An introduction to MPEG-TS

all you should know before transport a stream

Version IX, copied from others 😉 reassembled by BLANKOM

Topics

- MPEG transport streams
  - packets, sections, tables, PES, demux
- DVB SimulCrypt
  - architecture, synchronization, ECM, EMM, scrambling
- Standards
  - MPEG, DVB, others

Transport streams

packets and packetization

Standard key terms

- Service / Program
  - DVB term: service
  - MPEG term: program
  - TV channel (video and / or audio)
  - data service (software download, application data)
- Transport stream
  - aka. « TS », « multiplex », « transponder »
  - continuous bitstream
  - modulated and transmitted using one given frequency
  - aggregate several services
- Signalization
  - set of data structures in a transport stream
  - describes the structure of transport streams and services

MPEG-2 transport stream

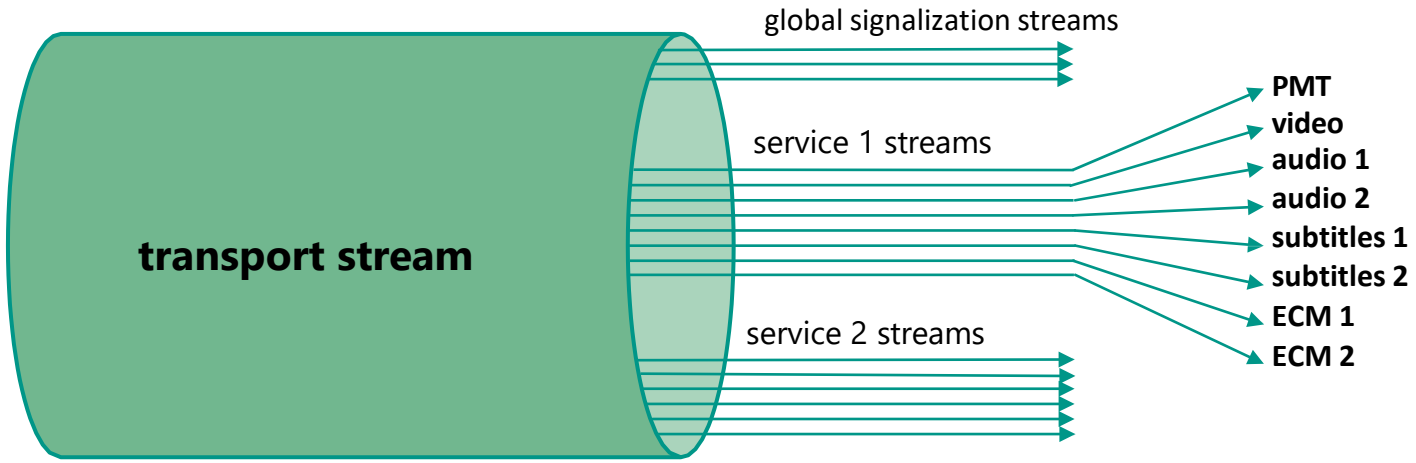
- Structure of MPEG-2 TS defined in ISO/IEC 13818-1
- One operator uses several TS
- TS = synchronous stream of 188-byte TS packets
  - 4-byte header
  - optional « adaptation field », a kind of extended header
  - payload, up to 184 bytes
- Multiplex of up to 8192 independent elementary streams (ES)
  - each ES is identified by a Packet Identifier (PID)
  - each TS packet belongs to a PID, 13-bit PID in packet header
  - smooth muxing is complex, demuxing is trivial
- Two types of ES content
  - PES, Packetized Elementary Stream: audio, video, subtitles, teletext
  - sections: data structures

Multiplex of elementary streams

- A transport stream is a multiplex of elementary streams
  - elementary stream = sequence of TS packets with same PID value in header
  - one set of elementary streams for global signalization

    describe the TS, the network, the operator, the services, the events, EMM's, etc.
  - one set of elementary streams per service

    a service is typically a TV channel



TS packet

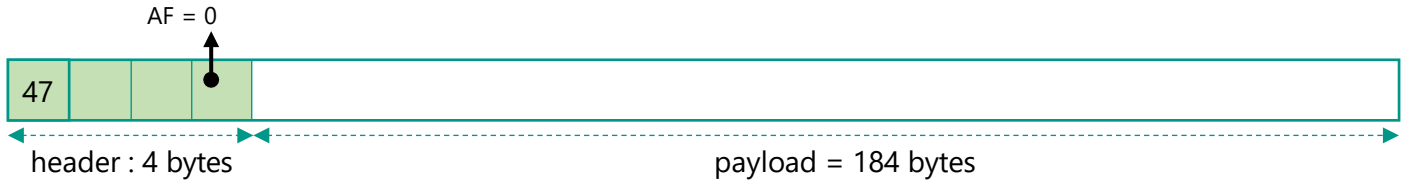
4-byte header includes:

- Sync byte = 0x47
- PID : 13 bits
- Continuity counter : 4 bits
- Payload Unit Start Indicator (PUSI) : 1 bit
- Transport scrambling control : 2 bits
- Adaptation field presence : 1 bit
- Payload presence : 1 bit
- More…

