DIGITAL TELEVISION

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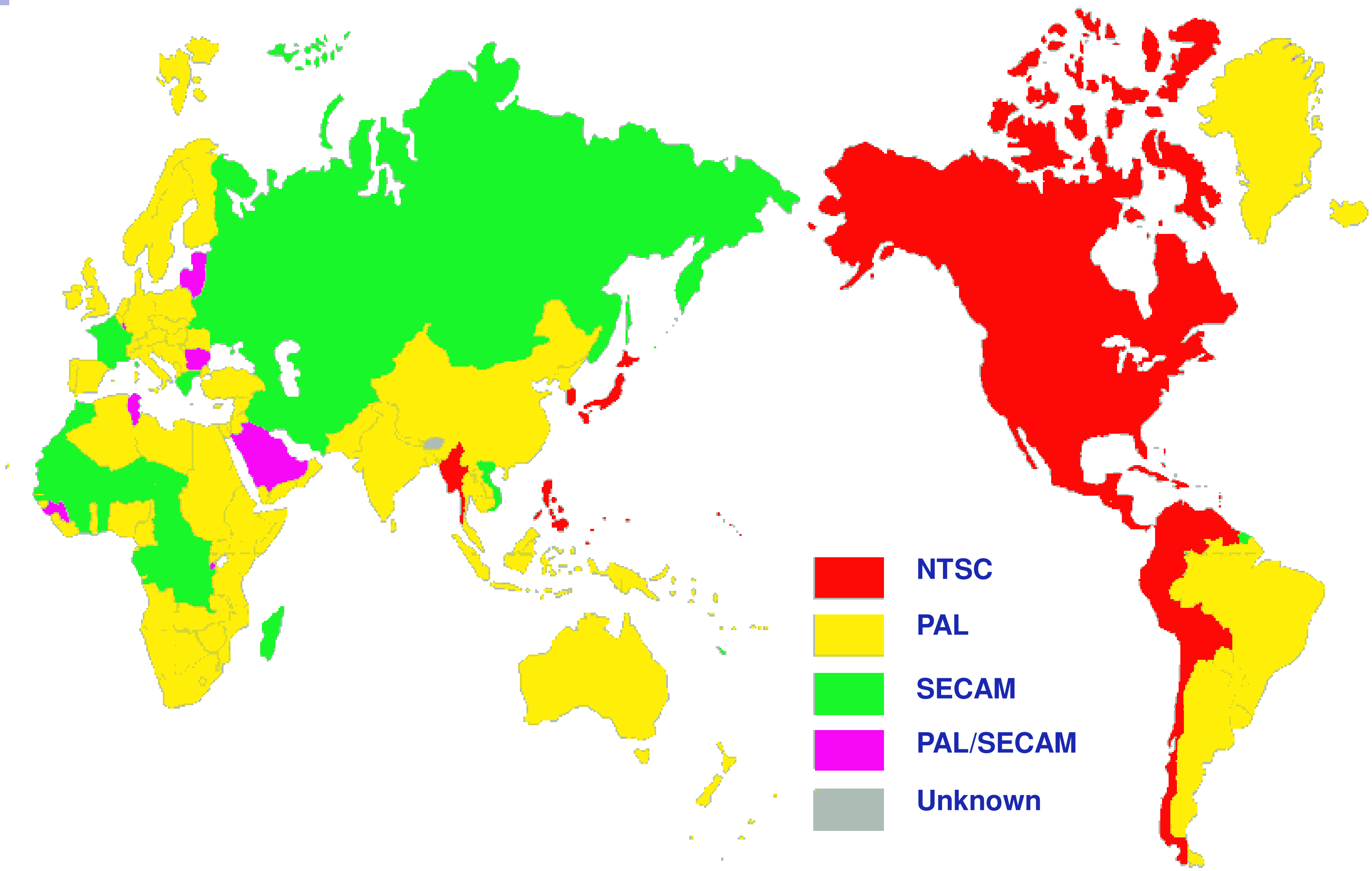
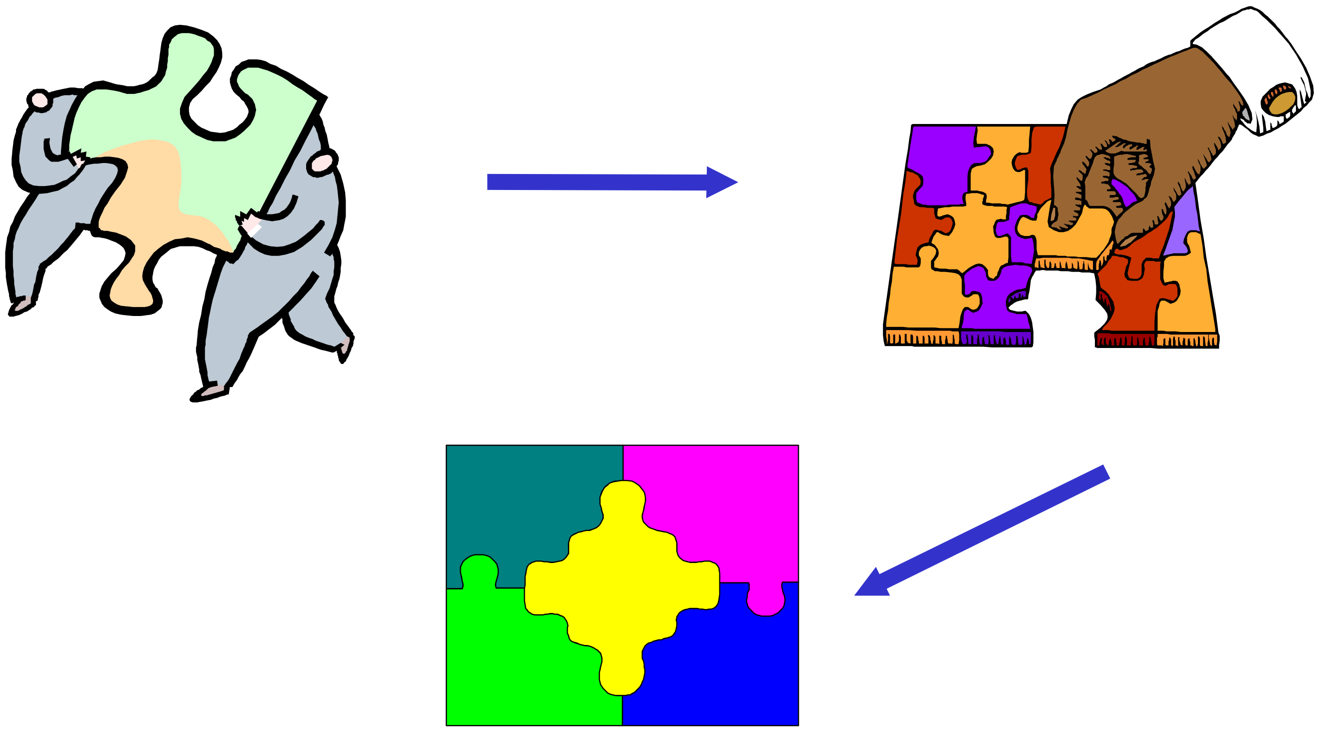
The Analogue TV World

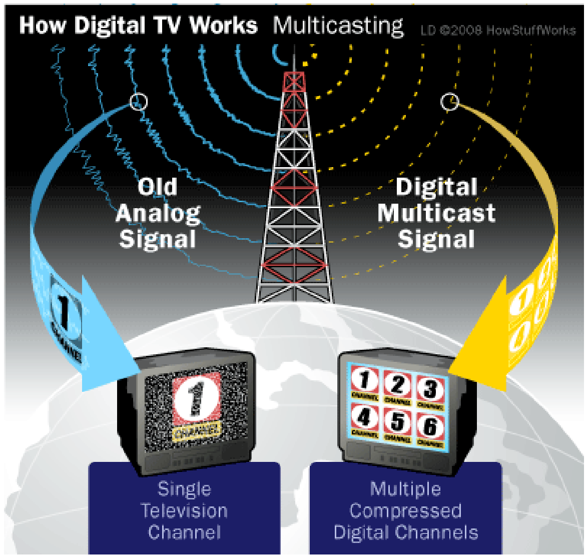


TV Digital: What is it Really ?



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 minimum acceptable quality !

Why Digital TV ?



- More efficient usage of the spectrum
- 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

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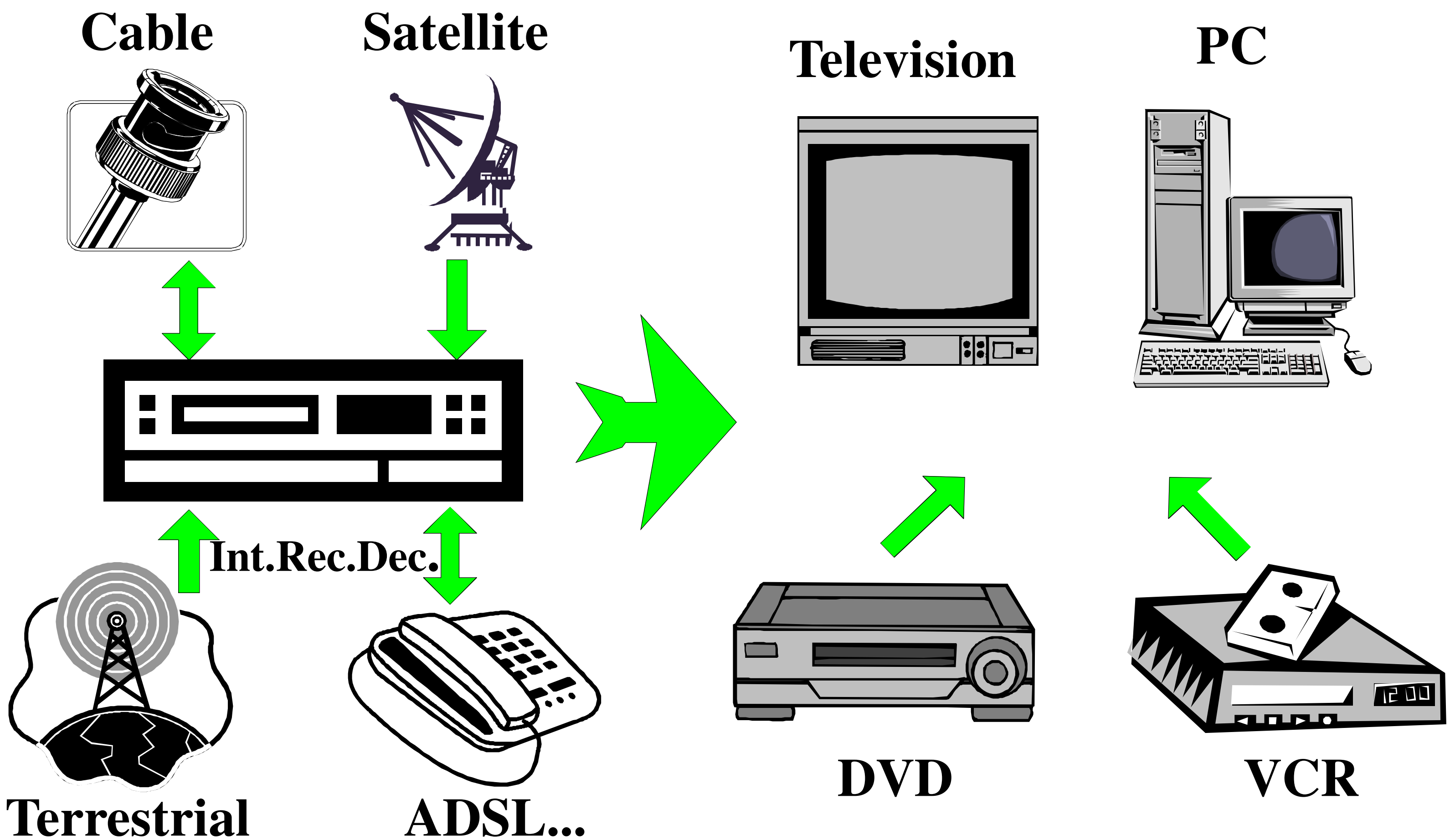
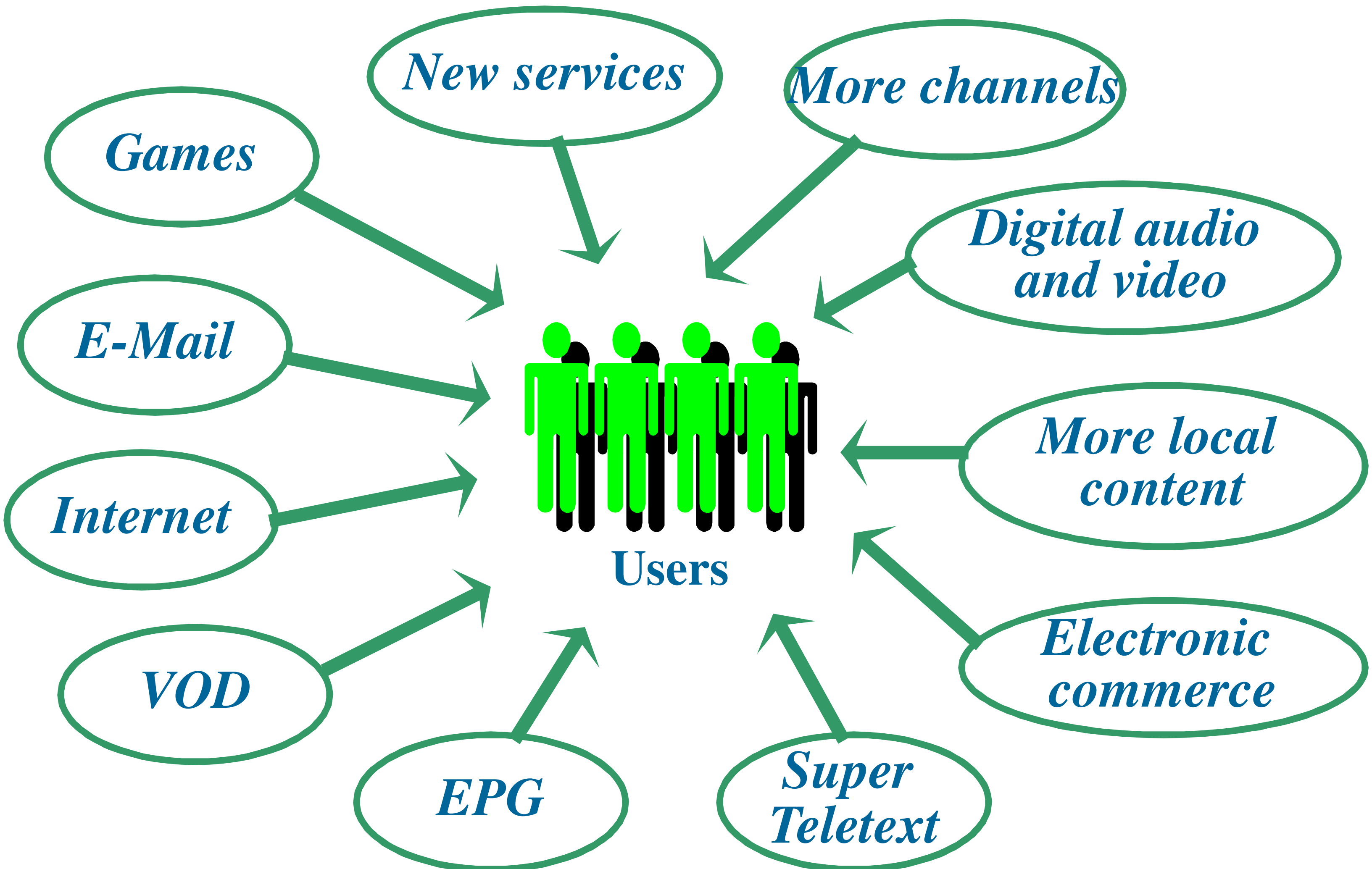
TV of the Future: How will it Look like ?

- **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 ?

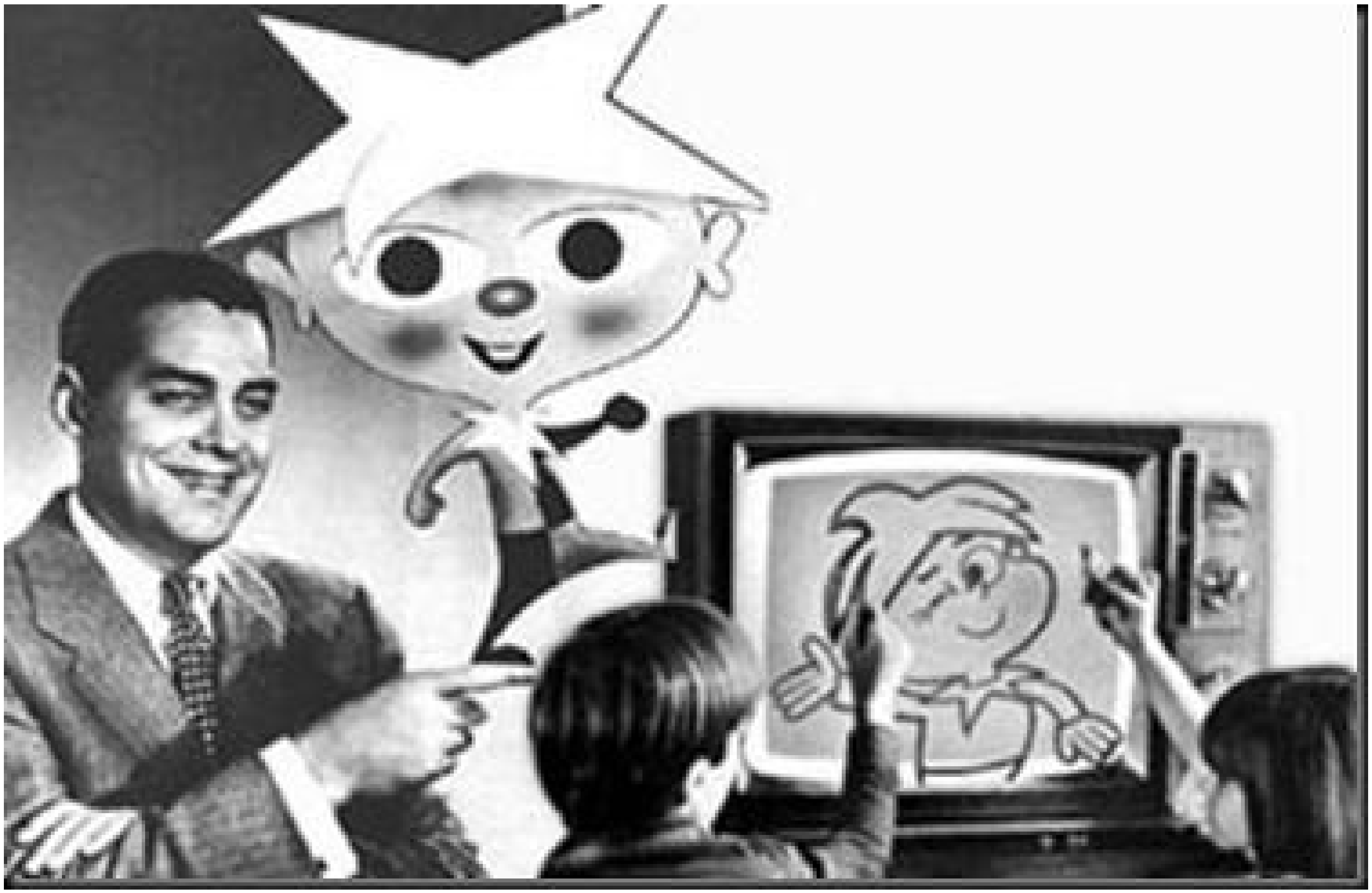
- **Satisfaction of important needs / added value / functionalities**
- **Interoperability at the application level – *users don't care much about the specific technical solution***
- **Quality and reliability**
- **Facility of usage**
- **Low cost of usage and equipment**
- **Variety and quality of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

Interactivity

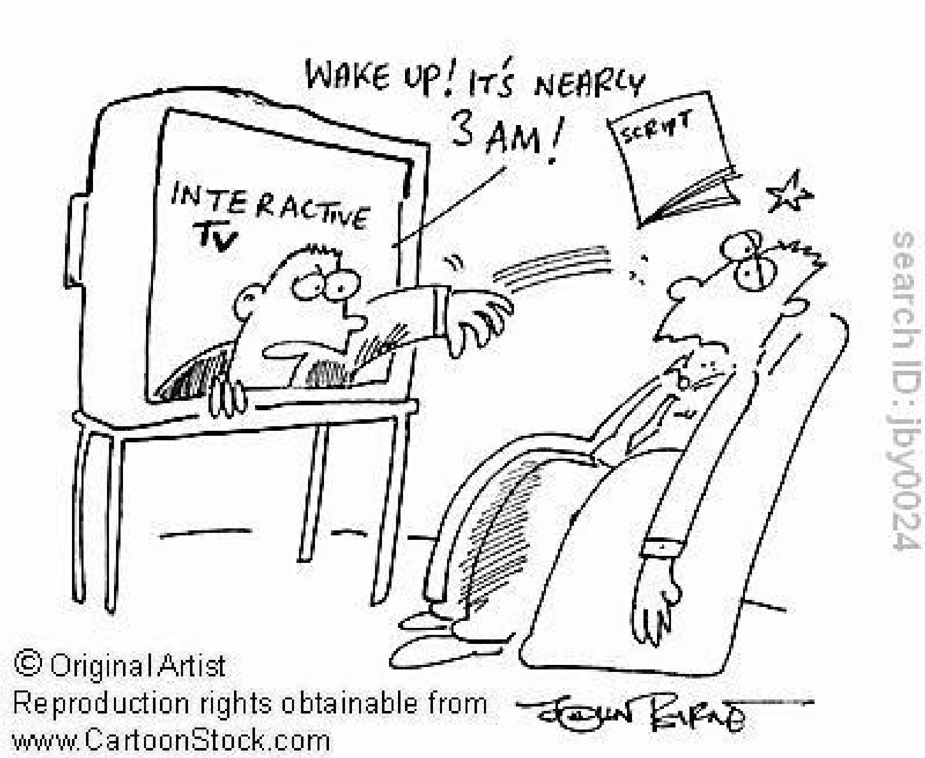
The digital representation of information facilitates the explosion of interactive capabilities – *user capability to select or change something, thus personalizing the television experience* - associated to television and thus the capability of the users to:

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

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



Types of Interactivity



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

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

Television: How is Changing ?

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

Main Digital TV Systems

After the satellite and the cable, the possibility to release bandwidth has brought digital TV also to the terrestrial systems … and more …

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)**
- **Audio Video coding Standard (AVS) – Driven by China**
- **Sistema Brasileiro de TV Digital Terrestre (SBTVD) – Driven by Brazil (large similarities with ISDB)**

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DVB

Digital Video Broadcasting

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

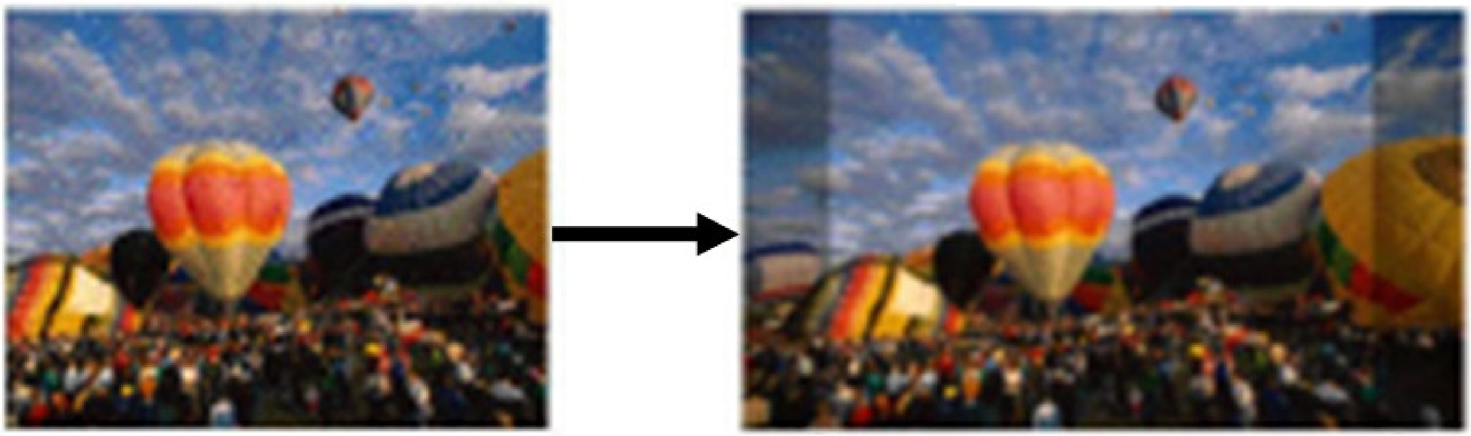
with the objective to define standards for digital television broadcasting over several transmission channels.

- **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 New DVB Vision: Combining Worlds …

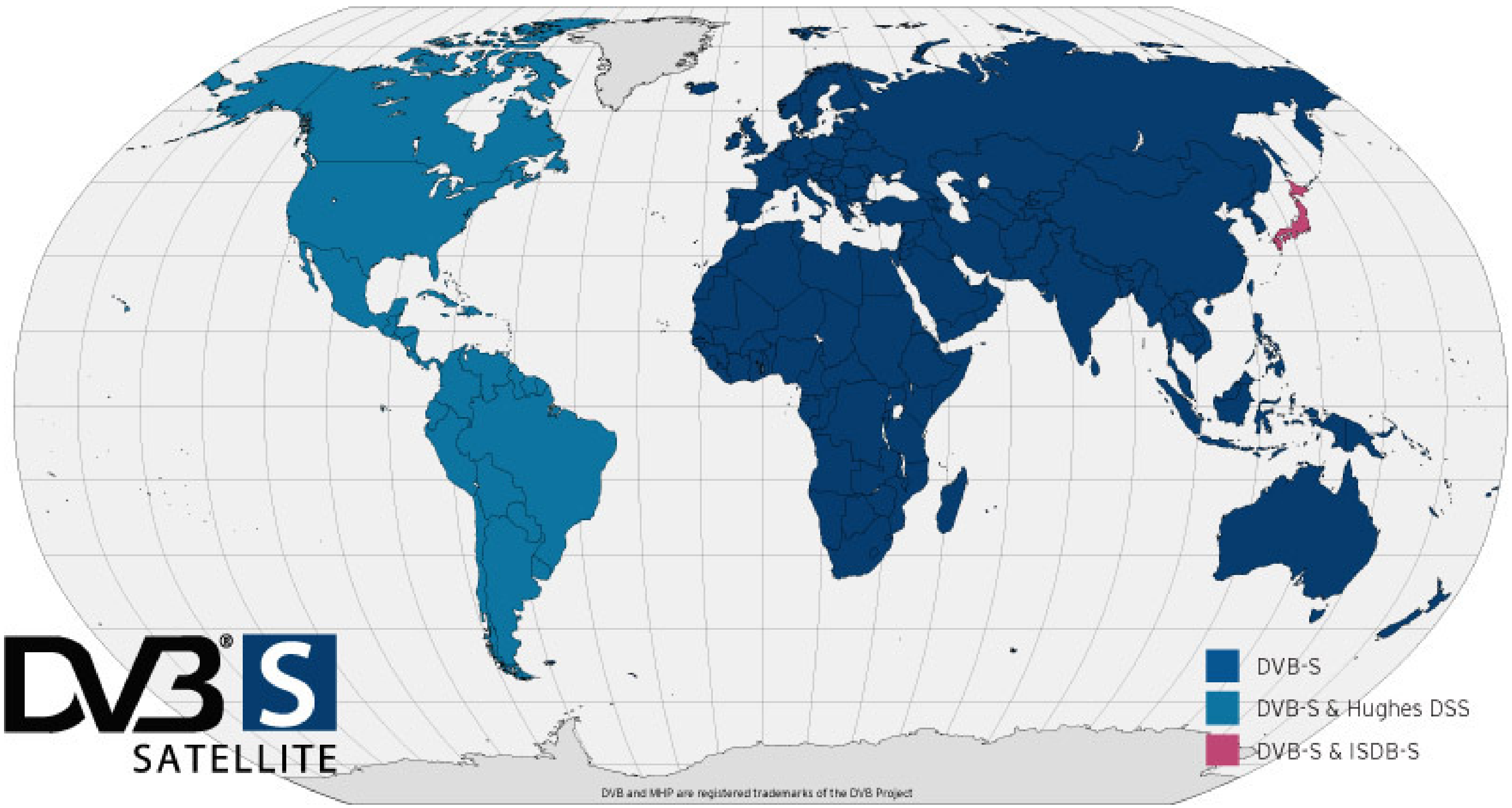
DVB's vision is to build a content environment that combines the stability and interoperability of the world of broadcast with the vigor, innovation, and multiplicity of services of the world of the Internet."

