Master Universitario di I livello in
Progettazione e gestione di sistemi di rete

Digital Terrestrial Television

Tecnologia di base

Part of the material shown on courtesy of Abe Elettronica, Andrews and Fondazione Ugo Bordoni

Raffaele Andreace – Unisolutions

Piccolo dizionario

- QAM - Quadrature Amplitude Modulation
- QPSK - Quadrature Phase Shift Keying
- COFDM - Coded Orthogonal Frequency Division Multiplexing
- DVB-S - Digital Video Broadcasting Satellite
- DVB-T - Digital Video Broadcasting Terrestrial
- DVB-H - Digital Video Broadcasting Hand-held
- MPEG-2 - Motion Picture Expert Group 2
- MHP - Multimedia Home Platform
- EPG - Electronic Programming Guide
- PVR - Personal Video Recording

Piccolo dizionario

- SFN - Single Frequency Network
- k-SFN - k > 1 SFN
- MFN - Multi Frequency Network
- MPX – Multiplex (Head-End)
- PNAF - Piano Nazionale di Assegnazione delle Frequenze
- MPEG-2 TS - MPEG-2 Transport Stream
- ITV Carousel - Interactive TV Carousel
- C/N – Carrier to Noise Ratio

Reti [k-]xFN

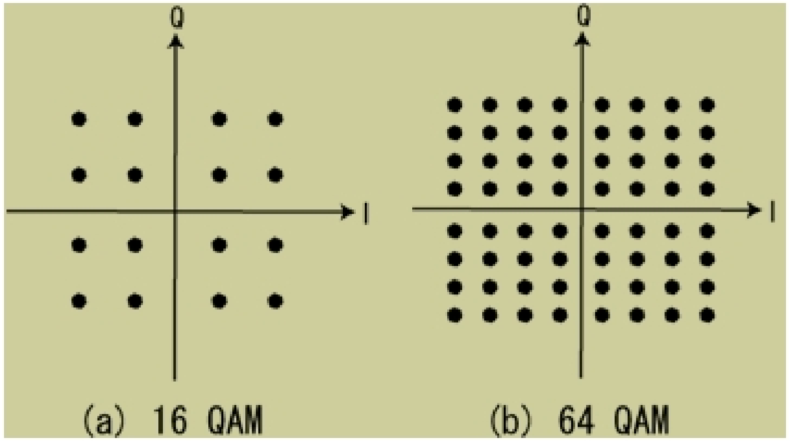
- Rete k-SFN detta anche rete MFN con estensioni realizzate attraverso SFN locali:
  - rete pianifi-cata a livello nazionale e costituita da k>1 “sottoreti” isofrequenziali SFN locali, ciascuna delle quali utilizza la composizione degli echi iso-frequenza che cadono all’interno della finestra di guardia. La copertura totale di una rete k-SFN nella specifica area geografica è data dalla somma delle coperture delle k “sottoreti”.
- Rete MFN Multi Frequency Network:
  - rete a copertura nazionale multifrequenza che non prevede la composizione costruttiva degli echi iso-frequenza che giungono al ricevitore all’interno della finestra di guardia.
- Rete SFN Single Frequency Network:
  - rete pianificata a livello nazionale che impiega una sola frequenza in tutti i siti di diffusione e che, grazie alle proprietà della tecnologia COFDM, è in grado di comporre positivamente gli echi iso-frequenza che giungano al ricevitore con un ritardo limitato ovvero, cadano all’interno della finestra di guardia.

QAM

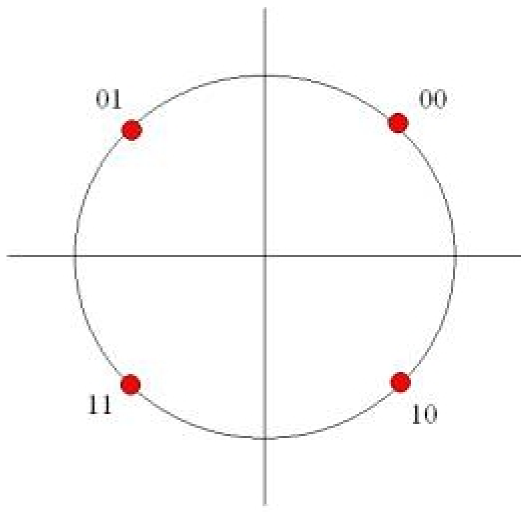
- The benefit of using 16-QAM or 64-QAM is that each symbol on each subcarrier can carry more bits of information. The number of bits that each symbol can carry is given by the following equation:
  - number of bits = log2 M

  where log2 is the logarithm to the base 2 and M is the order of the constellation.

So QPSK symbols (M=4) can carry 2 bits of information, 16-QAM symbols (M=16) can carry 4 bits of information, and 64-QAM symbols (M=64) can carry 6 bits of information.



QPSK



QPSK Signal Constellation

Rectangular Co-ordinate	Carrier Phase
0.707 + j0.707	45°
-0.707 + j0.707	135°
-0.707 - j0.707	225°
0.707 - j0.707	315°

DVB-T Background Information

- DVB-T networks can be planned in the same way as analogue networks, using an individual set of radio frequencies for each transmission site.
  - Migration is inherent in the system design

- Delayed signals arriving within the guard interval can be beneficial to a Coded Orthogonal Frequency Division Multiplex (COFDM) receiver, rather than interfering as with analogue signals.
  - Simulcast and multi-path are acceptable

- Single Frequency Networks (SFN) techniques can be used to fill gaps in coverage on both a small and large scale
  - F1-F1 Repeaters can be an important network component

DVB-T Background Information

- Coded Orthogonal Frequency Division Multiplex (COFDM) has many options for flexibility:
  - Number of Carriers: 8k-mode (896 μs) and 2k-mode (224 μs).
  - Modulation Schemes: QPSK, 16-QAM and 64-QAM
  - Bandwidth: 8MHz (preferred), 7MHz and 6MHz optional
  - Guard Intervals:

Proportion to the length of the useful interval	Length of the guard interval	
	8k-mode	2k-mode
1/4	224 μs	56 μs
1/8	112 μs	28 μs
1/16	56 μs	14 μs
1/32	28 μs	7 μs

Note: This guard interval is not enough to use most repeaters
All other guard intervals are acceptable

DVB-T C/N Requirements

- C/N requirements are higher for high priority signals than low priority signals