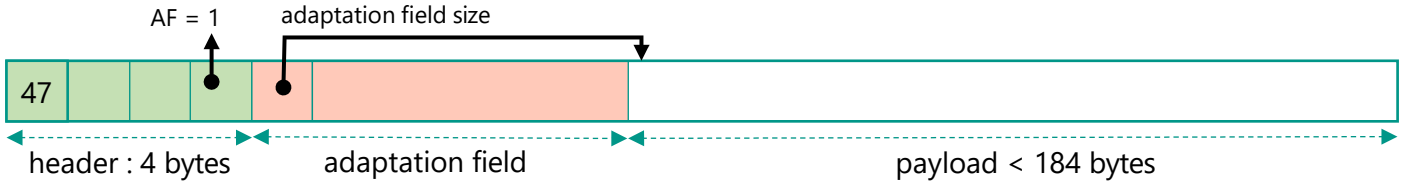
Adaptation field may include:

- Program Clock Reference (PCR / OPCR)
- Private data
- Stuffing (for PES stream padding)
- More…

TS packet without adaptation field



TS packet with adaptation field

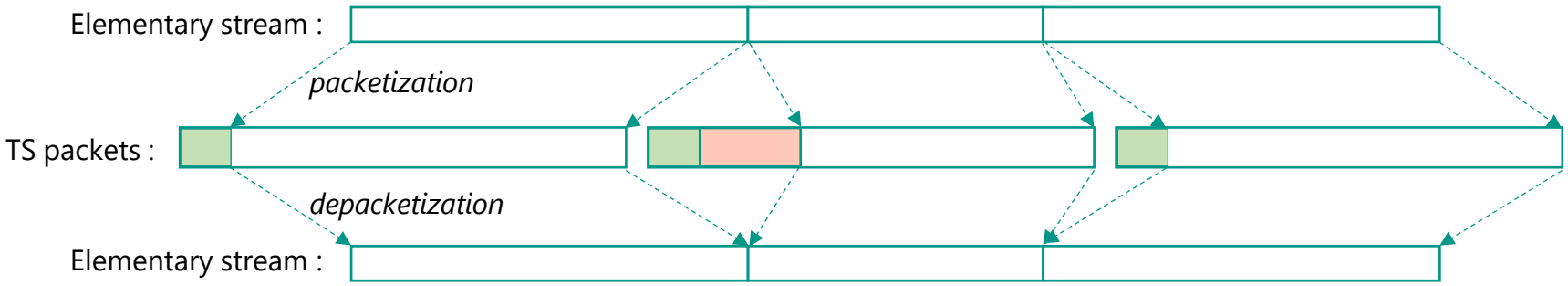


Multiplexing and demultiplexing

- Elementary stream = concatenation of all payloads of all TS packets with same PID
- Elementary stream transport
  - packetization = cutting ES into packets payloads with same PID

    setting Payload Unit Start Indicator (PUSI) in TS header on « unit » boundary
  - multiplexing = mixing with packets from other PID's to build a complete TS
  - demultiplexing = extracting all packets with same PID from TS
  - depacketization = rebuilding ES from packets payloads with same PID

    using PUSI to resynchronize on « unit » boundary



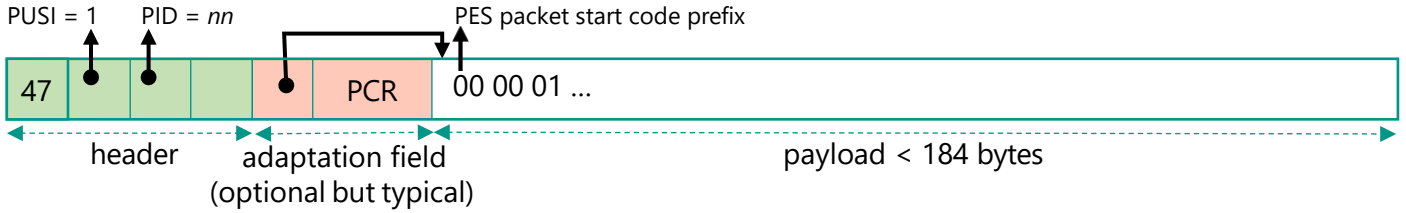
Packetized Elementary Stream (PES)

- A stream of PES packets
  - up to 65536 bytes per PES packet
  - start of PES packet identified by PUSI bit in TS header
- PES packets can contain
  - video : MPEG-2 (H.262), AVC (H.264), HEVC (H.265), etc.
  - audio : MPEG-2 Layer 2, AAC, HE-AAC, AC-3, DTS, DTS-HD, etc.
  - DVB subtitles (text or bitmap)
  - teletext (deprecated but still used)
- One elementary stream contains one single type of content
  - video
  - audio for one language (with or without « audio description »)

    multi-channel audio (stereo, 5+1, etc.) within same PID
  - subtitles for one language (with or without « for hard of hearing »)
  - exception : one teletext stream is a multiplex of several text streams (« pages »)