DVB, 2000

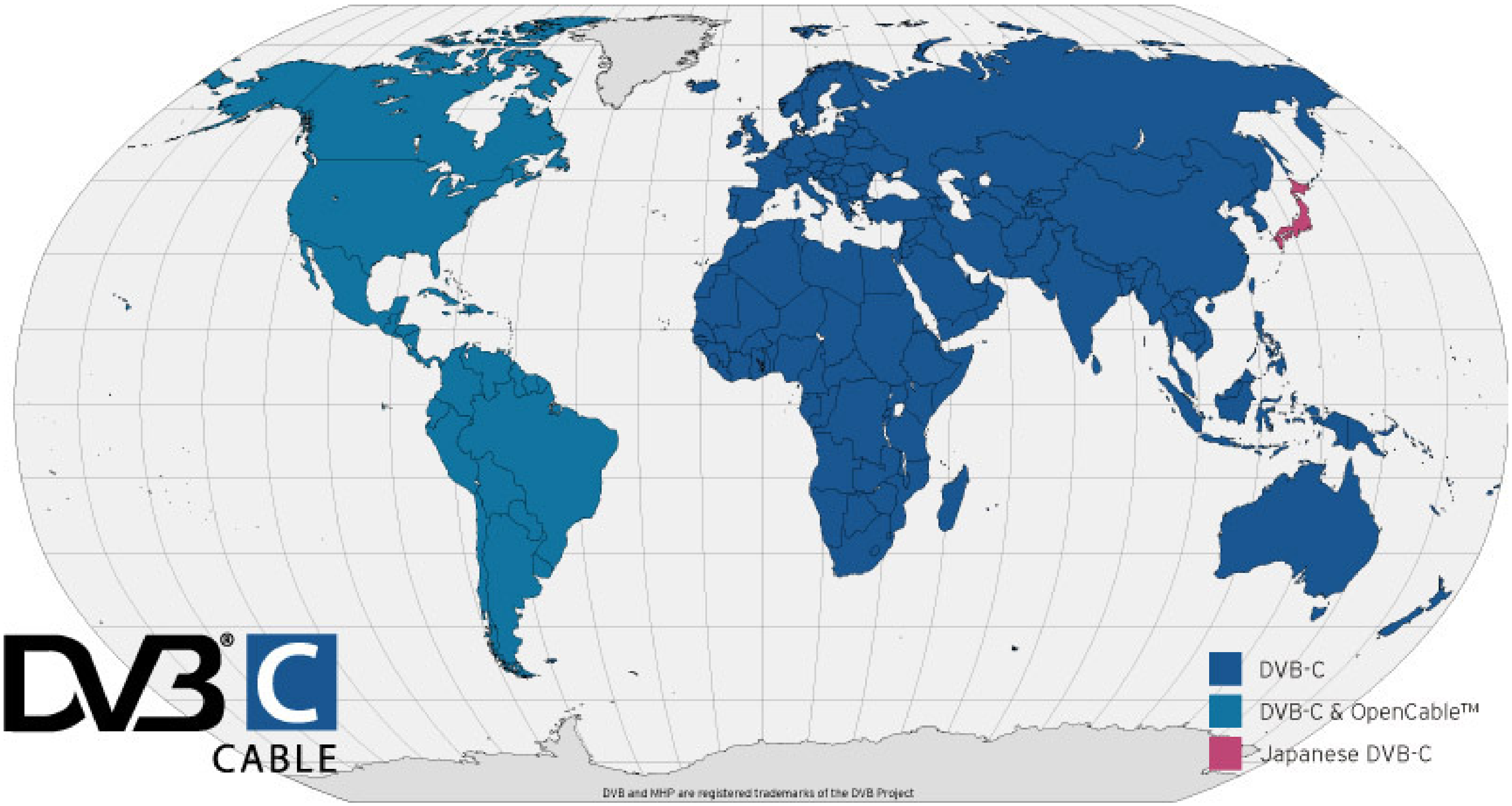
The DVB Scenarios and Standards

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

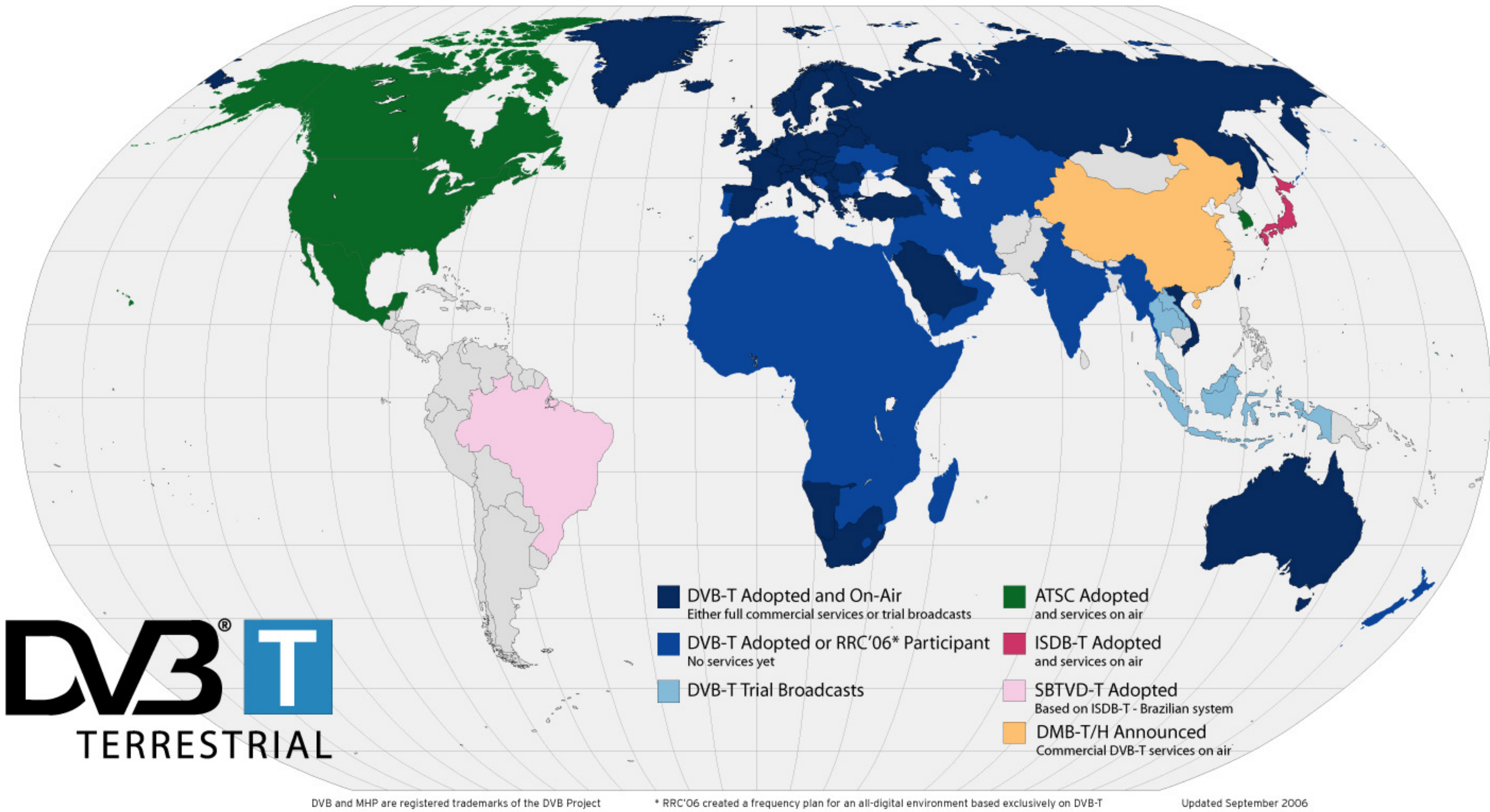
DVB-S: Adoption …



DVB-C: Adoption …



DVB-T: Adoption …



DVB Technologies

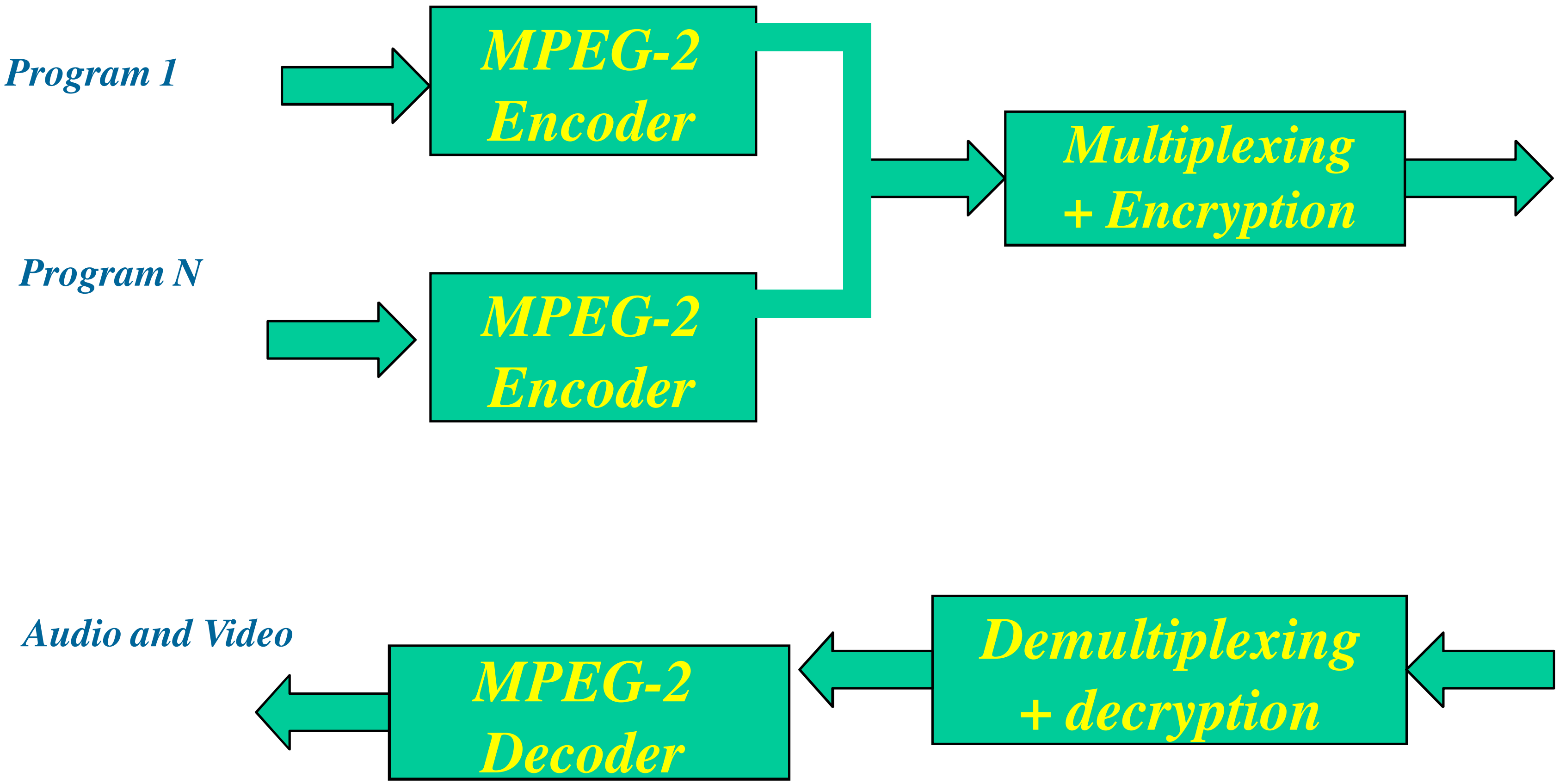
The DVB Specifications

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

The main modules specified are:

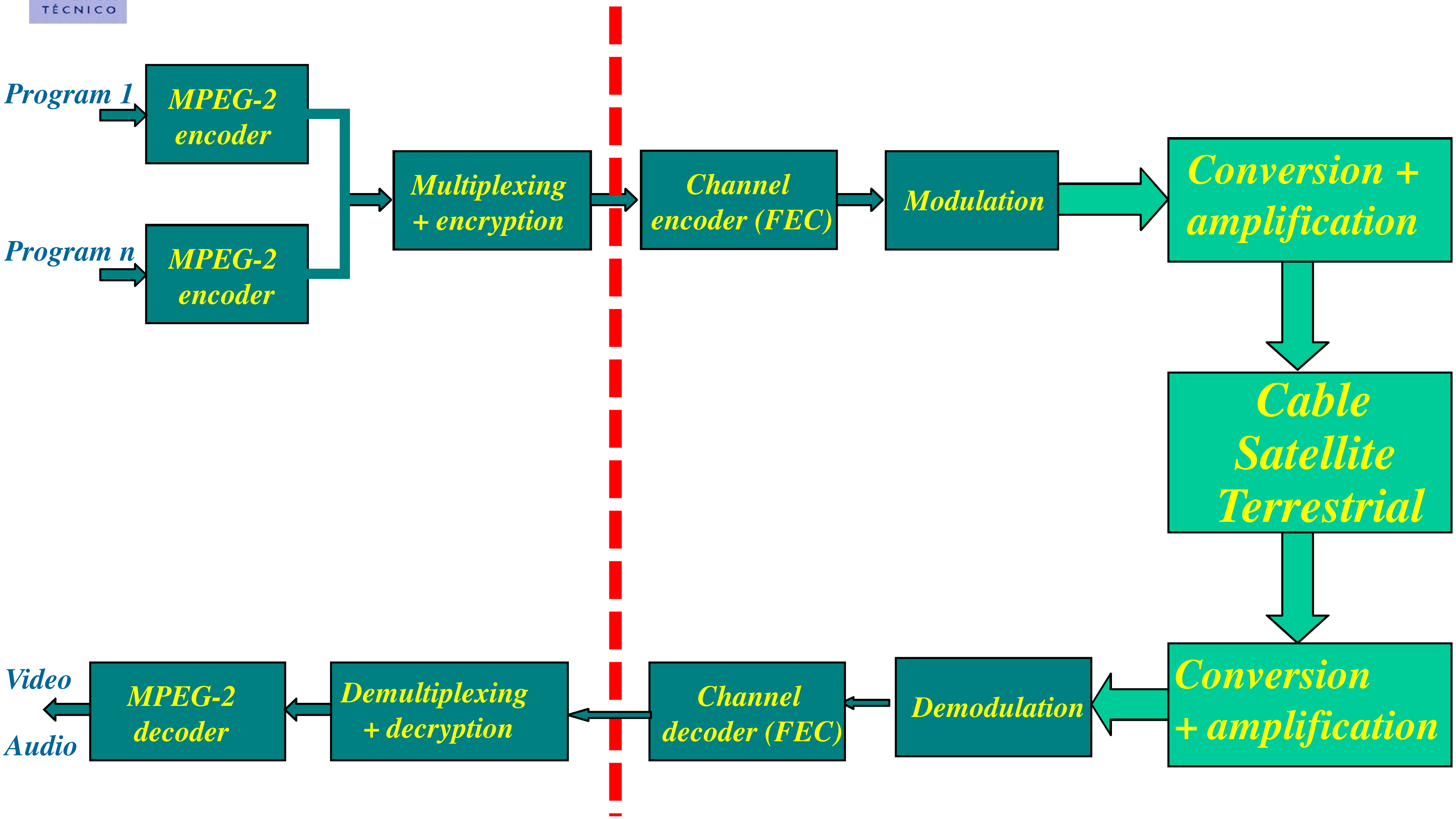
- **Audio and Video Source Coding -** MPEG-2 Audio and MPEG-2 Video are adopted; later also H.264/AVC has been adopted
- **Synchronization and Multiplexing -** MPEG-2 Systems is adopted
- **Channel Coding**
- **Modulation**
- **Conditional Access**

Source Processing: Starting with MPEG-2 ...

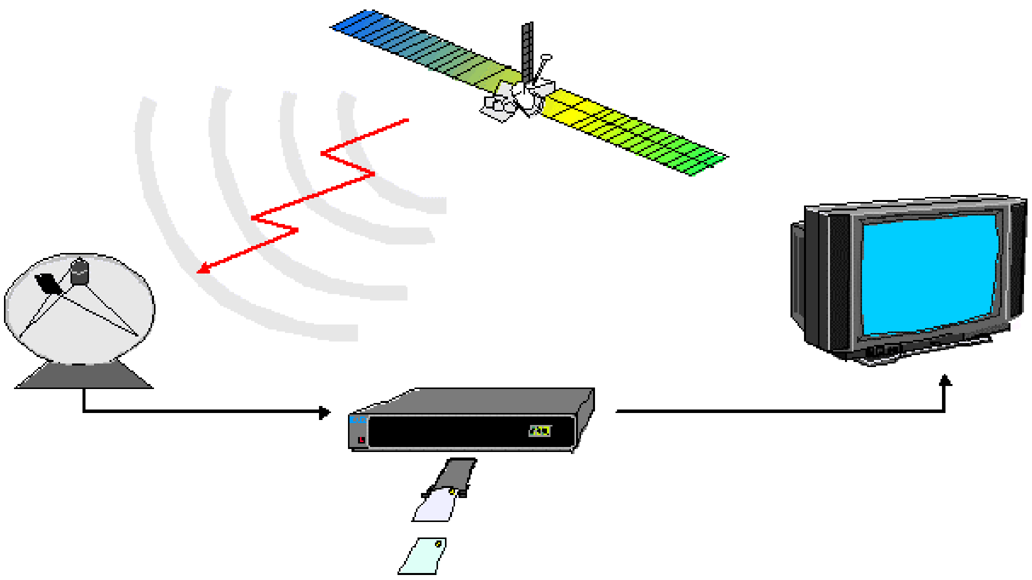


Note: No encryption is specified in MPEG-2 standards.

The Channel .. After the Source !



MPEG-2 Standard



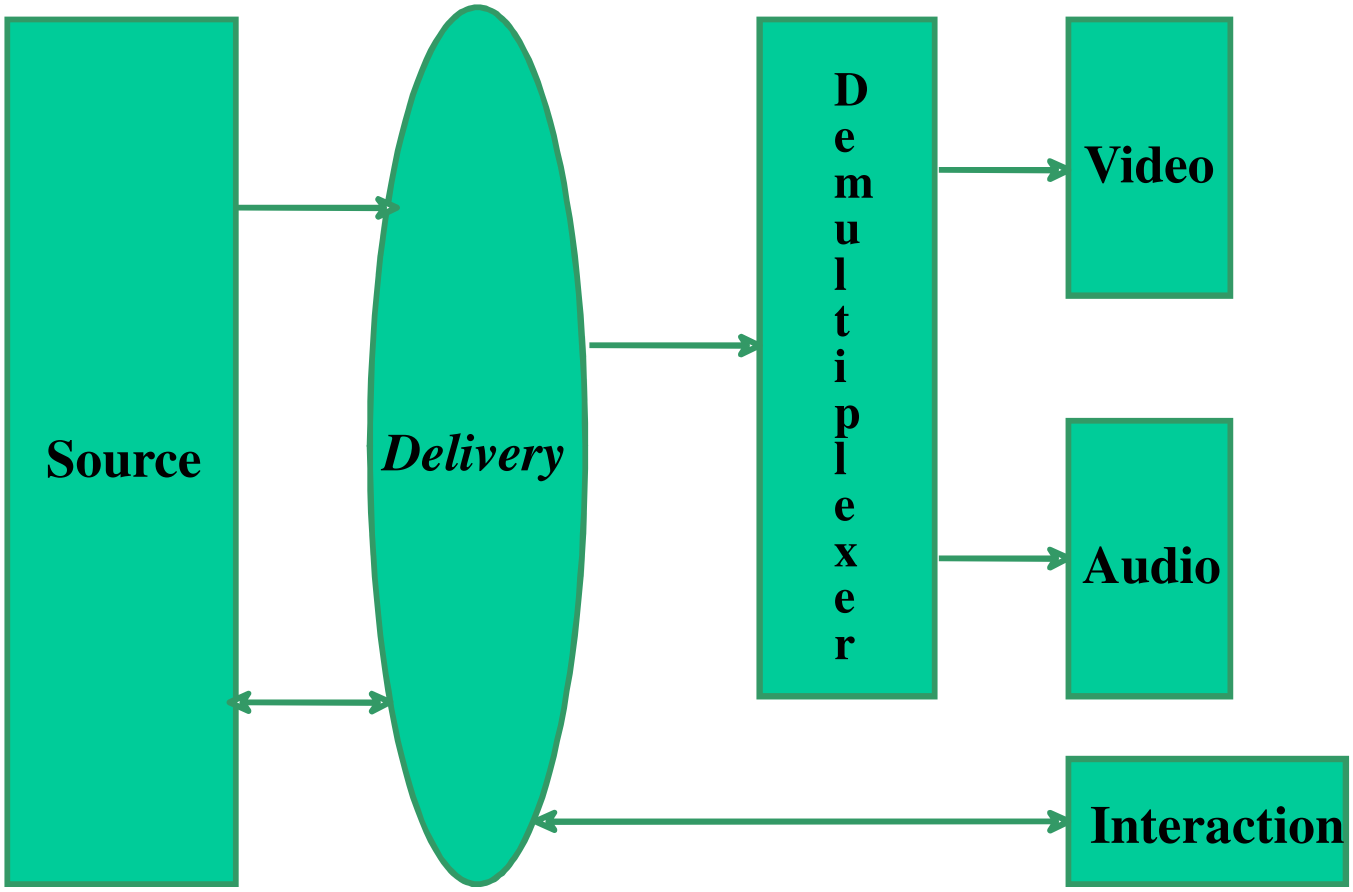
MPEG-2: Objectivos

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.

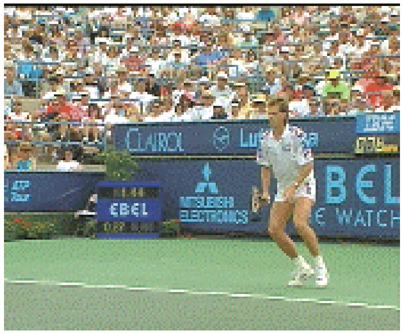
- **The ISO/IEC MPEG-2 Video standard is a joint development with ITU-T where it is designated as Recommendation H.262.**
- **The MPEG-2 standard should have covered audiovisual coding up to 10 Mbit/s, leaving to MPEG-3 the higher rates and higher definition. However, since the MPEG-2 standard addressed 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: Which 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

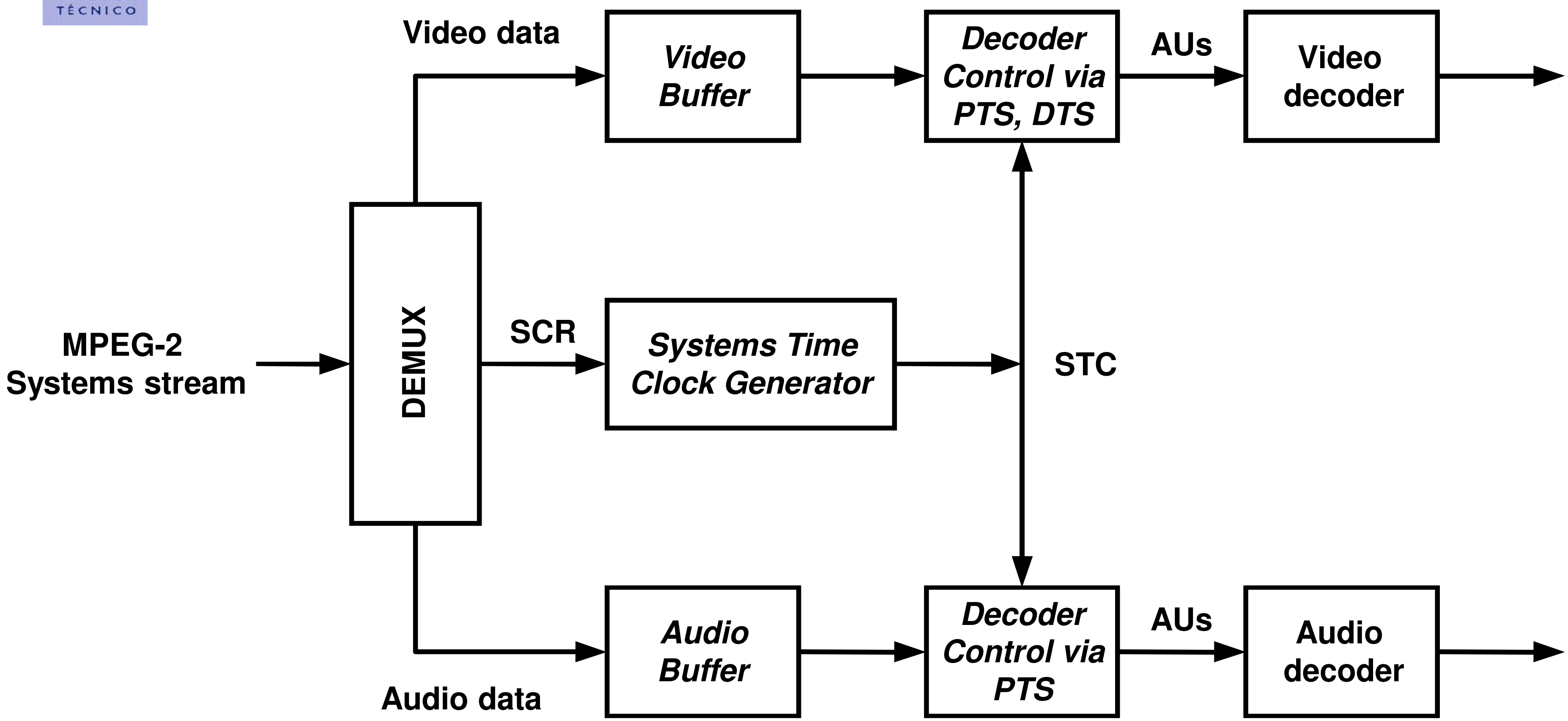
MPEG-2 Systems: Objective

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



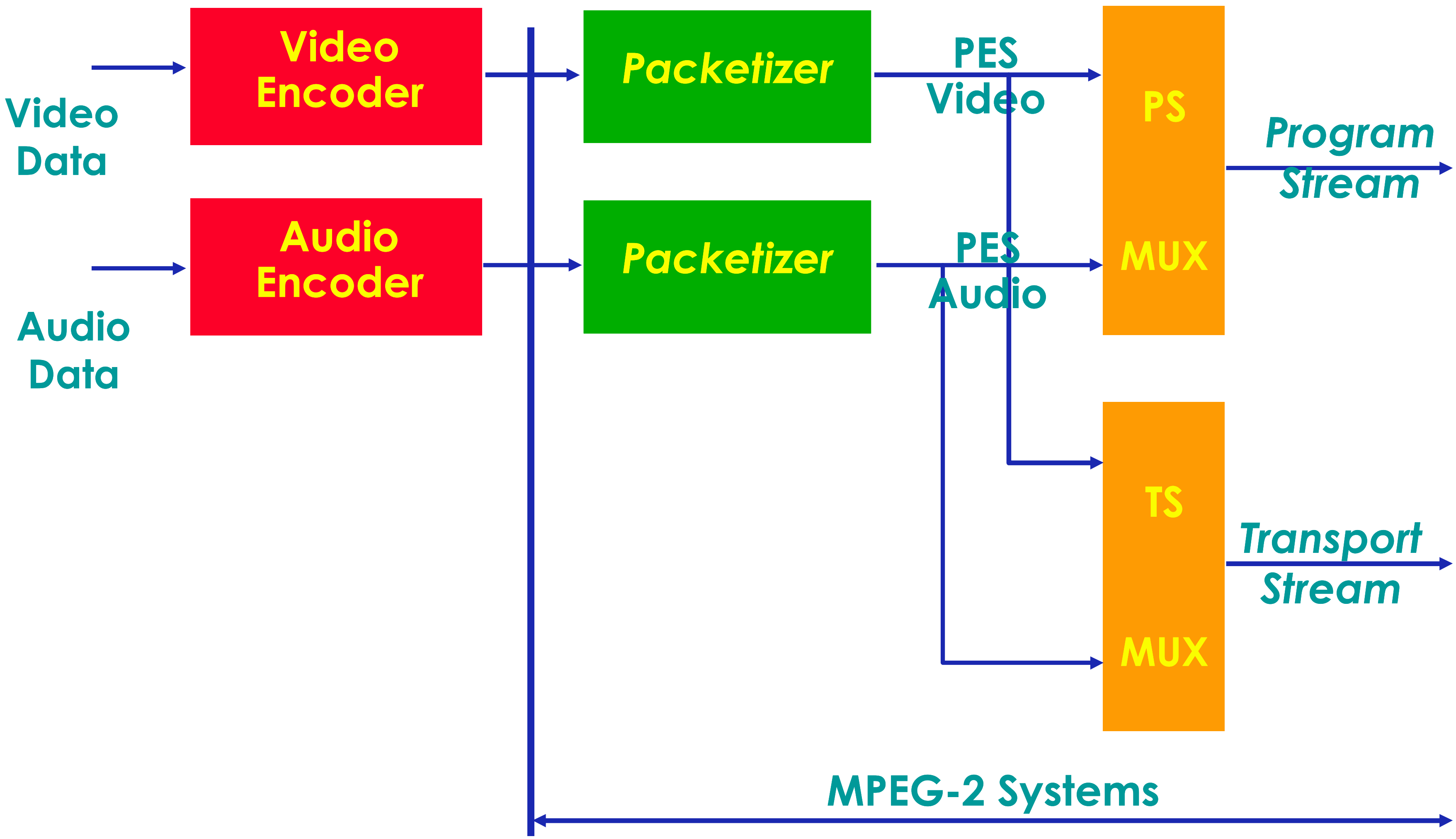
DTS - Decoding Time Stamp

SCR - System Clock Reference (SCR)

PTS - Presentation Time Stamp

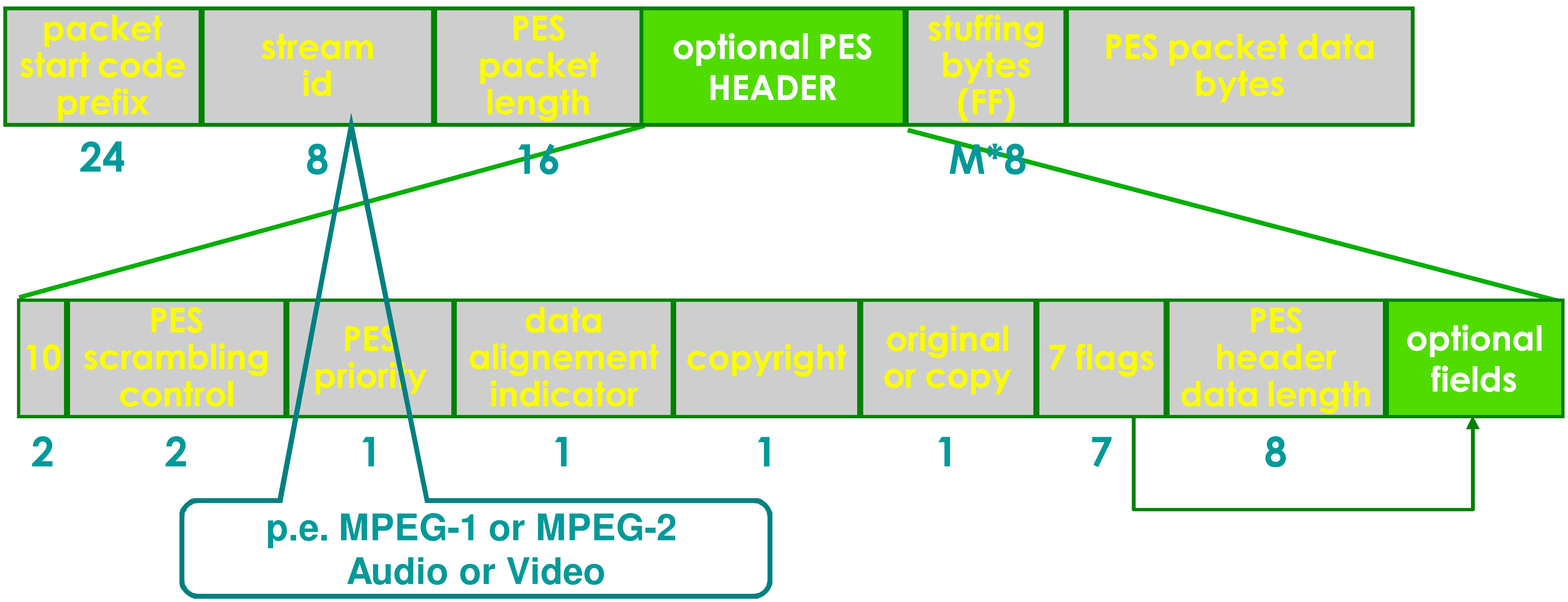
STC – System Time Clock

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.