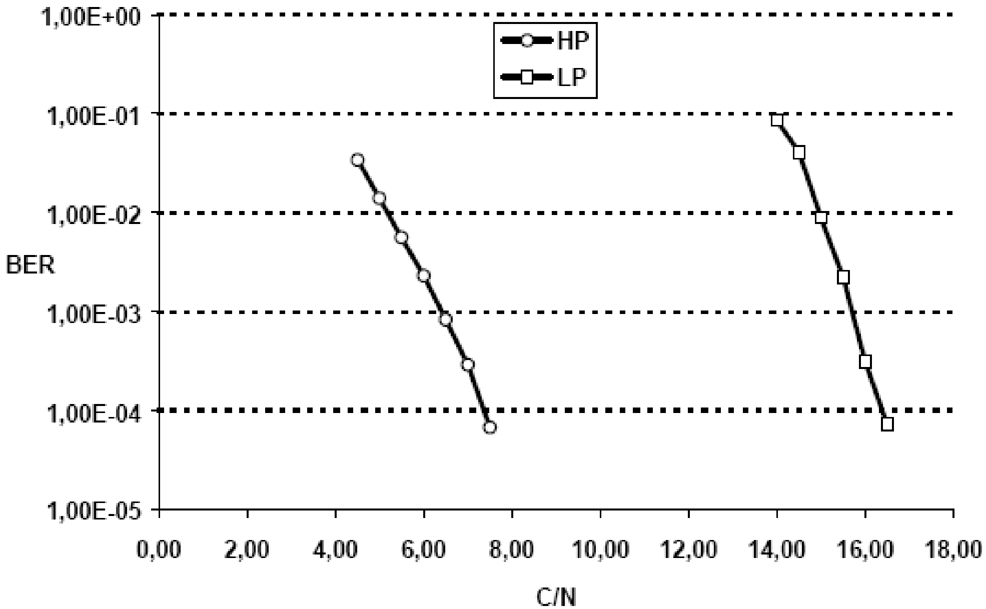


Figure 6: System performance for low and high priority bit-stream in a hierarchical transmission scenario (parameters: $\alpha = 2$; HP: QPSK, r = 2/3, LP: 16-QAM, r = 3/4)

Note: C/N dictates what feedback level is acceptable for F1-F1 repeaters
High priority requires a gain margin > C/N >15dB

C/N Carrier to Noise Ratio

- In communications, the carrier-to-noise ratio, often written CNR or C/N, is a measure of the received carrier strength relative to the strength of the received noise.

- High C/N ratios provide better quality of reception, and generally higher communications accuracy and reliability, than low C/N ratios.

- Engineers specify the C/N ratio in decibels (dB) between the power in the carrier of the desired signal and the total received noise power. If the incoming carrier strength in microwatts is P_c and the noise level, also in microwatts, is P_n, then the carrier-to-noise ratio, C/N, in decibels is given by the formula $C/N = 10 \log_{10}(P_c/P_n)$

- The C/N ratio is measured in a manner similar to the way the signal-to-noise ratio (S/N) is measured, and both specifications give an indication of the quality of a communications channel. However, the S/N ratio specification is more meaningful in practical situations.

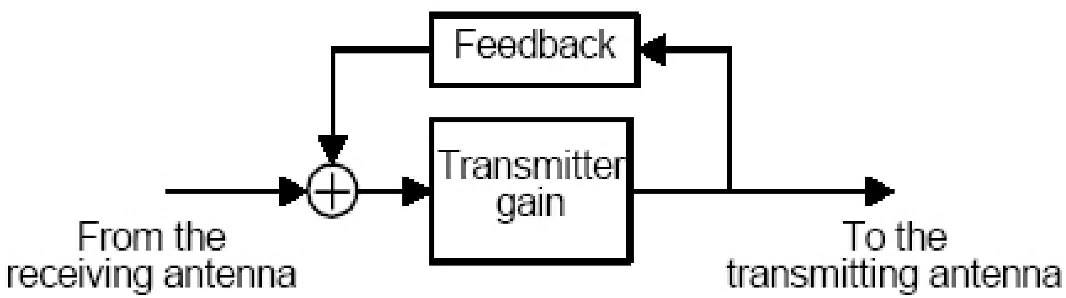
- The C/N ratio is commonly used in satellite communications systems to point or align the receiving dish; the best dish alignment is indicated by the maximum C/N ratio.

General Repeater Remarks

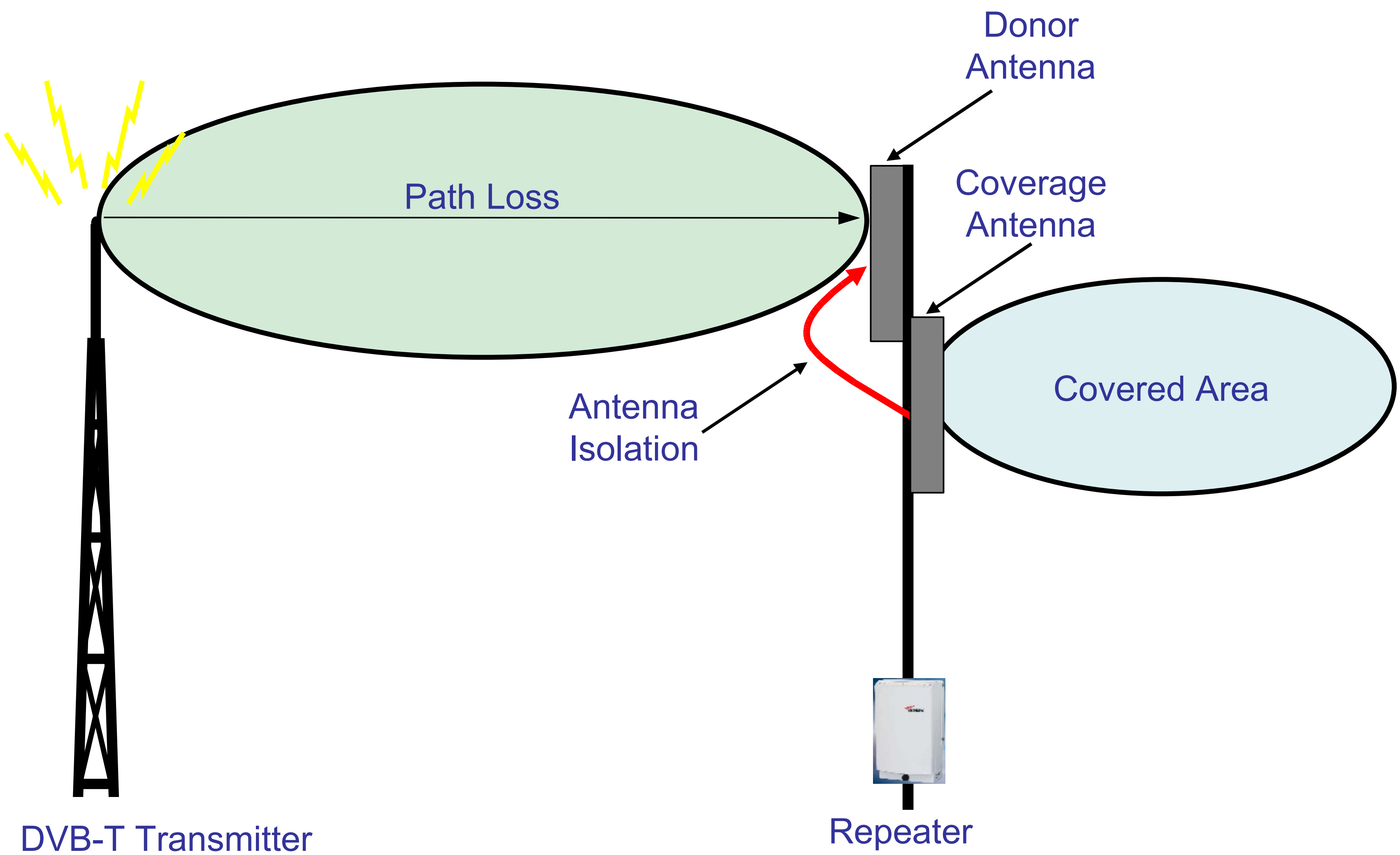
- An off-the-air RF repeater needs sufficient downlink input signal from the serving transmitter