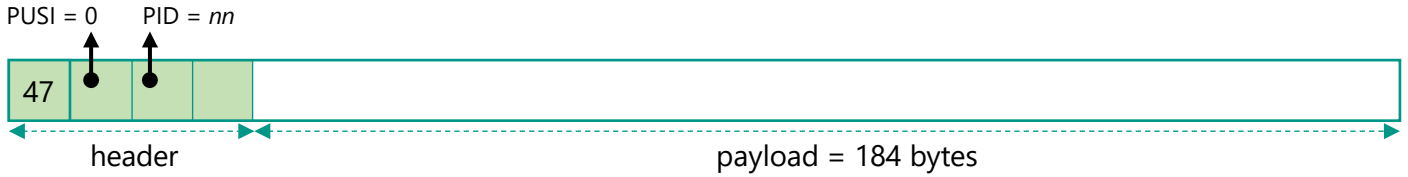
Typical PES packetization

First TS packet for PES packet

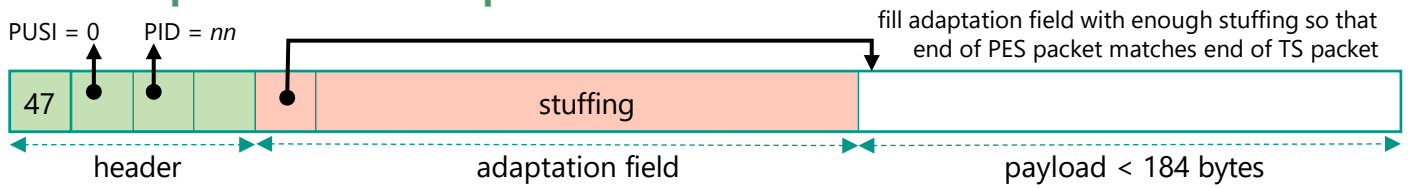


As many intermediate TS packets as required for current PES packet

(multiplexed with TS packets from others PID's)



Last TS packet for PES packet



PES streams robustness

- TS packet loss is tolerated in audio and video streams
  - video « macro-block » effect
  - audio « glitch » effect
  - quality of recovery based on decoder implementation
- TS packet loss detection based on *continuity_counter*
  - 4-bit field in TS packet header
  - cannot detect loss of an exact multiple of 16 TS packets
  - resynchronization on next TS packet with PUSI
- But video / audio decoders can resynchronize within PES packet
  - video / audio bitstream formats usually contain synchronization patterns
  - example: NAL unit boundary in AVC encoding

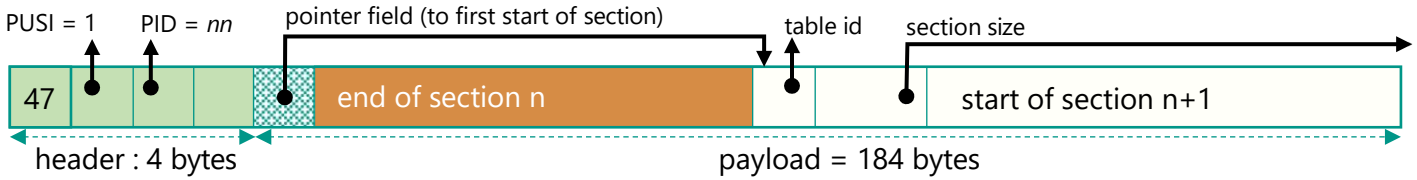
Sections streams

- Contain data structures named « tables »
- A table is split into one or more « sections »
  - section = smallest data unit, up to 4096 bytes
  - standard header and type-specific payload
  - table type identified by *table_id* in header
  - two types of section syntax: « short » and « long »

    based on 1 bit in header
- Each type of table defines its own syntax
  - use long or short sections
  - payload bitstream syntax
- Descriptor
  - standard substructure with standard header and type-specific payload
  - most tables use generic « lists of descriptors »

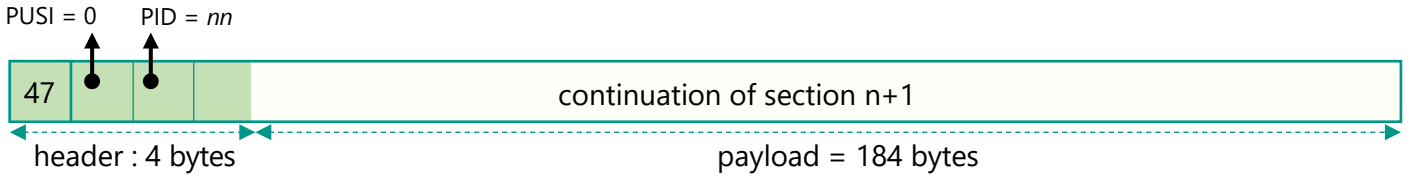
Typical section packetization

TS packet containing the start of section n+1

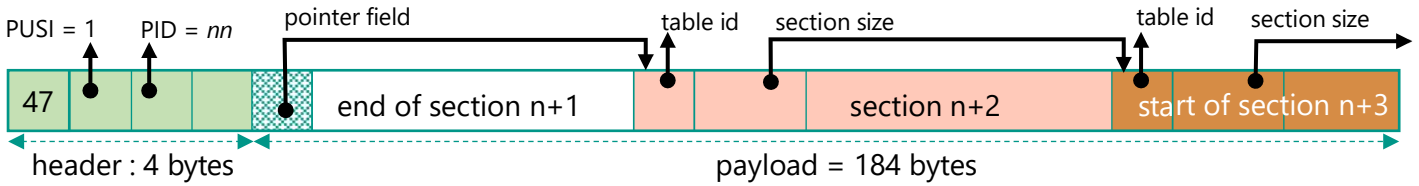


As many intermediate TS packets as required for section n+1

(multiplexed with TS packets from others PID's)