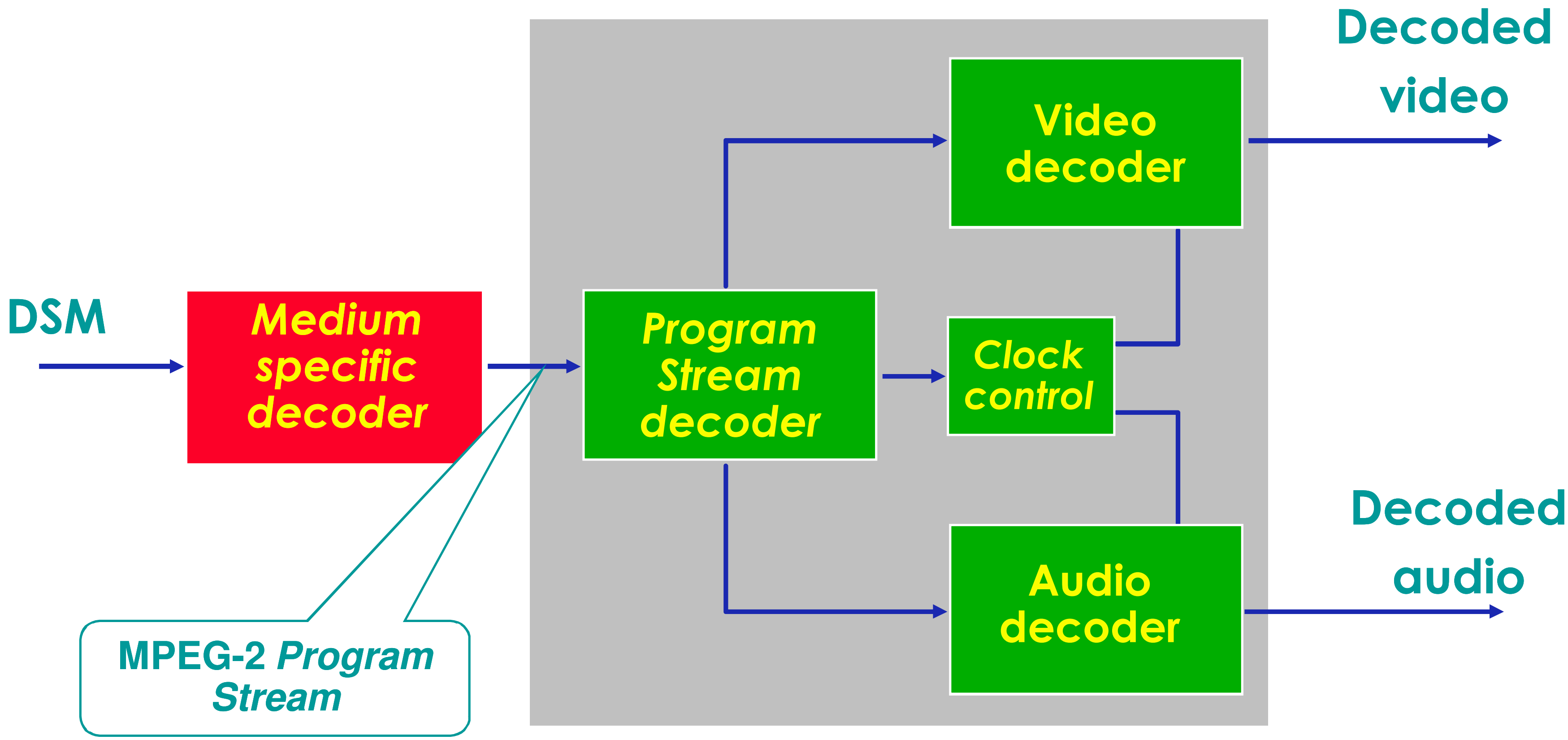


Program Stream and Transport Stream

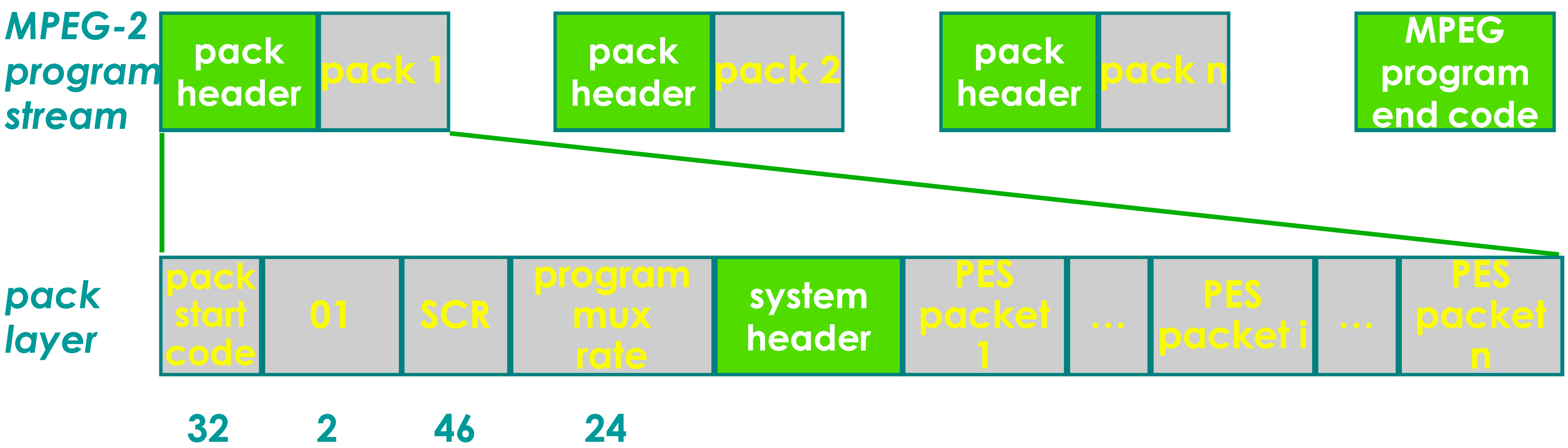
- **Program Stream:**
  - Stream with a single time base for all multiplexed streams
  - Adequate for transmission and storage in channels virtually without errors (BER < 10^{-10}), e.g. CD-ROM, DVD, hard disks
  - Variable length packets as for MPEG-1 Systems

- **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 …

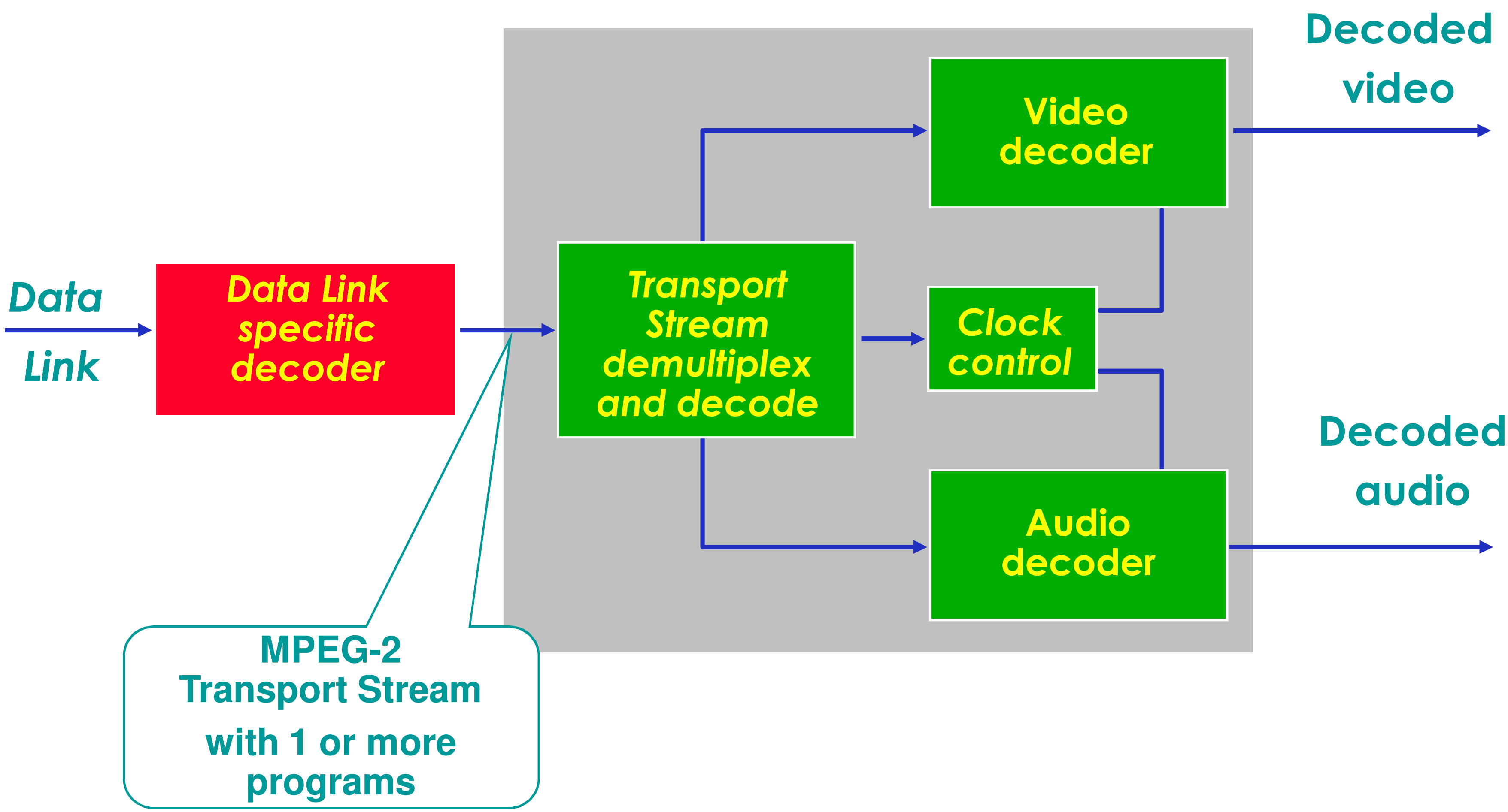


Program Stream Syntax

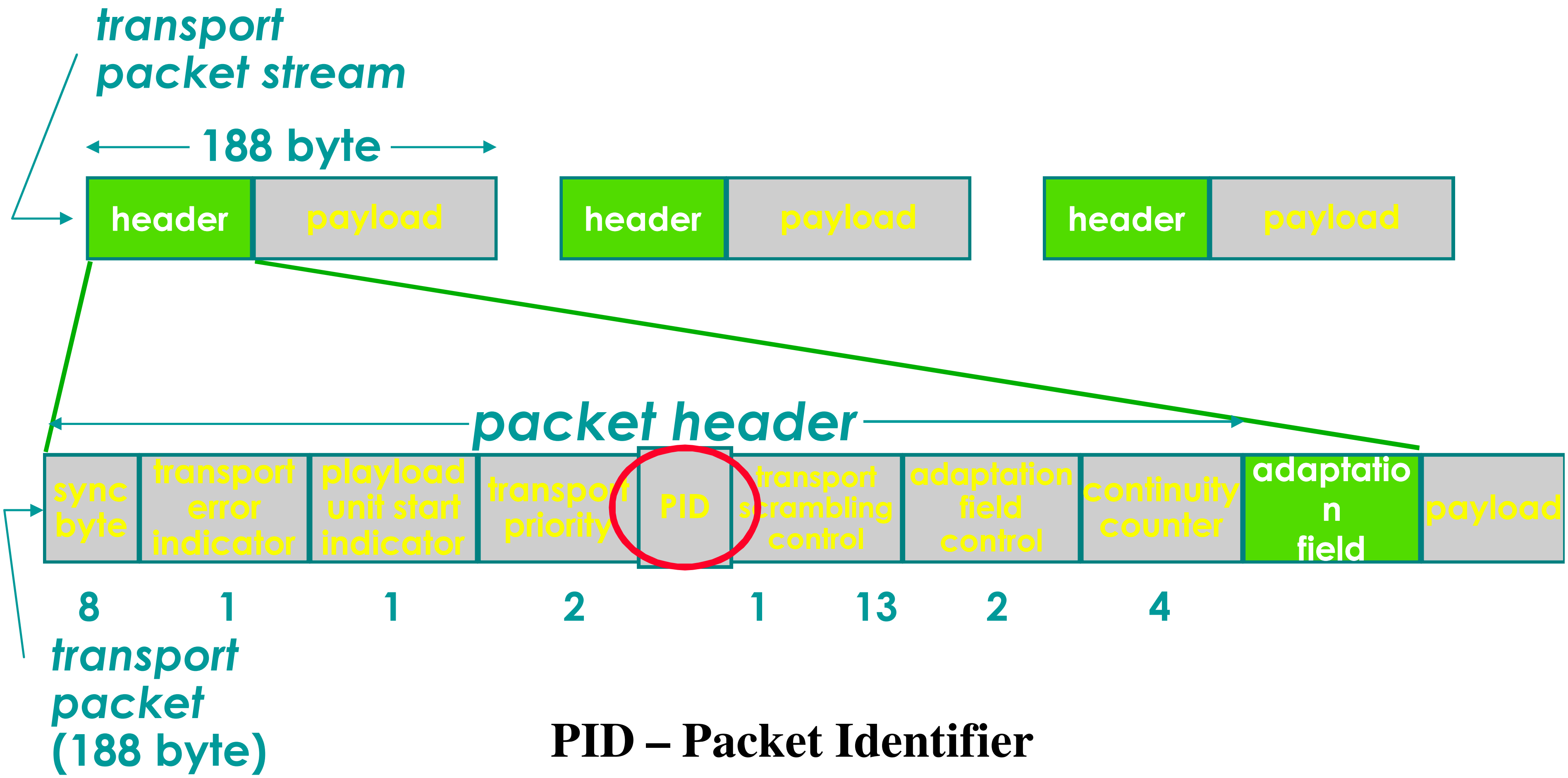


MPEG-2 Program Streams are similar to MPEG-1 Systems streams.

Decoding Transport Streams …

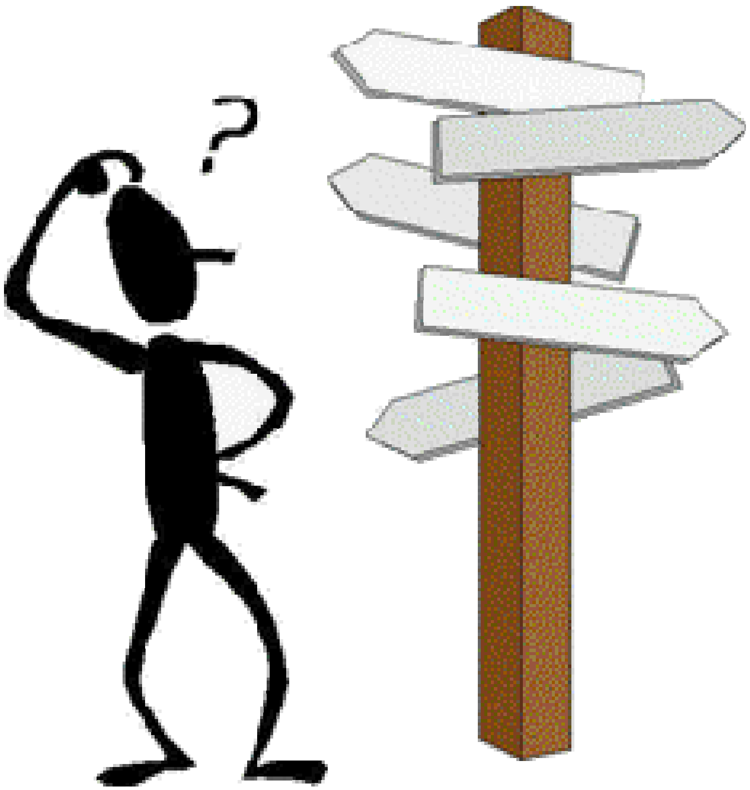


Transport Stream Syntax



PID – Packet Identifier

‘Surviving in the Labyrinth’ …



In order a user may find the elementary streams he/she needs in a MPEG-2 Transport Stream, e.g. audio and video for RTP 2 or SIC, 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**
- **A common syntax is defined to segment and carry the tables in Transport Packets**
- **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 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).**

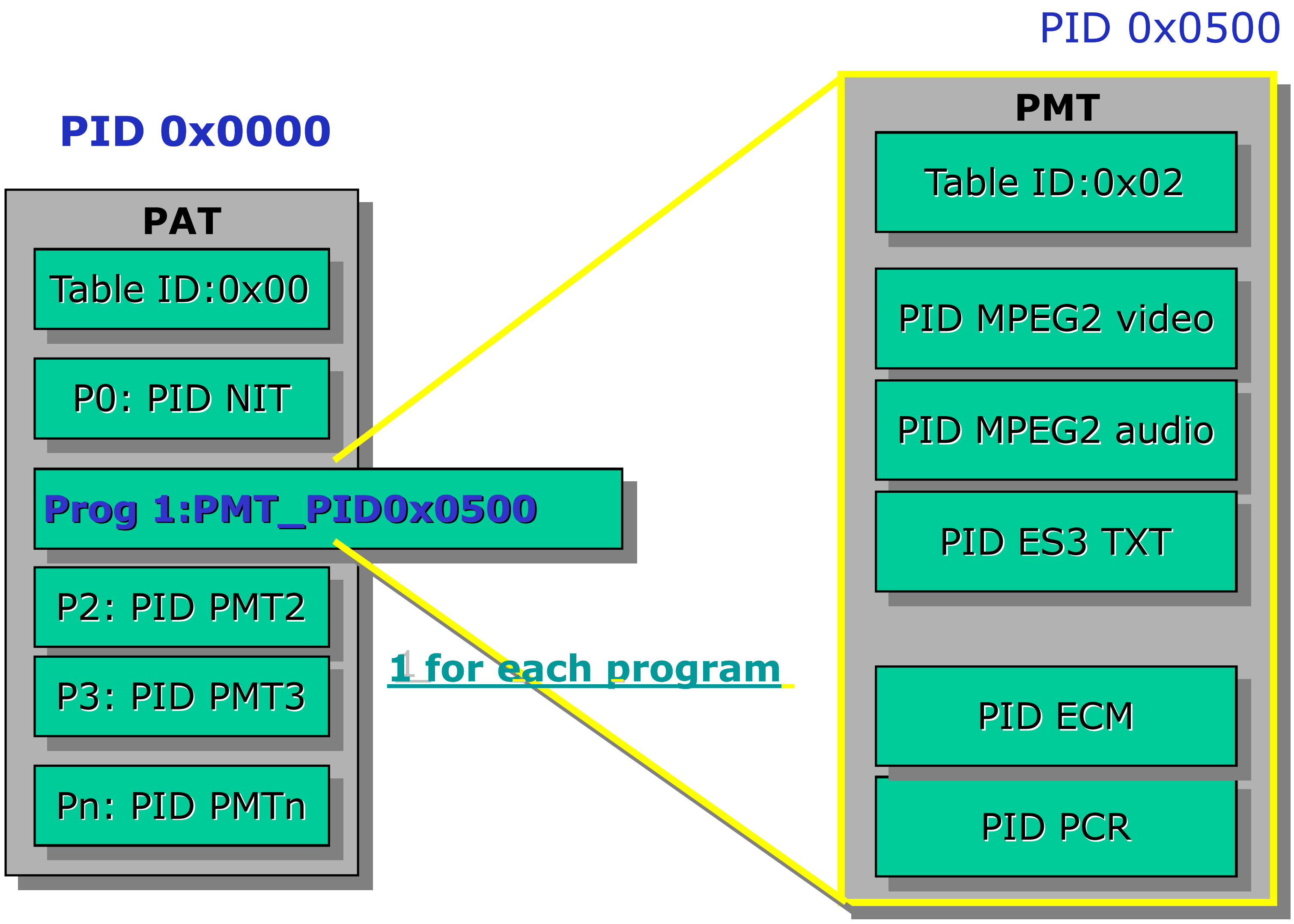
Program Association Table (PAT)

- 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**

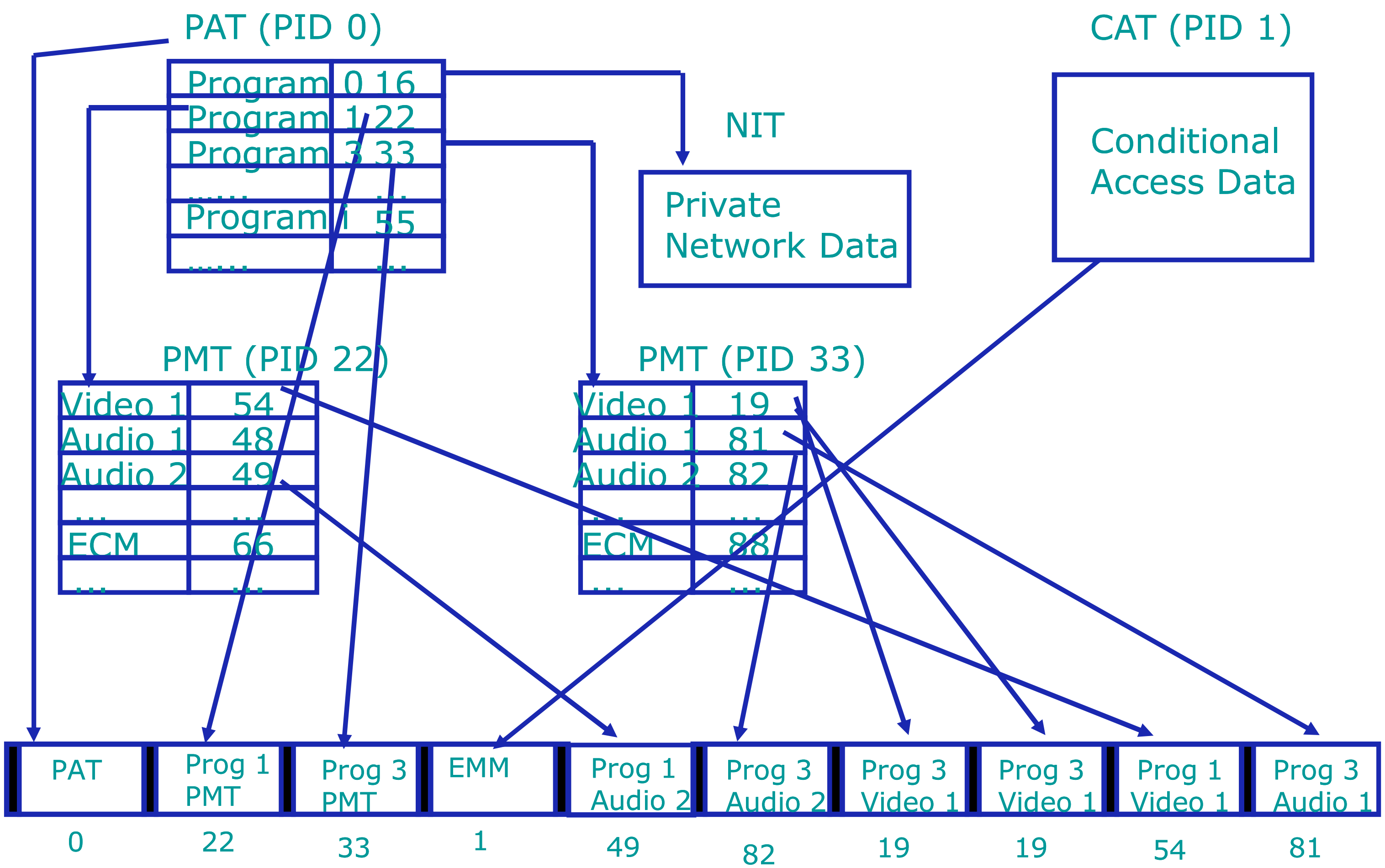
- **Should provide information about the physical network, e.g.**
  - Channel frequencies
  - Satellite details
  - Modulation characteristics
  - Service provider
  - Alternative available networks

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

Conditional Access Table (CAT)

- **Mandatory whenever there is, at least, one elementary stream in the transport stream which is protected**
- **Provides information about the used protection system (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 ...

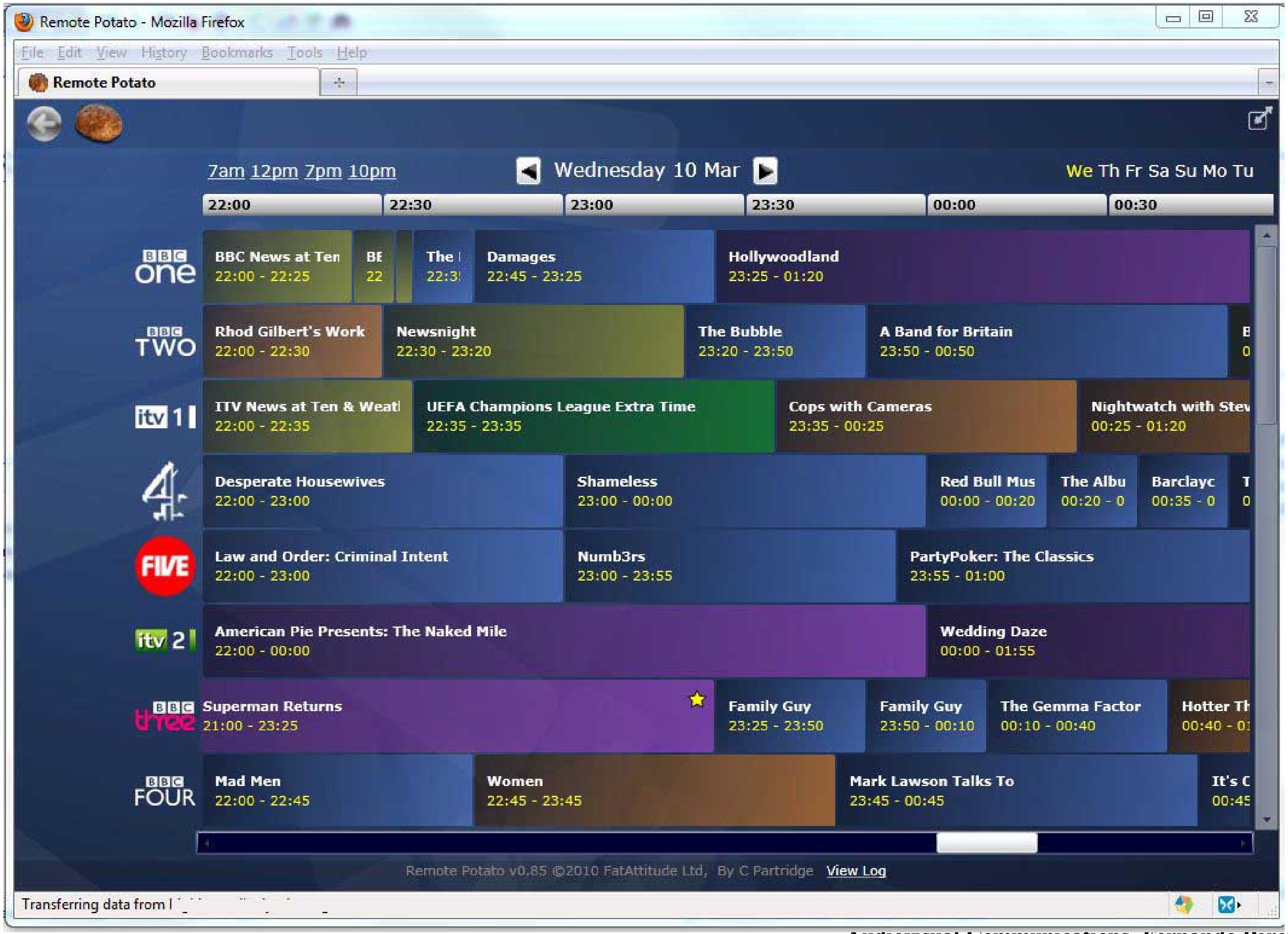


DVB Service Information (SI) Tables

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



Zapppping or Filtering ?

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

MPEG-2 Standard

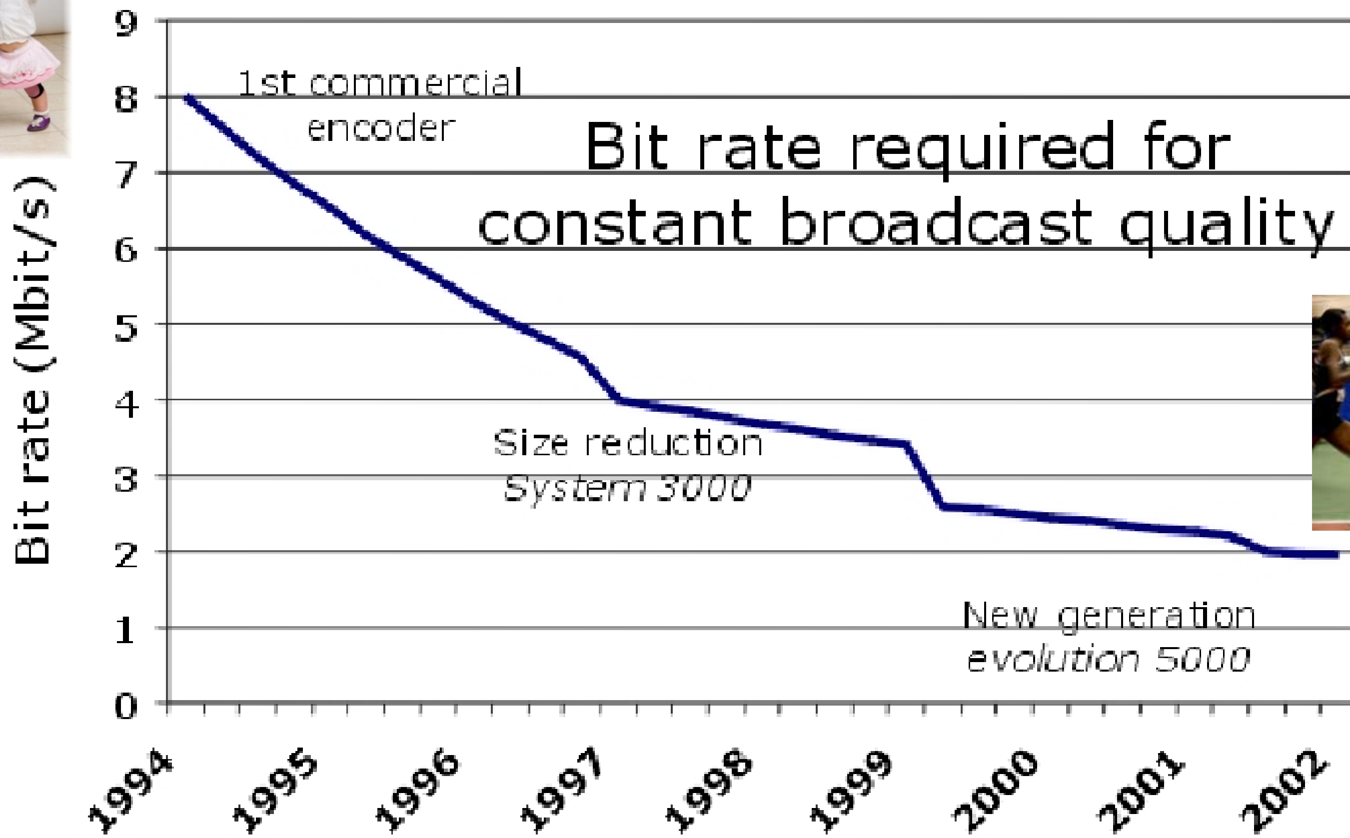
Part 2: Video

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

The following quality objectives 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) 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

- Large range of spatial and temporal resolutions, both in progressive and interlaced formats
- Several chrominance subsampling formats, e.g. 4:4:4, 4:2:2 and 4:2:0
- Flexibility in terms of bitrates, constant or variable
- Special modes, e.g. random access for edition and channel hoping, fast modes, conditional access, and easy transcoding to MPEG-1 Video, H.261 and JPEG
- Flexibility in adapting to different transmission and storage channels, e.g. in terms of synchronization and error resilience

MPEG-2 Video: the Compatibility

The compatibility among standards allows to offer some continuity regarding the already available standards – JPEG, H.261, MPEG-1 Video – providing some interoperability between the various applications.