- The selected repeater type should be capable of operating close to its rated power (limited by isolation usually)

- Antenna selection is important for DVB-T applications. Be aware the value of antenna gain as it is (nearly) intermodulation free. Antennas are much larger at lower frequency than higher frequency for the same gain



Repeater Setup Definitions



Interference Cancellation

- The Node-DVB-T has integrated ICE (Digital Interference Cancellation Equipment) algorithms are based on adaptive filtering techniques.

- This filter adapts to the dynamic multipath structure of the leakage signals and cancels them out.

- Node-C's ICE allows the unit to operate at negative gain margins while preventing oscillation and preserving wave form quality.

Node-DVB Gain Margin

Gain = Isolation + 20dB

Gain Margin (Node-C) = -20dB

Improvement = 35dB

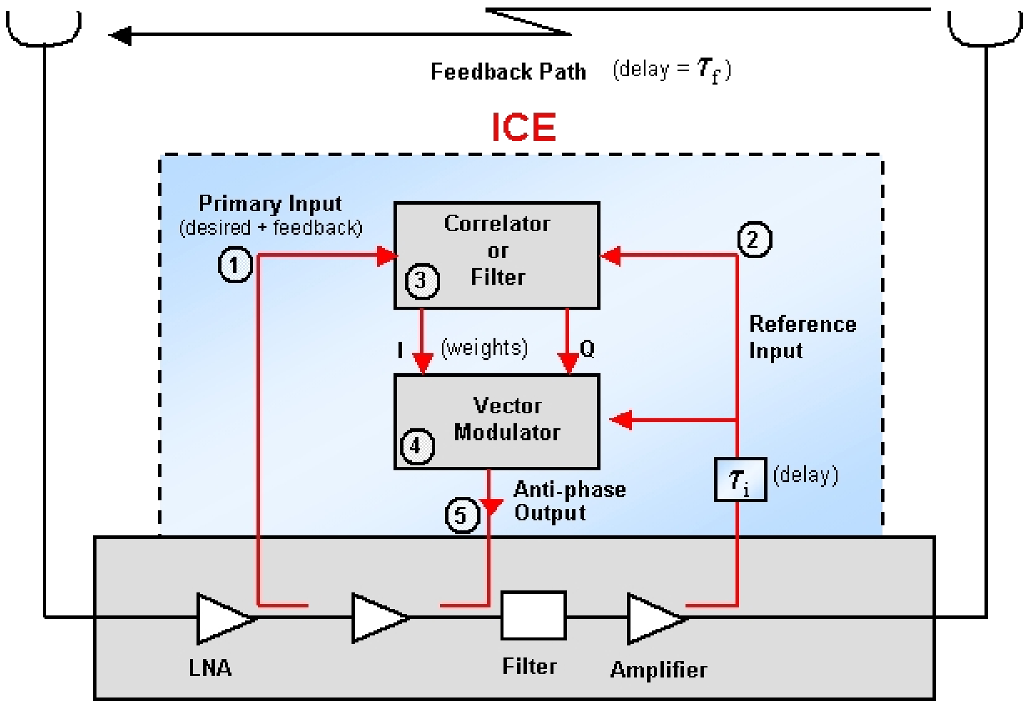
Standard Gain Margin

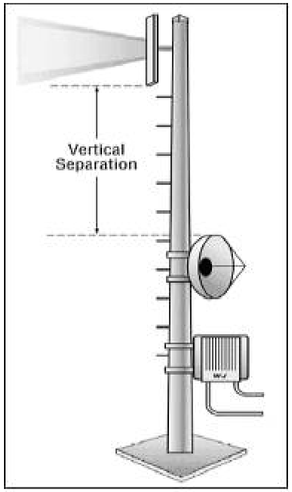
Gain = Isolation –15 dB

Gain Margin = +15dB

Interference Cancellation

- 16 MHz instantaneous bandwidth
- 35 dB cancellation (65 dB isolation for 85dB of gain)
- Automatic setup and continuous optimization





Node DVB-T Basic Specifications

- Power: 1-20W average
- Gain 50-85dB
- Bandwidth/Module: 1 or 2 * 8MHz blocks (3 blocks in roadmap)
- Expansion 2 modules possible (up to 6 blocks per unit)
- Raster: Variable
- Filtering: Selectable digital filter
- Setup: Possible measurement receiver
- Isolation: Interference cancellation
- Supervision Remote via a GSM/UMTS modem
- User Interface: Local and remote web based (http)
- Supervision: SNMP or SMS for connectivity