Last TS packet for section n+1, start of next section



Tables with short section

- One section per table
  - section and table are equivalent
- Each table brings new information
  - CAS EMM / ECM
  - date and time information (TDT / TOT)
- No standard integrity check
  - except section length in section header
  - some table-specific mechanisms

    cryptographic integrity in EMM / ECM CRC32

    in TOT

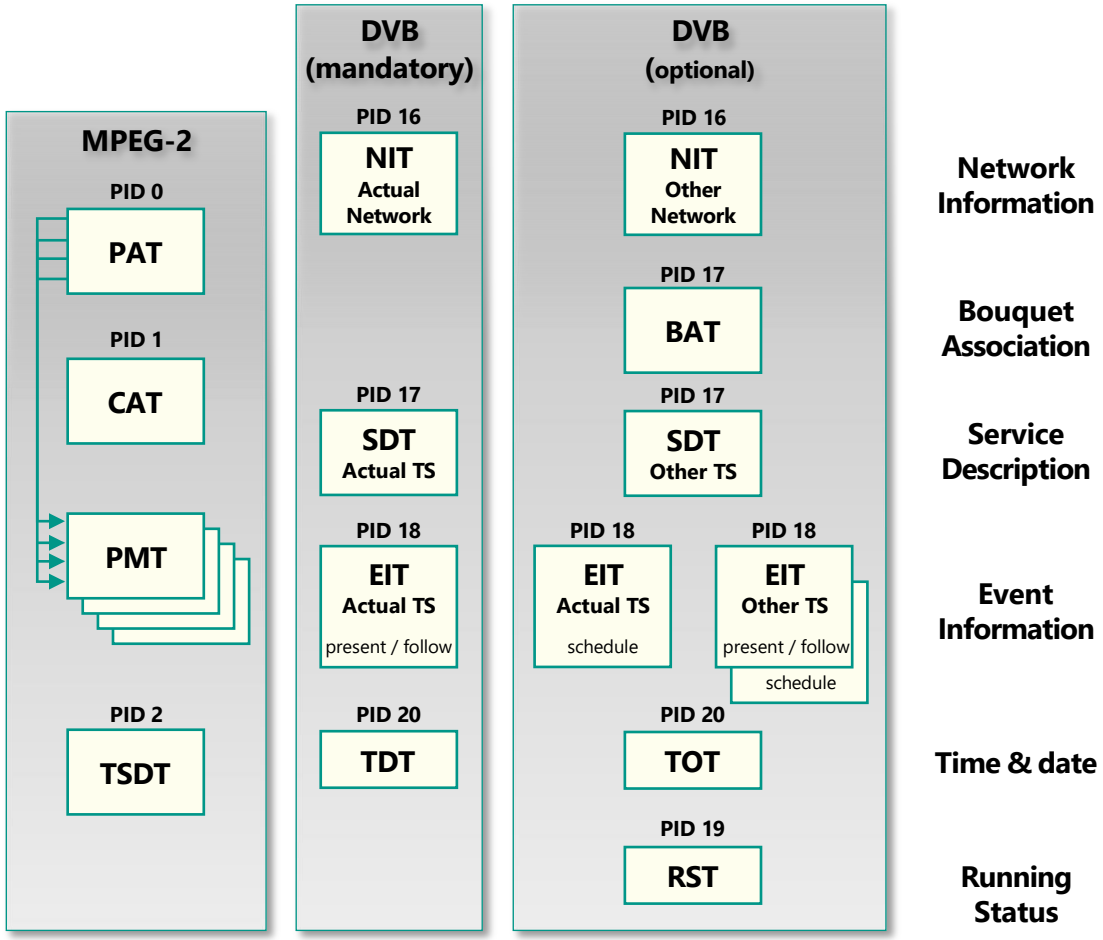
Tables with long sections

- Up to 256 sections per table
  - need to receive all sections to rebuild the complete table
- Same table repeatedly cycled
- Content change notification
  - version number in long section header
  - each table is repeatedly broadcast with same version number
  - version number changes when table content changes
  - STB software sets demux filters to be notified of new tables only
- Integrity check
  - CRC32 in each section
  - section rejected in case of corruption, can be detected at demux level
  - resynchronization on next TS packet with PUSI

Signalization: PSI / SI

- PSI : Program Specific Info.
  - MPEG-defined
  - ISO / IEC 13818-1
  - TS structure: PAT, PMT
  - CA : CAT
- SI : Service Information
  - DVB-defined
  - ETSI EN 300 468
  - private sections in MPEG terms

Extracted from DVB standard ETSI EN 300 468



MPEG-defined PSI

- PAT : Program Association Table
  - repeated in PID 0
  - list of « services » in the TS, ie. TV channels or data channels
  - service id and PMT PID
- PMT : Program Map Table
  - technical description of one service
  - list of elementary streams in the service
    - PID, type (audio, video, etc.), additional info using a list of descriptors
  - list of ECM streams for this service
- CAT : Conditional Access Table
  - repeated in PID 1
  - list of EMM streams on this TS
  - CAT not present when no EMM on TS

DVB-defined SI (1/2)

- SDT : Service Description Table
  - editorial description of the services in a TS
  - either in « actual » TS or « other » TS
  - service names and ancillary services
- BAT : Bouquet Association Table
  - commercial operator description and services
  - several commercial operators may sell the same services
- NIT : Network Information Table
  - technical description of a network
  - either « actual » network or « other » network
  - list of TS in this network

    usually with frequency and tuning parameters used for fast network scanning
  - list of services in each TS
  - service ids and « logical channel number »