Two main types of compatibility are relevant:

- **Backward compatibility – A MPEG-2 Video decoder is able to decode a coded bitstream compliant with a previously available standard.**
- **Forward compatibility – A decoder compliant with a previously available standard, e.g. MPEG-1 Video, is able to, totally or partially, decode in a useful way a bitstream compliant with MPEG-2 Video.**

MPEG-2 Video foresees some compatibility mechanisms with MPEG-1 Video (intrinsic to the MPEG-2 Video syntax) and H.261 (using spatial scalability).

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 complexity since the overall system cost is mainly related to the decoders which should have a reduced complexity (and cost).**

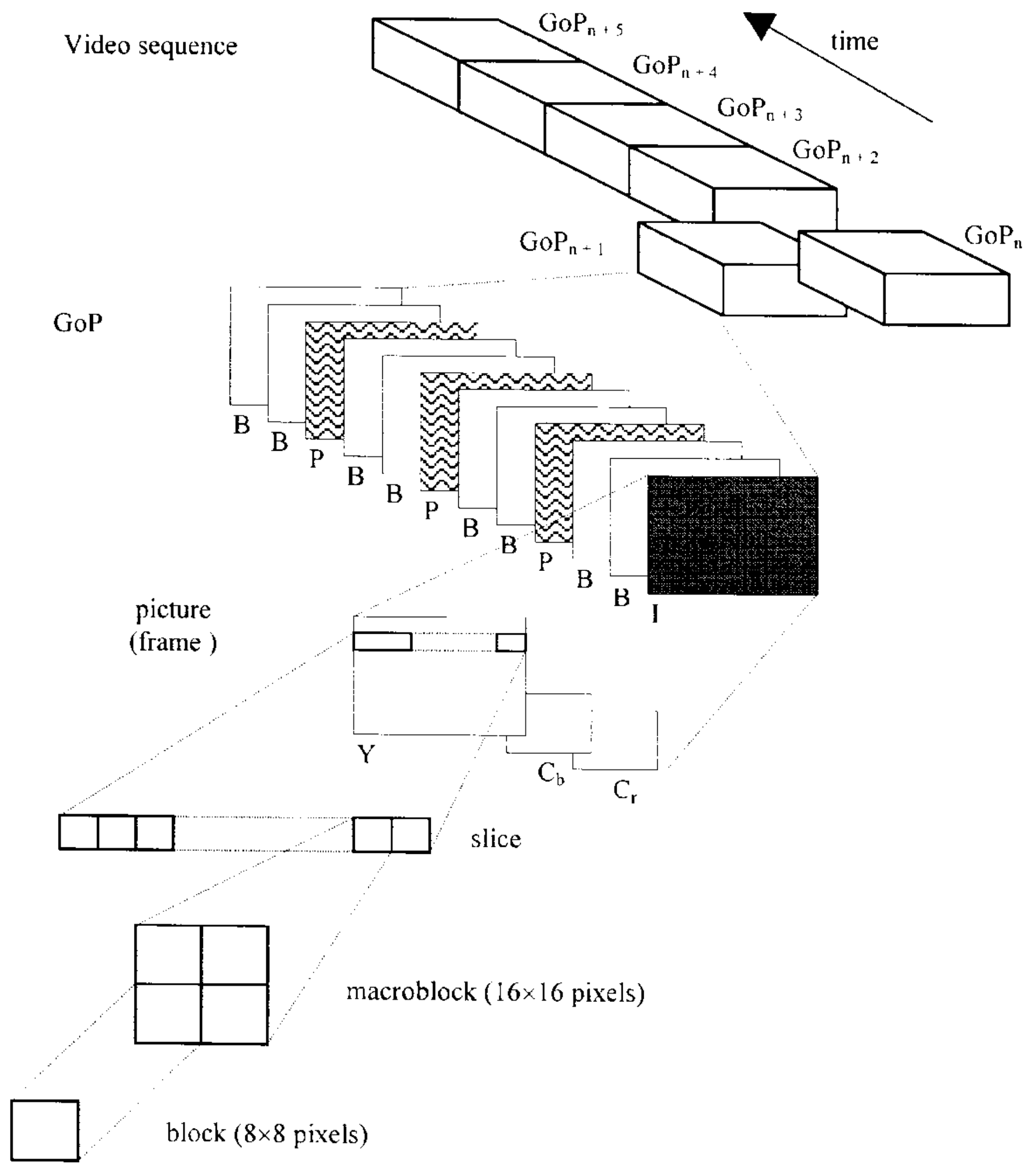
- **Symmetric Applications – For the 'one to one' type of applications, both the encoders and decoder should have a reasonable (low) complexity.**

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



MPEG-2 Video: the 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**

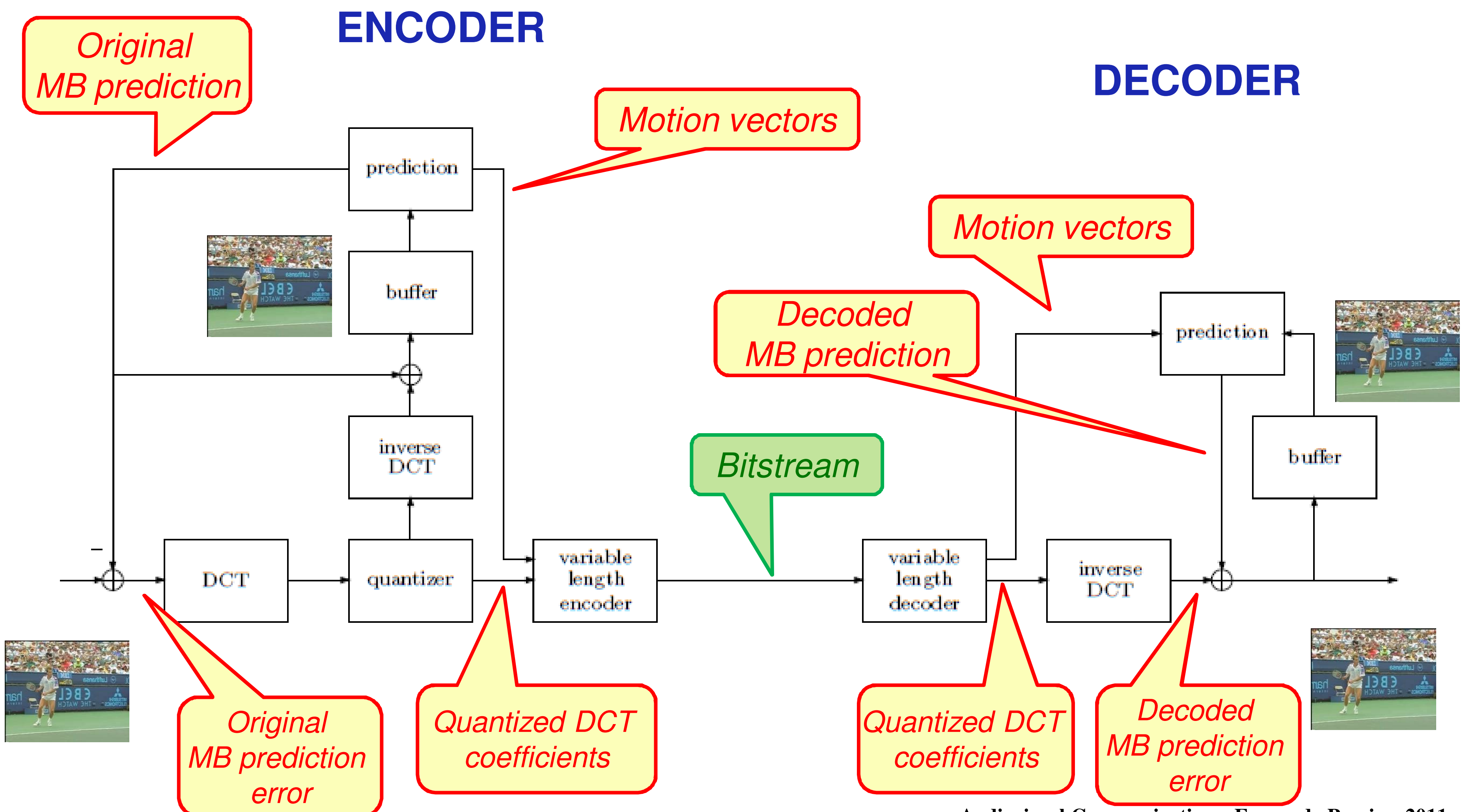
Huffman entropy coding

Lossy :-(

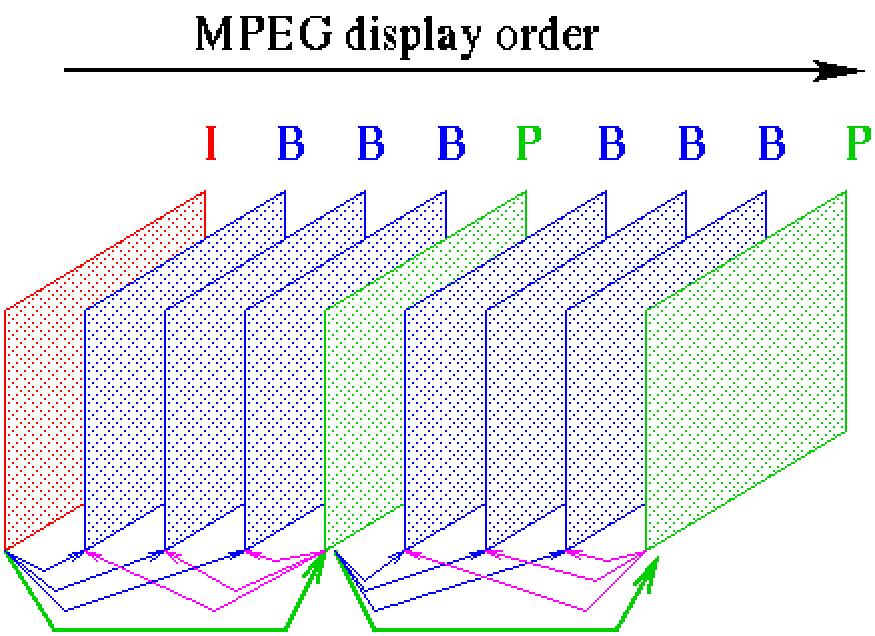
- **Irrelevancy**

DCT coefficients quantization

Starting Again with the same Architecture …



Temporal Prediction Structure



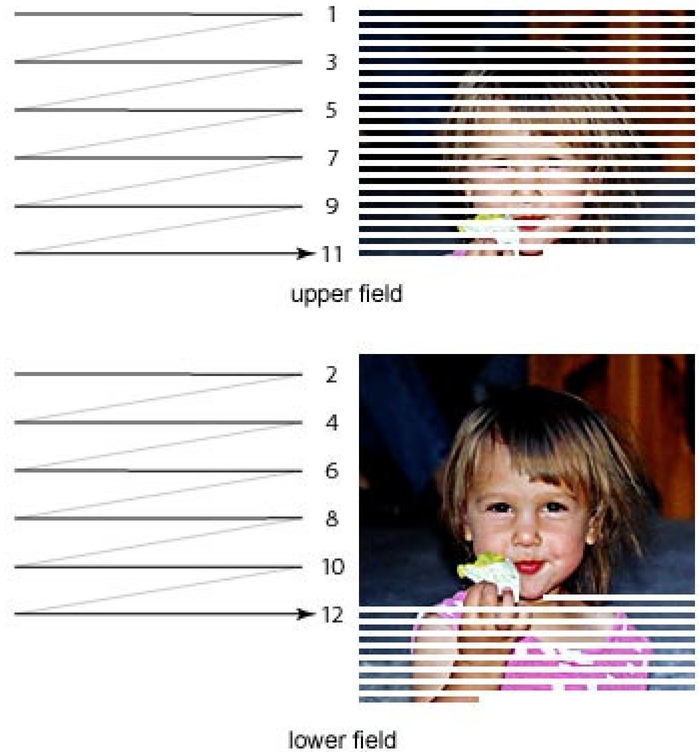
The "conflict" between coding efficiency and random access led to the definition of 3 frame types depending on the coding tools used:

- **Intra frames (I) – Don't use temporal predictions**
- **Predicted frames (P) – May only use forward prediction from previous I/P frame**
- **Bidirectionally predicted frames (B) – May use both forward and backward prediction from previous and future I/P frame**

MPEG-2 Video versus MPEG-1 Video

The main differences between the MPEG-1 Video and MPEG-2 Video standards are related to:

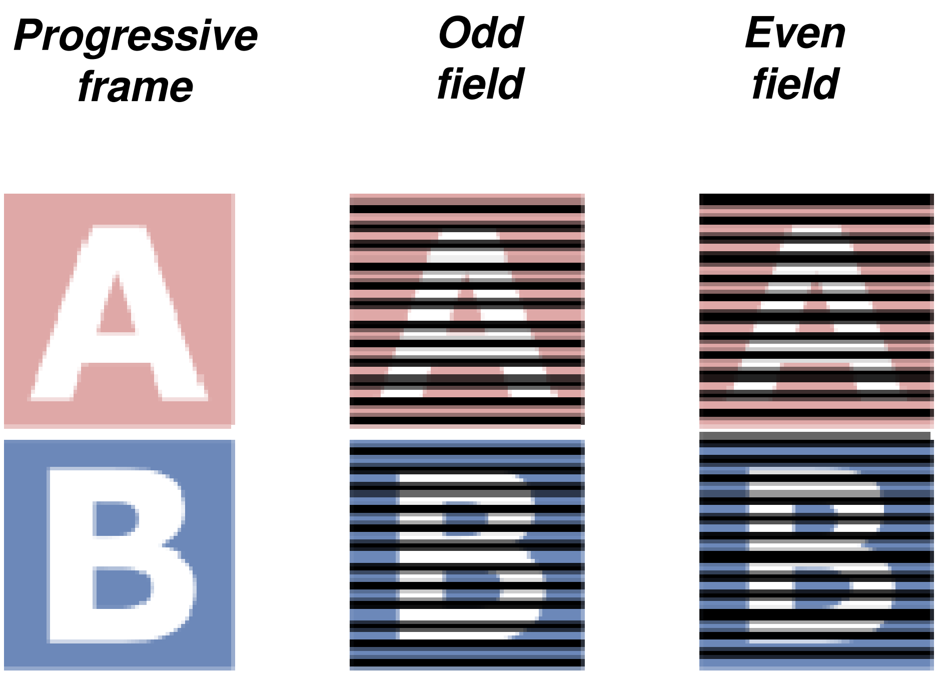
- **INTERLACING** - Coding of interlaced video content with MPEG-2 Video (which is not possible with MPEG-1 Video)
- **SCALABILITY** - Availability of scalable coding in MPEG-2 Video (only temporal scalabilility with the I/P/B structure is possible with MPEG-1 Video)



MPEG-2 Video

Interlaced Coding

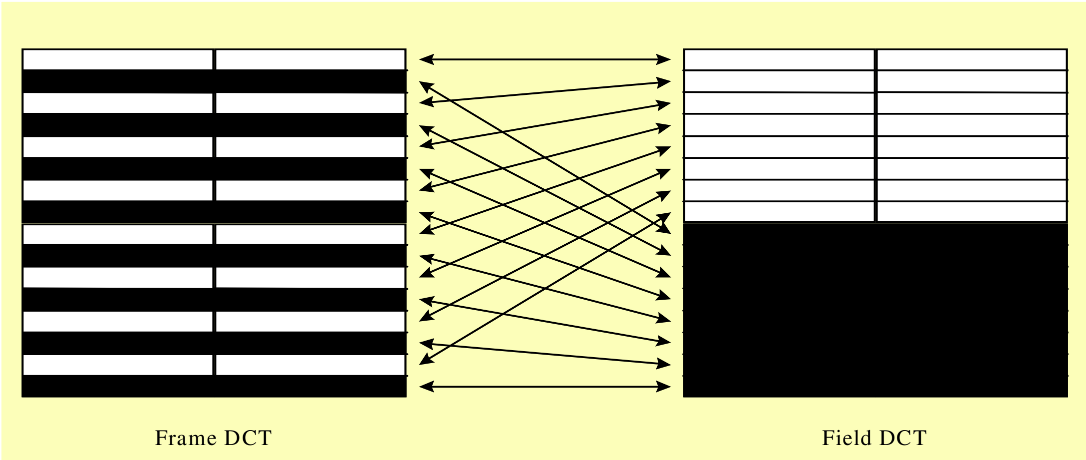
TV World: Progressive and Interlaced



Interlaced Content Coding

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

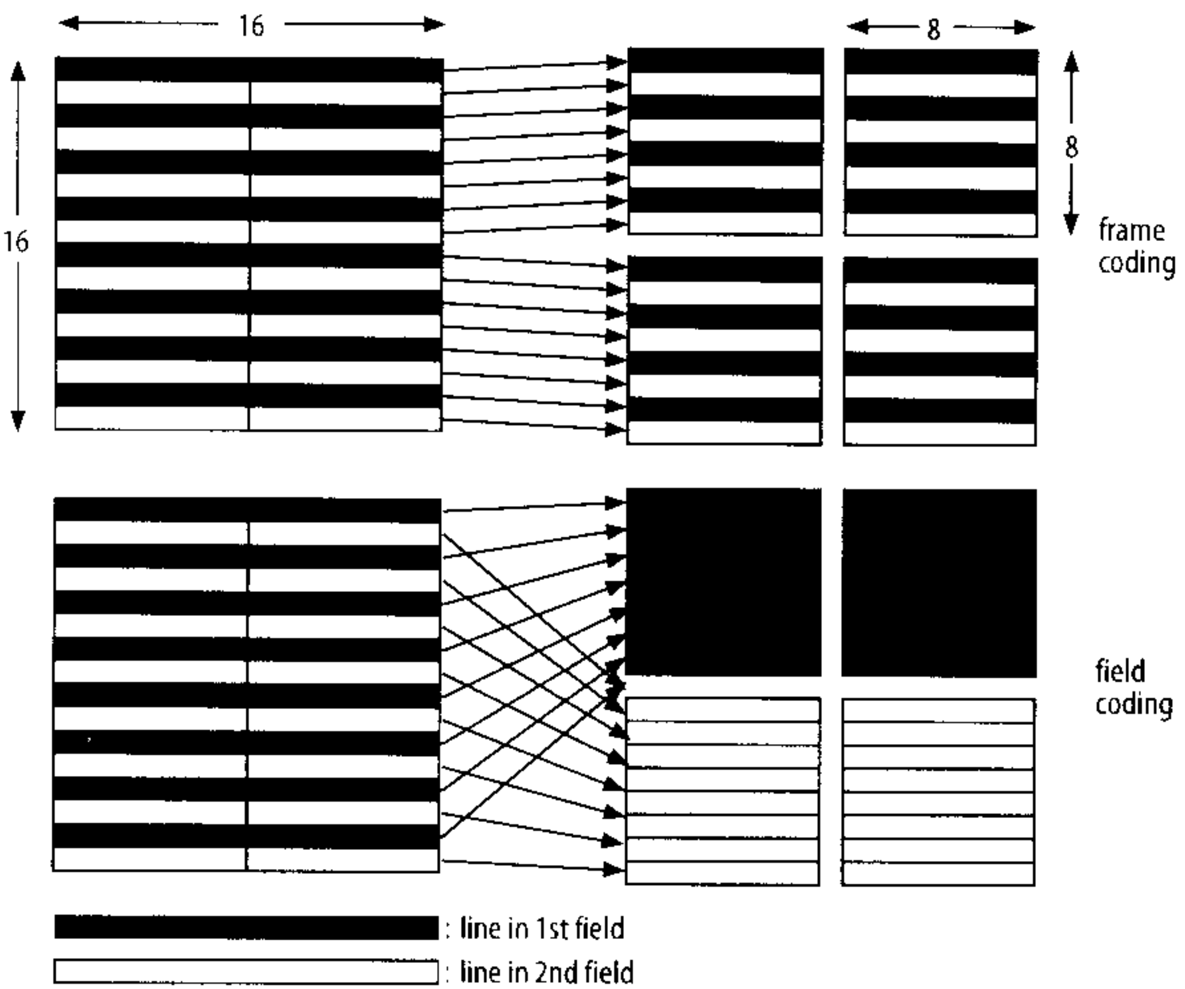
- **Frame-Picture** - The MBs to code are defined in the frame resulting from the combination of the 2 fields (top and bottom)
- **Field-Pictures**- The MBs to code are defined within each of the fields (top or bottom) which are independently processed



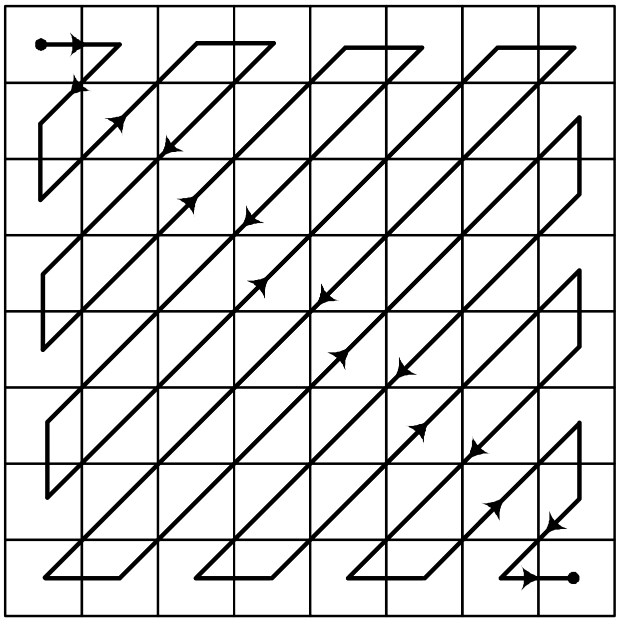
Main Prediction Modes

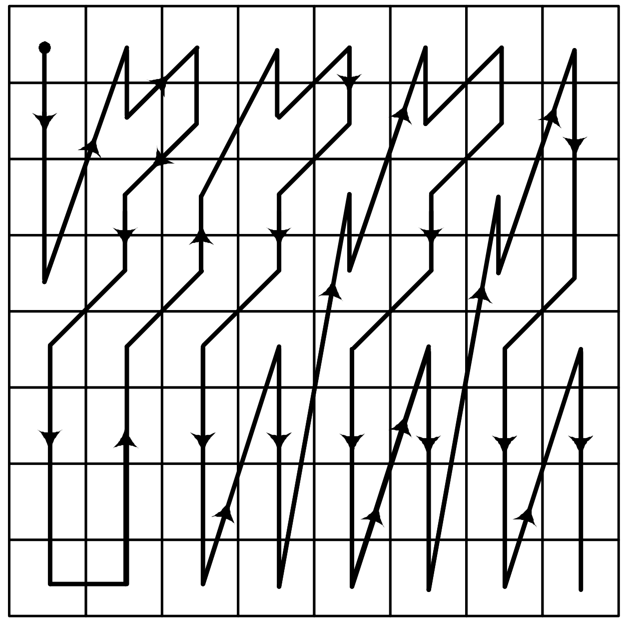
- **Frame Mode for Frame-Pictures** – Similar to MPEG-1 Video, frames are coded as I, P or B frames with current and prediction MBs defined in the frames; gives good results for content with low or moderate motion or pannings over detailed backgrounds.
- **Field Mode for Field-Pictures** – Conceptually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

Frame-Pictures: Frame Mode and Field Mode Predictions



Alternate Scanning Order …



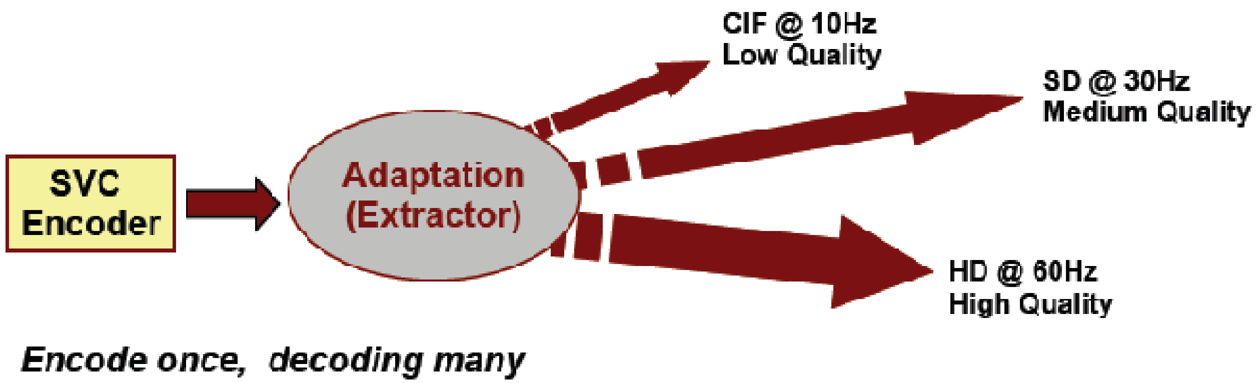


For frame-pictures, the correlation between lines is reduced for the pictures with more motion. Thus, it is possible to use another scanning order – ALTERNATE order – where the DCT coefficients corresponding to the vertical transitions (meaning horizontal edges) are privileged in terms of scanning order.

MPEG-2 Video

Scalable Coding

Scalable Coding: the Definition

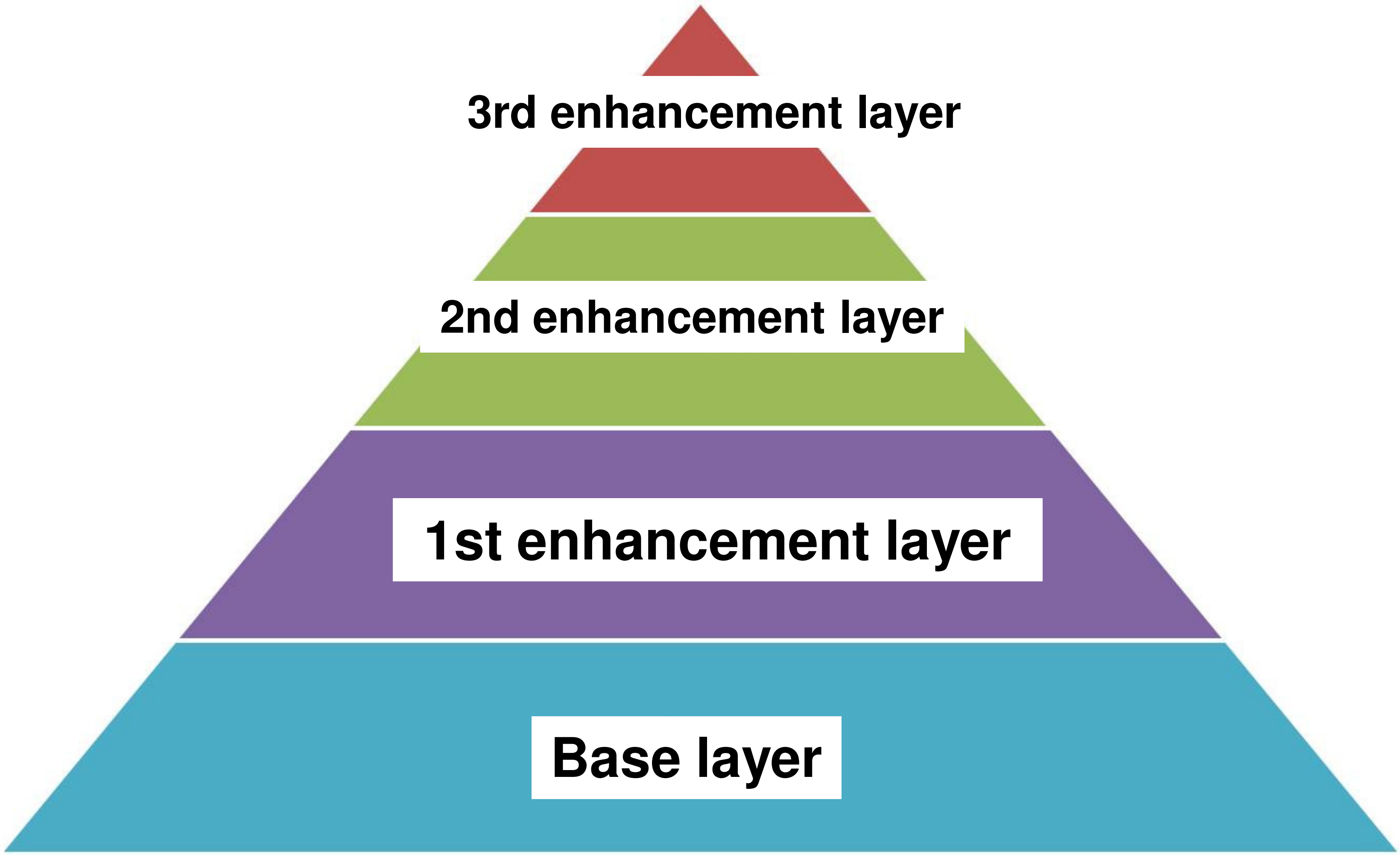


Scalability is a functionality regarding the useful decoding of parts of a coded bitstream, ideally

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**

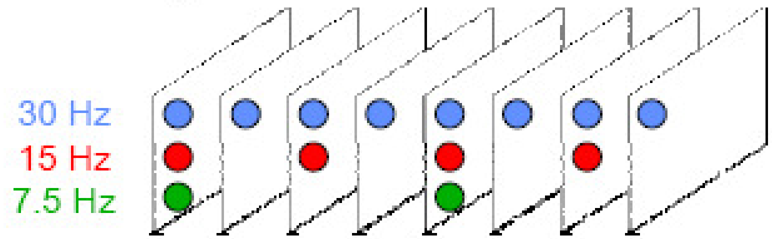
ii) **without significantly increasing the decoding complexity.**