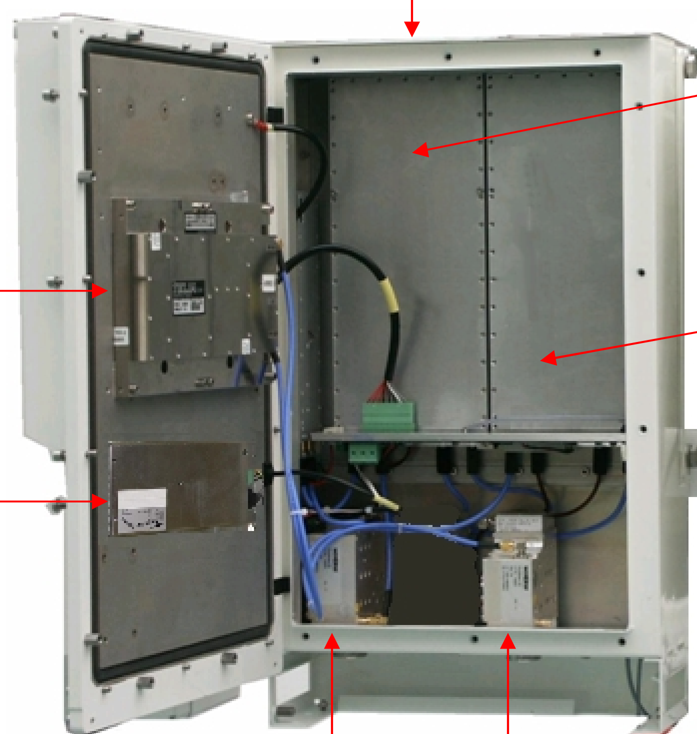
Node-DVB-T Unit

- Most components are field replaceable.

IP-65 Outdoor Cabinet

Linearized Multi-carrier Amplifier

Power Supply



Secondary Channel Module
- Filter (6-16MHz)
- Interference canceller

Primary Channel Module
- Filter (6-16MHz)
- Interference canceller
- Controller

Input and Output RF Filters

MPEG2 ENCODING COMMON PROFILES: 4:2:0 (MP@ML) AND 4:2:2

Uncompressed digital video and audio signals have high data rate - typically one programme requires a bit-rate of 270Mbit/s (Serial Digital Interface (SDI) 75 ohm BNC coaxial connectors).

If uncompressed data were to be transmitted as is, the occupied RF bandwidth would be much greater than in the analogue case → It is necessary, therefore, to compress such data to a lower rate, making it suitable for transmission over microwave links and for distribution or broadcasting to viewers.

This compression is required ideally, not to degrade the quality of the video or audio signals.

The designated international coding standard for this purpose is MPEG-2 (Motion Picture Expert Group version 2) which is able to compress a TV programme from 270Mbit/s **to only 5 or 6Mbit/sec while maintaining excellent quality characteristics.**

Compression to less than (3 or) 4Mbit/s is possible but quality will be compromised.

MPEG-2

Human visual perception is more sensitive to luminance than chrominance → Less information (data) about the colour is therefore transmitted.

Adjacent areas within the picture often have pixels with the same luminance and chrominance values. During encoding these are combined so as to transmit less data.

Only the differences between one picture frame and the next are transmitted.

This process is carried out several times over a Group Of Pictures (GOP) before eventually transmitting a complete frame again.

GOPs – Groups of Pictures – are made up from three different kinds of information frames:

- **I-frame**: the complete image or picture frame (the largest in terms of the data transmitted)
- **P-frame**: the differences between an actual and the previous I or P-frame (smaller than an I-frame)

I→P or P→P

- **B-frame**: the differences between the previous and the following I or P frames (the smallest frame, but which cannot be repeated too many times).

I←B→P or P←B→I or P←B→P or I←B→I

MPEG-2

Usually GOPs are constituted with one I-frame, some P-frames and, possibly, some B-frames.

They should not be too long because should an error occur, it would be perpetuated.

Furthermore, a decoder requires a complete picture (I-frame) to begin decoding, so has to wait for the start of a GOP.

One of the most usual and efficient GOP structures is 12 frames long and is constituted as follows: **I B B P B B P B B P B B.**

The most common encoding data profiles are 4:2:0 (Main Profile @ Main Level or MP@ML) and 4:2:2.

MPEG-2 MP@ML

MP@ML 4:2:0 – The video is encoded with a ratio of 4 data elements for luminance to 2 for chrominance.

ADVANTAGES:

- This encoding ratio matches the visual perception characteristic
- Optimum performance, particularly for low Bit-Rate transmission

USES:

- Broadcasting (the profile used in both terrestrial and satellite broadcasting)
- Contribution and Distribution networks
- Intra-studio links between analogue and digital mixers

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MPEG 2 4:2:2

4:2:2 – The Video is encoded with a ratio of 4 data elements for luminance to 4 for chrominance

ADVANTAGES:

- · Slightly better performance than 4:2:0 profile, but only when the Bit-Rate is over
- 10MBit/s

USES:

- · Intra-studio links between digital mixers

Why MP@ML

Comparative tests, according to ITU recommendations, were based on subjective evaluation by a group of observers, viewing digital TV pictures after encoding at 2, 3, 4 or 5Mbit/s. The results established that, for the each Bit-Rate, 4:2:0 was preferable to 4:2:2 encoding.

A video sequence encoded with 4:2:0 at 10Mbit/s has the same quality when encoded using 4:2:2 profile, but at 13Mbit/s

