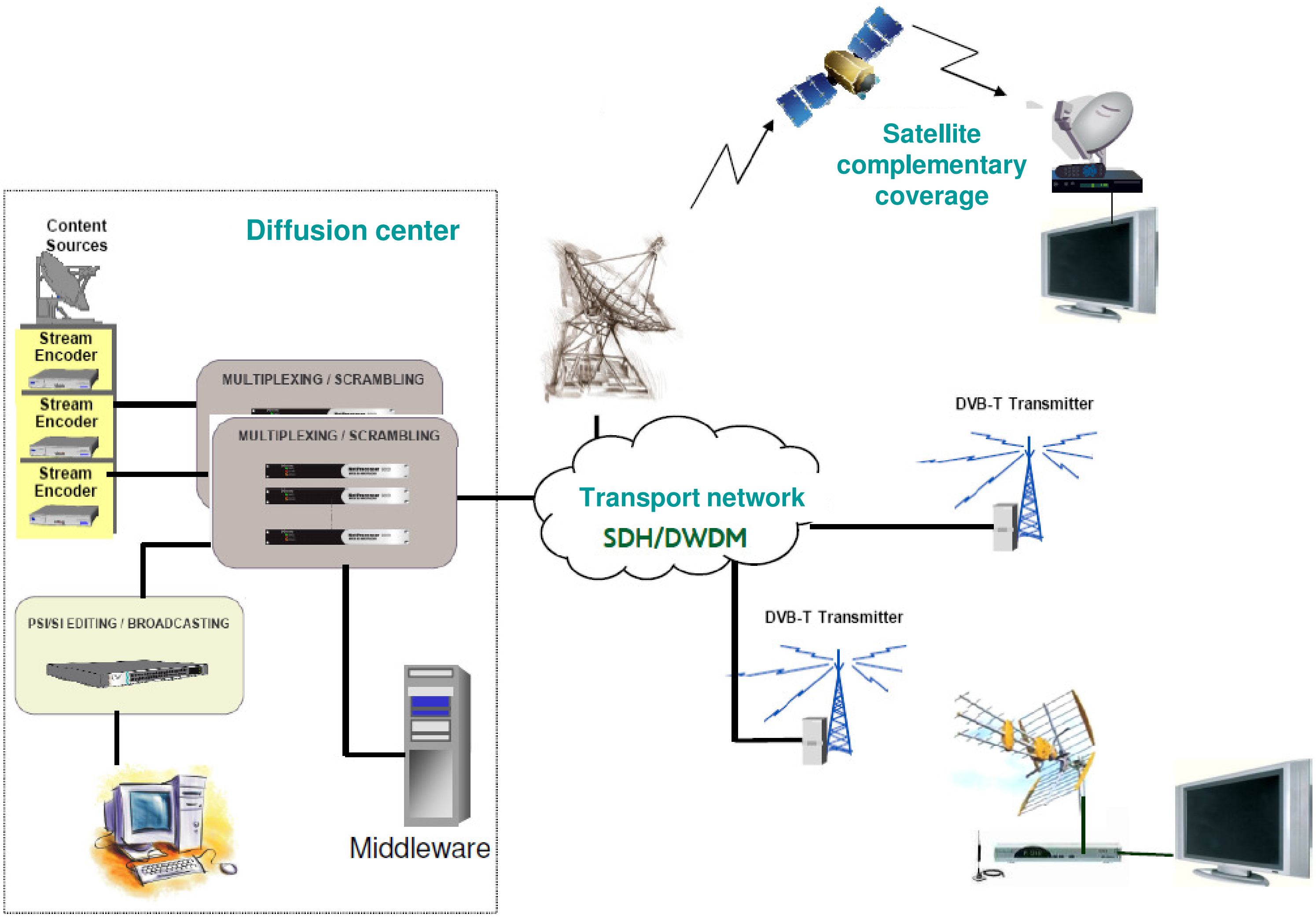
DVB-T: Terrestrial Broadasting

DVB TERRESTRIAL

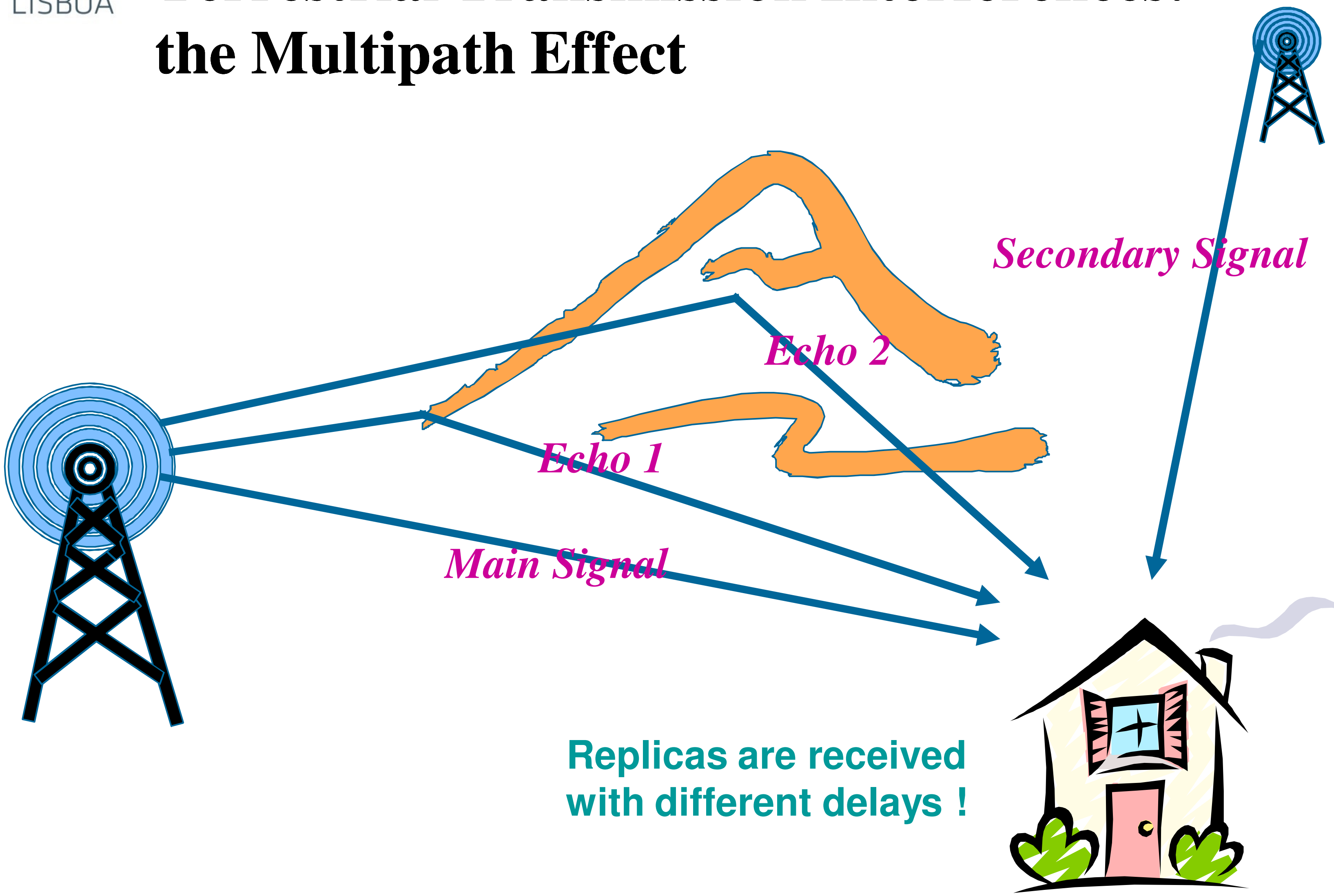
Digital Terrestrial TV: Requirements

- **Fixed, portable and mobile reception**
- **Immunity to multipath effects**
- **Single frequency networks**
- **Configuration flexibility, e.g. coverage/bitrate trade-offs, configuration hierarchies**
- **Robustness to analogue services interferences without interfering with those services (for the transition period)**
- **Easy transcoding to and from other transmission channels, e.g. satellite, cable, optical fiber**
- **Low cost receivers**

TDT Network: Generic Architecture

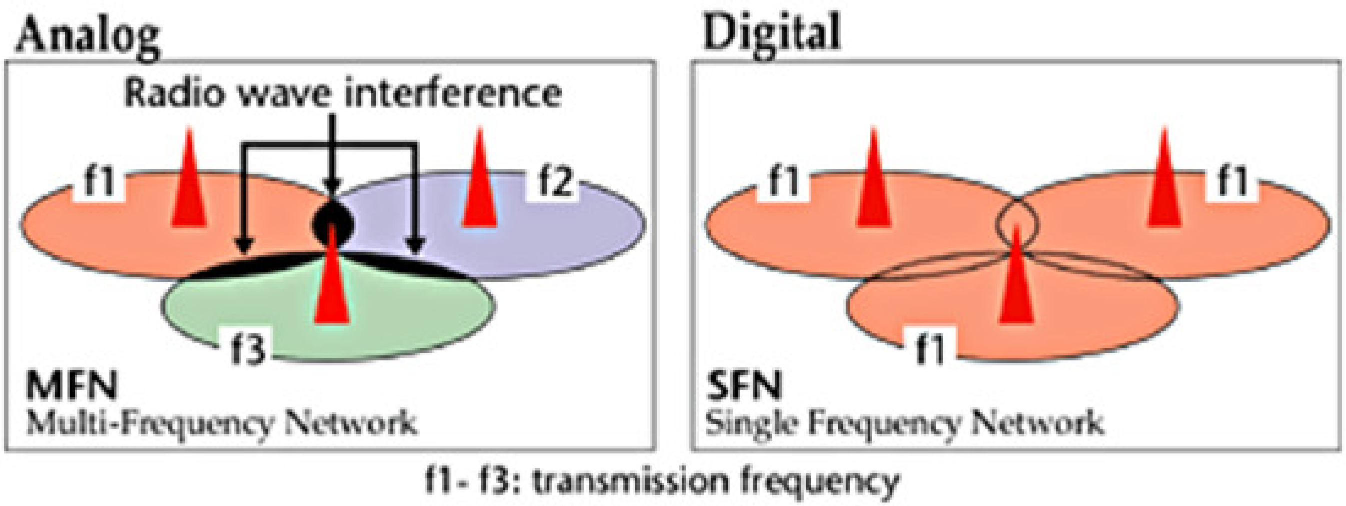


Terrestrial Transmission Interferences: the Multipath Effect



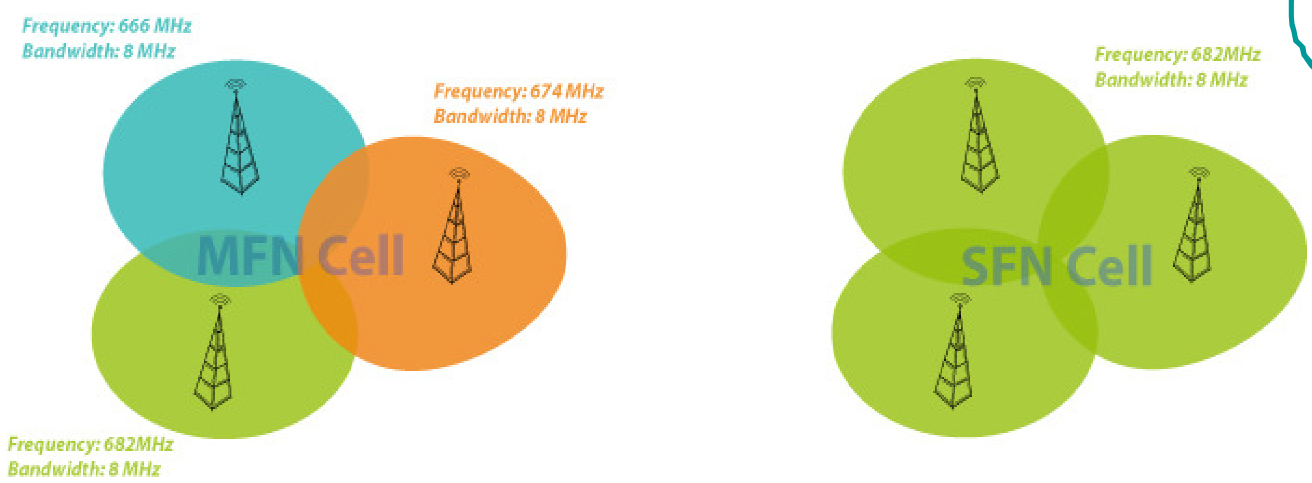
Replicas are received with different delays !