Scalable Hierarchical Coding



Scalability Types

- **Temporal**: change of frame rate



- **Spatial**: change of frame size

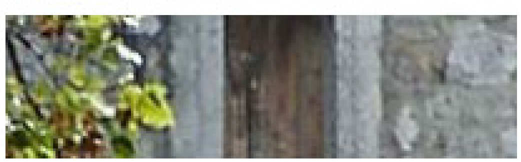
QCIF

CIF

TV

HDTV

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

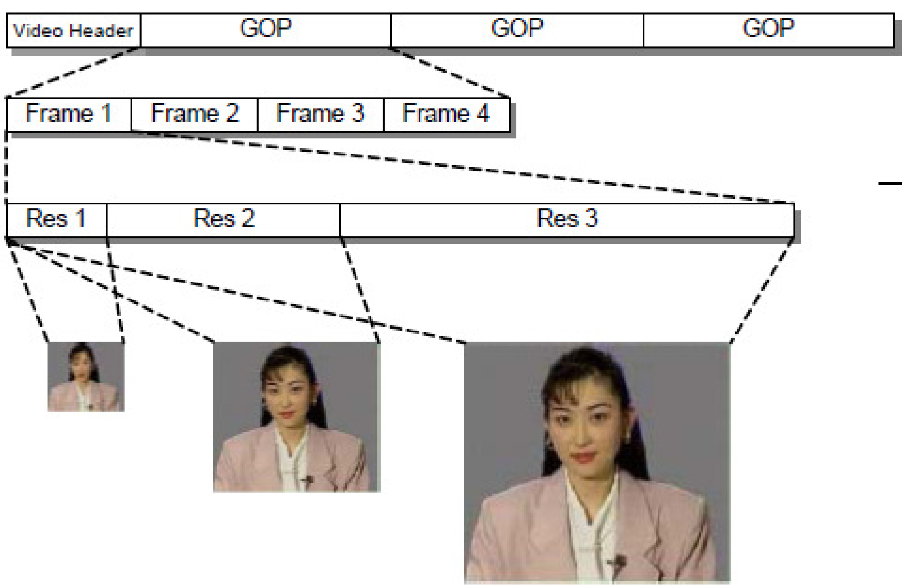


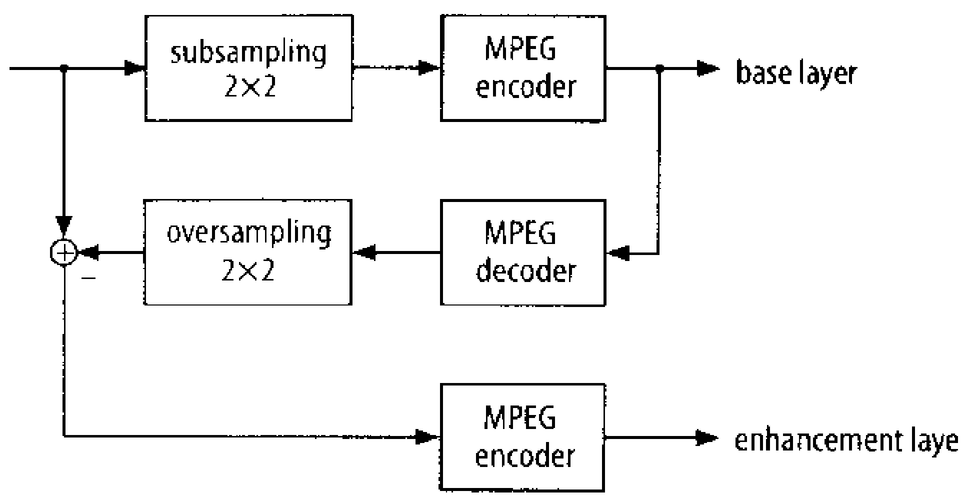
High rate

Low rate

Scalable Coding Types: Spatial Scalability

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

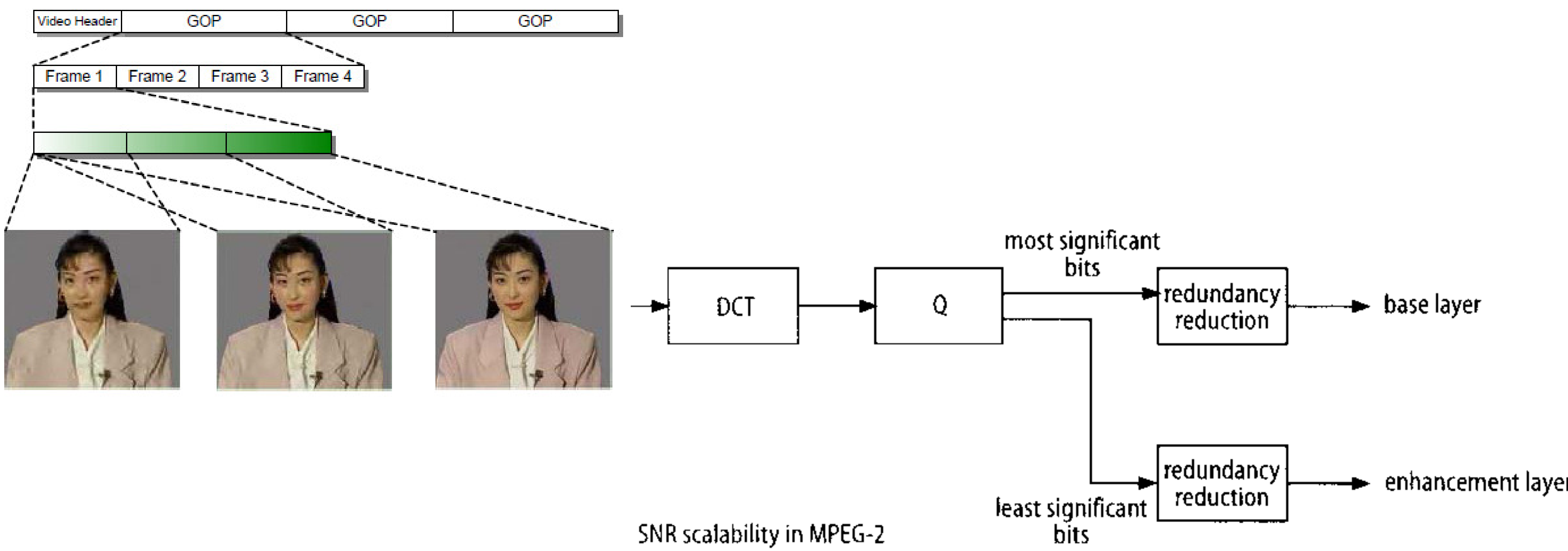




Spatial scalability in MPEG-2

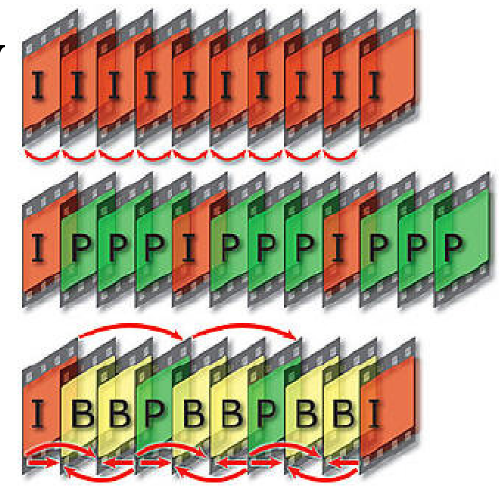
Scalable Coding Types: Quality Scalability

- **QUALITY (SNR) SCALABILITY – Special case of spatial scalability where the spatial resolution is kept the same between layers (base and enhancement); the enhancement layers contain the data produced after the requantization of the residual signal between the original signal and the previous layer decoded signal.**



SNR scalability in MPEG-2

Temporal and Frequency Scalability



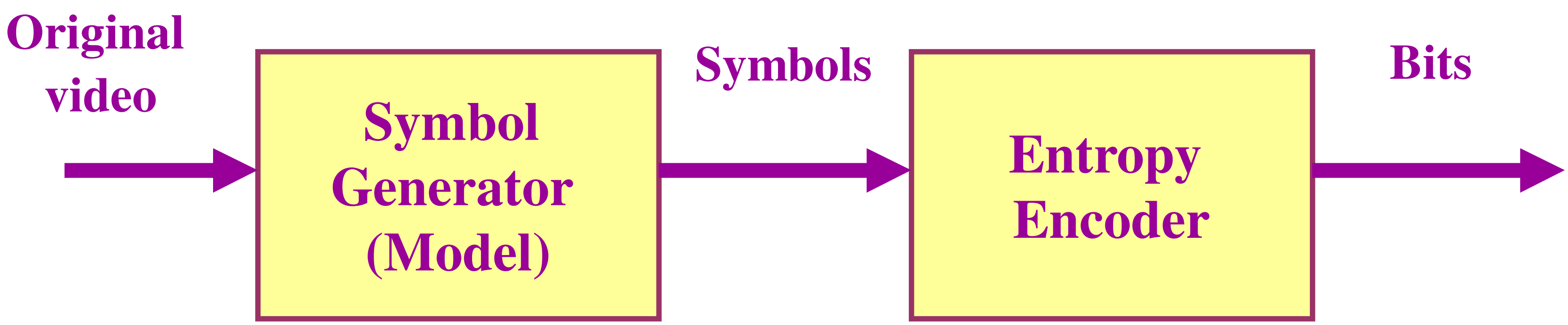
- **TEMPORAL SCALABILITY – The original signal is coded with 2 or more layers with increasing temporal resolution; an example is also the coding of the interlaced signal in two layers where one layer corresponds to the top field and the other layer to the bottom field. <u>Temporal scalability is already provided by the temporal I/P/B prediction structure.</u>**

- **FREQUENCY SCALABILITY (designated *data partitioning* in MPEG-2 Video) – The coded information is structured in layers corresponding to subsets of DCT coefficients with increasing frequency; in the specific case of MPEG-2 Video, the partition is made in two layers.**

Hybrid scalability combines two types of scalability in three or more scalable layers.

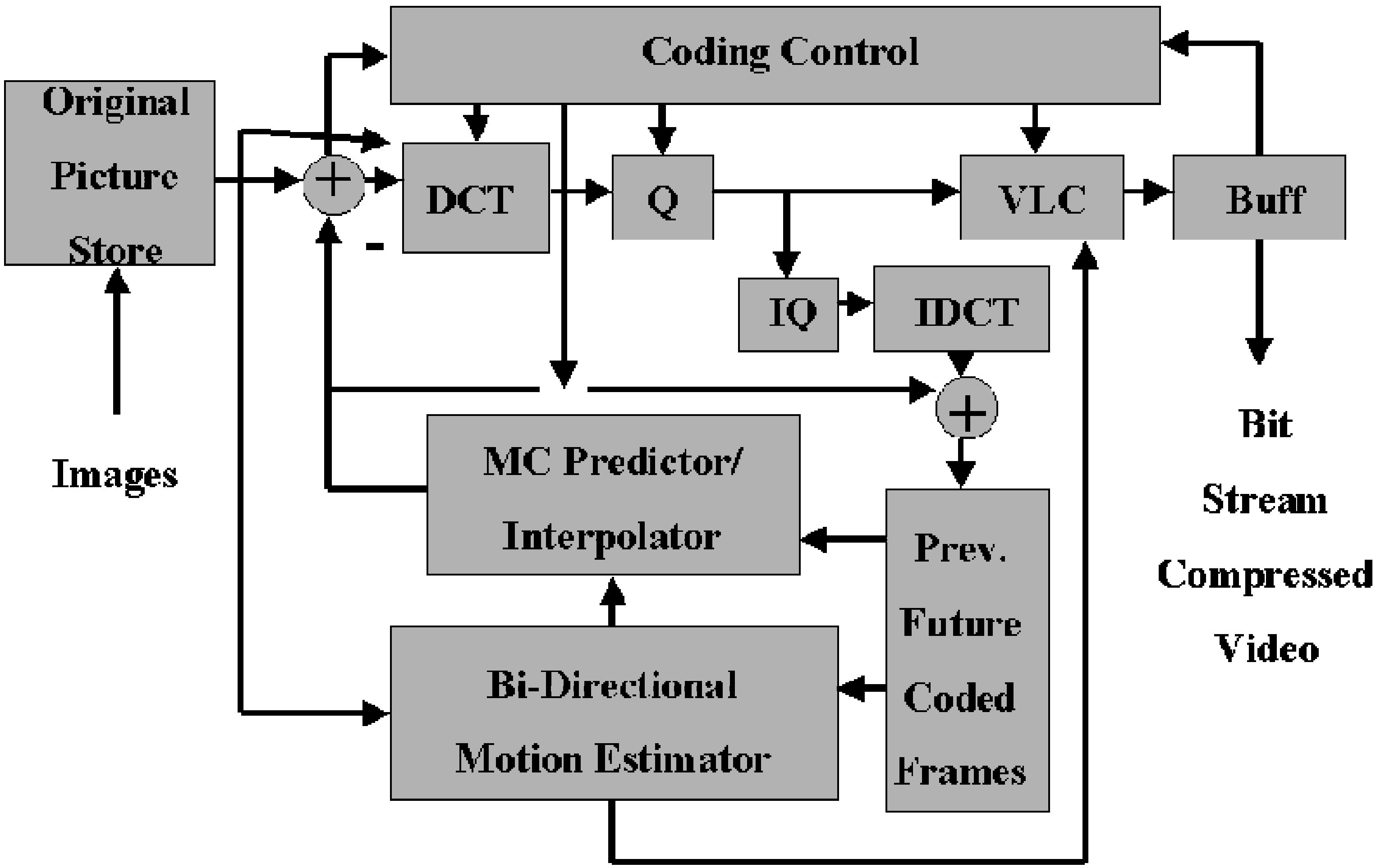
Combining the Coding Tools …

The MPEG-2 Video Symbolic Model

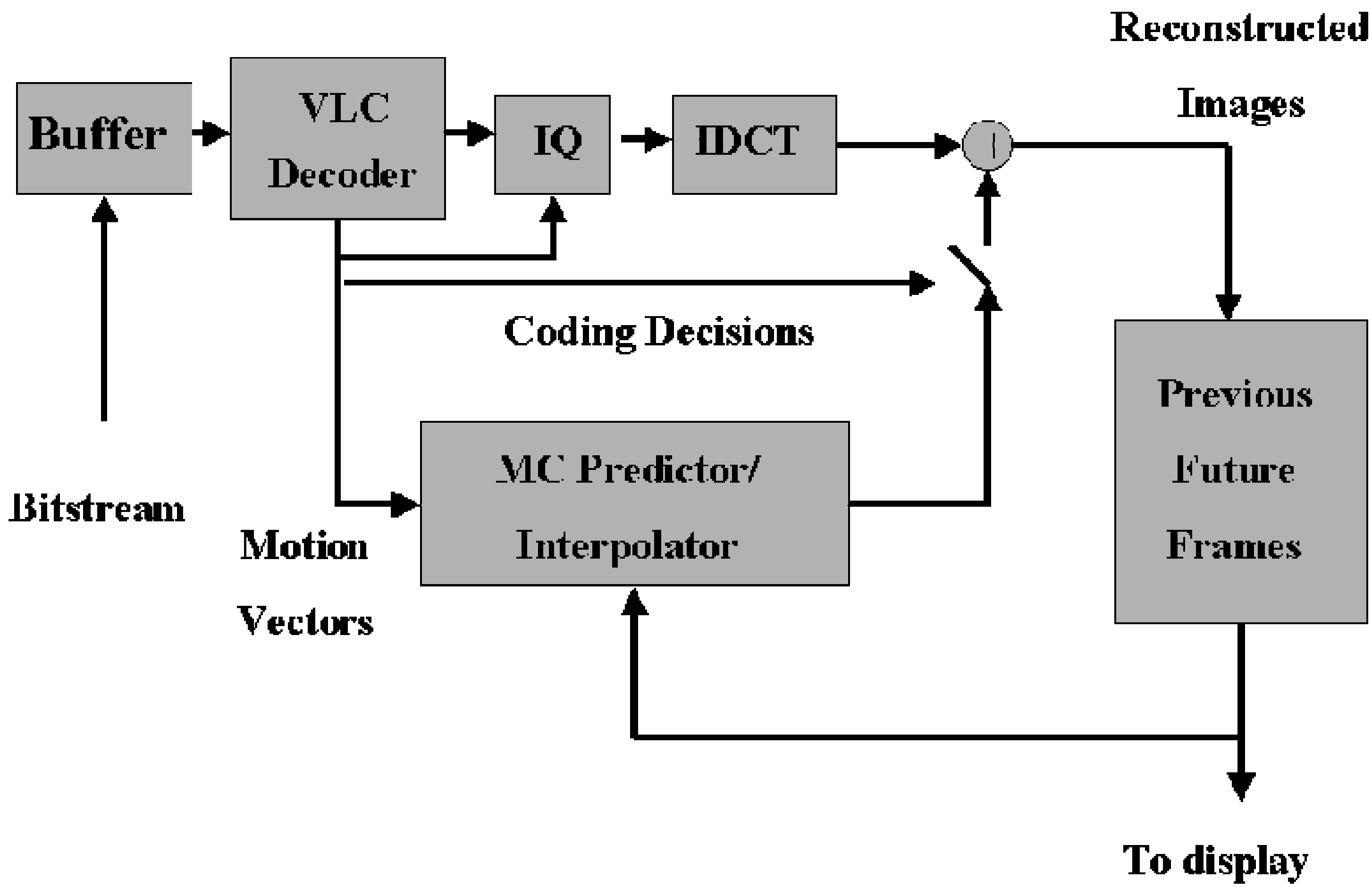


A video sequence (interlaced or progressive) is represented, in a scalable way or not, as a succession of GOPs including pictures coded as frames or fields and classified as I, P or B, structured in macroblocks, each of them represented using motion vectors and/or DCT coefficients, following the constraints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

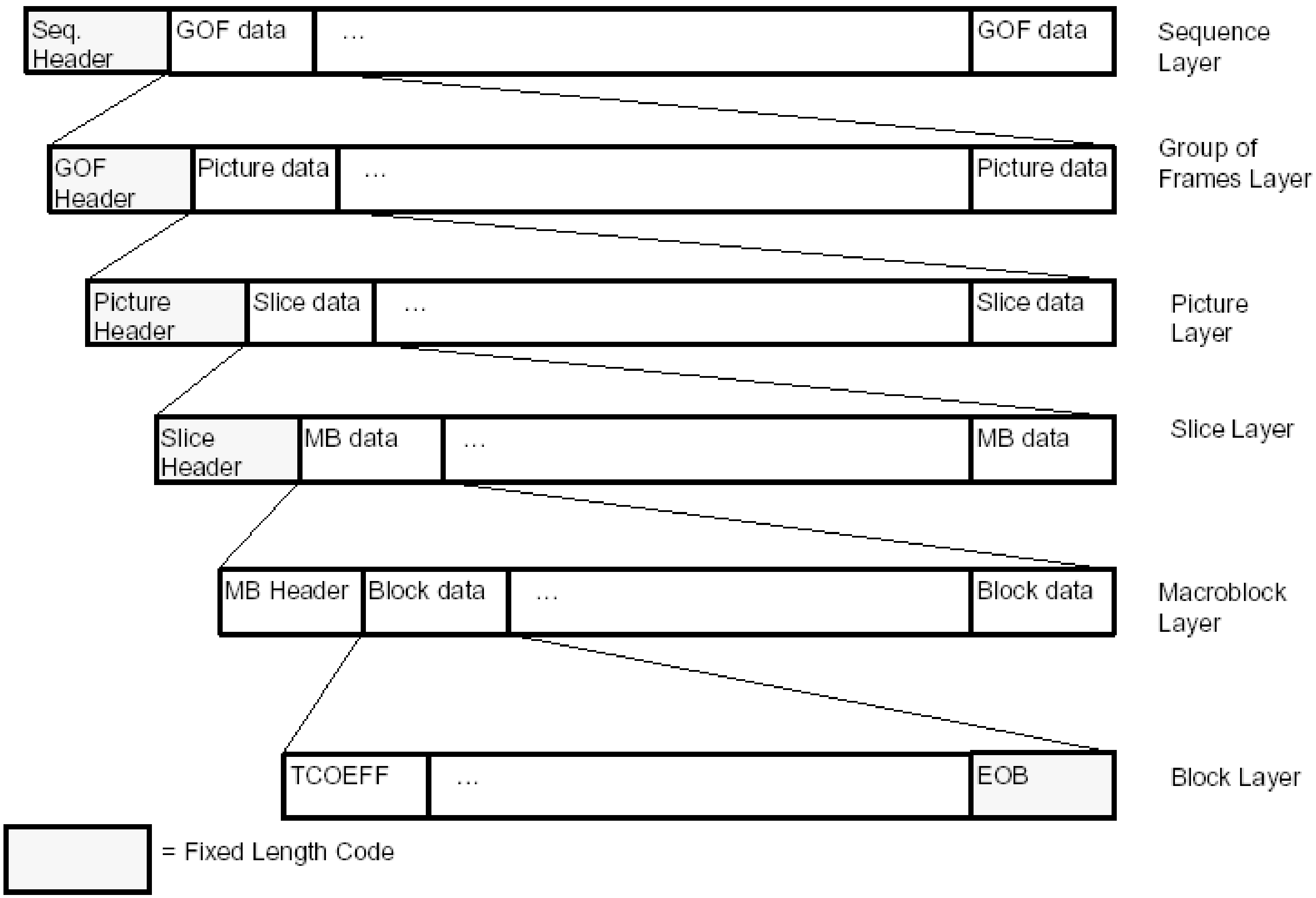
MPEG-2 Video: Encoder



MPEG-2 Video: Decoder



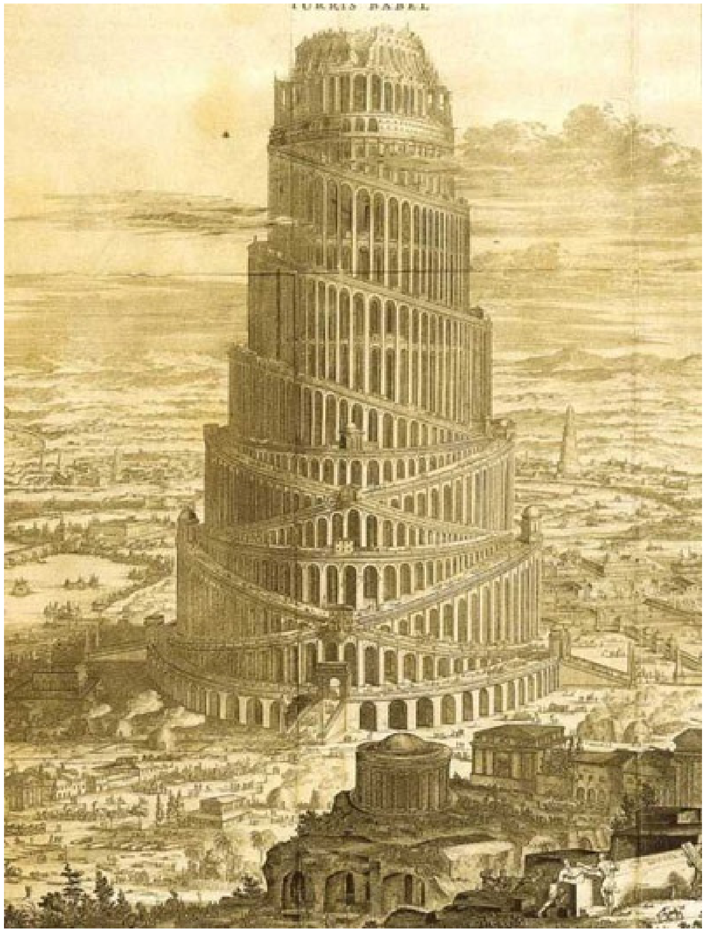
MPEG-2 Video Syntax



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

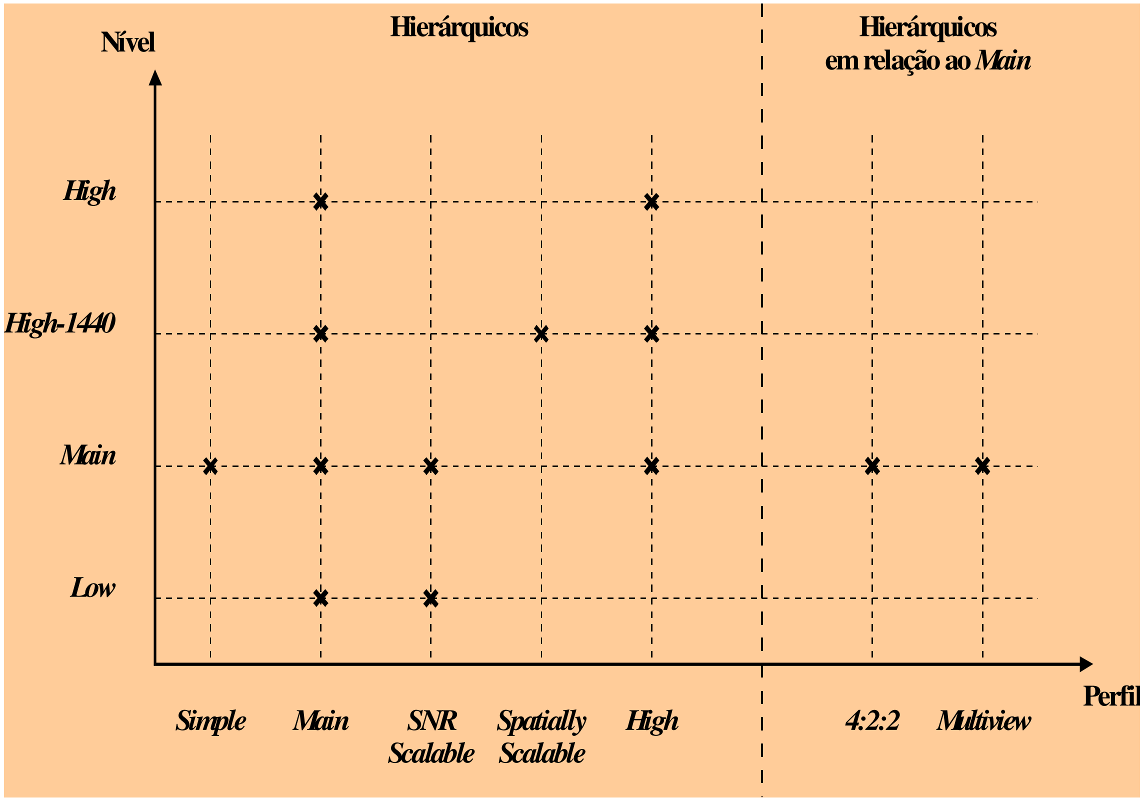
while guaranteeing the necessary compression efficiency capability required by the class of applications in question and limiting the codec complexity and associated costs.

- **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



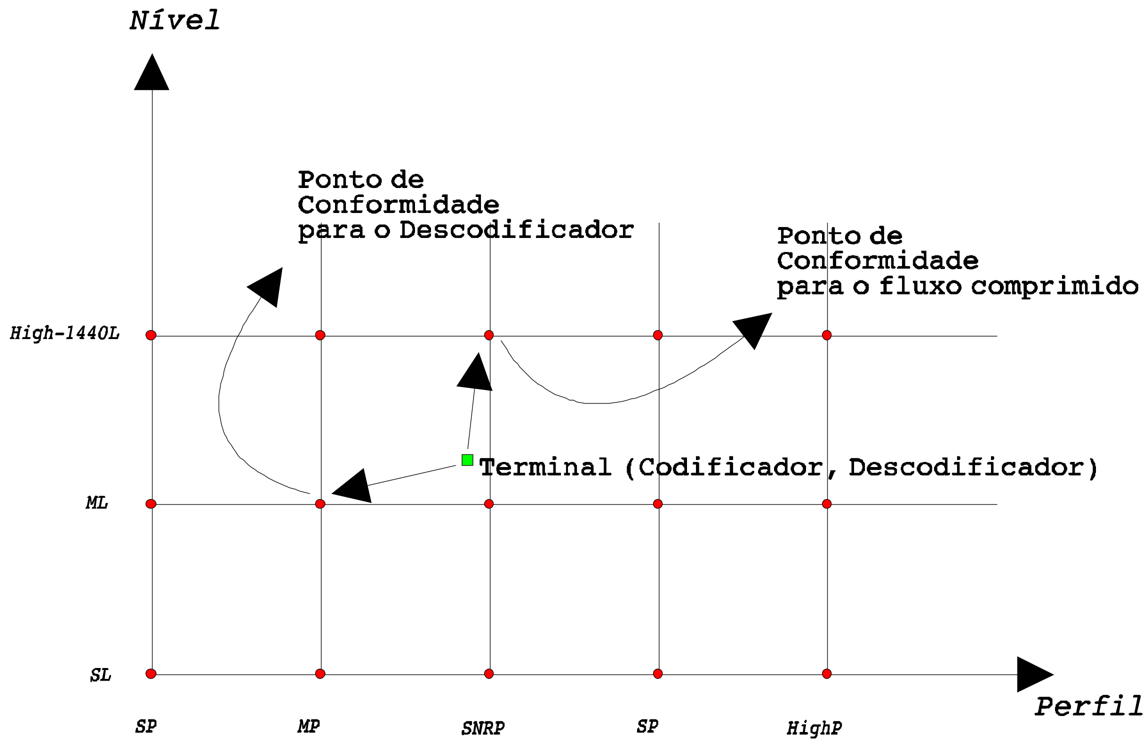
Some profiles are syntactically hierarchical this means one profile is syntactically a superset of another and so on.

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.

Profiles and Levels Classification



- If an encoder produces a bitstream which is over, even if only slightly, the predefined limits for a certain profile and/or level, than it is classified with the profile or/and level immediately above (to guarantee decoding).
- If the decoding capabilities of a decoder are below, even if only slightly, from those predefined for a certain profile and/or level, than it is classified with the profile and/or level immediately below (to guarantee decoding).

This type of classification is important for the deployment and compliance of MPEG-2 Video content and decoders !