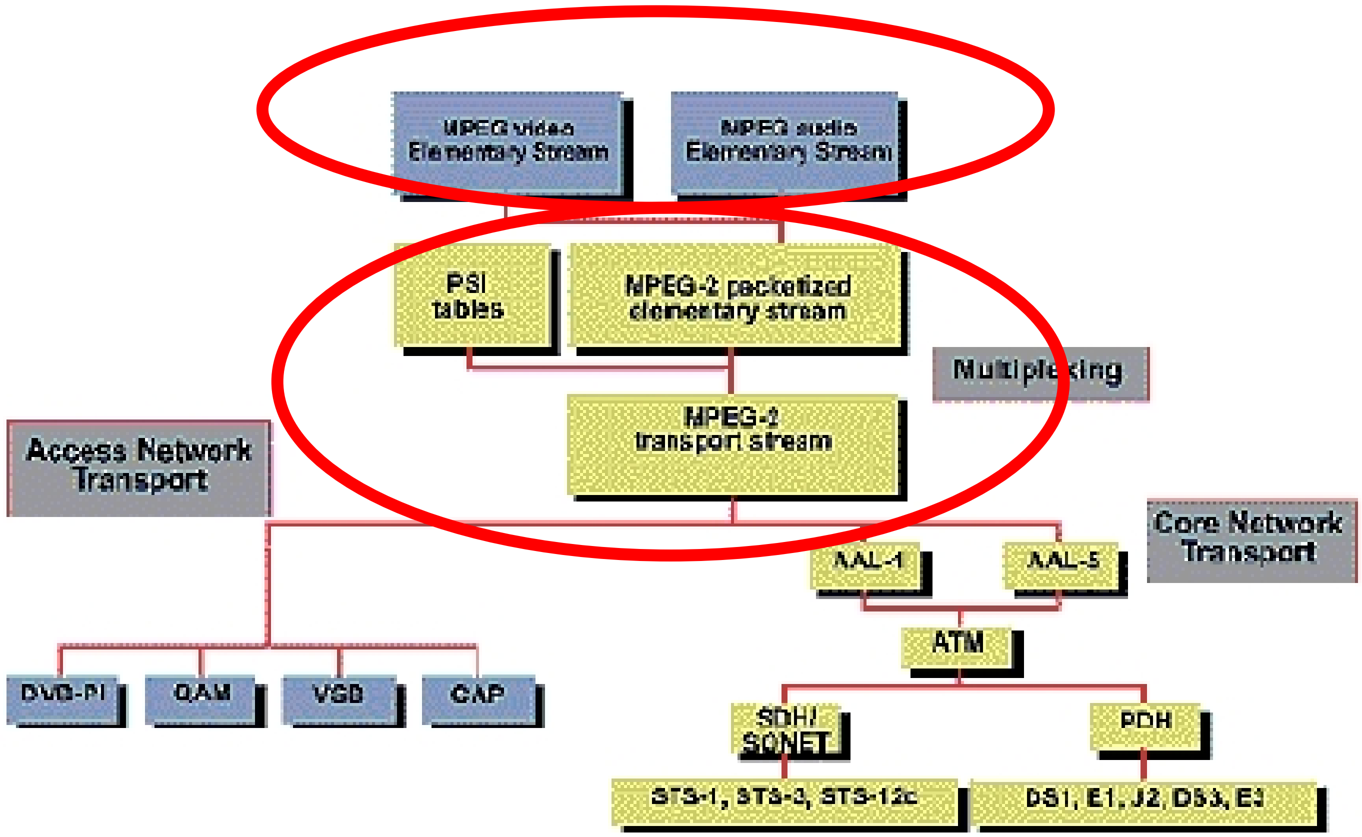
It is preferable to use the 4:2:0 profile for Bit-Rates under 10Mbit/s, especially for picture sequences with high motion content.

Note that it is extremely difficult to detect quality differences on picture sequences encoded at over 10Mbit/s, since the quality is already so high that differences are very difficult to perceive.

The limited advantages of the 4:2:2 profile compared with 4:2:0 with Bit-Rates over 10Mbit/s disappear if the source signals are analogue in origin and converted to digital.

Considering that it is now unusual (and expensive) to use Bit-Rates of 15-20Mbit/s just for a single programme, the encoding profile used is nearly always 4:2:0 (MP@ML)

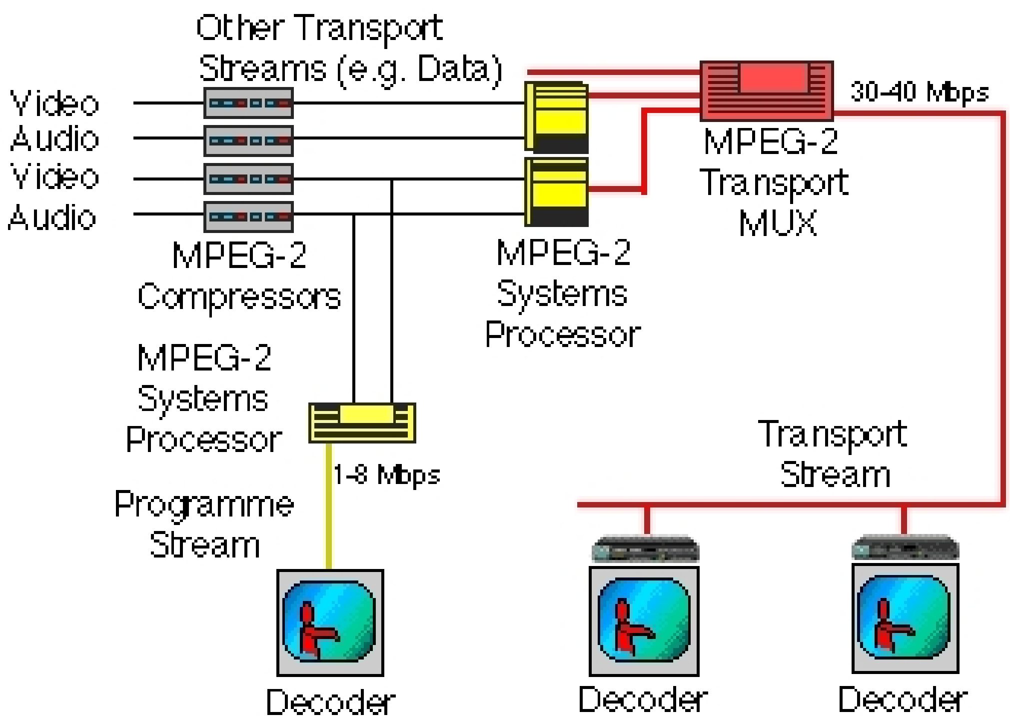
MPEG 2 ES, PSI, PES, TS



MPEG 2 ES

- ES = Elementary Stream (audio o video)
- PES = Packetized ES
- SI = (Program) Service Information
- PSI = Program Specific Information

MPEG 2 PS, TS = PES multiplexing



- **MPEG Program Stream**
  - A group of tightly coupled PES packets referenced to the same time base. Such streams are suited for transmission in a relatively error-free environment and enable easy software processing of the received data. This form of multiplexing is used for video playback and for some network applications.

MPEG Transport Stream

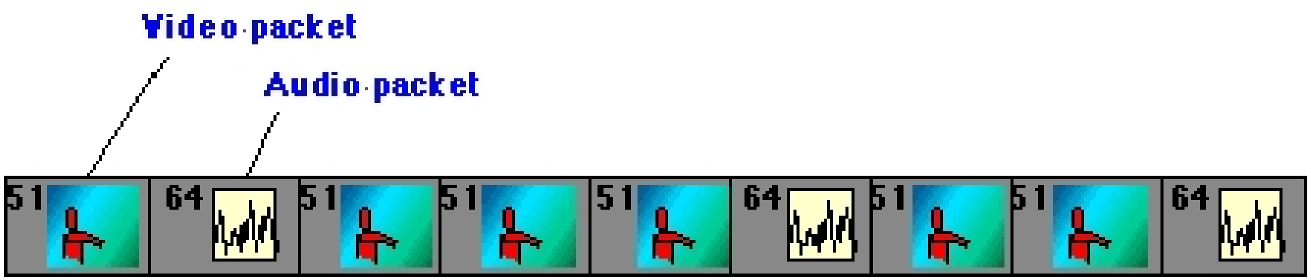
- Each **PES packet is broken into fixed-sized transport packets** forming a general purpose way of **combining one or more streams**, possibly with **independent time bases**. This is suited for transmission in which there may be potential packet loss or corruption by noise, or / and where there is a need to send more than one programme at a time.