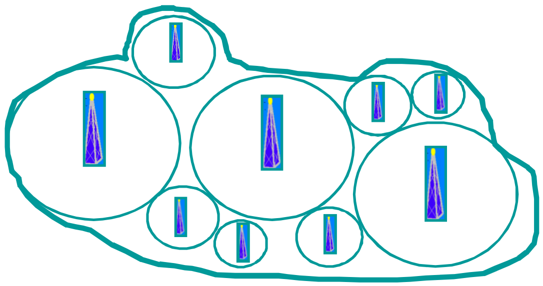
Multiple versus Single Frequency Networks



- **In analogue reception, the user tunes the best ‘behaving’ frequency for a certain TV channel (from different emitters), notably by pointing the antenna in the right direction.**
- **Due to the interference areas, it is not possible to use the same frequency for all cells as this would degrade the reception quality.**
- **In digital SFN, all transmitters within some area can transmit the same TV channel on the same frequency.**

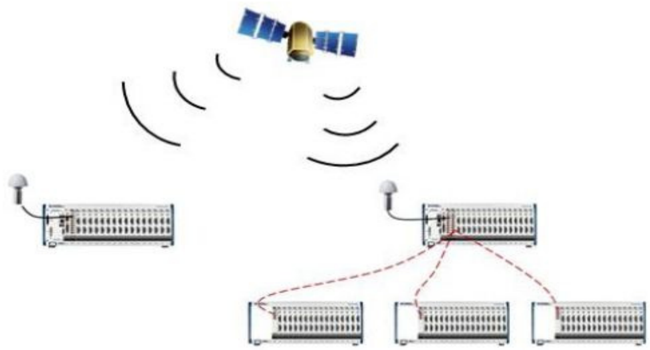
Digital Multiple and Single Frequency Networks





- 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 Single Frequency Network (SFN) operation significantly contributes to the efficient use of the radio frequency spectrum it requires addressing the multipath interferences.

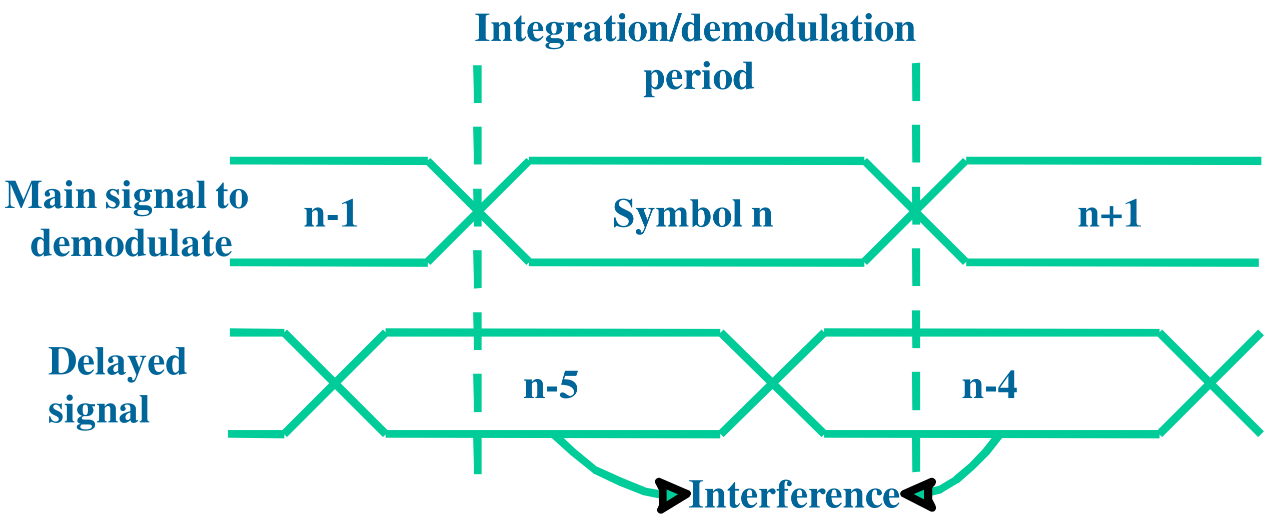
Single Frequency Networks Synchronization



- **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 Transport Stream. This allows each transmitter to wait until the indicated time to start broadcasting the particular packet.

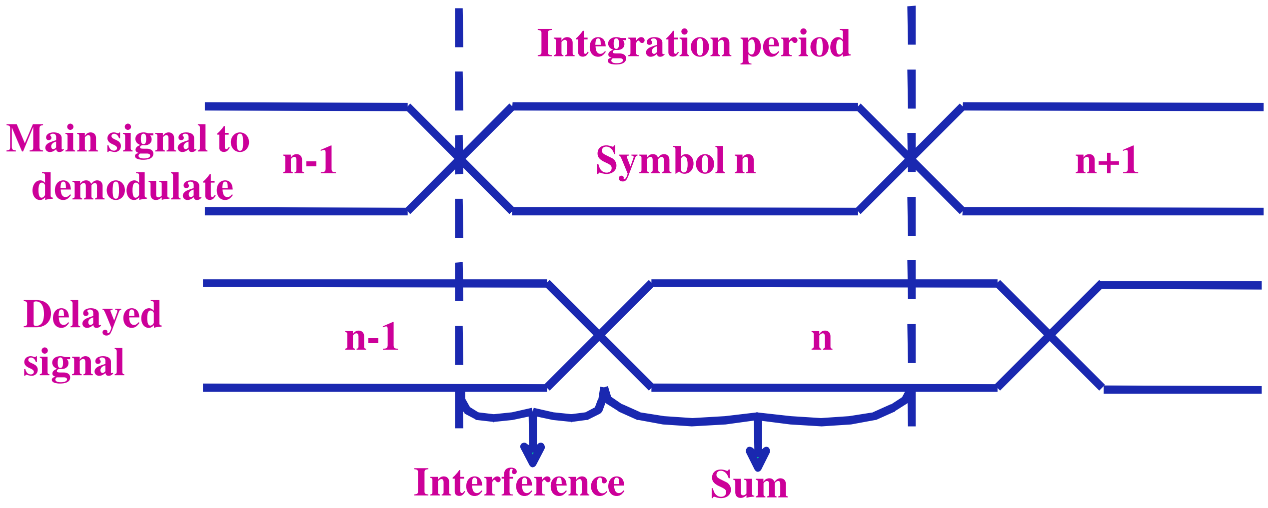
- **SFN Synchronization -** The frequency of transmitters operating in SFN network must also be synchronized. Usually, this is done with a GPS frequency and time reference. This allows the network to reach the accuracy and stability needed for SFN synchronization - better than 1 Hz in the frequency domain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

Symbol Interference ...



Interference between 'distant' symbols

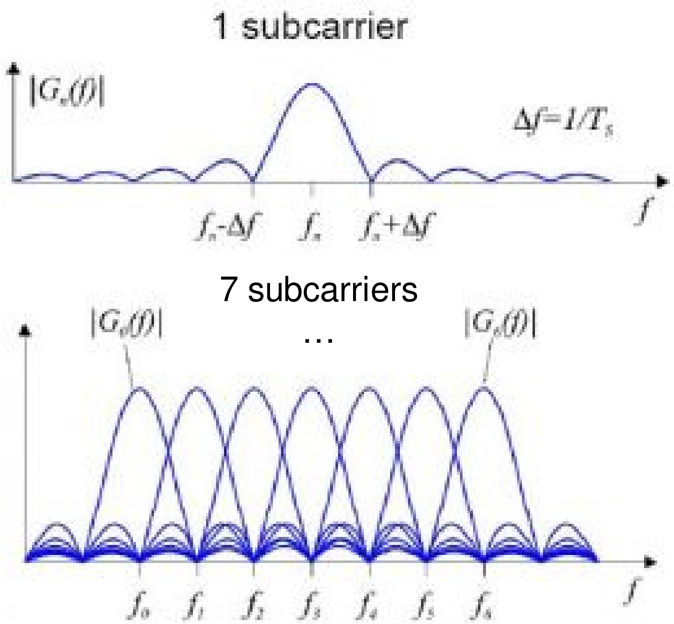
We need long modulated symbols without paying a bitrate reduction penalty !!!!



Interference between 'close' symbols

Multi-Carrier Modulation (MCM)

Since low symbol rate modulation schemes (i.e., where the symbols are relatively long compared to the channel time characteristics) suffer less from intersymbol interference, it is advantageous to transmit a number of low-rate streams in parallel instead of a single high-rate stream.