MPEG-2 Video in DVB

- **Standard Definition TV (SDTV) uses MP@ML**
  - Frame rate - 25 or 30 Hz
  - Aspect ratio - 4:3, 16:9 or 2.21:1
  - Spatial resolution - (720, 576, 480) $\times$ 576 or 352 $\times$ (576, 288) or (720, 640, 544, 480, 352) $\times$ 480 or 352 $\times$ 540
  - Chrominance subsampling - 4:2:2 or 4:2:0

- **HDTV uses MP@HL**
  - 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) – Codes up to 5 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; offers backward and forward compatibilities with MPEG-1 Audio, thus the name of *MPEG-2 Audio Backward Compatible* (BC).**

- **Advanced Audio Coding (Part 7) – Gives up on any compatibility with MPEG-1 Audio, increasing its rate-distortion performance, 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).**

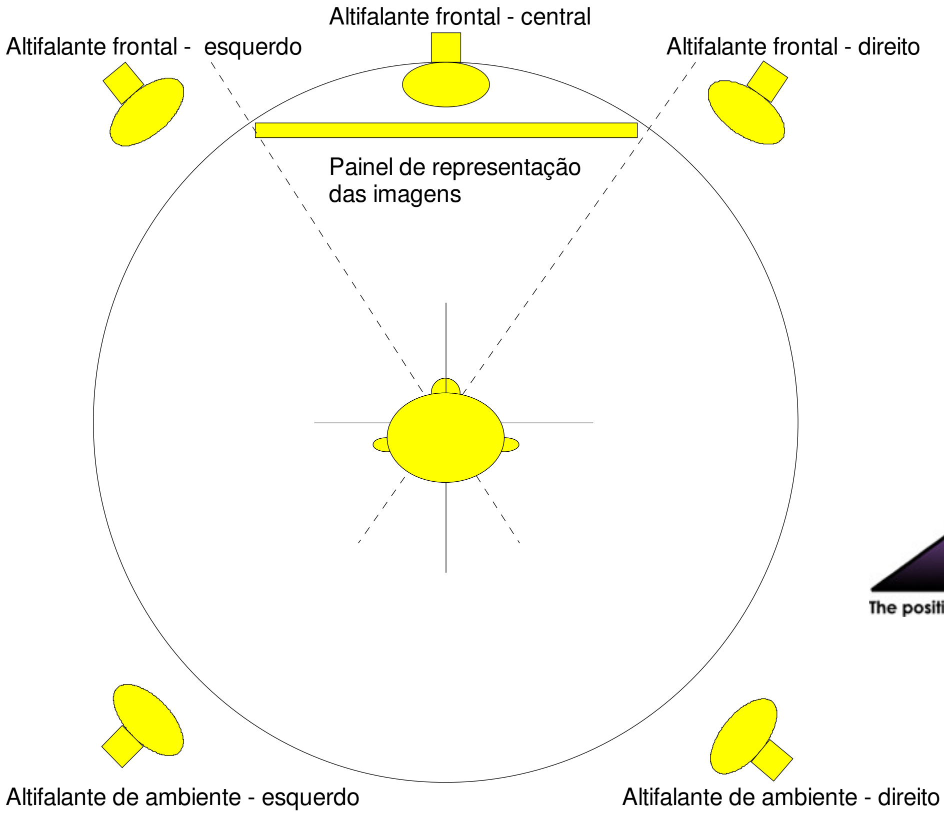
MPEG-2 Audio (Part 2): What's New ?

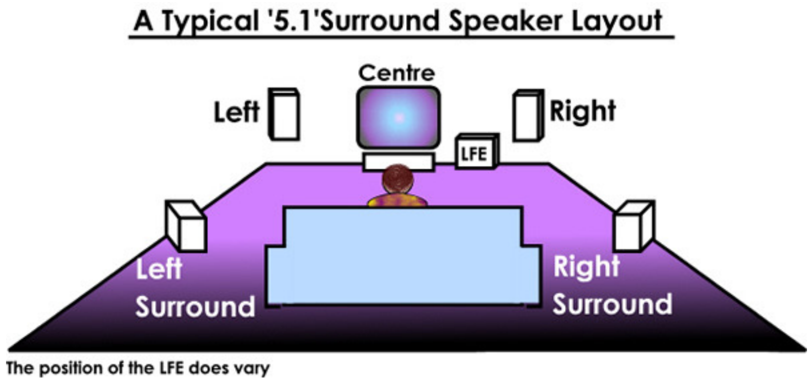
There are two main technical innovations in MPEG-2 Audio (BC or Part 2) regarding MPEG-1 Audio:

- 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 using 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-performance tradeoffs are again defined in MPEG-2 Audio Part 2.

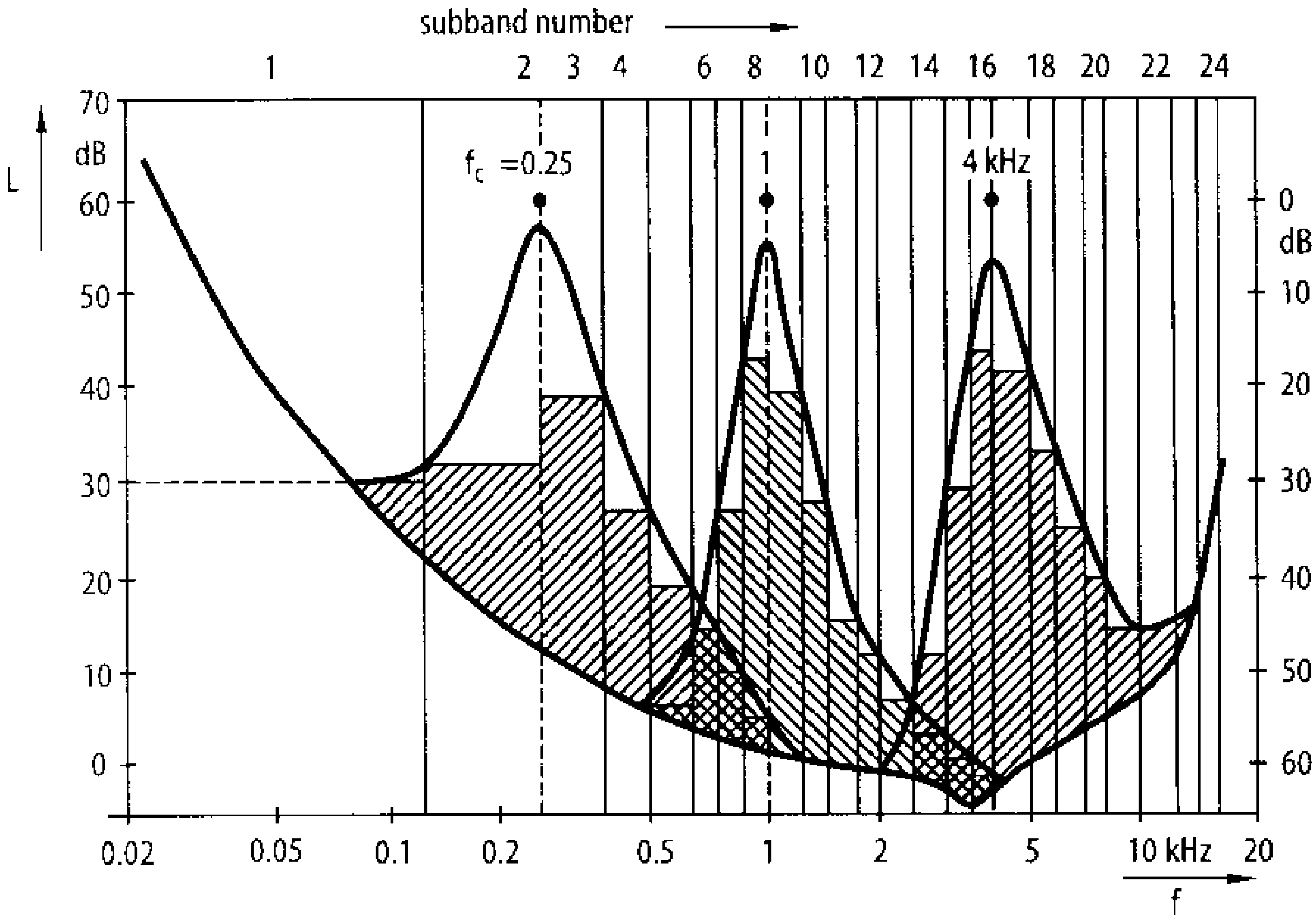
MPEG-2 Audio: Multichannel Configuration



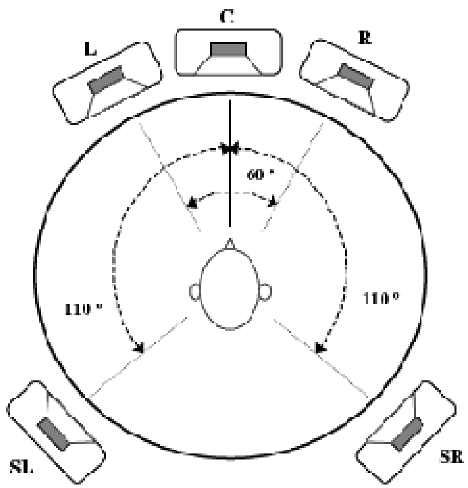


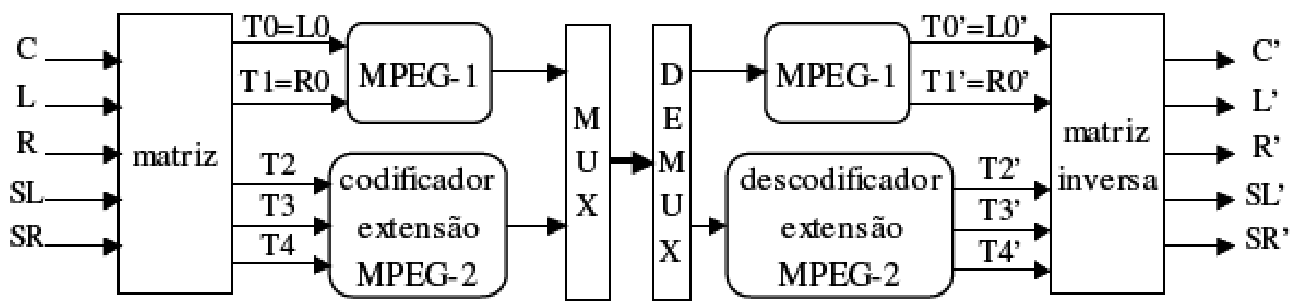
The 5.1 multichannel configuration includes 5 full bandwidth channels and a low frequency enhancement (LFE) channel covering frequencies below 200 Hz (less than 10% of the full bandwidth).

MPEG-2 Audio: the Secret !



MPEG-2 and MPEG-1 Audio Compatibility





Compatibility is provide through a MPEG-1 Audio compliant stereo pair and additional MPEG-2 Audio compliant data for the other channels.

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.
- Due to backward compatibility, it is possible to recover, with a MPEG-1 Audio decoder, a stereo pair from a multichannel MPEG-2 Audio BC coded bitstream (through downmixing).
- Sampling frequencies: 32, 44.1 and 48 kHz.

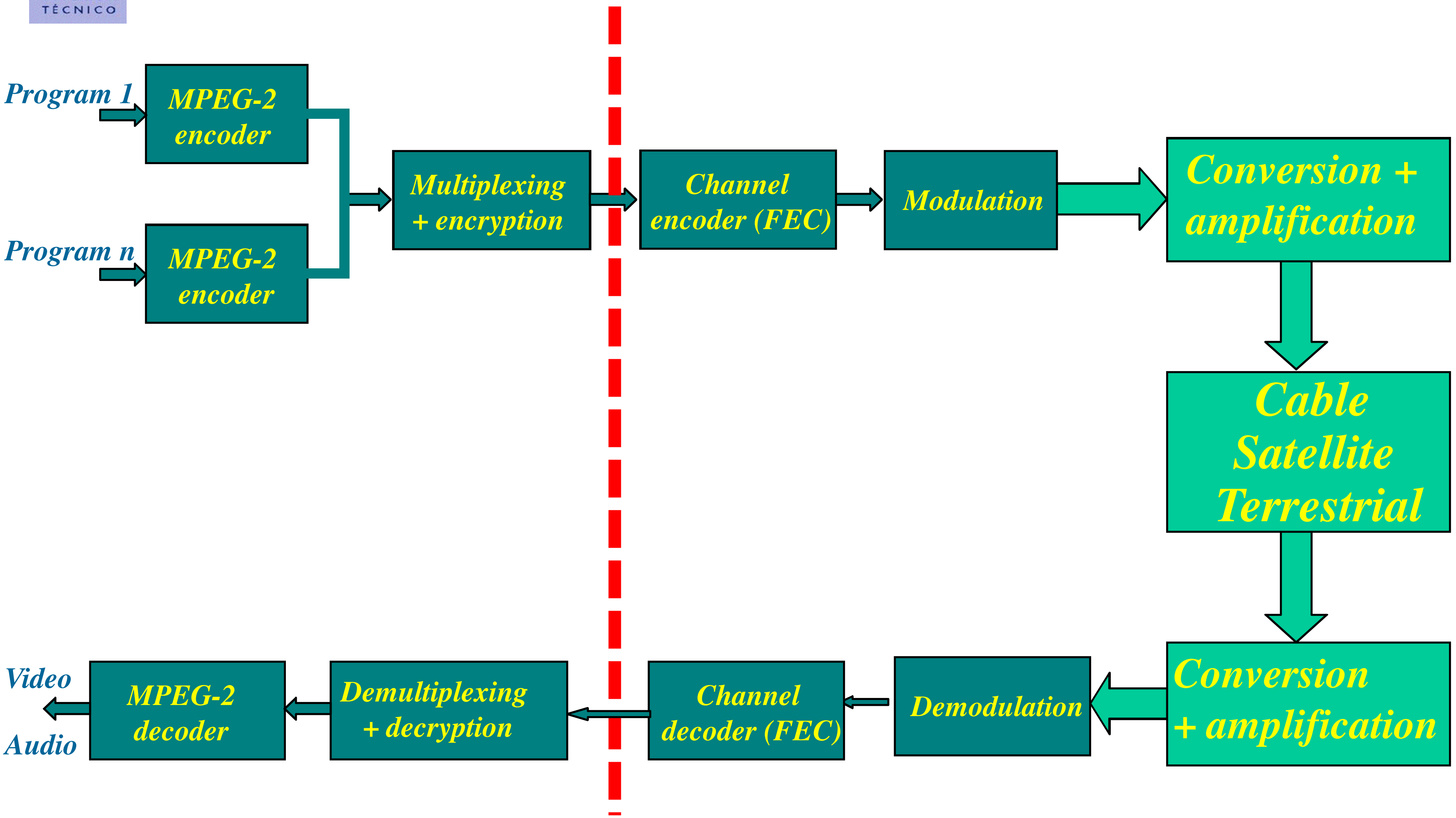
New Systems and … Business Models …

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

Technologies Developed by DVB

Channel Coding

The Channel .. After the Source !

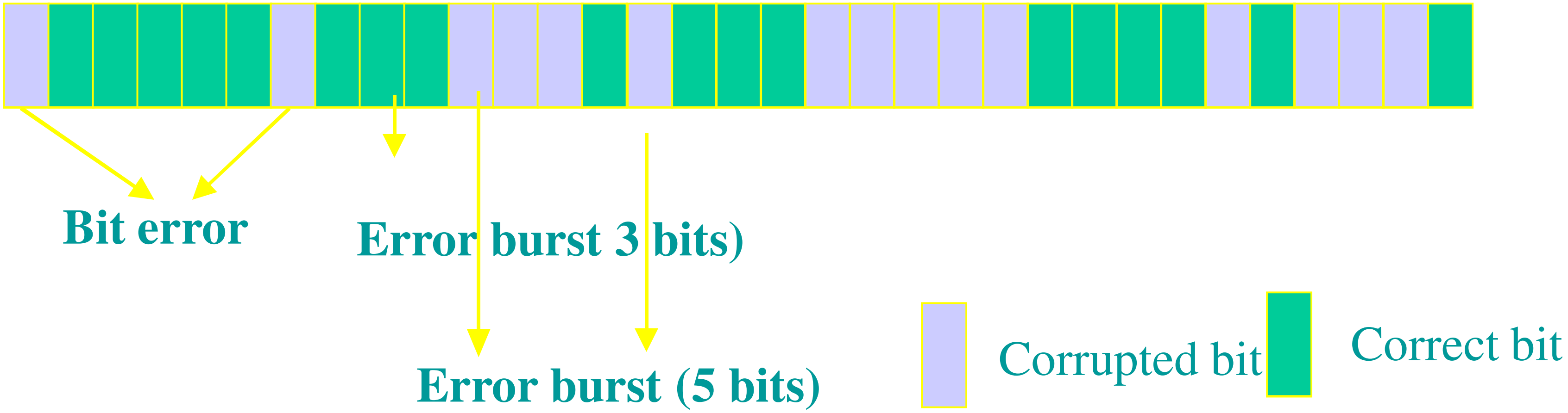


Channel Coding

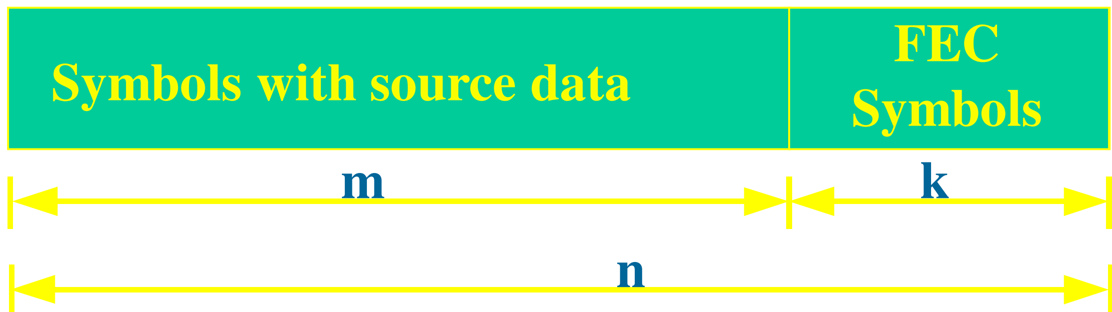
- **At sender, additional redundancy is included in the compressed signal in order to allow the channel decoder the detection and correction of channel errors.**

- **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.**



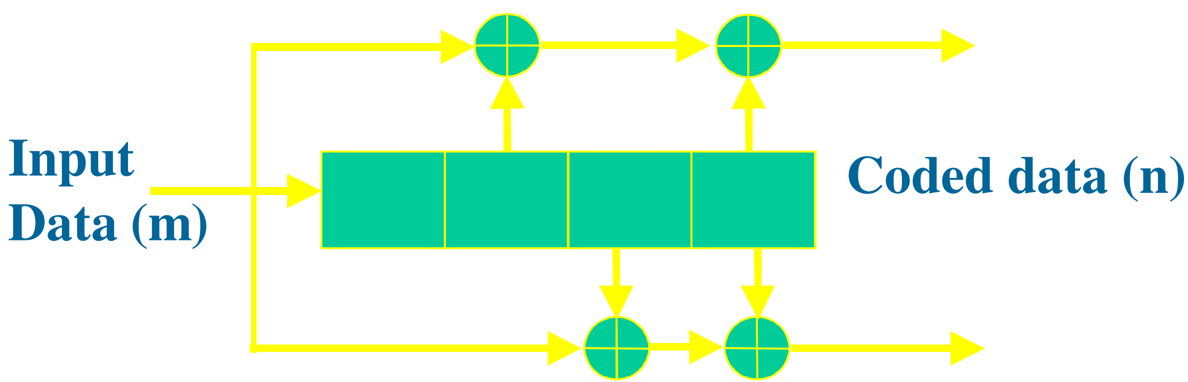
DVC Channel Coding Tools



R = m/n = 1 – k/n

Block codes

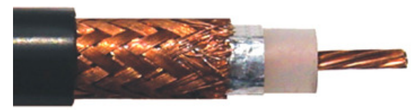
FEC – Forward Error Correction



Convolutional codes

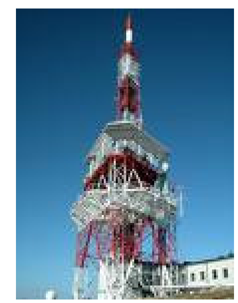
R = m/n – Coding rate, e.g. ½, 2/3, 9/10 …

DVB Channel Coding Solutions



DVB-C Channel Coding

Source encoder → **Reed Solomon** → ***Interleaver*** → Modulator



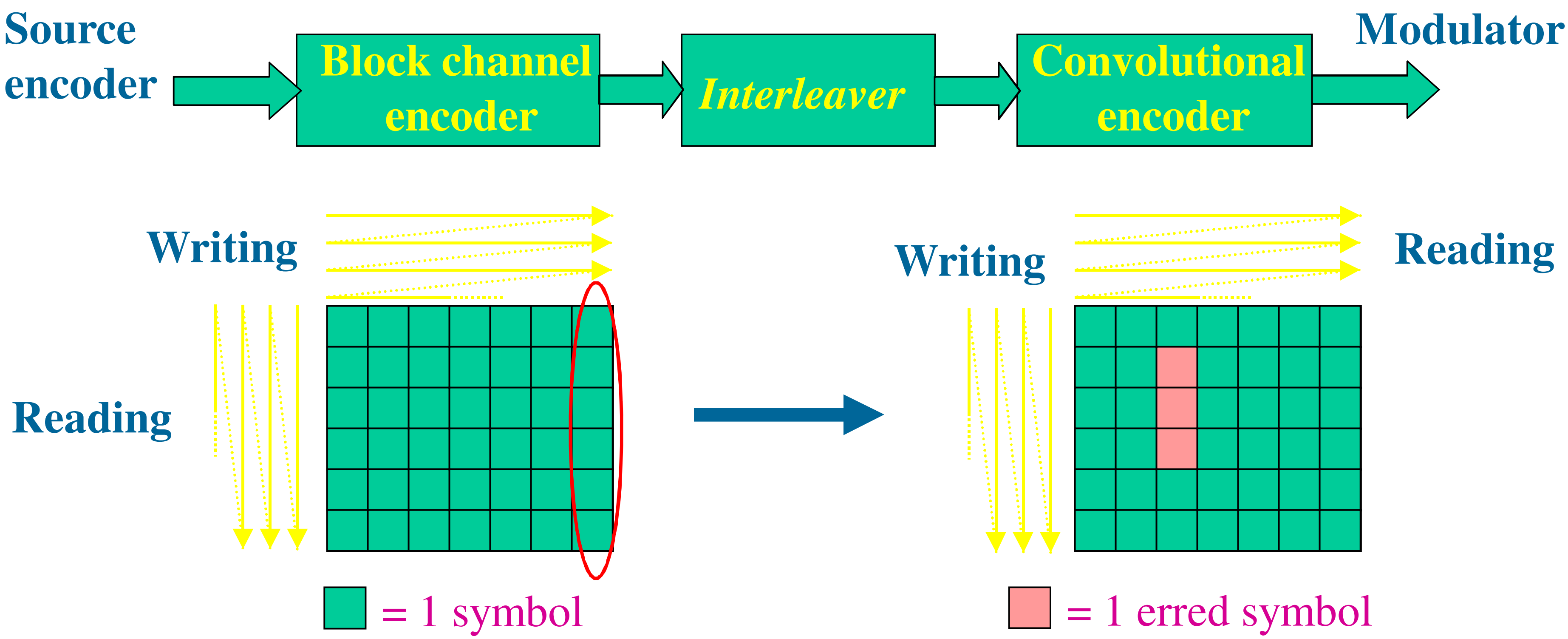
DVB-S and DVB-T Channel Coding

Outer code | *Inner code* | Modulator

Source encoder → **Reed Solomon** → ***Interleaver*** → [**Convolution encoder** → ***Puncturing***] →

Interleaving

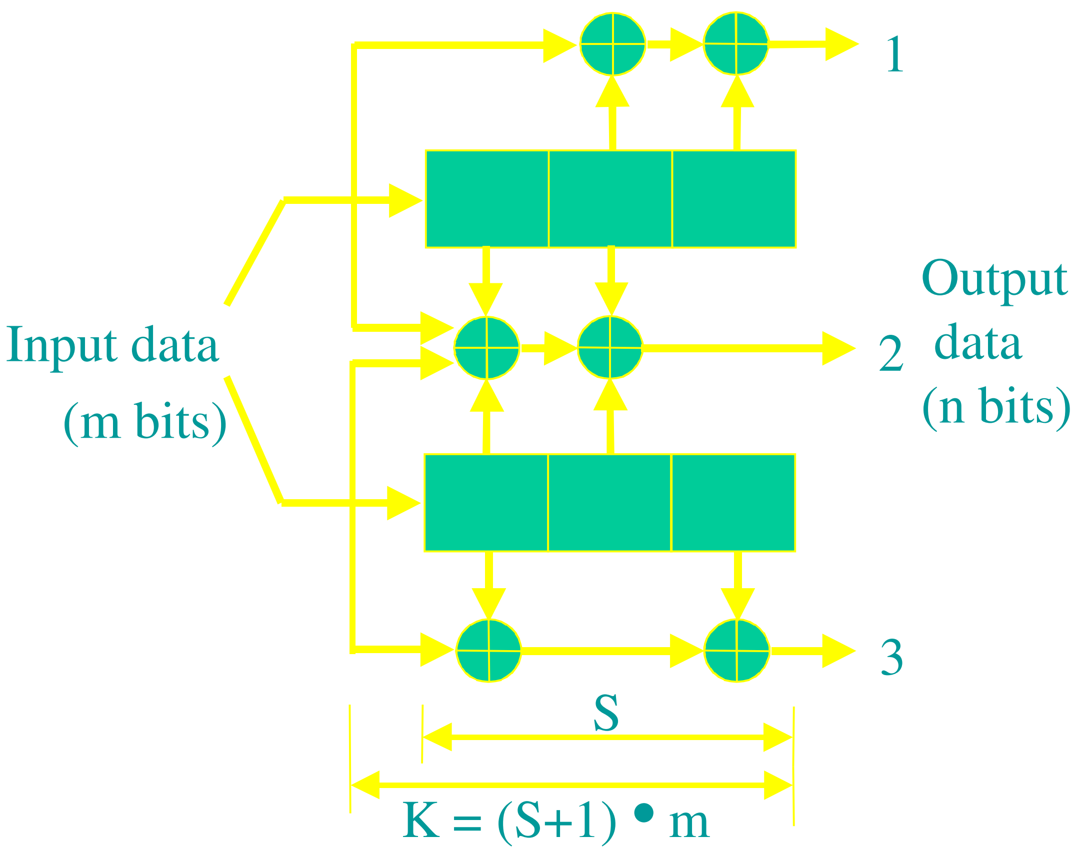
The interleaver does not provide error correction capabilities by itself; it rather reorganizes the symbols to have burst and bit errors more efficiently corrected when also using a channel code, e.g. a RS code.



Reed-Solomon Code

- The Reed-Solomon (RS) code is a block code:
  - Allowing the detection of corrupted symbols (up to a certain limit)
  - Allowing the correction of corrupted symbols (up to a certain limit)
- Good performance for burst errors … of course, in combination with the interleaver.
- The RS code used in DVB is RS(204,188), 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 block, the channel decoder signals the lack of capability to correct the errors in the block.

Convolutional Coding and Puncturing



- **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 coding rate is the ratio of the source rate to the total rate (1 when there is no channel coding)**
- **To improve the coding rate (to make it higher), puncturing is used which means that certain bits at the convolutional encoder output are not transmitted, reducing the overall rate.**

Puncturing Example

- **Source 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:**

11 00 01 11 00

- **Reconstruction for decoding:**

11 X0 0X 01 X1 1X 00

DVB-S2: Channel Coding

- **DVB-S2 (second generation of DVB specifications for satellite) uses a more complex and more powerful channel coding solution.**

- **The Reed- Solomon *outer code* in DVB-S is substituted by a BCH (*Bose, Ray-Chaudhuri, Hocquenghem*) code with the capacity to correct 8 to 12 bytes in the block.**

- **The convolutional *inner code* in DVB-S is substituted by a LDPC (*low density parity check*) code.**

- **The overall BCH&LDPC block length is 64800 bits for applications without critical delay requirements, and 16200 bits otherwise.**

- **Depending on the needs, the following coding rates may be used: 1/4, 1/3, 2/5, 1/2, 3/5, 2/3, 3/4, 4/5, 5/6, 8/9 and 9/10.**

Modulation

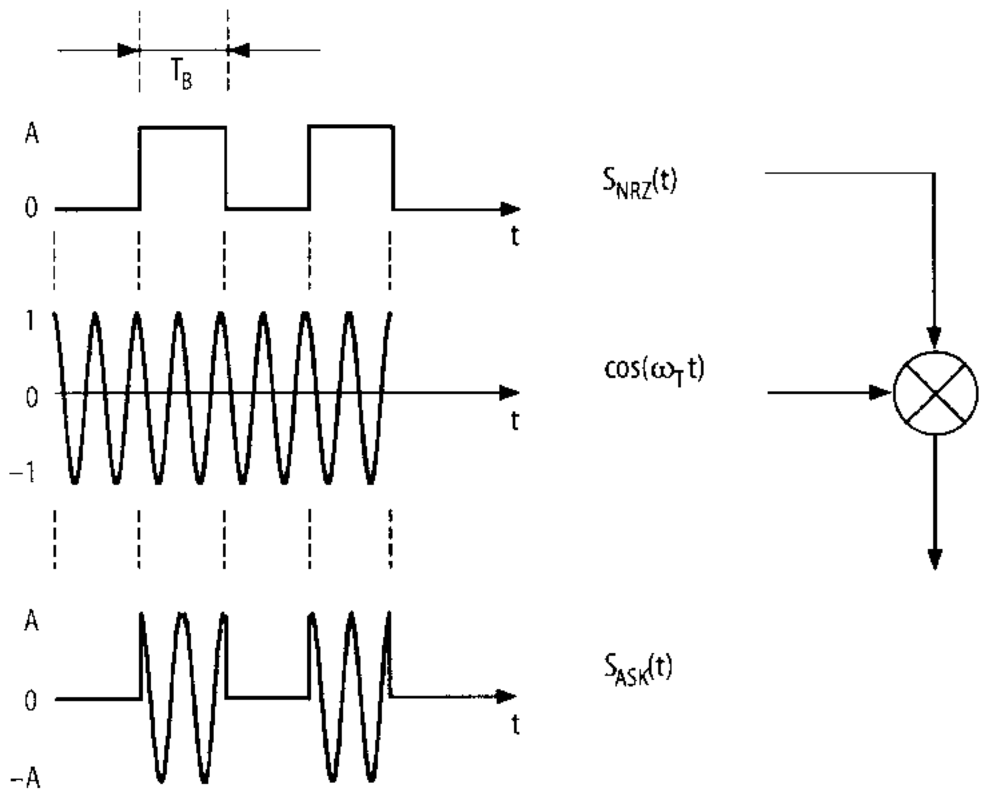
About Modulation …

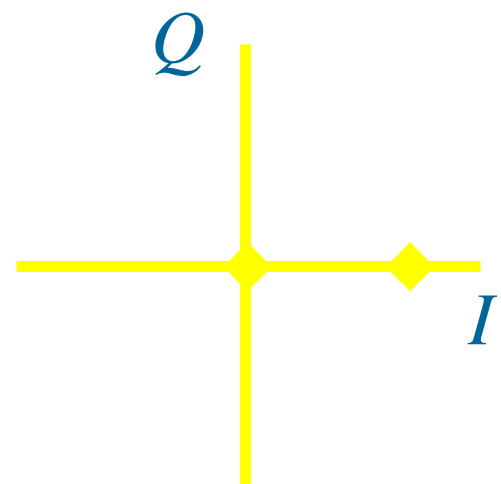
- **Factors to consider when selecting a modulation:**
  - Channel characteristics
  - Spectral efficiency, i.e. how many bits are transmitted per Hertz
  - Robustness to channel distortion
  - Tolerance to transmitter and receiver imperfections
  - Minimization of requirements for interference protection

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

Amplitude Modulation: ASK

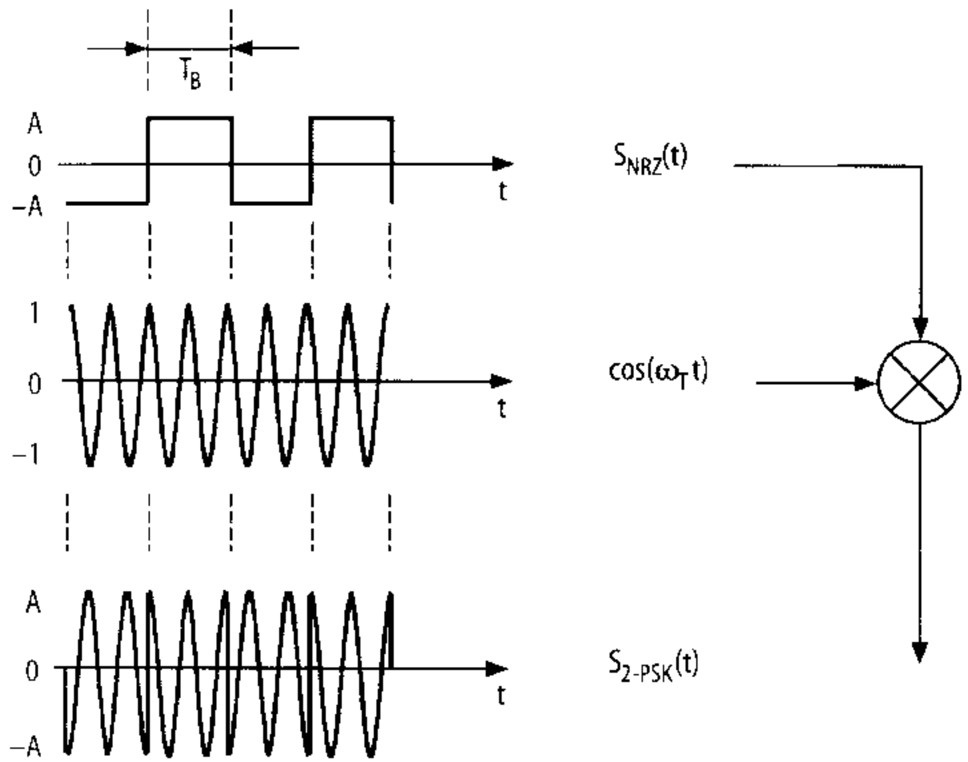
The information is transmitted in the signal amplitude !