DVB-defined SI (2/2)

- EIT : Event Information Table
  - editorial description of events
  - either in « actual » TS or « other » TS
  - EIT « present / following »

    short description of current and next event on each service used to display information banner on screen
  - EIT « schedule »

    long description of all events in the forthcoming days used to display the EPG

    optional, depends on operator's good will and bandwidth availability complete 7-day EPG for a large operator uses several Mb/s

    sparse EIT schedule sections, rarely complete tables
- TDT / TOT : Time and Date Table / Time Offset Table
  - current date and time, UTC (TDT) and local offset by region (TOT)
  - used to synchronize STB system time
  - typically, one table every 10 to 30 seconds only

DVB SimulCrypt

one network, several conditional access systems

Standard key terms

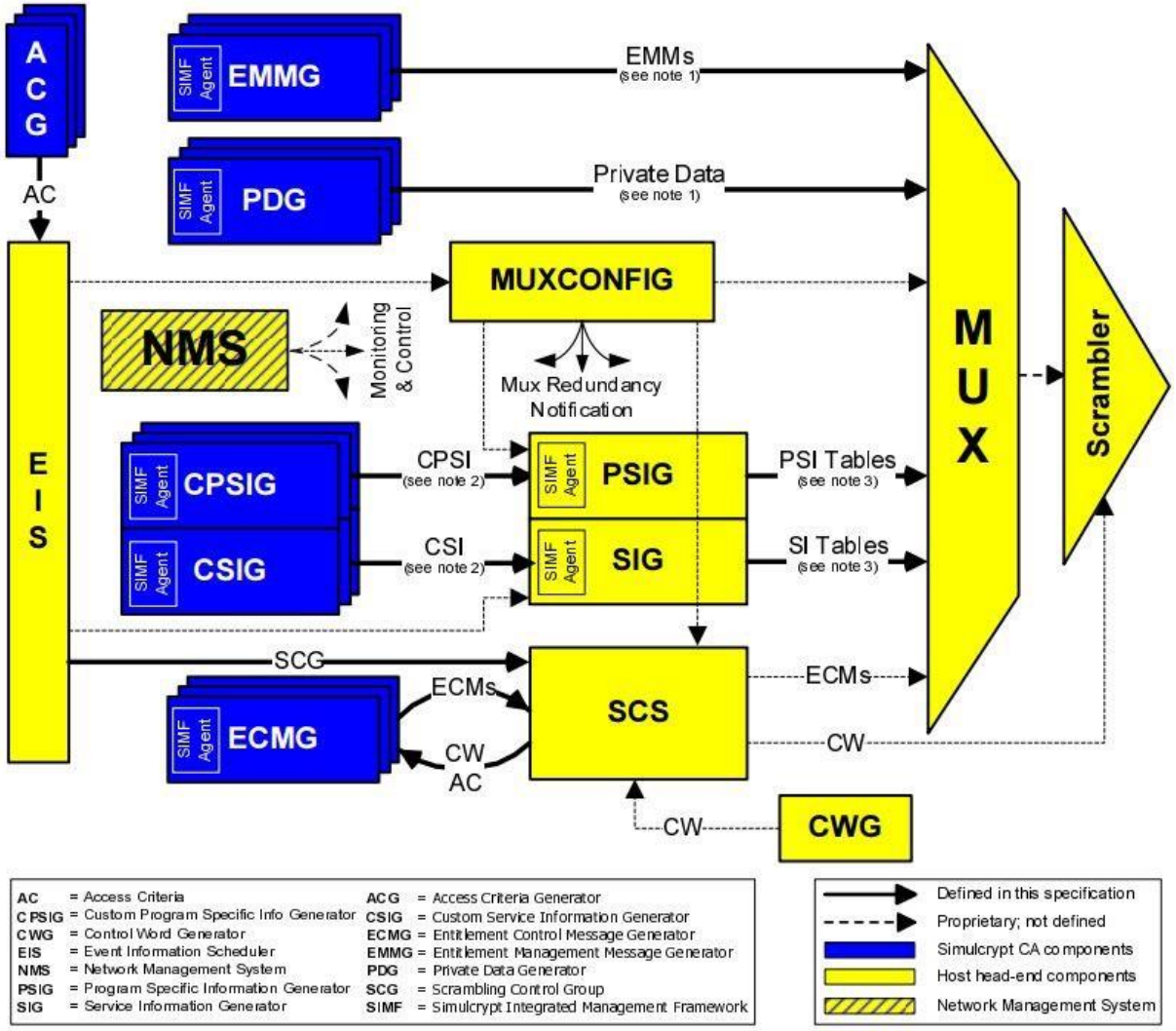
- CAS : Conditional Access System
- CW : Control Word
  - content encryption key for video & audio
- EMM : Entitlement Management Message
  - CAS-specific message to manage rights, smartcards, subscribers
  - sent to some identified set of subscribers, possibly only one
- ECM : Entitlement Control Message
  - CAS-specific message to control a scrambled service
  - sent to everyone willing to watch the service

DVB SimulCrypt

- Enforce coexistence of multiple CAS to protect the same content
  - DVB-defined standard
- Use-cases
  - one broadcast operator, multiple commercial operators
  - transition between CAS generations
- Broadcast
  - very simple architecture
  - common scrambling
  - multiple EMM and ECM streams with standard signalization
- Head-end
  - complex architecture
  - multiple CAS equipment
  - common synchronization