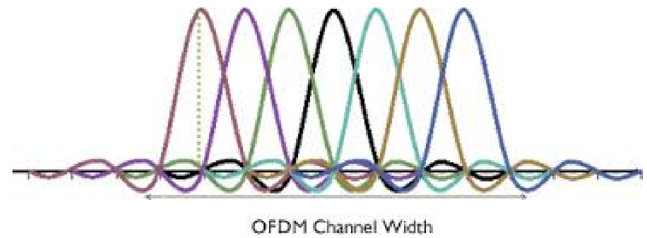


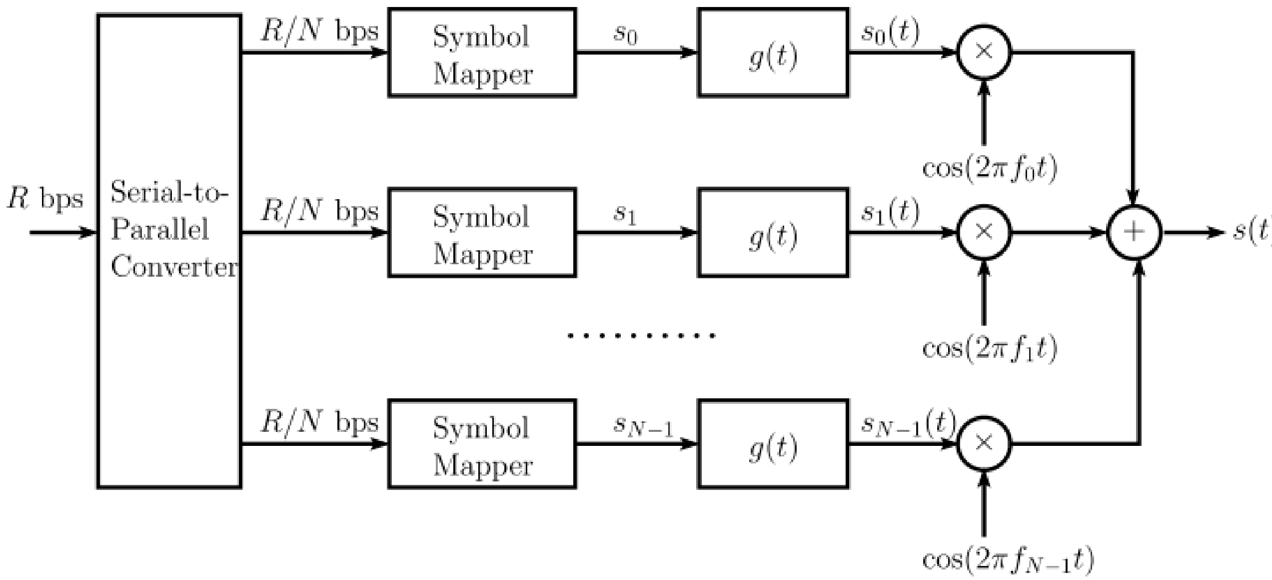
The main tool to solve the symbol interference problem is a multi-carrier modulation scheme.

Multi-carrier modulation (MCM) is a method of transmitting data by splitting it into several components, and sending each of these components over separate carrier signals.

The individual carriers have narrow bandwidth (low rate), but the composite signal can have broad bandwidth (high rate).

Multi-Carrier Modulation



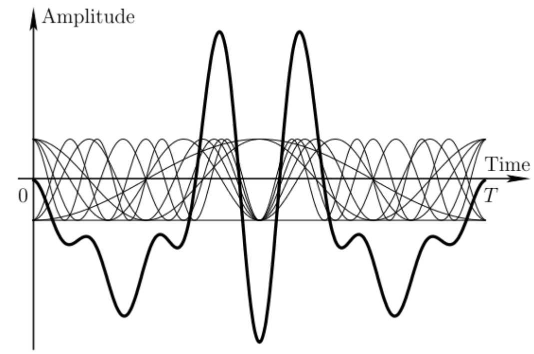


Each sub-symbol s_k (defining a sub-stream *k*) modulates (in amplitude or/and phase) the subcarrier f_k.

g(t) is a waveform-shaping pulse, such as raised cosine pulse. It serves to make the transmitted signal better suited to the channel, typically by limiting the bandwidth. By filtering the transmitted pulses this way, the intersymbol interference caused by the channel can be kept in control. In RF communication, pulse shaping is essential for making the signal fit in its frequency band.

The Multi-Carrier (Modulated) Symbols

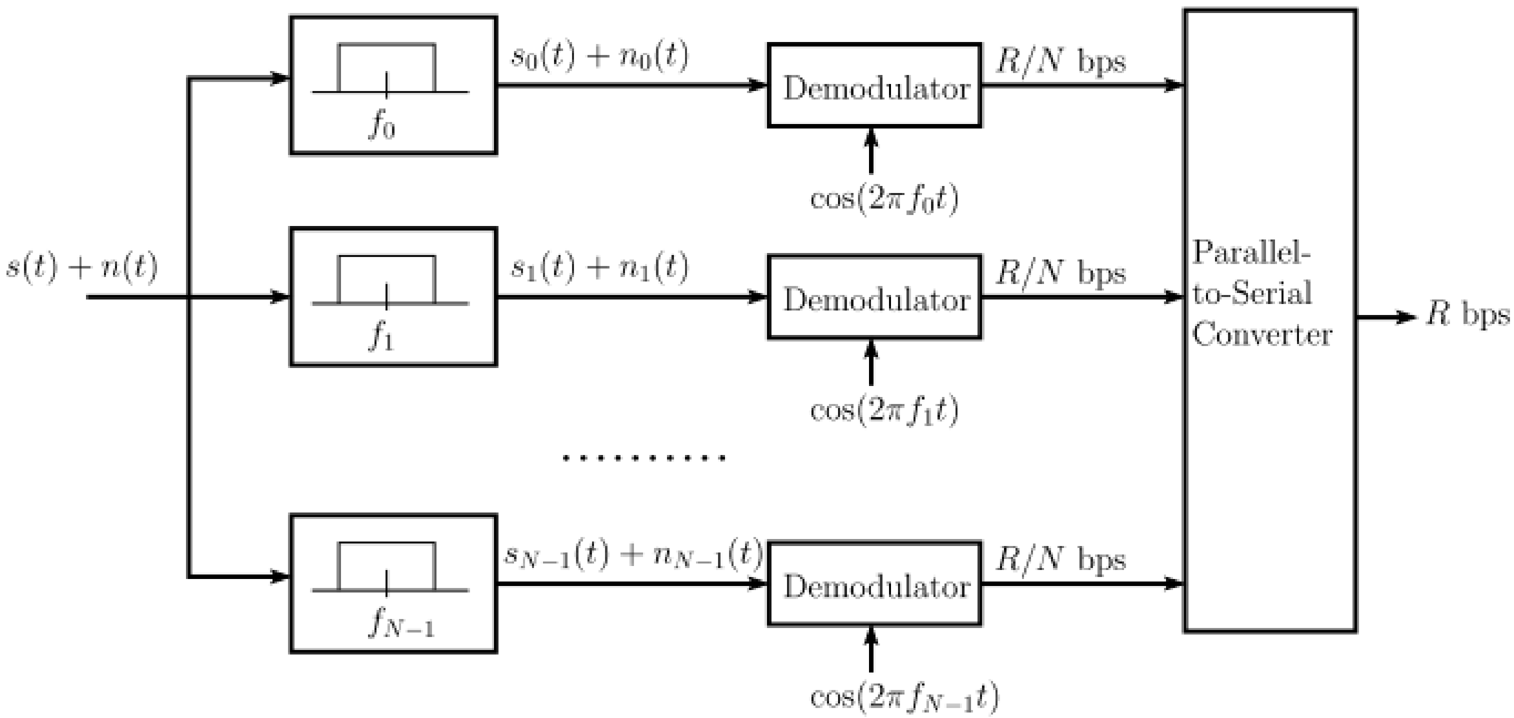
$$s(t) = \sum_{i=0}^{N-1} s_i g(t) \cos(2\pi f_i t + \phi_i)$$



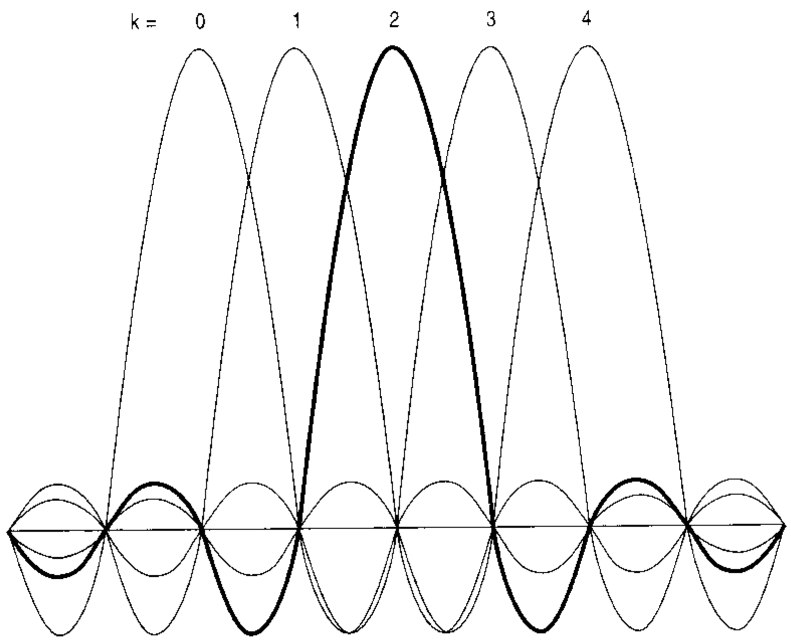
where

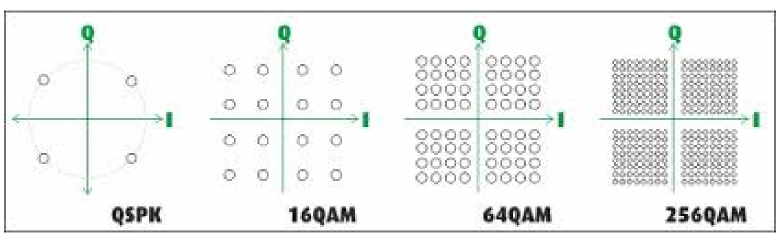
- ✔ s_i: complex data symbol (QAM, PSK, etc.) transmitted on the ith subcarrier;
- ✔ ϕ_i: phase offset of the ith subcarrier;
- ✔ $f_i = f_0 + i(B_N)$: central frequency of the ith subcarrier;
- ✔ $g(t)$: waveform-shaping pulse, such as raised cosine pulse.

Multi-Carrier Reception



Orthogonal Sub-Carriers





The sub-carriers are said orthogonal if they are uniformly spaced in frequency in a way that all other sub-carriers are zero at the central position of any specific sub-carrier which means

$w_k = 2\pi k f_0$ **with k=0, 1, …, n-1**

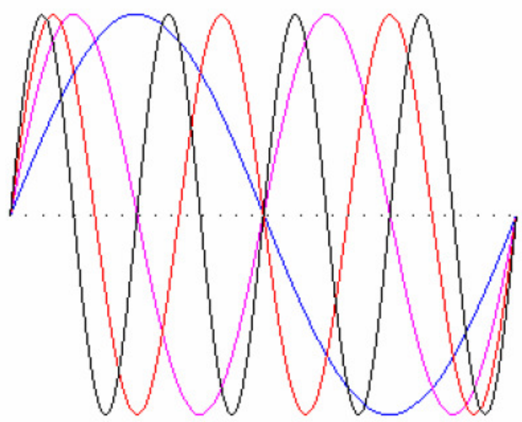
where f_0 is the base frequency.

The orthogonality of the subcarriers eliminates the inter-carrier interference and provides a high spectral efficiency by allowing spectral overlapping (differently from classical FDM).

Each of the many thousand sub-carriers may carry from 2 bits of data per symbol in QPSK to 8 bits in 256-QAM.