MPEG Transport Streams

- A transport stream consists of a sequence of fixed sized transport packet of 188 B. Each packet comprises 184 B of payload and a 4 B header. One of the items in this 4 B header is the 13 bit *Packet Identifier (PID)* which plays a key role in the operation of the Transport Stream.
- The format of the transport stream is described using the figure below which shows two elementary streams sent in the same MPEG-2 transport multiplex.
- Each packet is associated with a PES through the setting of the PID value in the packet header (the values of 64 and 51 in the figure).
- The audio packets have been assigned PID 64, and the video packets PID 51 (these are arbitrary, but different values).

MPEG Transport Streams

- As is usual, there are more video than audio packets, but you may also note that the two types of packets are not evenly spaced in time.
- The MPEG-TS is not a time division multiplex, packets with any PID may be inserted into the TS at any time by the TS multiplexor.
- If no packets are available at the multiplexor, it inserts null packets (denoted by a PID value of 0x1FFF) to retain the specified TS bit rate.
- The multiplexor also does not synchronise the two PESs, indeed the encoding and decoding delay for each PES may (and usually is different). A separate process is therefore require to synchronise the two streams



Single Program Transport Stream (Audio and Video PES).

Single and Multiple Program Transport Streams

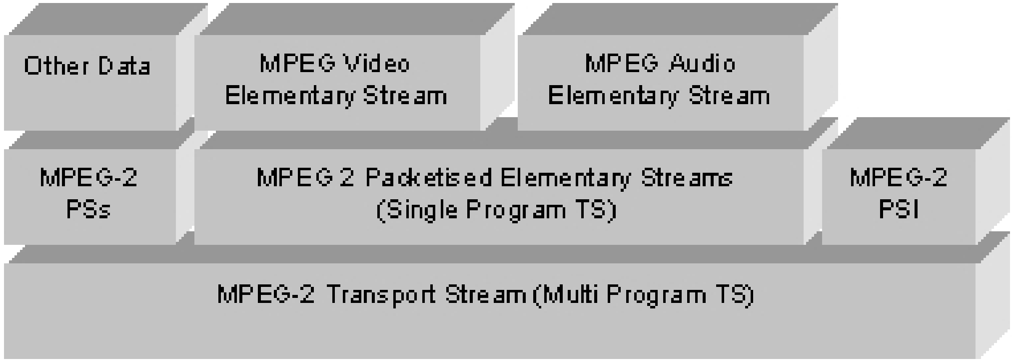
- A TS may correspond to a single TV programme, or multimedia stream (e.g. with two a video PES and an audio PES). This type of TS is normally called a *Single Programme Transport Stream (SPTS)*.

- An SPTS contains all the information requires to reproduce the encoded TV channel or multimedia stream. It may contain only an audio and video PESs, but in practice there will be other types of PES as well. Each PES shares a common timebase. Although some equipments output and use SPTS, this is not the normal form transmitted over a DVB link.

- In most cases one or more SPTS streams are combined to form a *Multiple Programme Transport Stream (MPTS)*.

- This larger aggregate also contains all the control information *(Program Specific Information (PSI))* required to co-ordinate the DVB system, and any other data which is to be sent.

Single and Multiple Program Transport Streams



Streams supported by the MPTS

Synchronization (Timestamping)

- Most transport streams consist of a number of related elementary streams (e.g. the video and audio of a TV programme). The decoding of the elementary streams may need to be co-ordinated (synchronised) to ensure that the audio playback is in synchronism with the corresponding video frames.

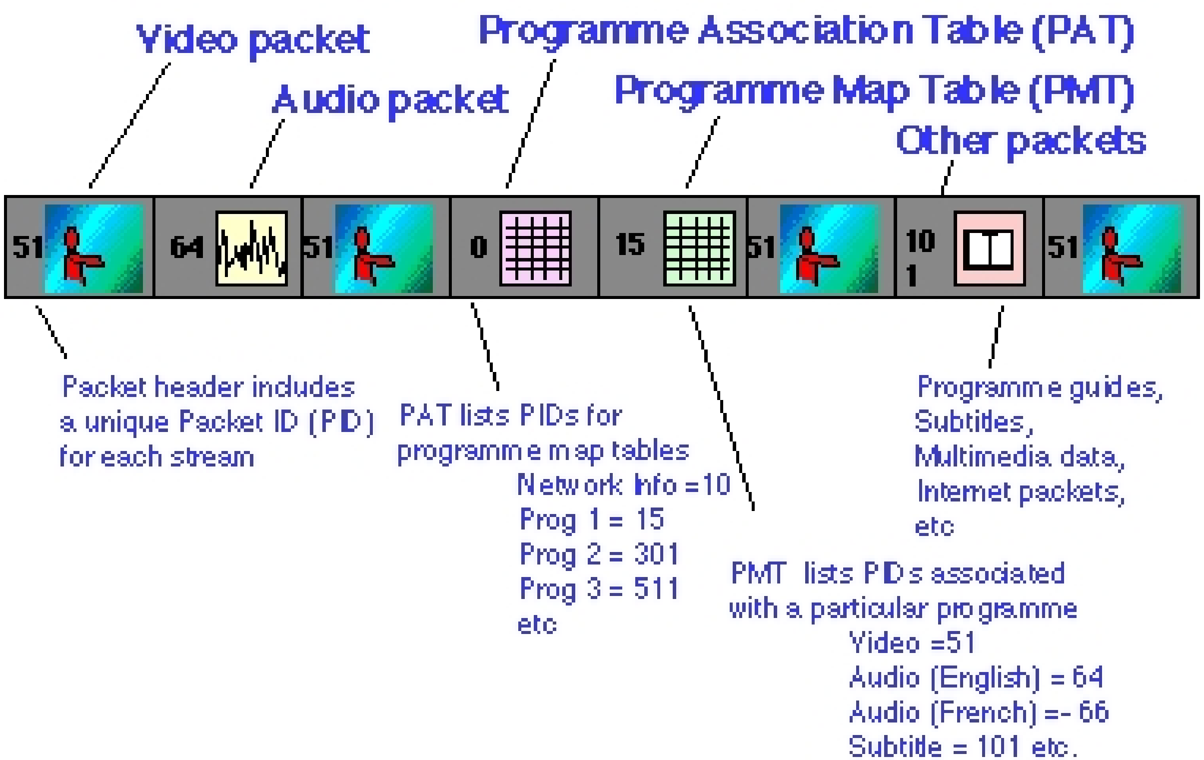
- Each stream may be tightly synchronised (usually necessary for digital TV programs, or for digital radio programs), or not synchronised (in the case of programs offering downloading of software or games, as an example). To help synchronisation time stamps may be (optionally) sent in the transport stream.