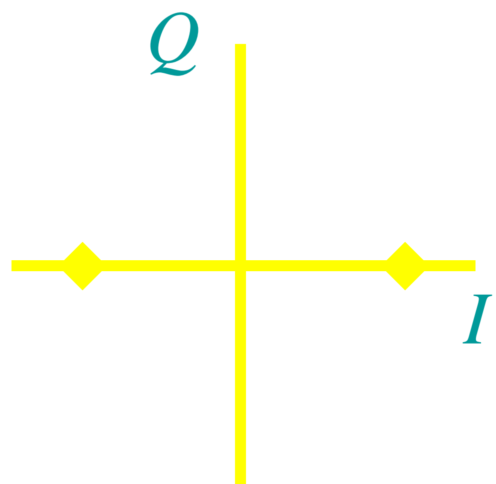




Phase Modulation: PSK

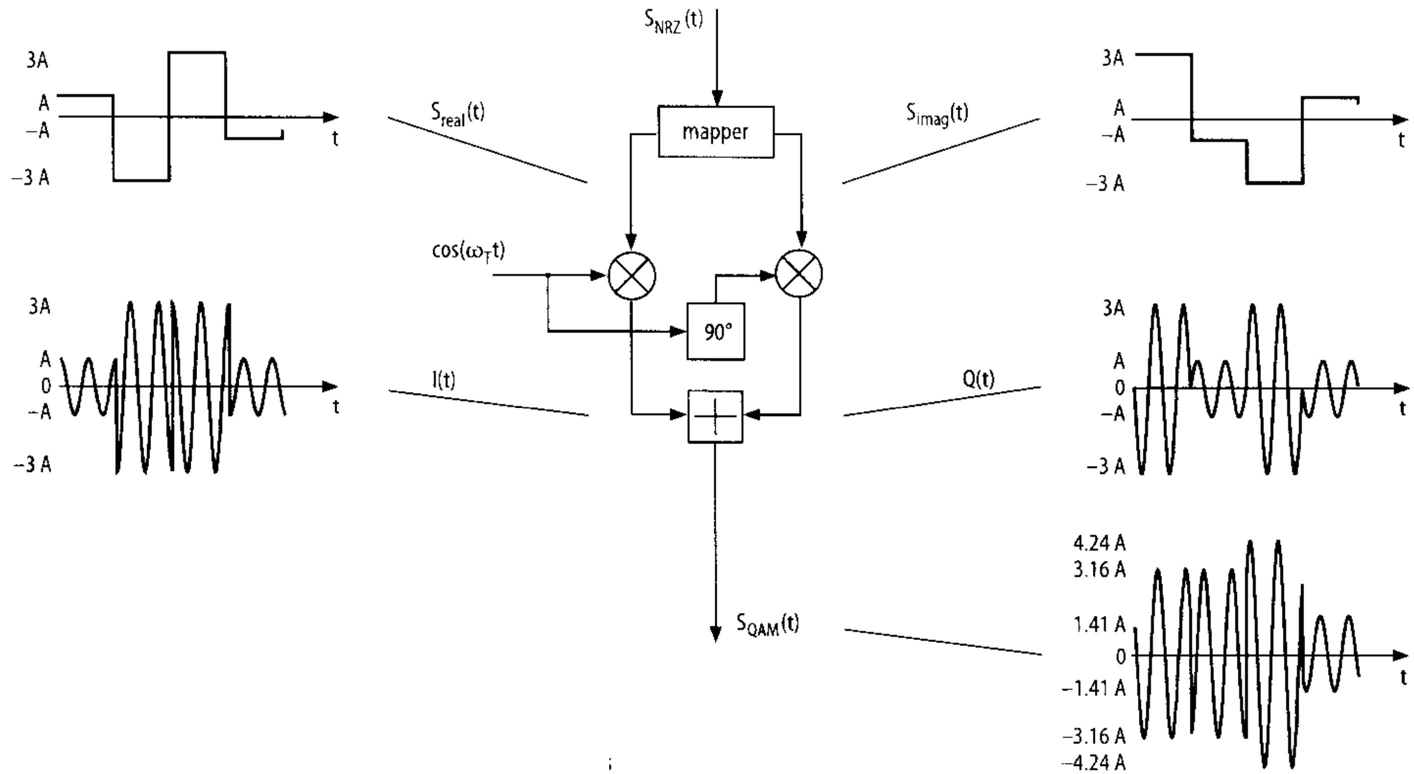
The information is transmitted in the signal phase !



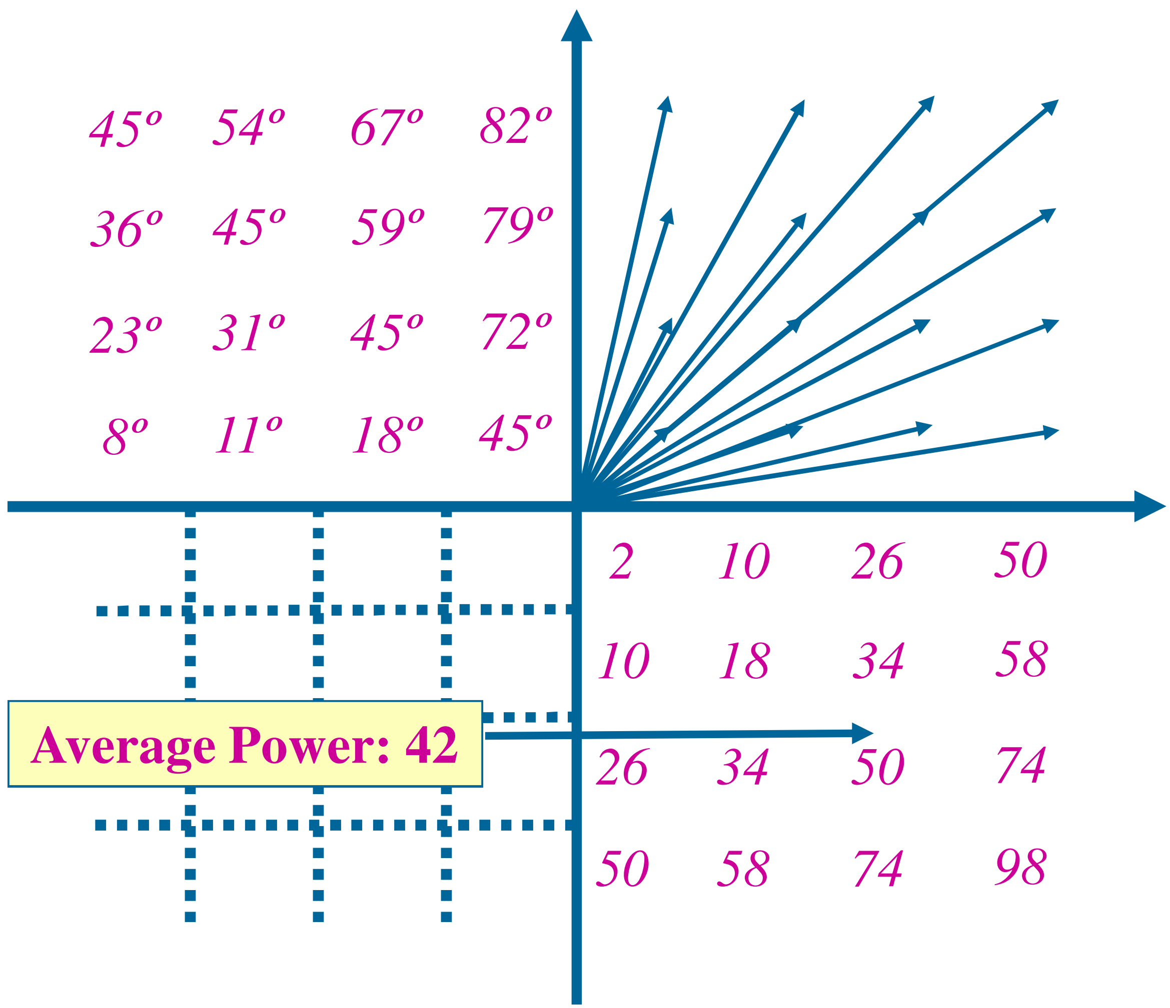


QAM Modulation

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

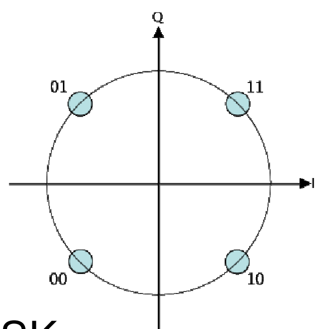


64-QAM Modulation Constellation …

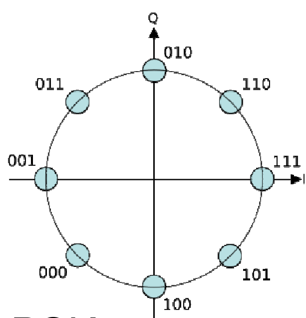


DVB Modulations

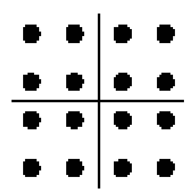
- **DVB-S - QPSK (low SNR and rather high available bandwidth); amplitude modulation is difficult due to the high attenuation.**
- **DVB-S2 – QPSK, 8PSK, 16APSK, 32APSK (Asymmetric Phase Shift Keying, also called Amplitude and Phase Shift Keying).**
  - **APSK has advantages over QAM due to the lower number of possible amplitude levels, resulting in less problems with non-linear amplifiers.**
- **DVB-C – Essentially 64-QAM.**
- **DVB-T and DVB-H - Orthogonal Frequency Division Multiplex (OFDM) based on QPSK and QAM modulations (very robust to multipath effects).**



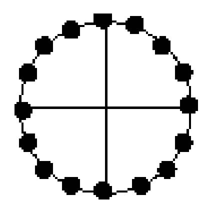
QPSK



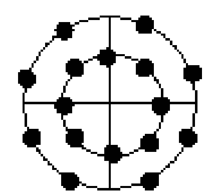
8-PSK



16 QAM

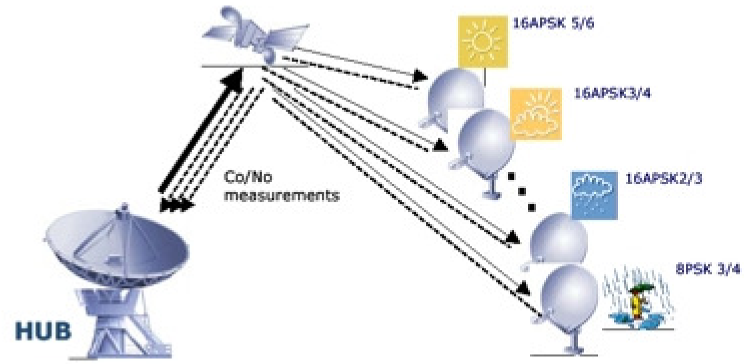


16 PSK



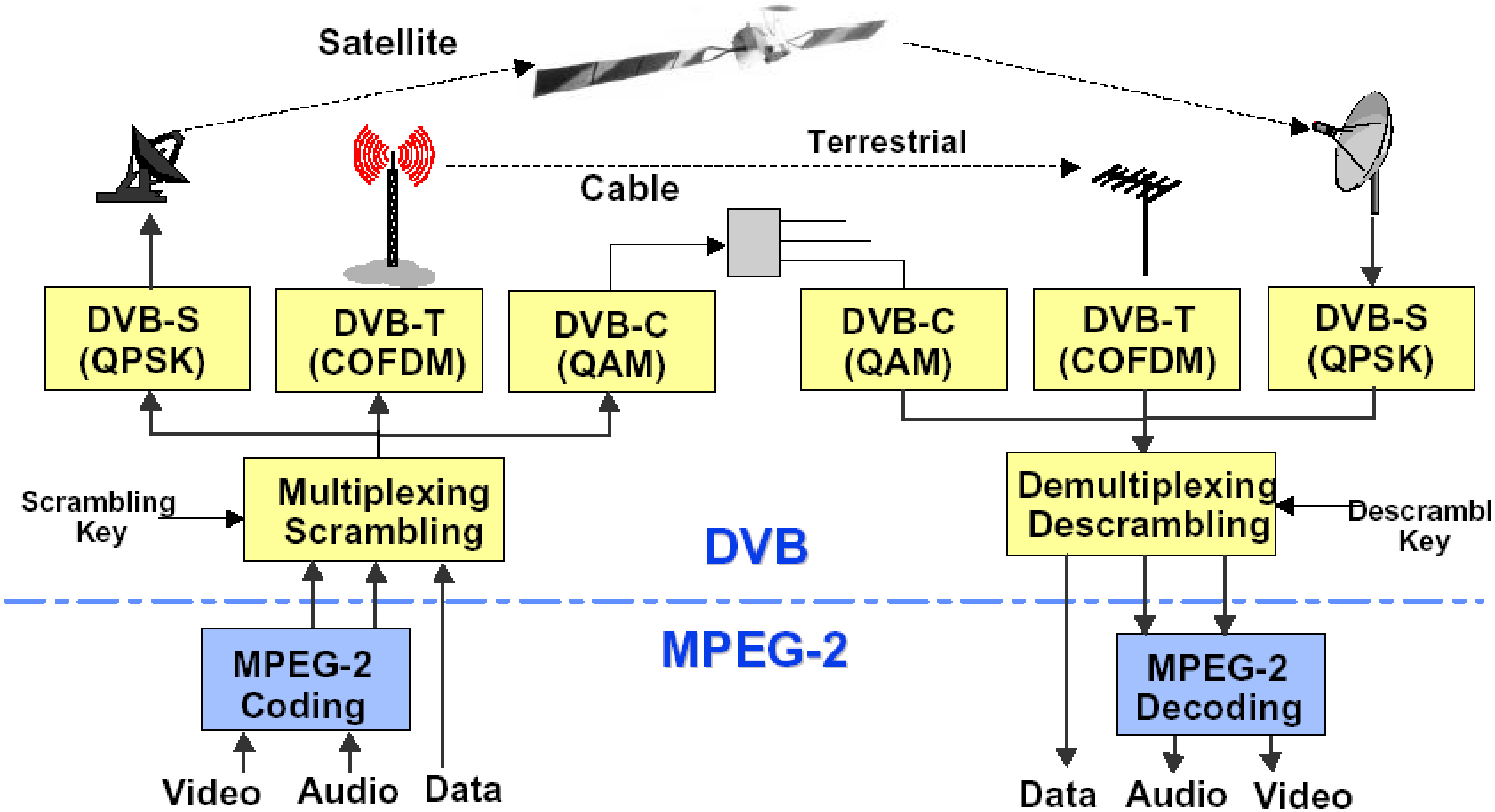
16 APSK

DVB-S2 versus DVB-S



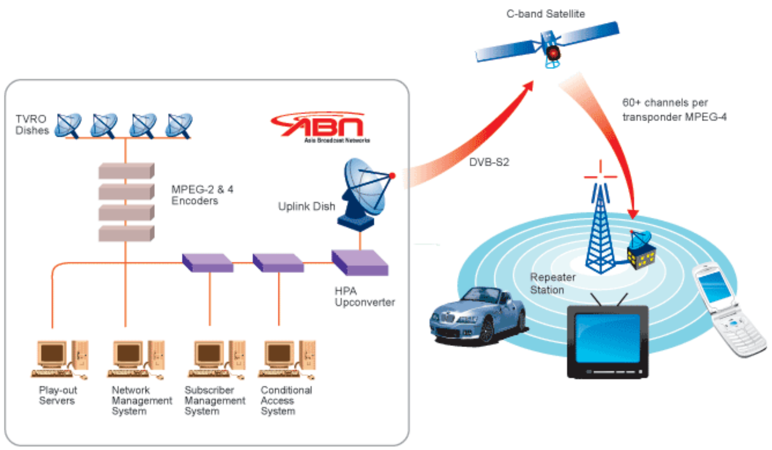
- The spectral efficiency depends on the selected modulation constellation and coding rate; it may vary between 0.5 and 4-5 bit/symbol.
- The 16APSK and 32APSK performances are comparable to the 16-QAM and 32-QAM performances.
- QPSK and 8PSK are typically used for television due to their constant amplitude (and higher reliability).
- DVB-S2 increases the DVB-S transmission capacity in about 30%.

DVB Systems Architecture



DVB-T:
Terrestrial Broadasting

Digital Terrestrial TV: Requirements

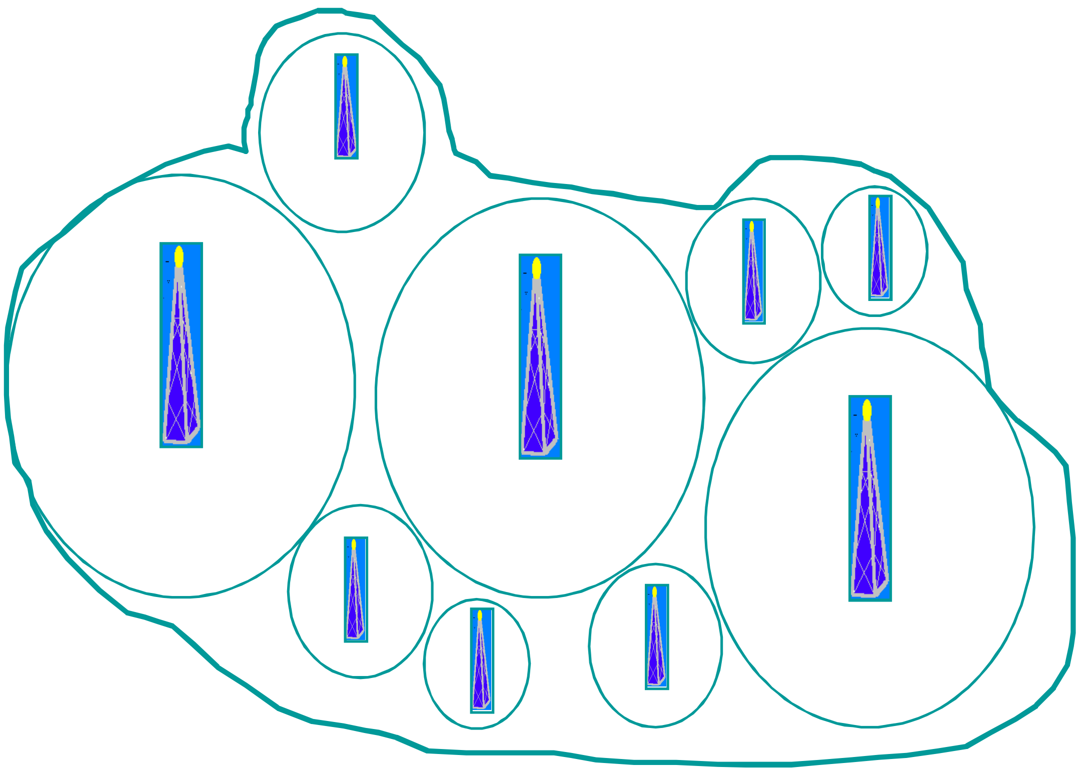


- Fixed, portable and mobile reception
- Immunity to multipath effects
- Single frequency networks
- Configuration flexibility, e.g. coverage/bitrate trade-offs, configuration hierarchies
- Robustness to analogue services interferences without interfering with those services
- Easy transcoding to and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

Main DVB-T Technical Characteristics

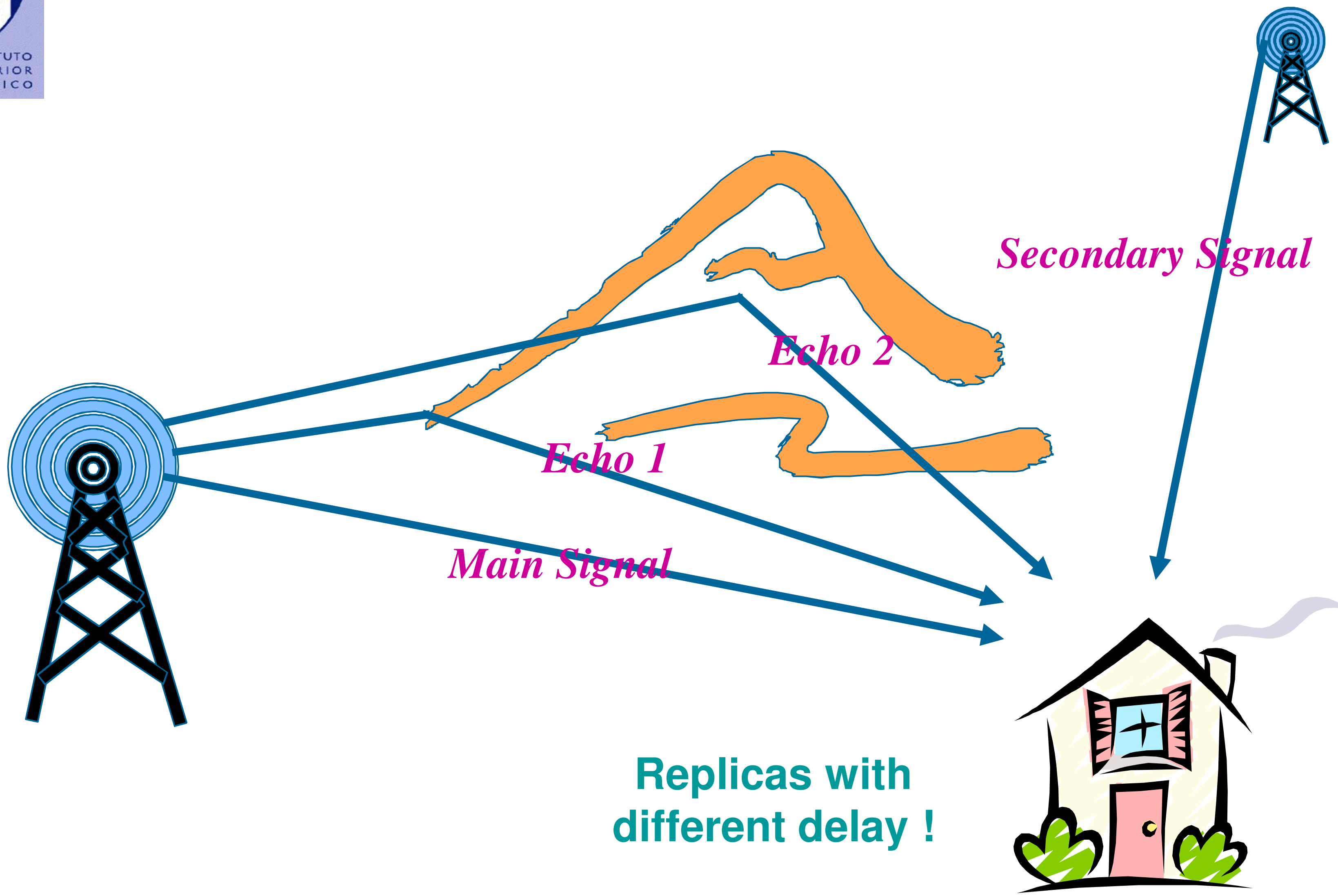
- Many characteristics common to the DVB-S and DVB-C systems
- Inclusion of the convolutional channel coding from DVB-S
- OFDM modulation based on QPSK and QAM (very robust to multipath effects) with 2k and 8k options
- Two hierarchical layers of channel coding and modulation
- MPEG-2 Video (Main profile)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

Single Frequency Networks



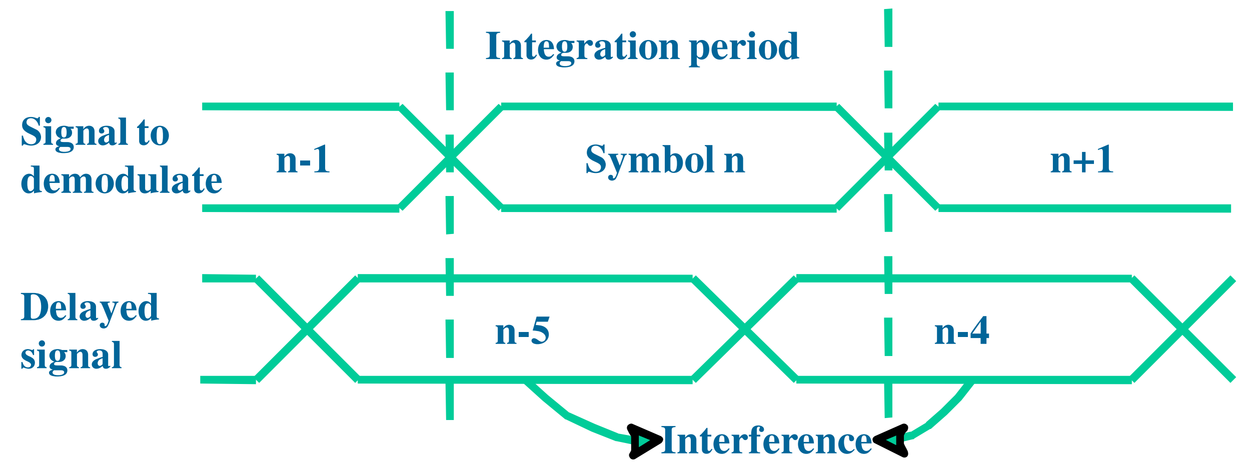
While in analogue reception, the user tunes the best behaving frequency for a certain channel (from different senders), in digital SFN reception all received signals for a certain channel are in the same frequency; thus, it is important to filter the signals from the other transmitters using an antenna with an adequate radiation diagram.

Terrestrial Diffusion Interferences

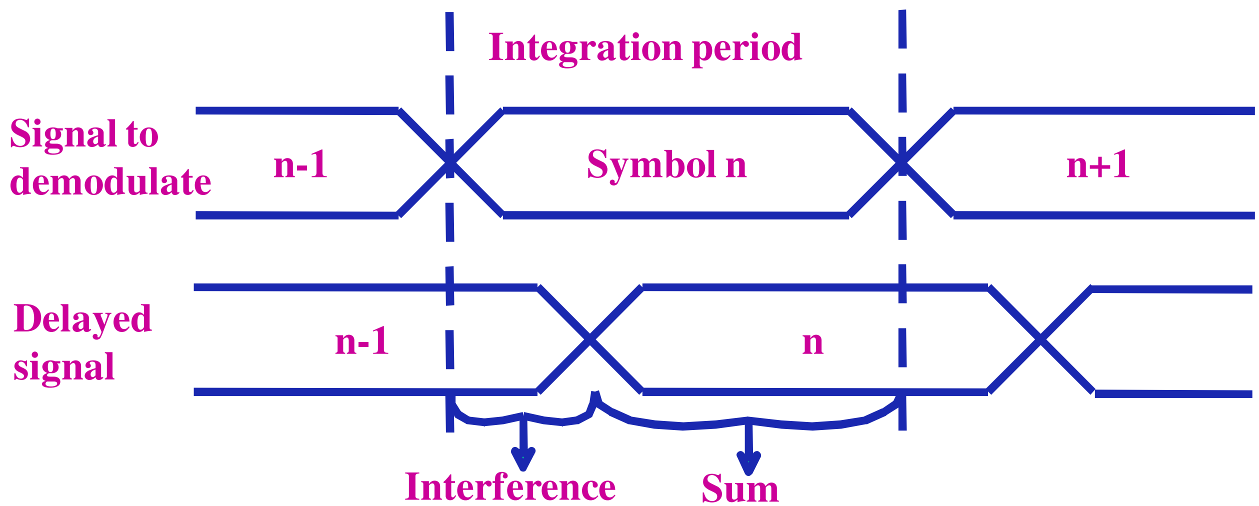


Replicas with different delay !

Symbol Interference ...