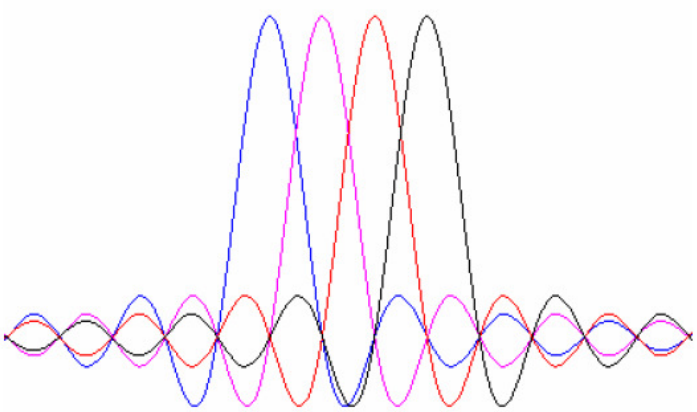
OFDM Carriers: Time versus Frequency

Time domain



Example of four subcarriers within one OFDM symbol

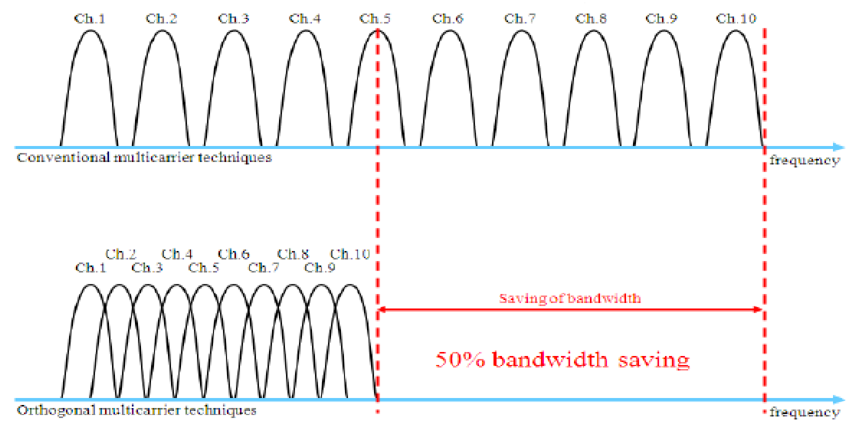
Frequency domain



Spectra of individual subcarriers

OFDM versus FDM

- **OFDM is a special case of FDM (Frequency Division Multiplexing). In FDM, the given bandwidth is subdivided among a set of carriers. There is no relationship between the carrier frequencies in FDM.**
  - For example, consider that the given bandwidth has to be divided among 5 carriers (say *a,b,c,d,e*). There is no relationship between the subcarriers; *a,b,c,d* and *e* can be anything within the given bandwidth.



- **If the carriers are harmonics, say (*b=2a,c=3a,d=4a,d=5a* , integral multiple of fundamental component *a*) then they become orthogonal. This is a special case of FDM, which is called OFDM (as implied by the word 'orthogonal' in OFDM)**

DFT and IDFT

- Let $x[n],\ 0 \leq n \leq N-1$, denote a discrete time sequence. The N-point discrete Fourier transform (DFT) of $\{x[n]\}$ is defined as

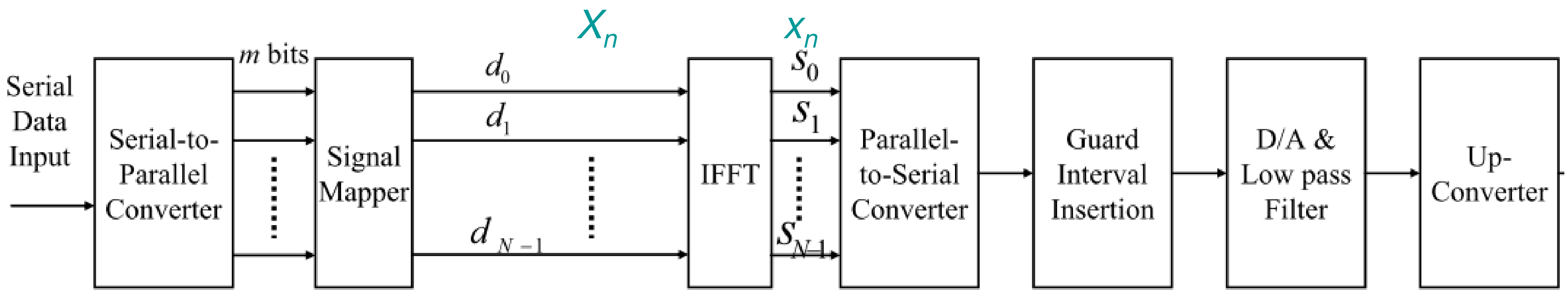
$$\begin{aligned} X[i] &= \mathrm{DFT}\{x[n]\} \\ &\triangleq \frac{1}{\sqrt{N}} \sum_{n=0}^{N-1} x[n] \exp\left(-\frac{j2\pi ni}{N}\right),\ 0 \leq i \leq N-1 \end{aligned}$$

- Correspondingly, given $\{X[i]\}$, the sequence $\{x[n]\}$ can be recovered by the inverse DFT (IDFT) defined as

$$\begin{aligned} x[n] &= \mathrm{IDFT}\{X[i]\} \\ &\triangleq \frac{1}{\sqrt{N}} \sum_{i=0}^{N-1} X[i] \exp\left(\frac{j2\pi ni}{N}\right),\ 0 \leq n \leq N-1 \end{aligned}$$

Orthogonal Frequency Division Multiplex

For orthogonal sub-carriers, multi-carrier modulation corresponds to applying the *Inverse Discrete Fourier Transform* (IDFT) to the sub-carriers in parallel, creating the so-called *Orthogonal Frequency Division Multiplex* (OFDM) modulation.



- At the transmitter, OFDM uses IDFT to convert samples of the spectrum of the OFDM signal into a corresponding equal number of samples from the OFDM signal at the time domain. The IDFT generates a baseband signal.
- At the receiver, OFDM uses DFT to restore the signal representation in the frequency domain and proceed with symbols detection.

Why is it a IDFT ?

By the mapping and ordering process, the frequency components of the OFDM symbol are created. To transmit them, the signal must be represented in the time domain what is accomplished by the IDFT.

- Let the N data symbols (thought as in the **frequency-domain**) to be transmitted on the N subcarriers within a DFT period is given by

$$\boldsymbol{X} = [X_0, X_1, \ldots, X_{N-1}]^T$$

- After the IDFT on $\boldsymbol{X}$, it generates N **time-domain** coefficients expressed as

$$x_n = \frac{1}{\sqrt{N}} \sum_{m=0}^{N-1} X_m \exp\left(j\frac{2\pi mn}{N}\right), \; n = 0, 1, \ldots, N-1$$

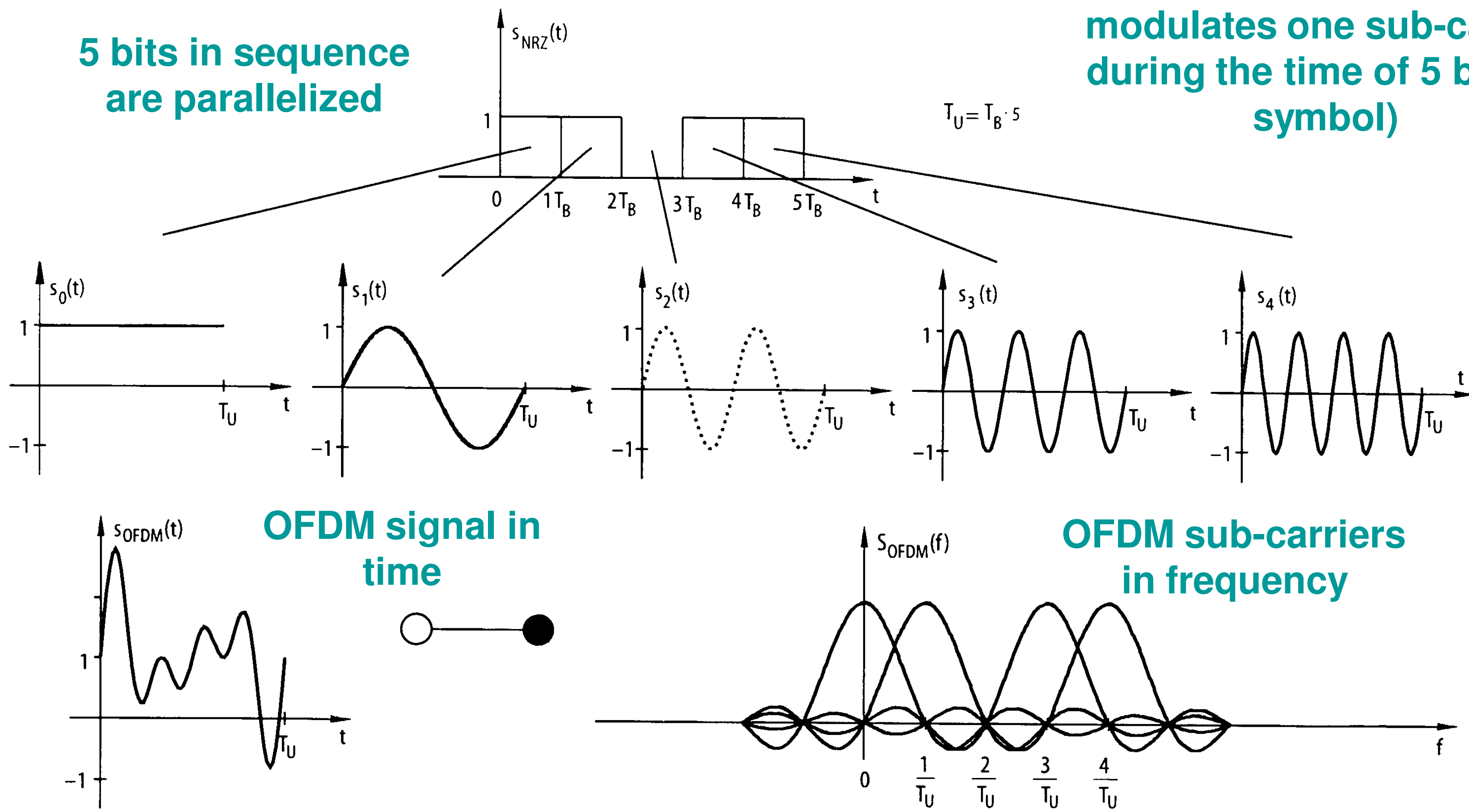
IDFT implementation of OFDM avoids the needs for oscillators to generate the OFDM signal.

x_n corresponds to the temporal evolution within one OFDM symbol !