- They are two types of time stamps:
  - The first type is usually called a ***reference time stamp***. This time stamp is the indication of the current time. Reference time stamps are to be found in the PES syntax (ESCR), in the program syntax (SCR), and in the transport packet adaption *Program Clock Reference (PCR)* field.
  - The second type of time stamp is called ***Decoding Time Stamp*** *(DTS)* or ***Presentation Time Stamp*** *(PTS)*. These time stamps are inserted close to the material to which they refer (normally in the PES packet header). They indicate the exact moment where a video frame or an audio frame has to be decoded or presented to the user respectively. **These rely on reference time stamps for operation.**

Signalling Tables (no synch)

- For a user to receive a particular transport stream, the user must first determine the PID being used, and then filter packets which have a matching PID value.
- To help the user identify which PID corresponds to which programme, a special set of streams, known as *Signalling Tables*, are transmitted with a description of each program carried within the MPEG-2 Transport Stream.
- Signalling tables are sent separately to PES, and are not synchronised with the elementary streams (i.e they are an independent control channel).
- The tables (called *Program Specific Information (PSI)* in MPEG-2) consist of a description of the elementary streams which need to be combined to build programmes, and a description of the programmes.
- Each PSI table is carried in a sequence of PSI *Sections*, which may be of variable length (but are usually small, c.f. PES packets). Each section is protected by a *CRC* (checksum) to verify the integrity of the table being carried. The length of a section allows a decoder to identify the next section in a packet.
- **A PSI section may also be used for down-loading data to a remote site**. Tables are sent periodically by including them in the transmitted transport multiplex.

Signalling Tables (no synch)



DVB Signalling Tables and Transport Layer PIDs

MPEG-2 SI

Programme Service Information (SI) provided by MPEG-2 and used by DVB

PAT - Program Association Table (lists the PIDs of tables describing each programme). The PAT is sent with the well-known PID value of 0x000.

CAT - Conditional Access Table (defines type of scrambling used and PID values of transport streams which contain the conditional access management and entitlement information (EMM)).

The PAT is sent with the well-known PID value of 0x001.

PMT - Program Map Table (defines the set of PIDs associated with a programme, e.g. audio, video, ...)

NIT - Network Information Table (PID=10, contains details of the bearer network used to transmit the MPEG multiplex, including the carrier frequency)

DSM-CC - Digital Storage Media Command and Control (messages to the receivers)

DVB Signalling Tables
Service Information (SI) provided by DVB

- To identify the required PID to de-multiplex a particular PES, the user searches for a description in a particular table, the *Program Association Table (PAT)*. This lists all programmes in the multiplex. Each programme is associated with a set of PIDs (one for each PES) which correspond to a *Programme Map Table (PMT)* carried as a separate PSI section. There is one PMT per programme. DVB also adds a number of additional tables including those shown below.

- In addition to the PSI carried in each multiplex (MPTS), a service also carries information relating to the service as a whole. Since a service may use a number of MPTS to send all the required programs. Information is provided in the PSI tables defined by DVB. Each PSI table refers to the MPTS in which it is carried and any other MPTSs which carry other TS which are offered as a part of the same service.

BAT- Bouquet Association Table (groups services into logical groups)

SDT- Service Description Table (describes the name and other details of services)

TDT - Time and Date Table (PID=14, provides present time and date)

RST - Running Status Table (PID=13, provides status of a programmed transmission, allows for automatic event switching)

EIT - Event Information Table (PID=12, provides details of a programmed transmission)

PES insertion in TS

Two options are possible for inserting PES data into the TS packet payload:

- The simplest option, from both the encoder and receiver viewpoints, is to send only one PES (or a part of single PES) in a TS packet. This allows the TS packet header to indicate the start of the PES, but since a PES packet may have an arbitrary length, also requires the remainder of the TS packet to be padded, ensuring correct alignment of the next PES to the start of a TS packet. In MPEG-2 the padding value is the hexadecimal byte 0xFF.

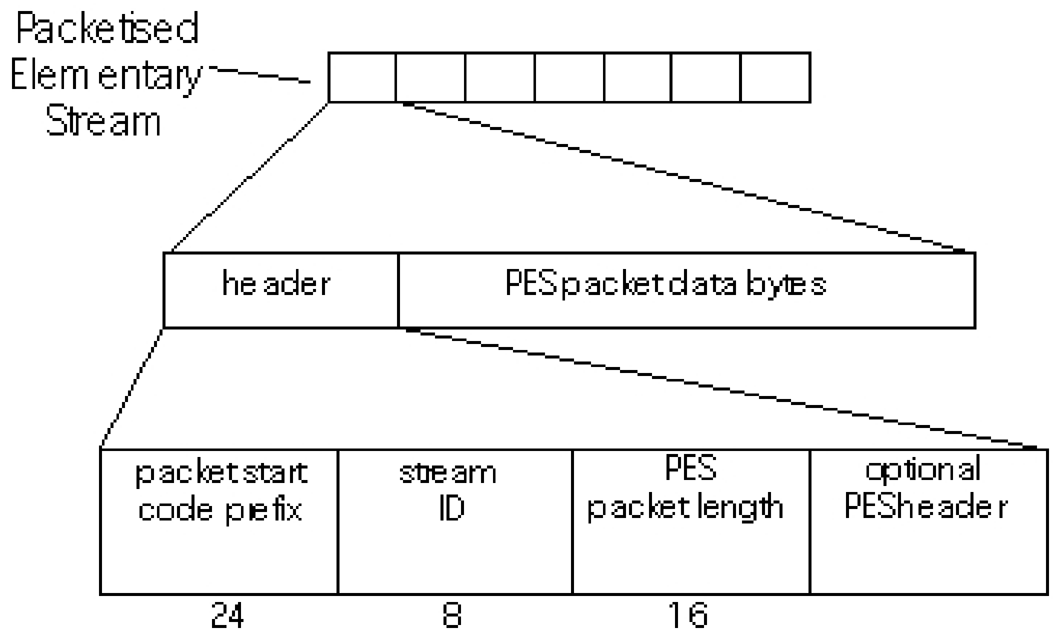
- In general a given PES packet spans several TS packets so that the majority of TS packets contain continuation data in their payloads.