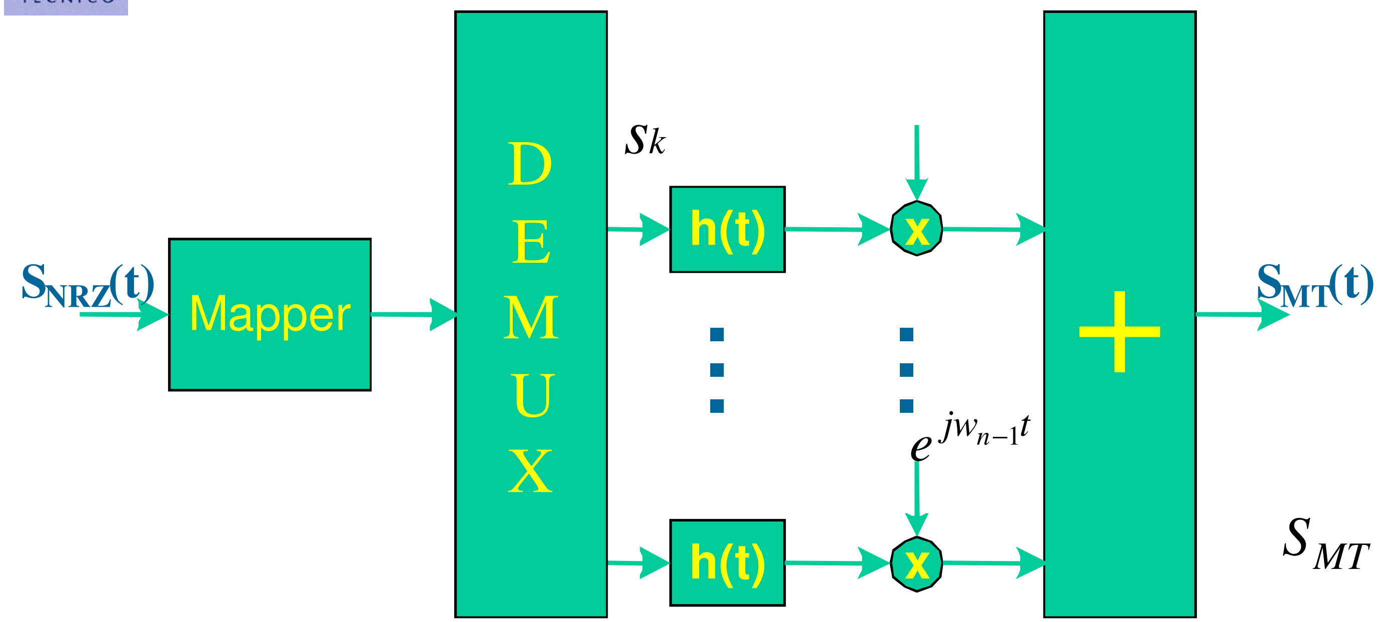


Interference between ‘distant’ symbols



Interference between ‘close’ symbols

Multi-Carrier Modulation

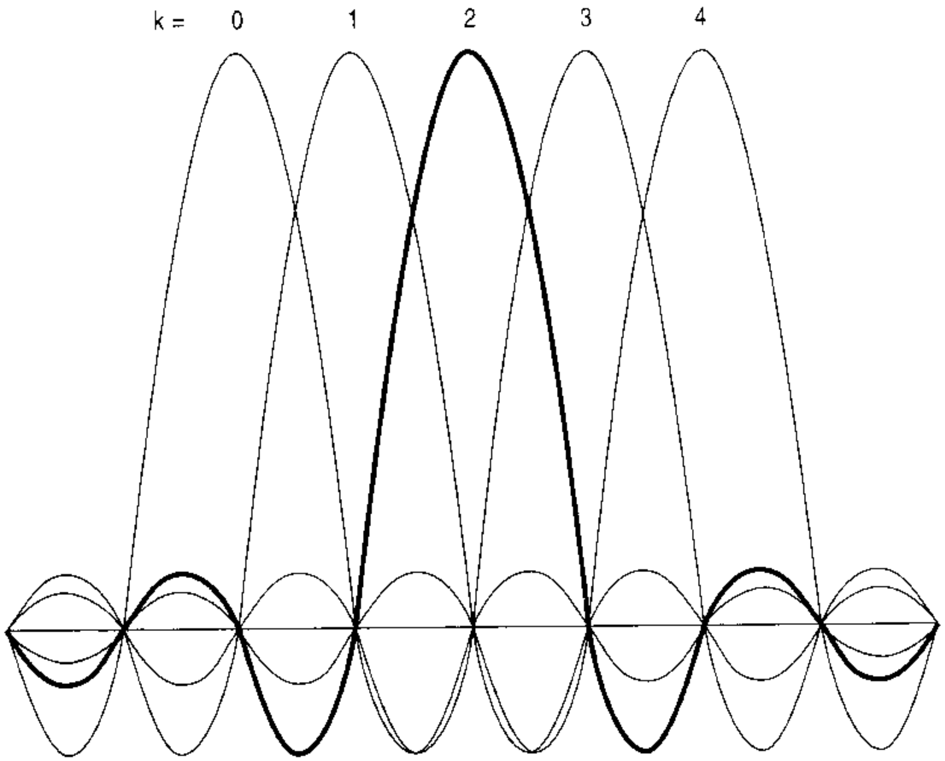


$$S_{MT}(t) = \sum_{k=0}^{n-1} s_k . h_t(t) . e^{jw_k t}$$

One way to reduce the number of symbols which mutually interfere is to increase their duration; this can be achieved by transmitting symbols in parallel and not only sequentially; instead of a single carrier modulated at a high rate, many carriers are used, each modulated at a lower rate.

Each sub-symbol s_k may be modulated in amplitude or phase.

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

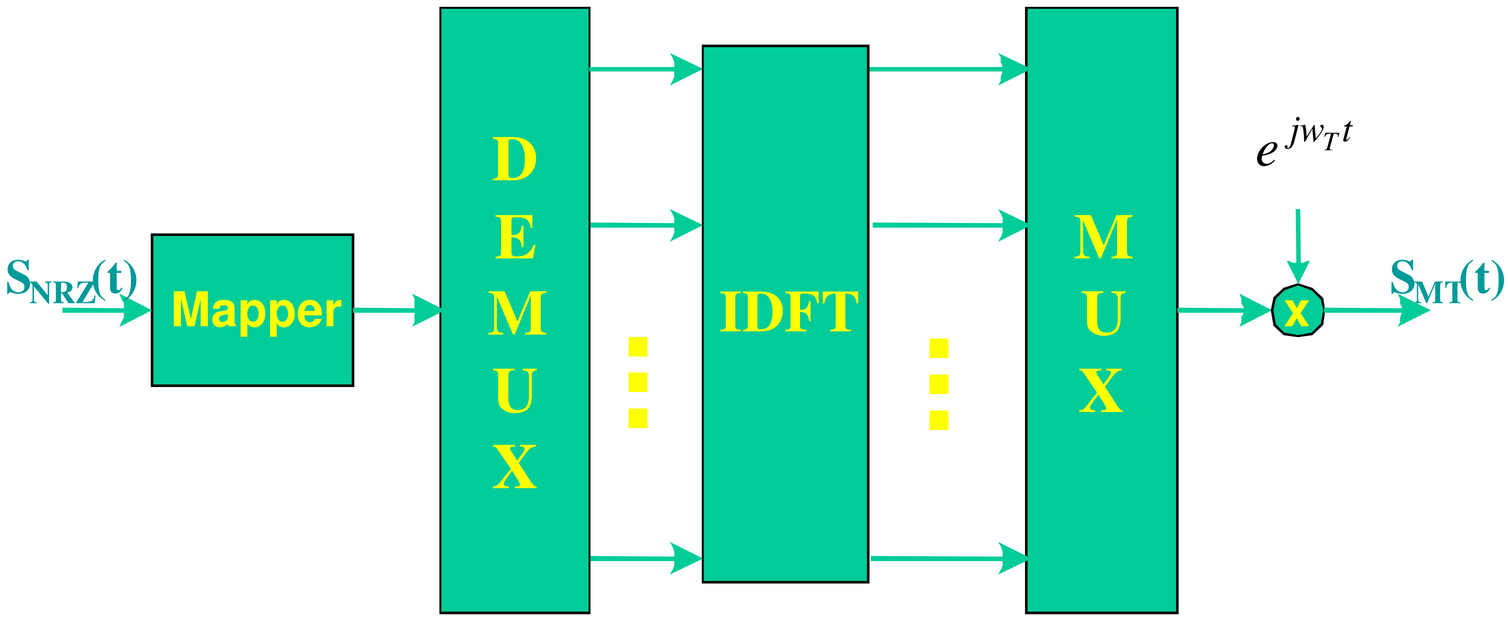
$w_k = 2\pi k f_0$ with $k=0, 1, \ldots, n-1$

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.

Orthogonal Frequency Division Multiplex

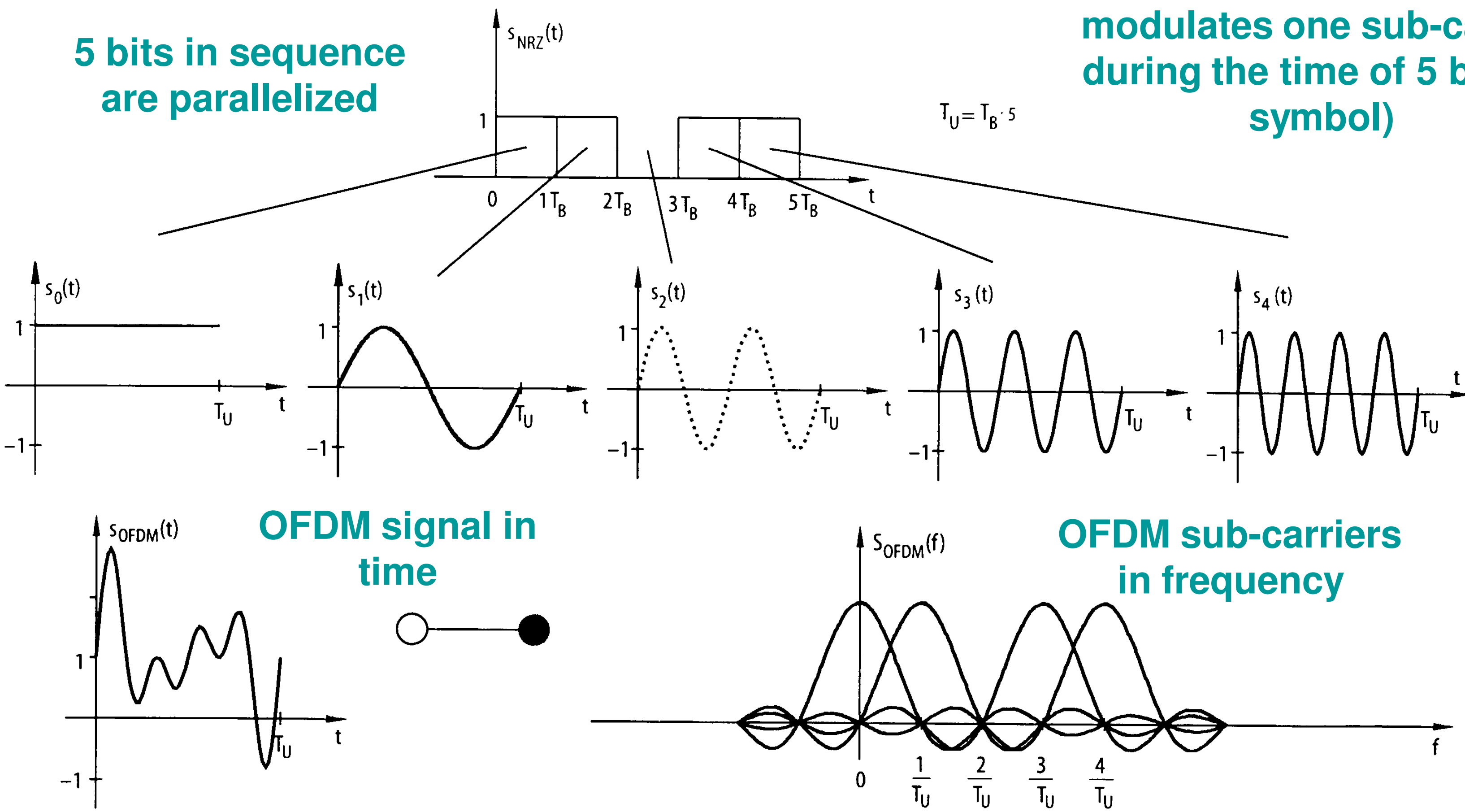
For orthogonal sub-carriers, multi-carrier modulation corresponds to applying the *Inverse Discrete Fourier Transform* (IDFT) to the sub-carriers in parallel, creating the so-called *Orthogonal Frequency Division Multiplex* (OFDM) modulation.



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)

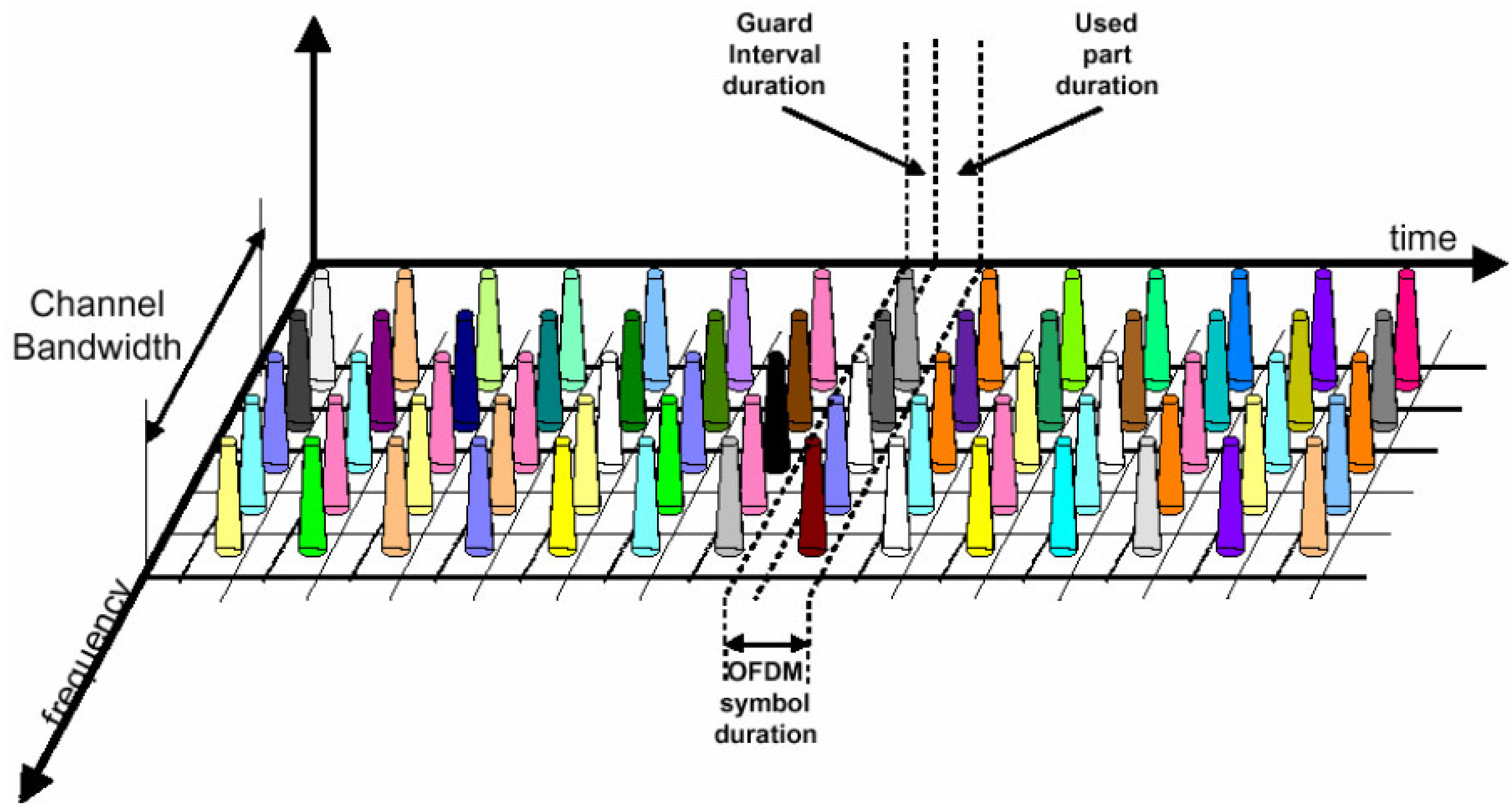


OFDM signal in time

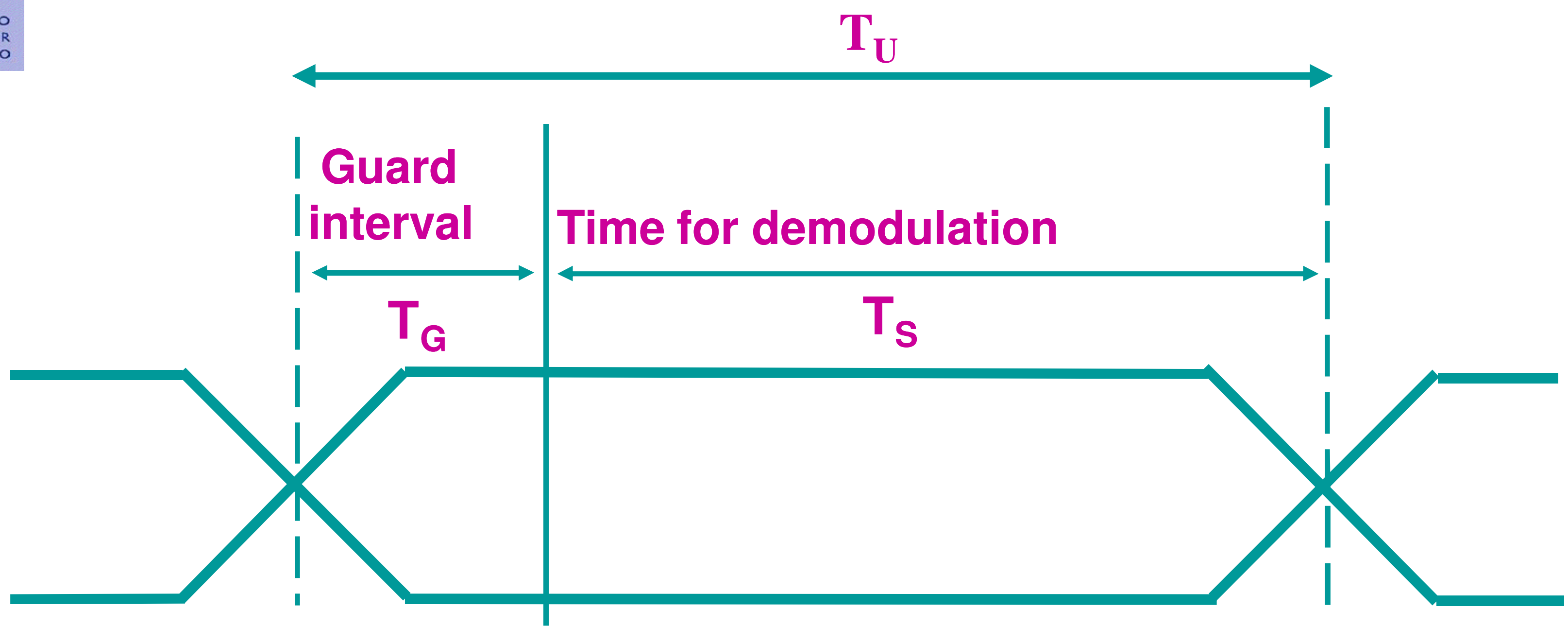
OFDM sub-carriers in frequency

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

OFDM Symbol: Union is Strength …



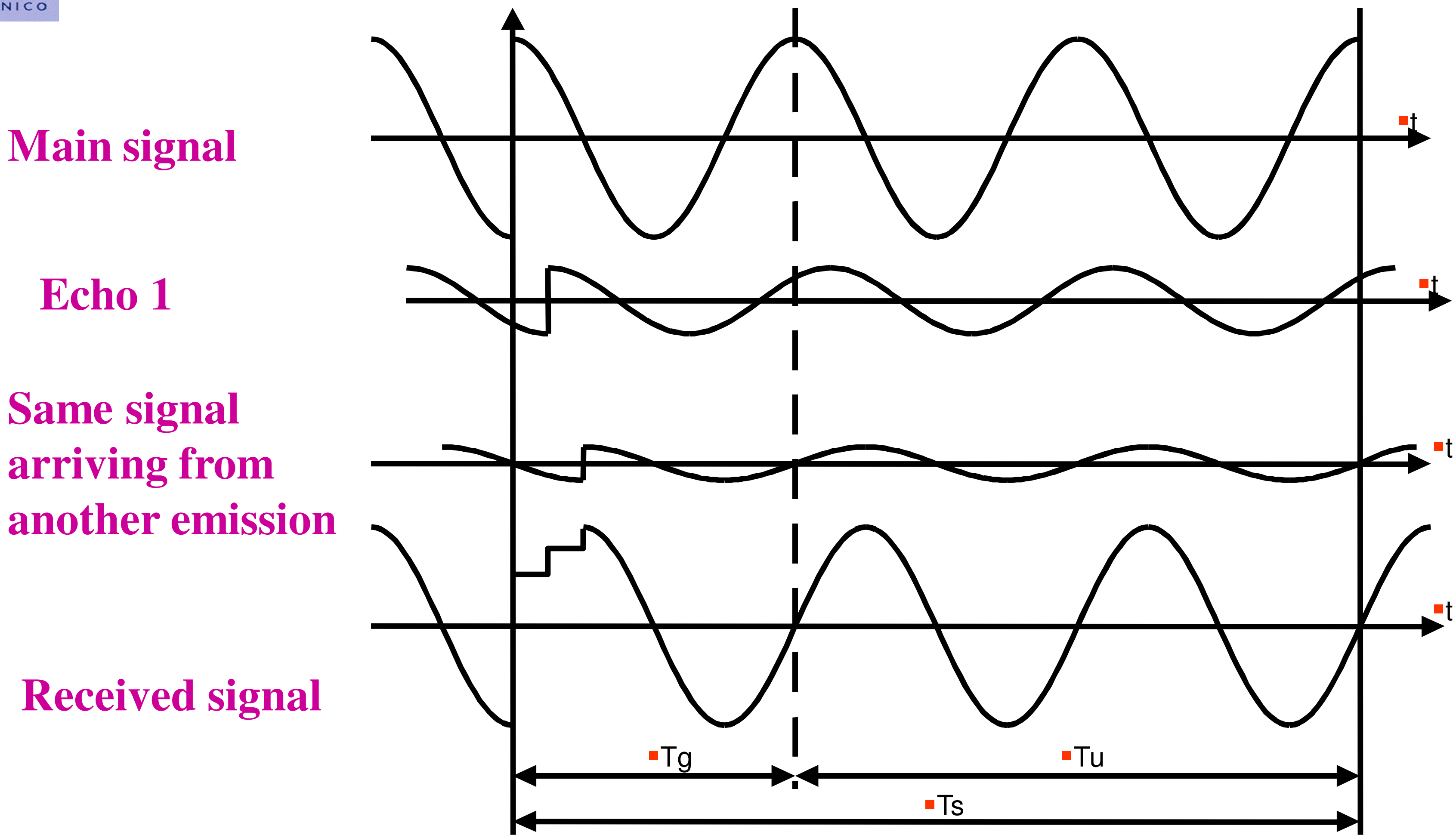
The Guard Interval



- The adoption of a guard interval allows to create 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 biggest delay corresponding to the interfering signals (and this depends on the diffusion cells).

Guard Interval: an Example



The attenuation and delay of the signal received from another emission depends on the distance between transmitters.

The COFDM (Coded OFDM or OFDM) Variants

DVB-T defines two variants for data transmission (in 8 MHz channels):

- **2k Variant (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 Variant (6048 signal sub-carriers and 769 synchronization sub-carries – 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).

Bitrate (Mbit/s) versus Modulation for each 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

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 difference resolutions.

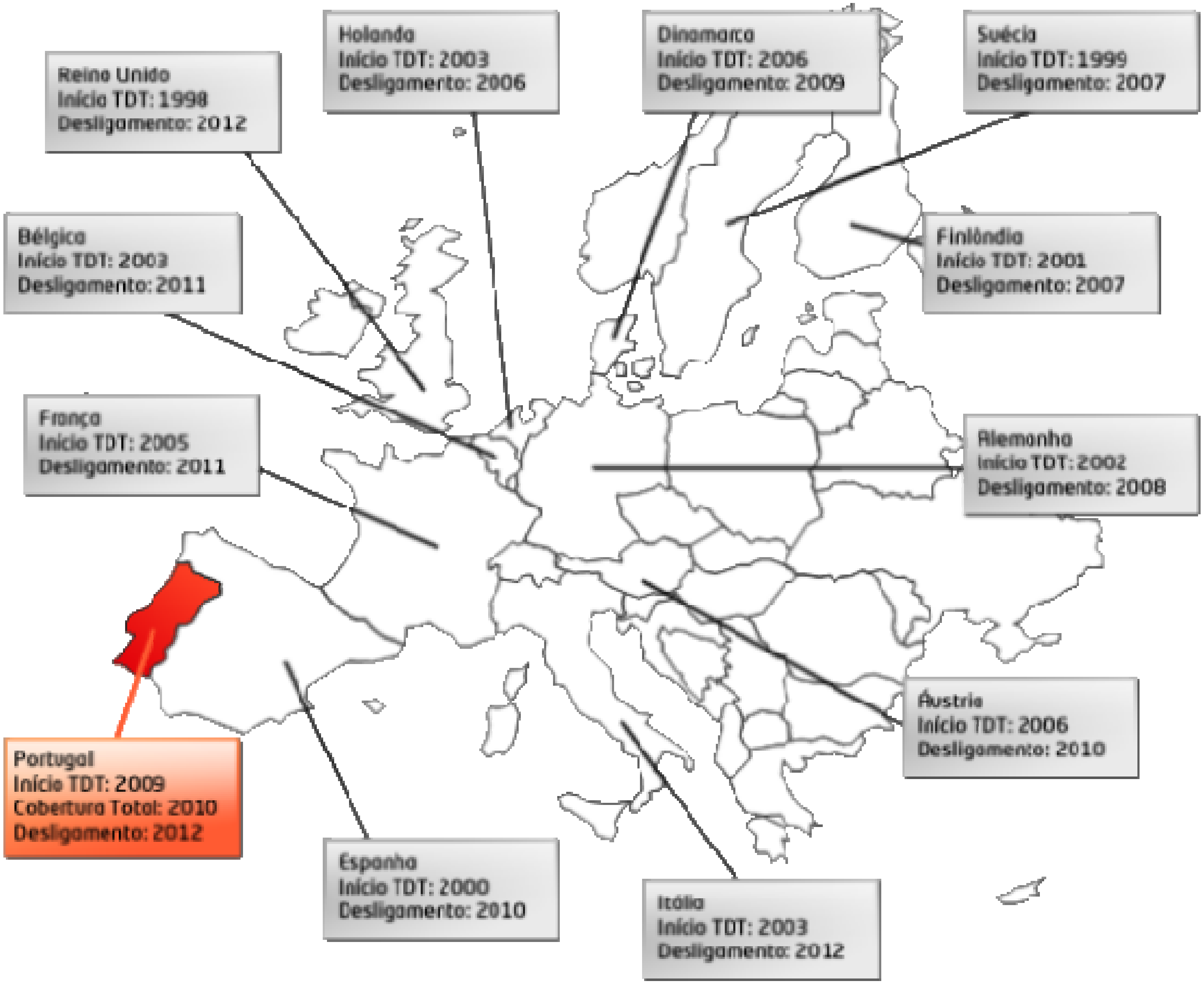
When the transmission conditions degrade, 16 points in the 64-QAM constellation may be taken as a single point in a QPSK constellation, allowing to receive, in good conditions, at least the 2 MSB bits.

DVB-T: Excellent Mobile Reception

Reception with spatial, temporal and frequency diversity …

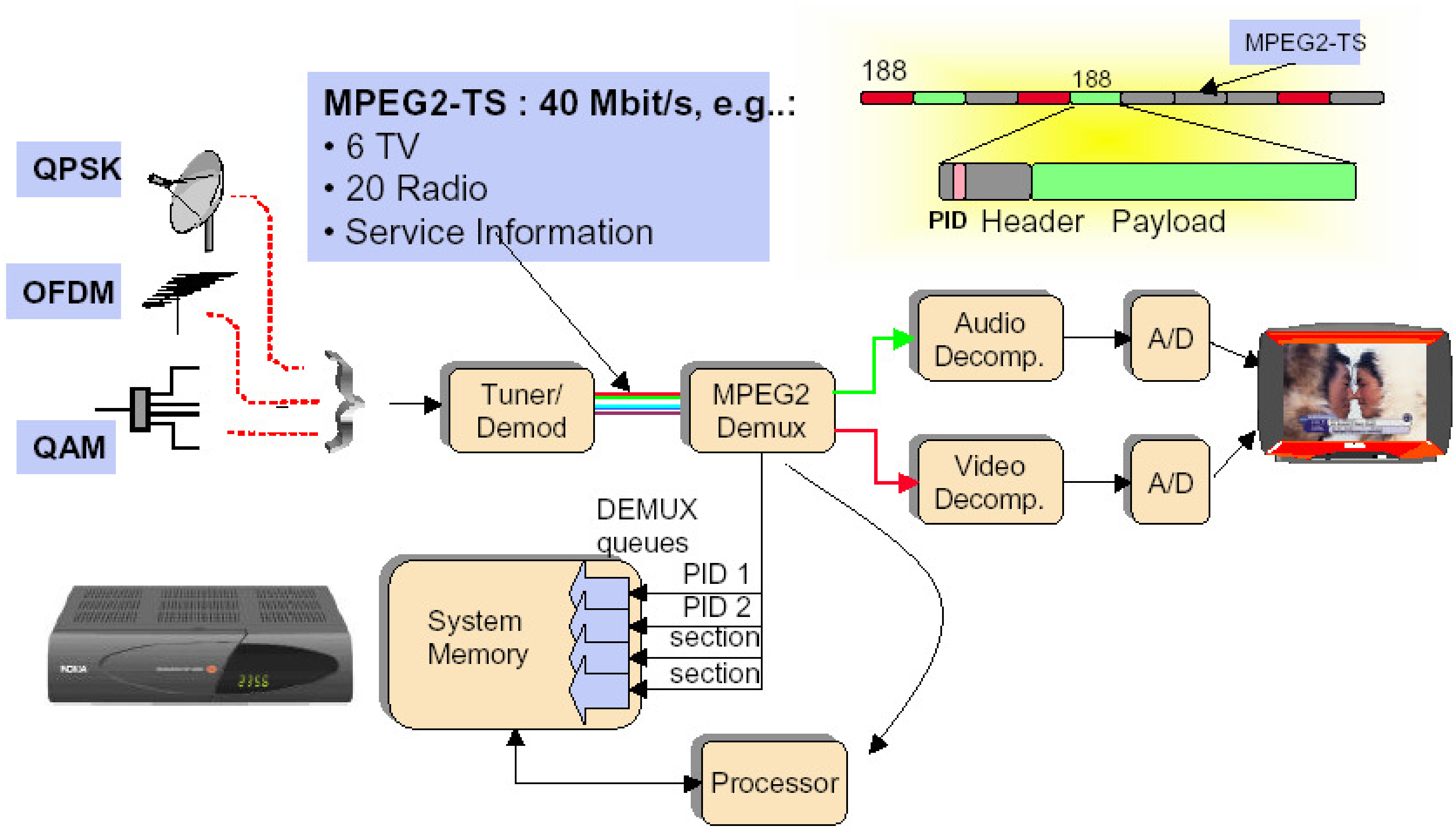
TDT in Portugal

- TDT in Portugal will use 6 multiplexers (A, B, C, D, E e F) and Single Frequency Networks (SFN).
- Multiplexer A will transmit the free channels already with license (RTP 1, RTP 2, SIC e TVI); the fifth channel was intended for this multiplexer but plans for it were withdrawn.
- Multiplexers B to F should be for pay TV.
- 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).
- By the 26th April 2012, the switch-off to digital should be 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 set-top boxes sold, especially in USA and Europe.**
- **Both Europe (DVB) and US (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.**

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

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- **R. de Bruin, J. Smits, *Digital Video Broadcasting*, Artech House, 1998**