OFDM: an Example

5 bits in sequence are parallelized

Each one of the 5 bits modulates one sub-carrier during the time of 5 bits (1 symbol)

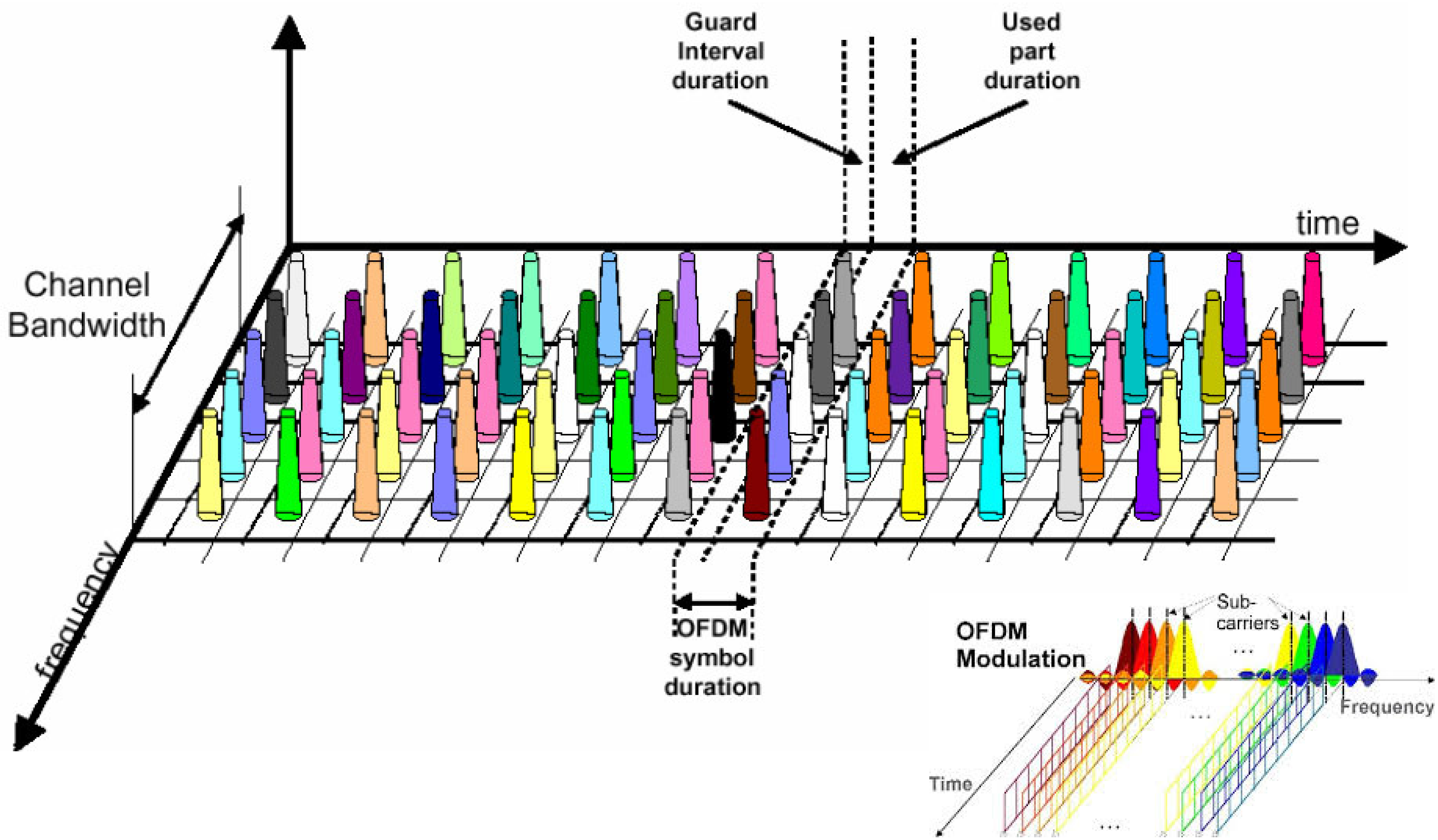


OFDM signal in time

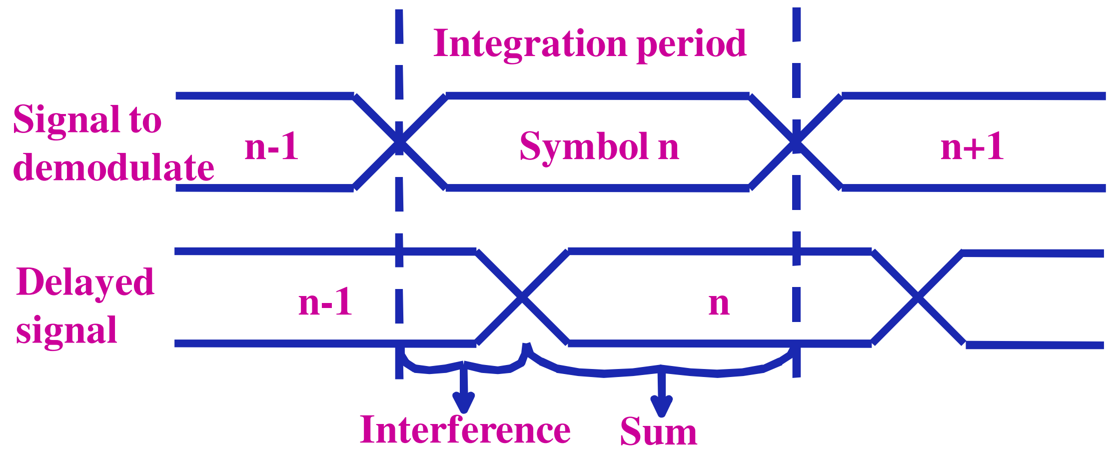
OFDM sub-carriers in frequency

The longer is TU, the smaller is the number of adjacent OFDM interfering symbols !

OFDM Symbol: Union is Strength …



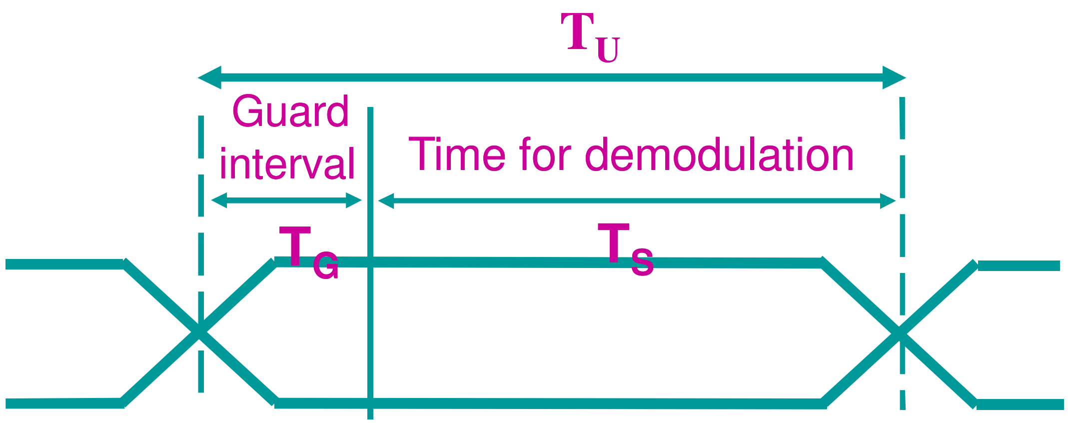
Longer Symbols for Less Interference

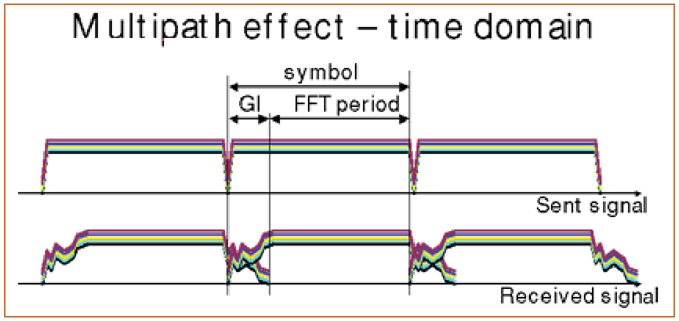


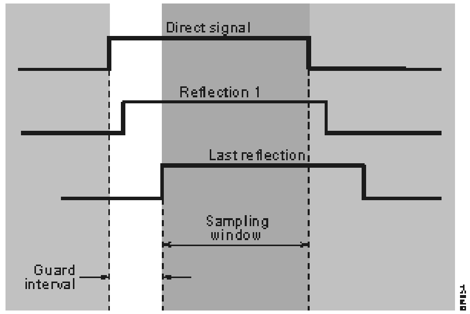
- **Because of finite speed of radio waves at each reception point, the propagation delay from various paths/transmitters is different (different distances). Therefore, without some mechanism there would be interference receiving digital data from more than one path/transmitter operating on the same frequency.**

- **To avoid this, each subcarrier transmits its payload (symbol) during an elementary period of several hundred microseconds which is much longer than the multipath propagation delay.**

Guard Interval for an Interference Free Zone







- The adoption of a guard interval allows creating a time zone free of interferences between different modulated symbols received through multiple paths.

- The length of the guard interval must be longer than the largest delay corresponding to the interfering signals (and this depends on the diffusion cells, notably their size).

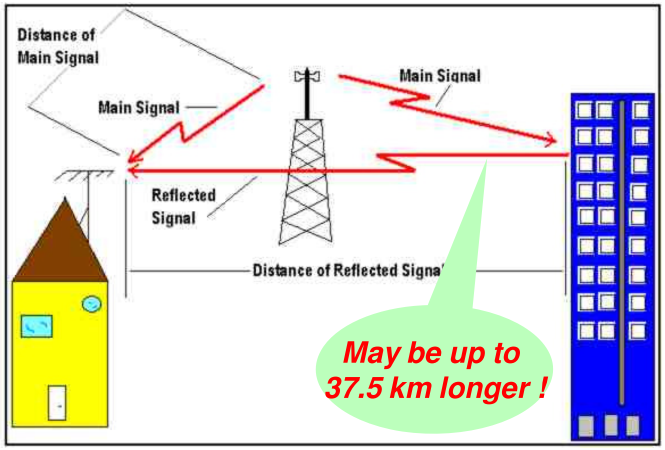
Example: Absorbing Delay with a Guard Interval

1. **SINGLE-CARRIER MODULATION CASE**

- **If *1 Msymbol/s* are to be sent, then the duration of each symbol would be *1 μs* or less.**
  - This imposes severe constraints on synchronization and necessitates the removal of multipath interference.

2. **MULTI-CARRIER MODULATION CASE**

- **If the same *1 Msymbol/s* are spread among 1000 sub-channels, the duration of each symbol can be longer by a factor of 1000 (i.e., *1 ms*) with approximately the same bandwidth.**
- **If a guard interval of *1/8 of the symbol length* is inserted between each symbol (with *1 ms*), intersymbol interference can be avoided if the multipath time-spreading (the time between the reception of the first and the last echo) is shorter than the guard interval, i.e. *125 μs*).**
- **This corresponds to a maximum difference of *37.5 km* between the lengths of the paths (at light speed).**



The COFDM (Coded OFDM or OFDM) Modes

DVB-T defines two variants/modes for data transmission (e.g. in a 8 MHz channel):

- **2k Mode (1512 signal sub-carriers and 193 synchronization sub-carriers) – Solution adequate for small areas coverage; less robust to interferences, less complex; 224 μs/symbol; 4464 Hz between sub-carriers.**

- **8k Mode (6048 signal sub-carriers and 769 synchronization sub-carriers) – Solution adequate for large areas coverage; more robust to interferences, more complex; 896 μs/symbol; 1116 Hz between sub-carriers.**

The modulation of each sub-carrier may be made with QPSK (2 bit/symbol), 16-QAM (4 bit/symbol) or 64-QAM (6 bit/symbol), with guard intervals of $T_S/4$, $T_S/8$ or $T_S/32$, and 7.6 MHz between the extreme sub-carriers (for a 8 MHz channel).

The label "Coded" means that the transmitted data contains actual data and additional FEC (Forward Error Correction) information for protection.