- When a PES packet is starting, however, the payload_unit_start_indicator bit is set to ‘1’ which means the first byte of the TS payload contains the first byte of the PES packet header.

- Only one PES packet can start in any single TS packet.

- The TS header also contains the PID so that the receiver can accept or reject PES packets at a high level without burdening the receiver with too much processing. This has an impact on short PES packets

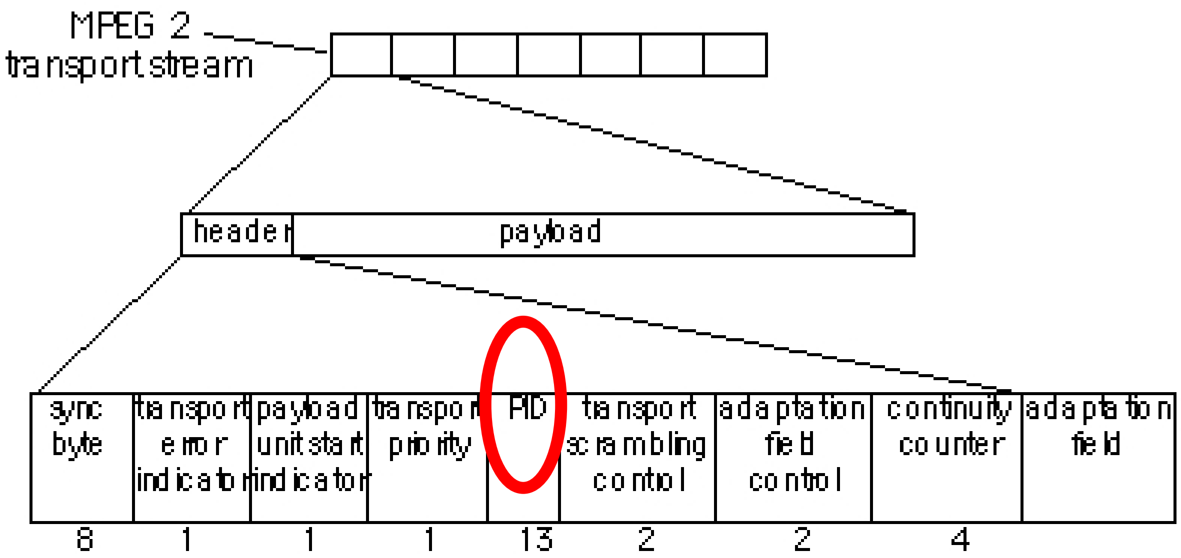
PES insertion in TS



MPEG PES mapping onto the MPEG-2 TS

Format of a Transport Stream Packet

- Each MPEG-2 TS packet carries 184 B of payload data prefixed by a 4 B (32 bit) header.



Multiple TS

- Each MPEG-2 MPTS multiplex carries a number of streams which in combination deliver the required services. Here is a sample break-down of the various MPEG-2 streams being used to provide a terrestrial 24 Mbps TV multiplex:

Stream	bit rate (kbps)
SI	300
PSI	546
Digital Teletext	754
Total per Mux	1600

Sample per-multiplex overheads

Stream	bit rate (kbps)
TV Video *	5000
Stereo Audio	270
SubTitles	50
Conditional Access	600
Total Programme	5920

Bit rate per programme

- This allows a standard 8 MHz channel to carry 5 TV channels or 4 higher quality channels without conditional access or 3 high quality channels with conditional access.

- The remaining bandwidth may be used for other services such EPG Audio Descriptions for the visually impaired (~ 70 kbps), Signing for the deaf (~ 400 kbps using a separate window), house pages, digital data, software down-loads, application etc.

Digital Satellite TV (DVB-S)

- A typical satellite channel has **36 MHz bandwidth**, which may support transmission at up to **35-40 Mbps** (assuming delivery to a 0.5m receiving antenna) using Quadrature Phase Shift Keying (QPSK) modulation.

- The video, audio, control data and user data are all formed into fixed sized MPEG-2 transport packets. The MPEG TS packets are grouped into 8 packet frames (1503 B).

- The frames do not have any additional control information, but to enable the receiver to find the start of each frame, the TS-header byte is inverted (0xB8) in the first TS packet of each frame.

- The frames are then passed through a convolutional (organ-pipe) interleaver to ensure the data follows an approximately random pattern, assuring frequency dispersion of the modulated signal.
- At the start of each frame, the scrambler is re-initialised.

- 16 bytes of Reed Solomon (RS) coding are added to each 188 byte transport packet to provide Forward Error Correction (FEC) using a RS(204,188,8) code. For the satellite transmission, the resultant bit stream is then interleaved and convolutional coding is applied.

- The level of coding ranges from 1/2 to 7/8 depending on the intended application and available bandwidth.
- The digital bit stream is then modulated using QPSK modulation.

Digital Satellite TV (DVB-S)

The complete coding process may be summarised by:

- Inverting every 8th Synchronisation byte
- Scrambling the contents of each packet
- Reed-Solomon (RS) coding at 8% overhead
- Interleaved convolutional coding (the level of coding ranges from 1/2 to 7/8 depending on the intended application)
- The resulting bit stream is modulated using Quadrature Phase Shift Keying (QPSK).

Digital Terrestrial TV (DVB-T)

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- A standard TV channel is 8 (7) MHz wide, accommodating the TV signal in Phase Alternate Line (PAL) format and the sound subcarrier.

- The same 8 MHz of bandwidth may be used to provide a **24 Mbps** digital transmission path using Coded Orthogonal Frequency Division Multiplexing (COFDM) modulation. This may support up to 6 digital TV channels.

- The information is transmitted in the following manner:
  - COFDM or Quadrature Phase Modulation (QPSK) (COFDM uses either 1705 carriers (usually known as '2k'), or 6817 carriers ('8k'))
  - Reed-Solomon (RS) coding at 8% overhead
  - Interleaved convolutional coding (the level of coding depends on the intended application)

- Multiplex: RAI = 2 (+ RAI3 …) , Mediaset = 2, LA 7 = 1 …