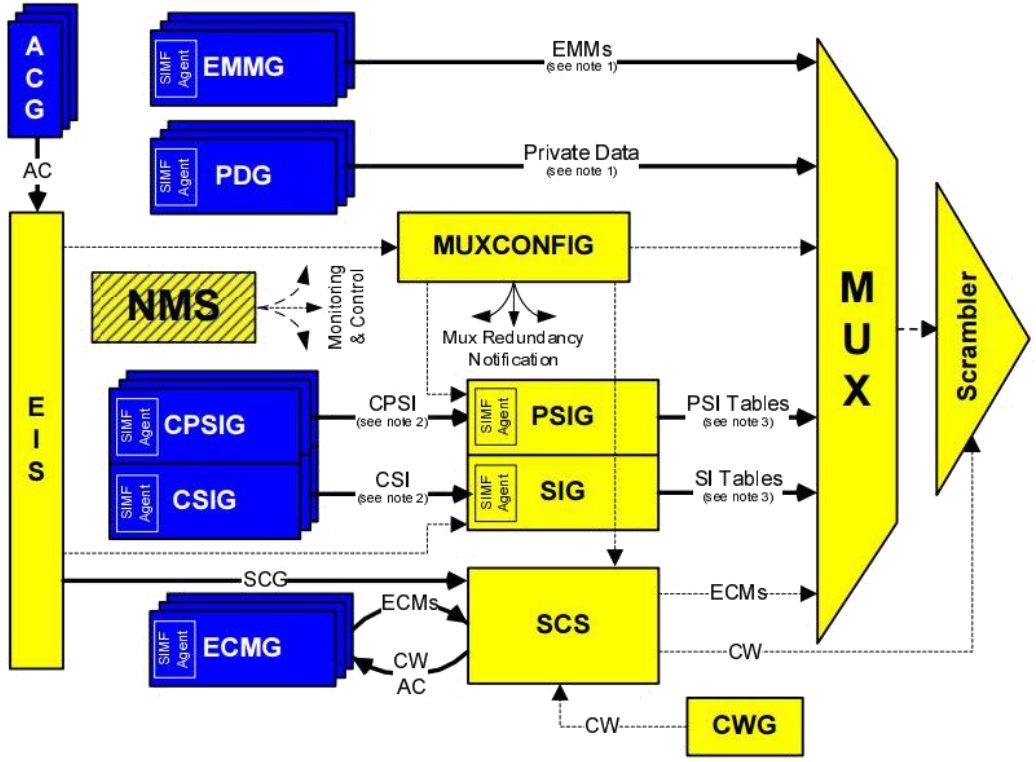
DVB SimulCrypt head-end diagram

Extracted from DVB standard ETSI TS 103 197



DVB SimulCrypt head-end

- Interface between two worlds
  - one « MUX system » vendor
    yellow components
  - multiple CAS vendors
    blue components
- DVB SimulCrypt protocols
  - specified between components of distinct worlds
  - protocols within the same world are not specified
    proprietary, vendor specific
  - consistent nested tag-length-value (TLV) structures
    using logical « channels » and « streams »
    except ACG ⊠ EIS protocol (XML protocol)
  - EIS ⊠ SCS protocol is specified
    so that EIS and SCS may in fact come from distinct vendors



EMM signalization

- Using CA_descriptor in the CAT of the TS
  - standard part of CA_descriptor: CA system id, EMM PID

    CA_system_id are allocated by DVB

    http://www.dvbservices.com/identifiers/ca_system_id
  - private part of CA_descriptor: CAS-specific

    used by the CA software in the STB
- Number of EMM streams is CAS-specific
  - for instance, one EMM stream may contain all EMM's for

    one operator

    one EMM type (e.g., individual, group, global) or

    any other configuration

    when they exist, operator id and EMM types are CAS-specific concepts they are usually identified in the private part of the CA_descriptor

ECM broadcast

- An ECM usually transports a CW pair and access criteria
  - specific to one or more audio or video streams
  - specific to one CAS
- Each service (i.e. channel) has dedicated ECM streams
  - per scrambling group
  - per CAS

    base mechanism for DVB SimulCrypt
- Scrambling group
  - a set of audio or video elementary streams scrambled with the same CW
  - subtitles are usually not scrambled in practice (but could be in theory)
  - usually, all audio/video streams of a service are in the same scrambling group
  - in rare cases, audio and video streams are scrambled with distinct CW

ECM signalization

- Using CA_descriptor in the PMT of the service
  - standard part of CA_descriptor : CA system id, ECM PID
    same as EMM signalization
  - private part of CA_descriptor: CAS-specific
    used by the CA software in the STB
    CA_descriptor private part is usually different in CAT (EMM) and PMT (ECM) sample content: operator id, public subset of access criteria
- Two possible positions for CA_descriptors in PMT
  - at program level
    only if one single scrambling group
  - at stream level
    mandatory if different ES use different CW
    take precedence over program level if both are used for same CA_system_id