Bitrate (Mbit/s) versus Modulation per 8 MHz Channel …

Modulation	Coding rate	Relative length of the guard interval			
		1/4	1/8	1/16	1/32
QPSK	1/2	4.98	5.53	5.85	6.03
	2/3	6.64	7.37	7.81	8.04
	3/4	7.46	8.29	8.78	9.05
	5/6	8.29	9.22	9.76	10.05
	7/8	8.71	9.68	10.25	10.56
16-QAM	1/2	9.95	11.06	11.71	12.06
	2/3	13.27	14.75	15.61	16.09
	3/4	14.93	16.59	17.56	18.10
	5/6	16.59	18.43	19.52	20.11
	7/8	17.42	19.35	20.49	21.11
64-QAM	1/2	14.93	16.59	17.56	18.10
	2/3	19.91	22.12	23.42	24.13
	3/4	22.39	24.88	26.35	27.14
	5/6	24.88	27.65	29.27	30.16
	7/8	26.13	29.03	30.74	31.67

Continental solution

Madeira and Açores

Hierarchical Modulation

64-QAM (4+2 bit/symbol)

64-QAM hierarchical modulation allows the simultaneous diffusion of a priority stream (2 MSB bits) in QPSK and another stream (remaining 4 bits), e.g. for different programs or different resolutions.

When the transmission conditions degrade, 16 positions in the 64-QAM constellation may be taken as a single position in a QPSK constellation, allowing to receive, in good conditions, at least the 2 MSB bits.

DVB-T: Excellent Mobile Reception

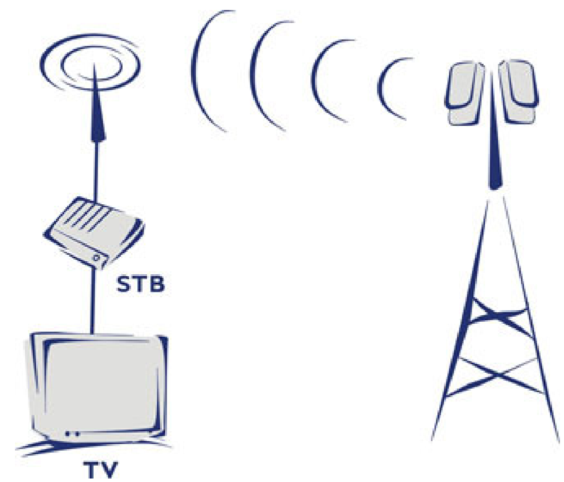
Reception with spatial, temporal and frequency diversity …

Main DVB-T Technical Characteristics

- Many characteristics common to the DVB-S and DVB-C systems
- Inclusion of the convolutional channel coding from DVB-S
- OFDM modulation based on QPSK and QAM (very robust to multipath effects) with 2k and 8k OFDM modes
- Two hierarchical layers of channel coding and modulation
- MPEG-2 Video (Main profile) and later H.264/AVC source coding
- Definition of national and regional broadcasting networks (Single Frequency Networks (SFN) and Multiple Frequency Networks (MFN))

DVB-T System Main Relevant Parameters

- **Emmited power**
- **Antennas size**
- **Available bandwidth**
- **Frequency position**
- **Number of carriers**
- **Carriers modulation efficiency**
- **Cell size**
- **Coding rate**
- **Guard interval size**
- **Target probability of error**



The project designer has to 'play' with all these parameters to provide the target service with the desired quality for the lowest initial and regular cost.

DVB-T

Deployment

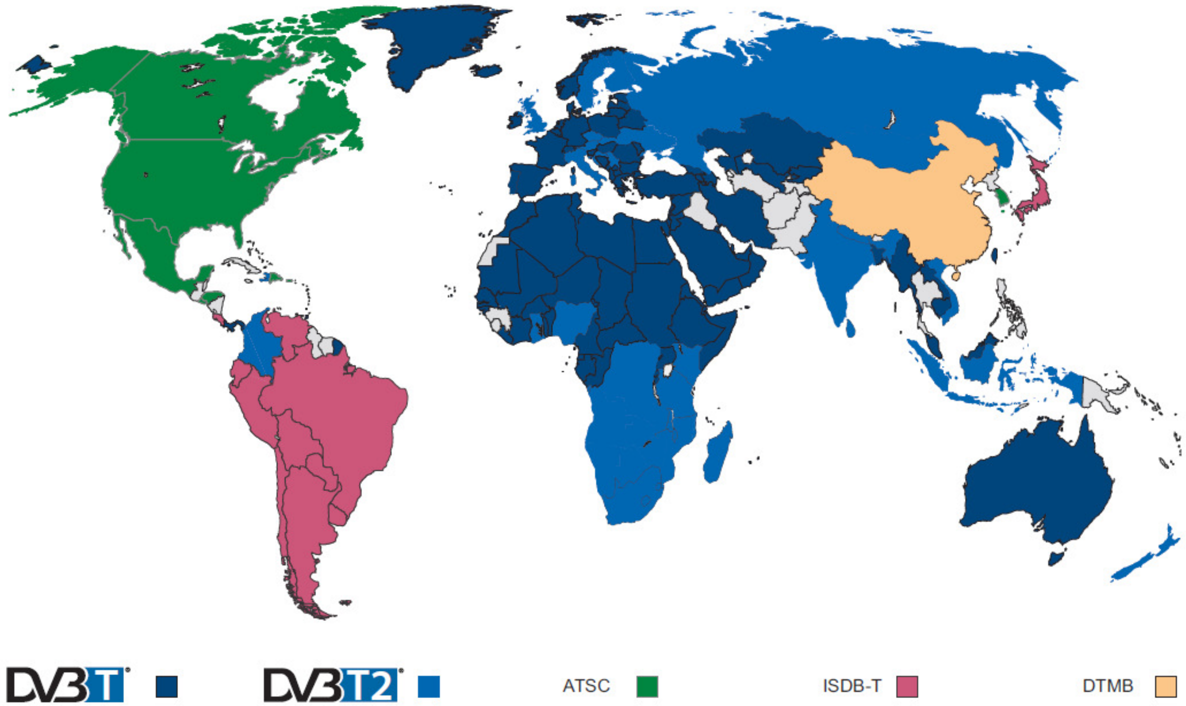
DVB TERRESTRIAL

1997

DVB T2

2008

DVB-T: Adoption …

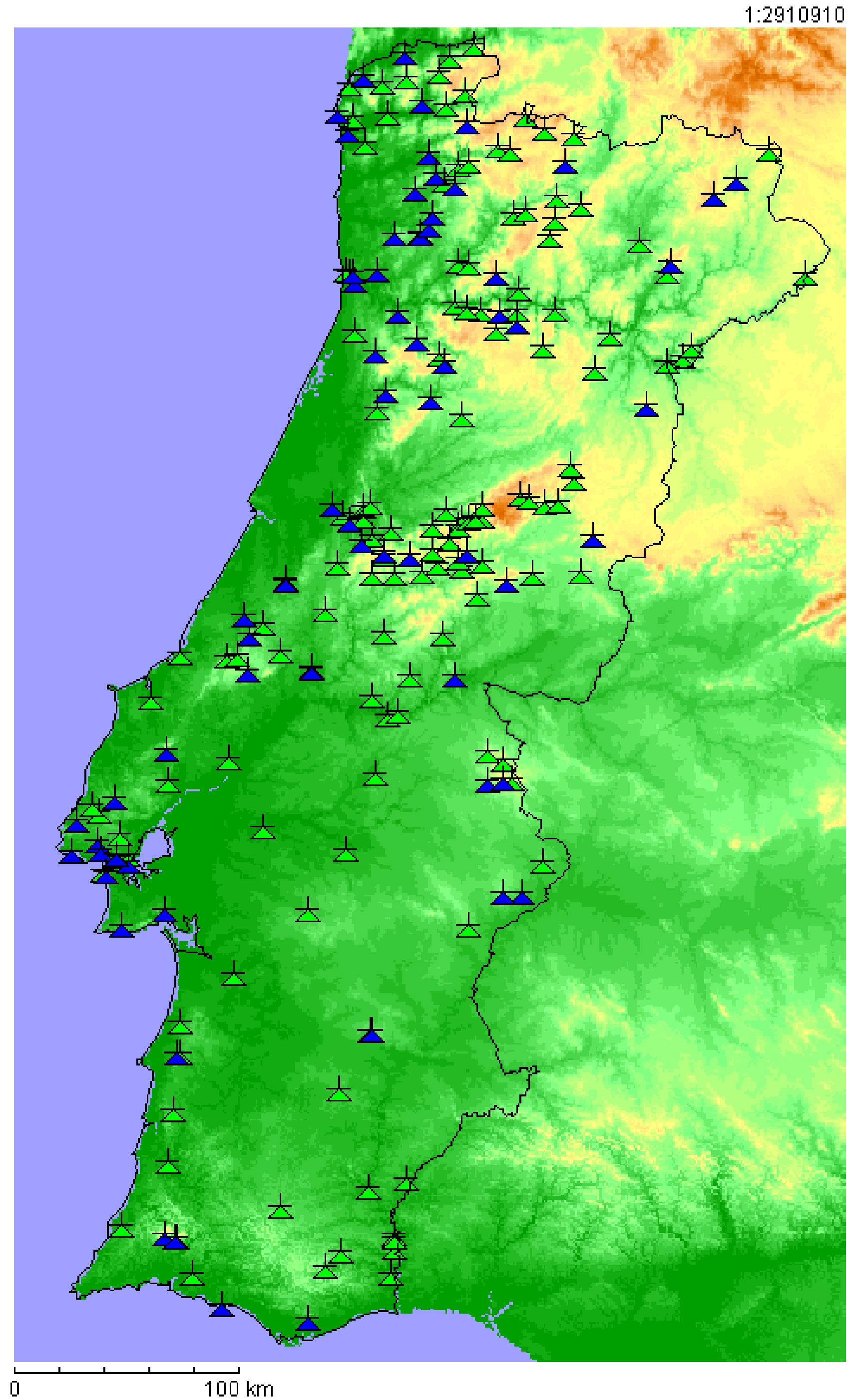


- DVB-T is the most widely adopted and deployed DTT standard. Since its publication in 1997, over 70 countries have deployed DVB-T service and 45 more have adopted (but not yet deployed) DVB-T.
- The first country to deploy DVB-T2 was UK in March 2010, next to an existing DVB-T service.

Current Situation: Terrestrial TV Transmission

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

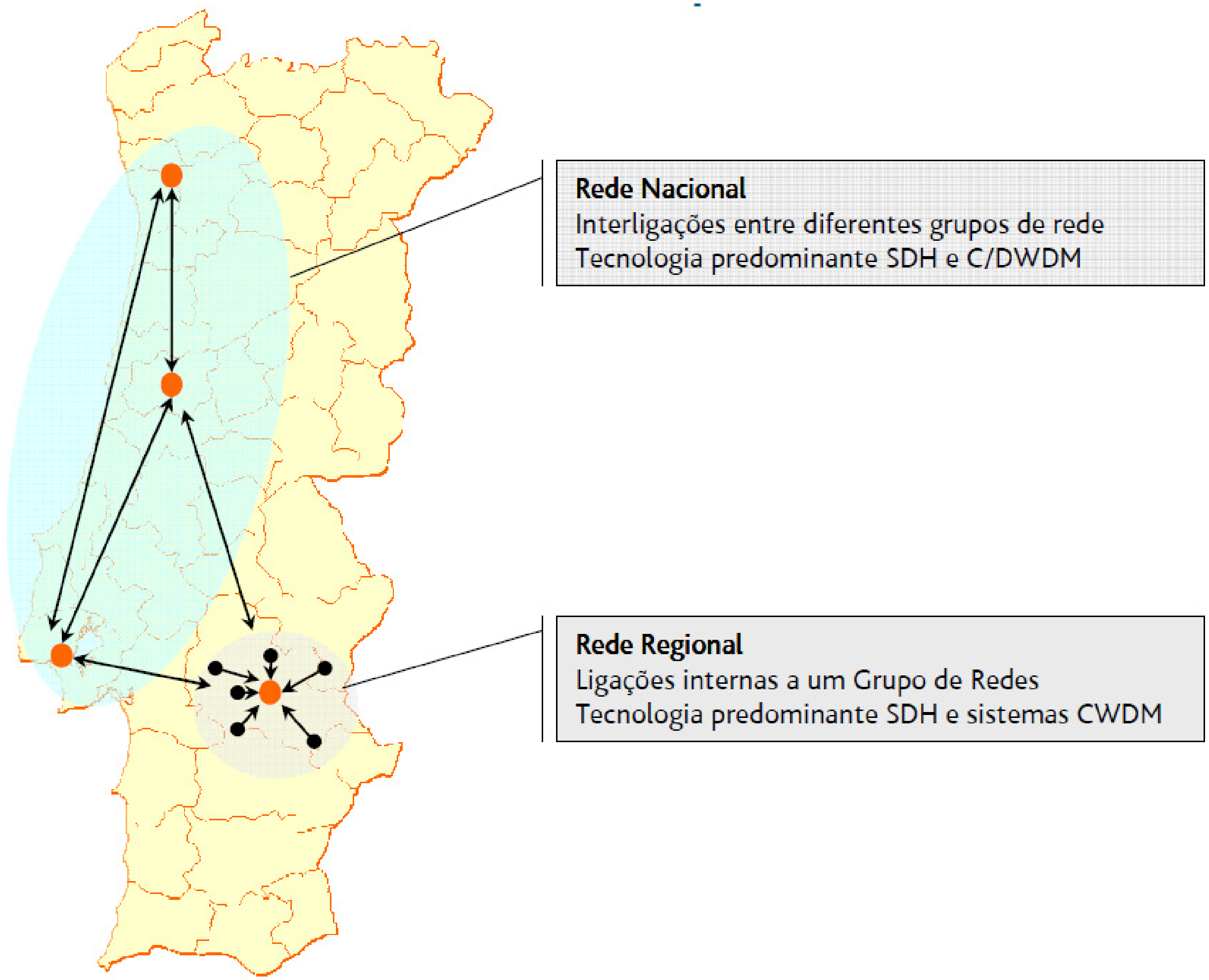
- PT Comunicações (green in the map) network which included the network that was initially from RTP and TDP
- RETI, Rede Teledifusora Independente, (blue in the map) network which developed from the radio network from Rádio Renascença; this network was bought by PT in 2008 and fused with the other network



TDT in Portugal

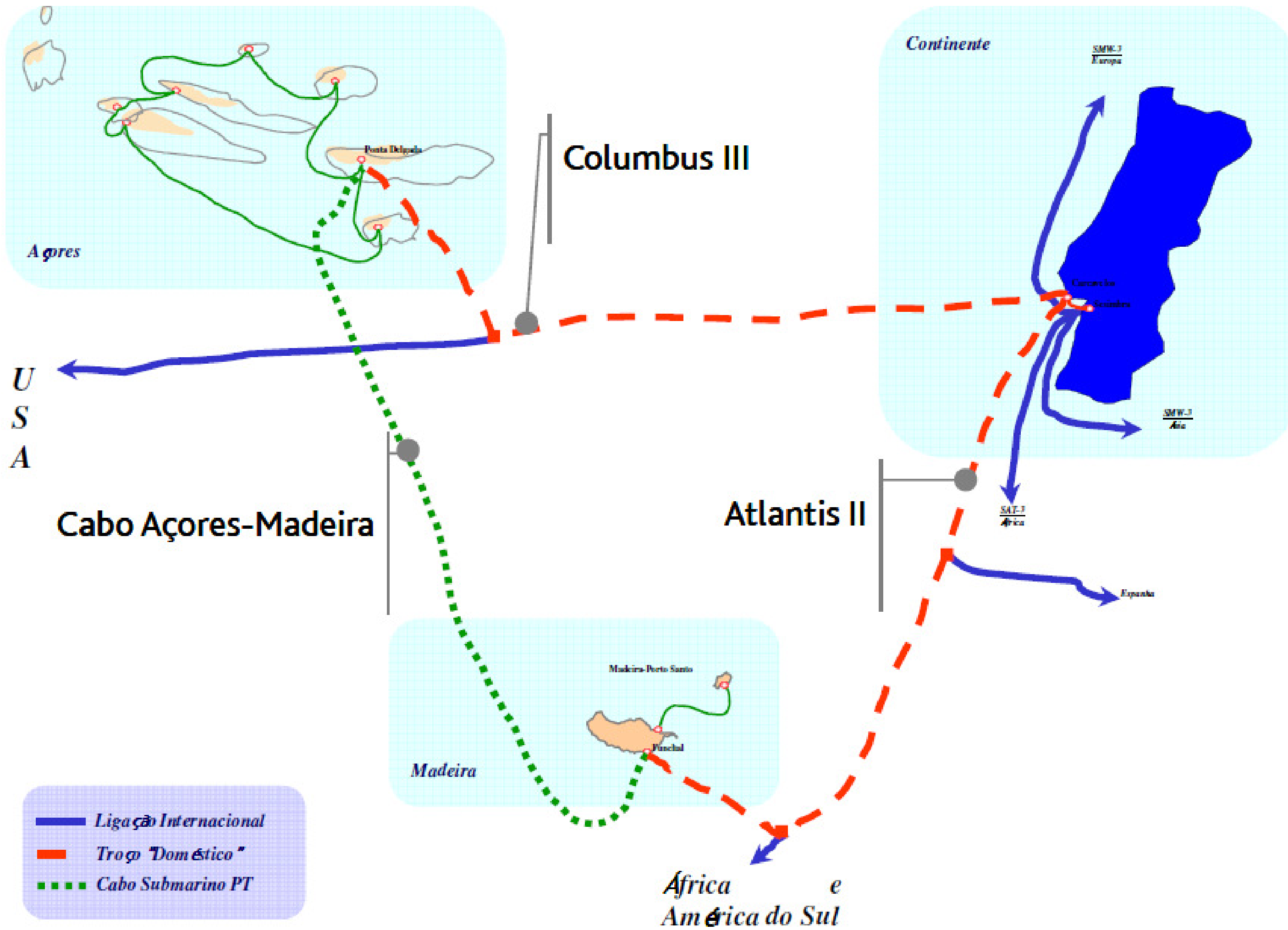
- Portugal adopted DVB-T.
- TDT in Portugal uses 6 multiplexers (A, B, C, D, E e F) of 8 MHz and Single Frequency Networks (SFN).
- Multiplexer A transmits the free channels already with license (RTP 1, RTP 2, SIC and TVI); the fifth channel was intended for this multiplexer but plans for it were withdrawn.
- Multiplexers B to F should be for ‘pay TV’ (no current plans to deploy).
- Multiplexers B and C are national and Multiplexers D, E, F have partial coverage with a save zone of 80 km from the border with Spain (meaning that part of the population will not see these channels).

SDH Transport Network

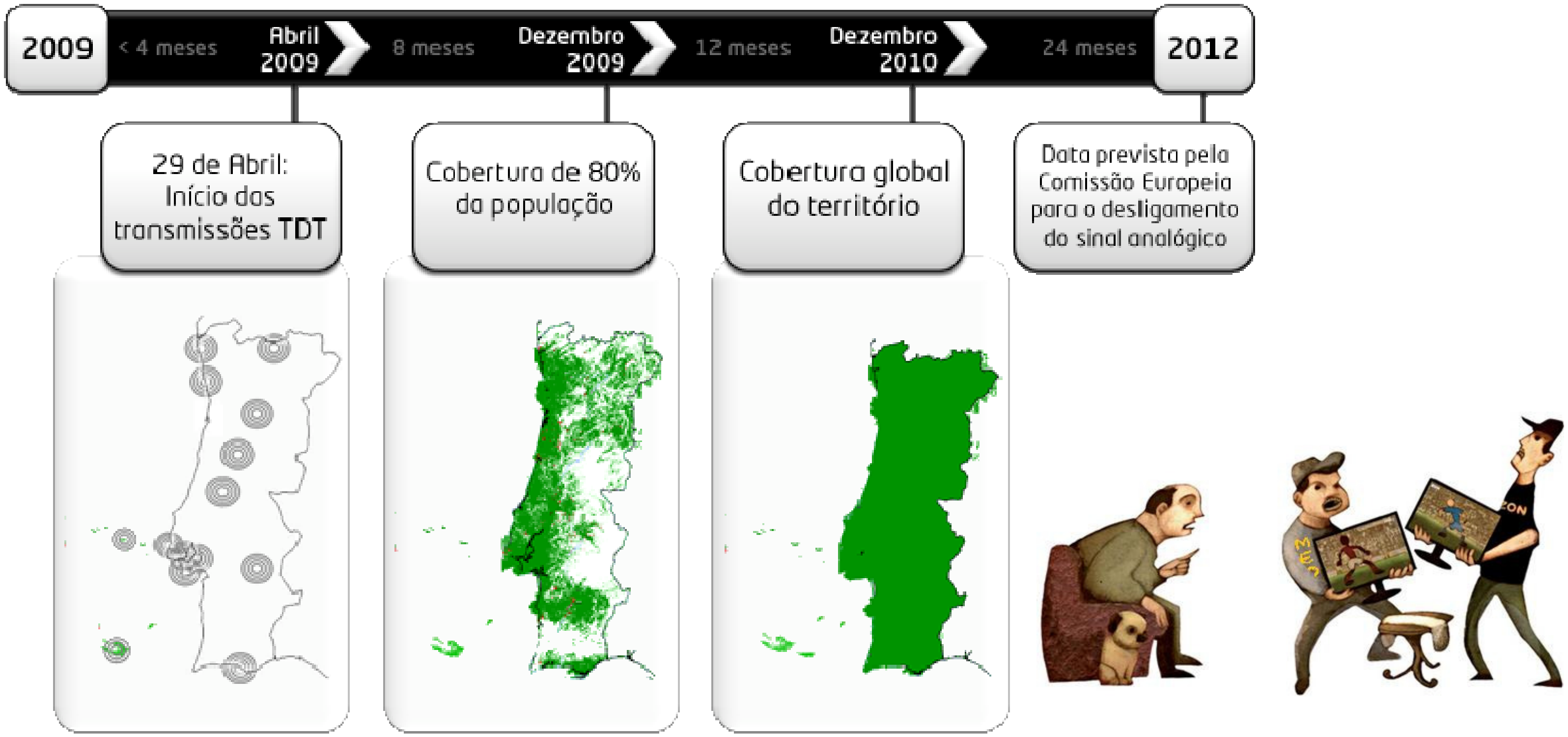


Synchronous Digital Hierarchy (SDH) are standardized protocols that transfer multiple digital bitstreams over optical fiber using lasers or highly coherent light from light-emitting diodes (LEDs).