Scrambling synchronization: principles

- During one crypto-period (CP) number N
  - typically, 10 seconds
  - scrambling using same CW_N
- ECM_N carries CW_N and CW_{N+1}
  - initial ECM broadcast delayed from start of CP (CAS specific)
  - ECM_N is repeated several times during CP_N (typically 10 ECM/s)
  - if first ECM_{N+1} is missed, the descrambler already knows CW_{N+1} anyway
- The CA software configures the descrambler with both CW_N and CW_{N+1}
  - either N or N+1 is « even », the other one is « odd »
- TS packet header contains 2-bit *transport_scrambling_control*
  - used by the descrambler to select the appropriate CW

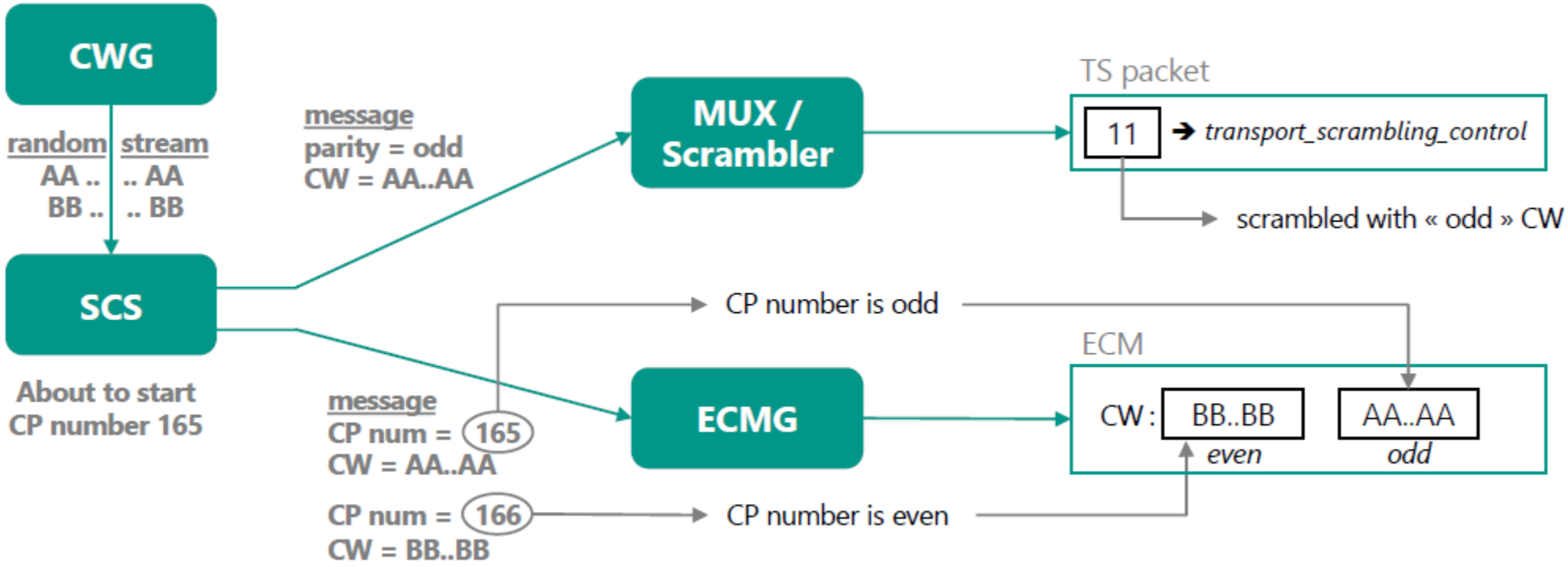
    00 : clear, do not descramble (MPEG-defined: ISO 13818-1)

    10 : use even CW (DVB-defined: ETR 289)

    11 : use odd CW (DVB-defined: ETR 289)

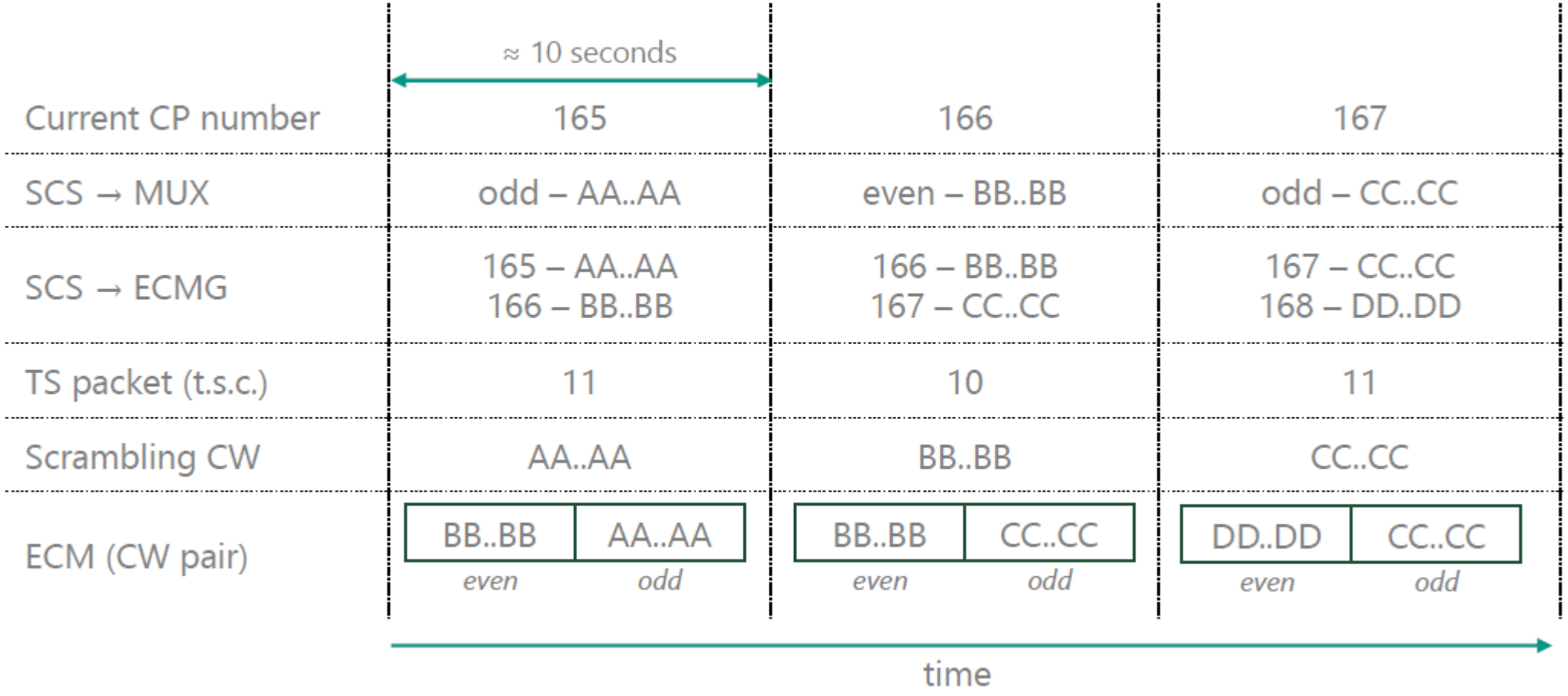
Scrambling synchronization: head-end view