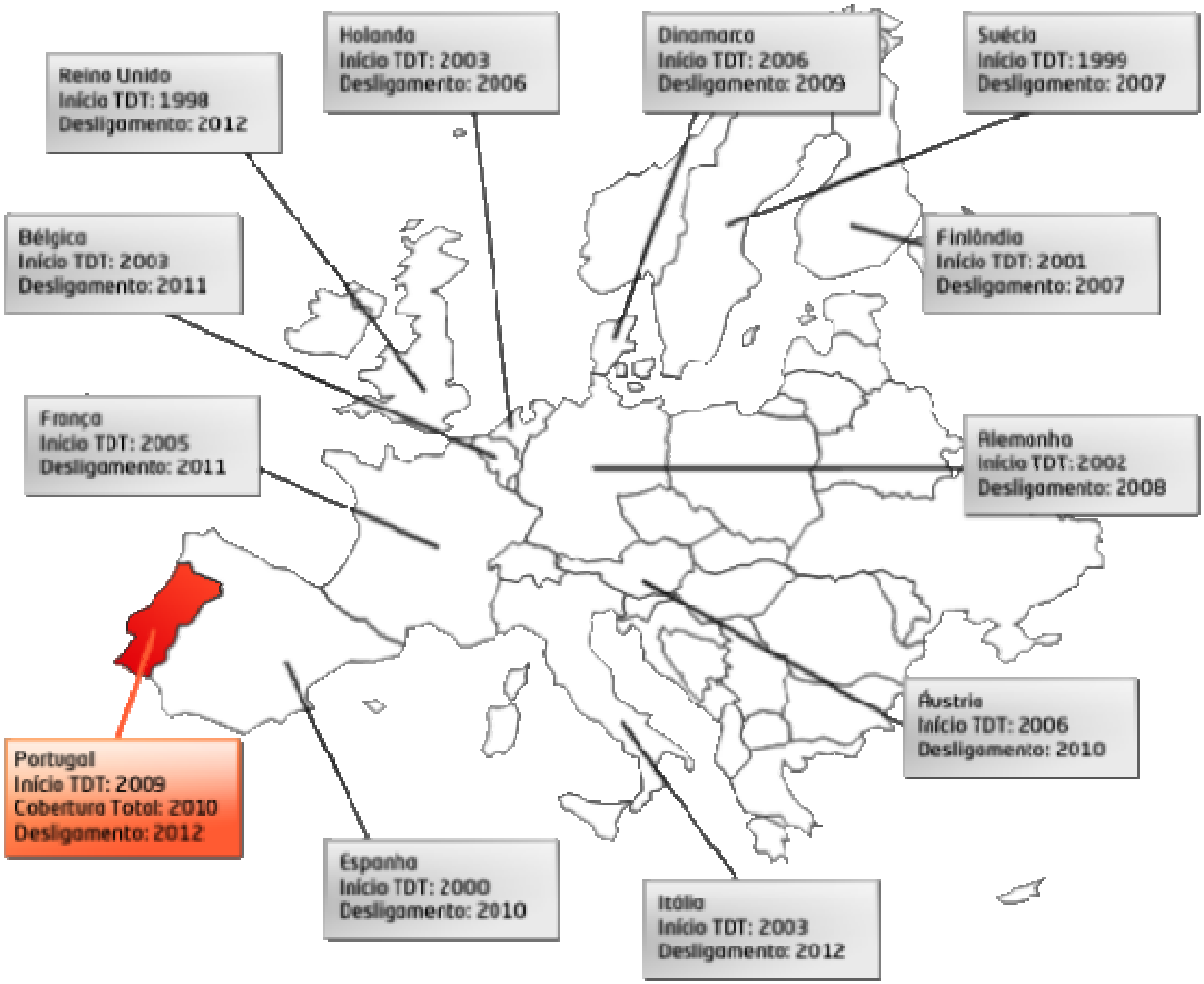
Transport Network: Cable Connections to Madeira and Açores



TDT in Portugal: Evolution in Time

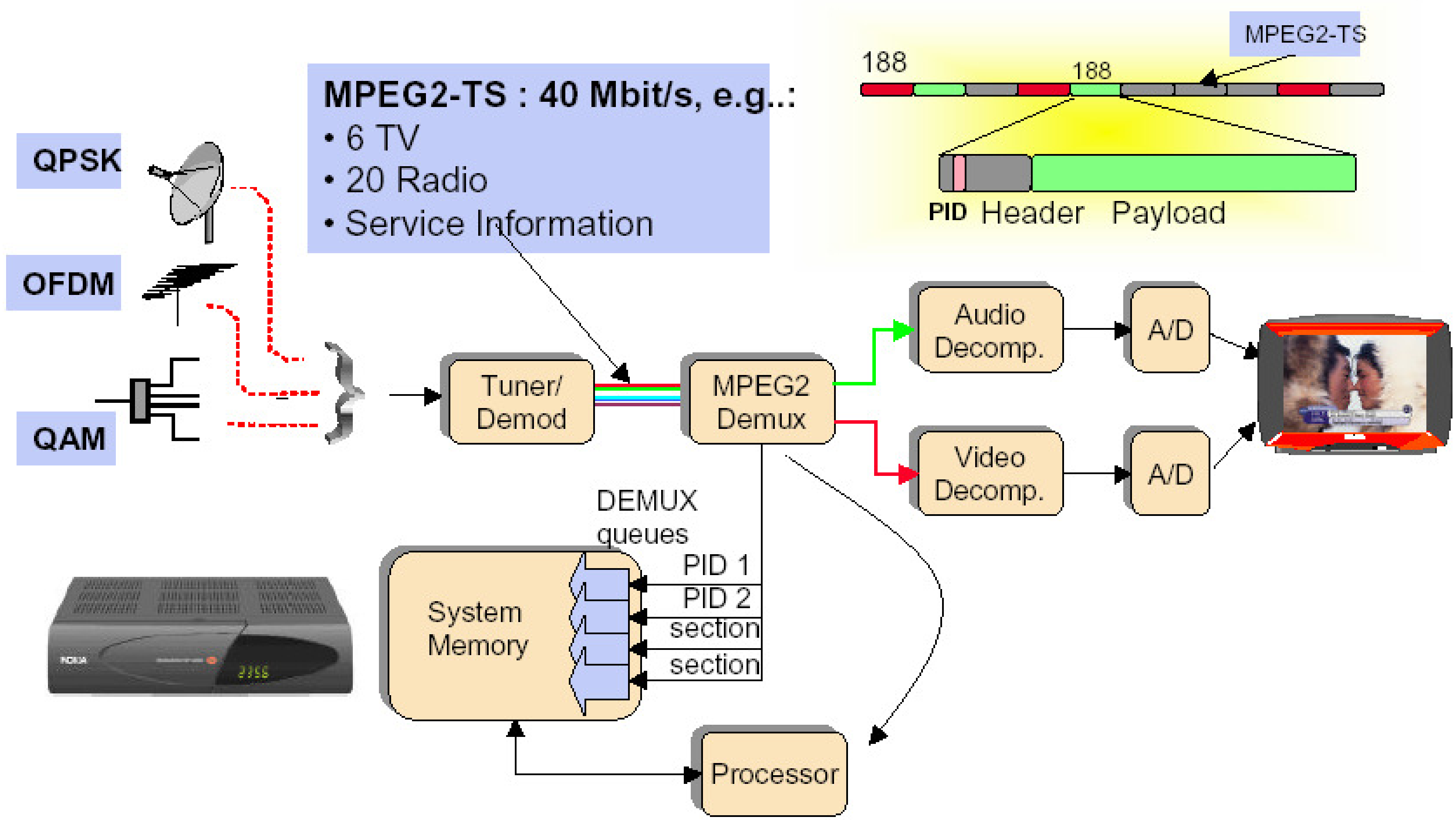


- **TDT emissions started on the 29th April 2009; the coverage was gradually enlarged until 2011.**
- **Between 2009 and 2011, there was analog and digital simulcasting.**
- **By 26 April 2012, the deployment of digital terrestrial TV was finished.**


Reino Unido
Início TDT: 1998
Desligamento: 2012
Holanda
Início TDT: 2003
Desligamento: 2006
Dinamarca
Início TDT: 2006
Desligamento: 2009
Suécia
Início TDT: 1999
Desligamento: 2007
Bélgica
Início TDT: 2003
Desligamento: 2011
Finlândia
Início TDT: 2001
Desligamento: 2007
França
Início TDT: 2005
Desligamento: 2011
Alemanha
Início TDT: 2002
Desligamento: 2008
Áustria
Início TDT: 2006
Desligamento: 2010
Portugal
Início TDT: 2009
Cobertura Total: 2010
Desligamento: 2012
Espanha
Início TDT: 2000
Desligamento: 2010
Itália
Início TDT: 2003
Desligamento: 2012

DVB Terminals

What Does a Set-top Box ?



DVB Integrated Receiver-Decoders (IRDs)

The DVB IRDs are classified according to 5 dimensions:

- **"25 Hz" or "30 Hz" depending if they use 25 Hz or 30000/1001 Hz (approximately 29,97 Hz) picture rates; some IRDs may be *dual-standard* which means they may accept both 25 Hz and 30 Hz video content.**
- **"SDTV" or "HDTV" depending if they are limited or nor to decode conventional resolution images (ITU-R 601); a SDTV IRD has capabilities which are a sub-set of an HDTV IRD capabilities.**
- **"With digital interface" or "Baseline" depending if they can be used for storage as with a VCR (*Video Cassete Recorder*) or not; a *Baseline* IRD has capabilities which are a sub-set of the digital interface IRD capabilities.**
- **"MPEG-2 Video" or "H.264/AVC" depending if they use one or the other video coding format.**
- **Audio Coding Format, several, e.g. MPEG-1/2 Audio (Layers 1 e 2), Dolby AC-3, and recently MPEG-4 Audio HE AAC.**

Video in DVB

- MPEG-2 Main Profile @ Main Level is used to code SDTV with MPEG-2 Video
- MPEG-2 Main Profile @ High Level is used to code HDTV with MPEG-2 Video
- H.264/AVC Main Profile @ Level 3 is used to code SDTV with H.264/AVC
- H.264/AVC High Profile @ Level 4 is used to code HDTV with H.264/AVC
- Both the 25 Hz MPEG-2 SDTV IRDs and 25 Hz H.264/AVC SDTV IRDs use 25 Hz
- The 25 Hz MPEG-2 HDTV IRDs and the 25 Hz H.264/AVC HDTV IRDs use both 25 and 50 Hz

Audio in DVB

- The DVB audio formats are MPEG-1 Audio Layer I, MPEG-1 Audio Layer II or MPEG-2 Audio Layer II backward compatible.
- The usage of Layer II is recommended when MPEG-1 Audio is used.
- Sampling rates are 32 kHz, 44,1 kHz and 48 kHz.
- IRDs may, optionally, decode multi-channel MPEG-2 Audio Layer II backwards compatible audio (Part 2).
- The usage of MPEG-4 Audio High Efficiency AAC (HE-AAC) is optional, and thus the IRDs may, optionally, decode or not these streams.

Final Remarks

- The DVB solutions for digital TV are recognized as the best, notably for mobile and portable reception.
- 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.

Much deployed digital TV is still MPEG-2 based … however, another more efficient video coding solution is quickly taking over: H.264/AVC (see next episode)!

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