- Based on crypto-period (CP) number
  - CP numbers are sequentially allocated by SCS
  - the full CP number stays on head-end
  - its parity is used in TS packets and ECM's

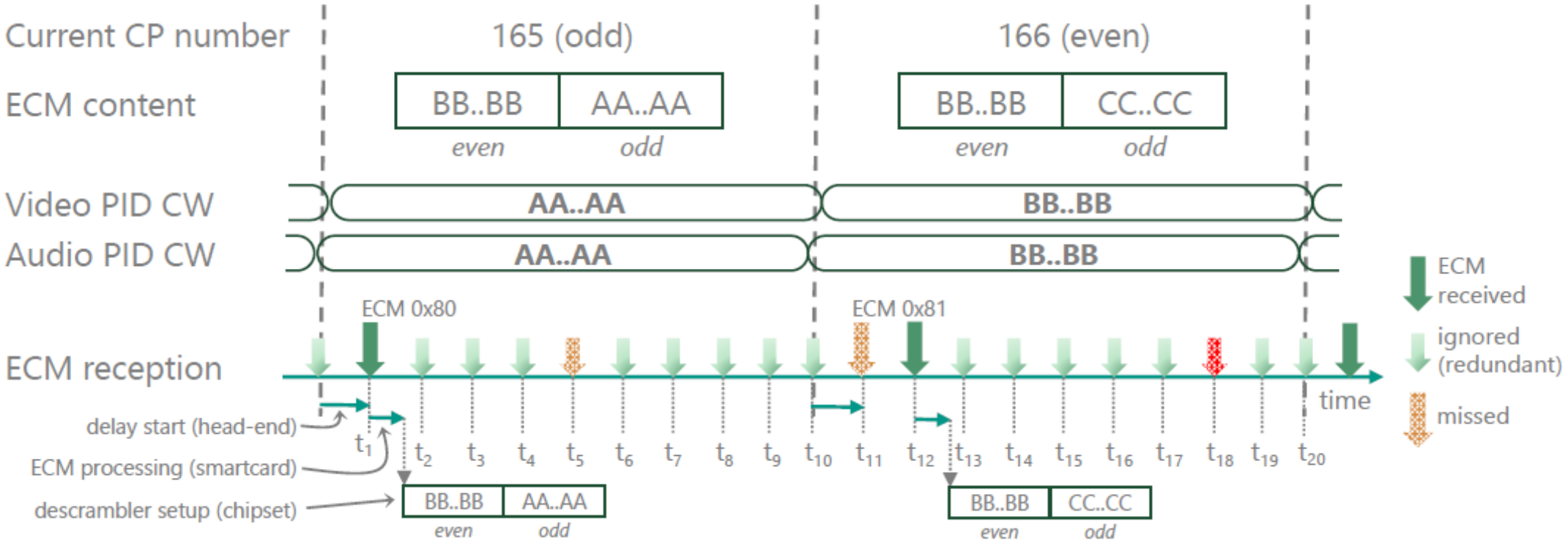


Scrambling synchronization: head-end timeline

- Crypto-periods timeline



- Loose synchronization
  - ECM's may be missed
  - CW transition is blurry (video & audio PID's)
  - No explicit synchronization between ECM's and video/audio crypto-periods



TS vs. PES scrambling

- ISO 13818-1 defines two possible levels of scrambling
  - TS level
    - each TS packet is scrambled individually
    - clear TS header and adaptation field, scrambled TS payload
  - PES level
    - each demuxed PES packet is scrambled individually TS packet header marked as clear
    - PES packet header contains similar 2-bit *PES_scrambling_control*
    - clear PES header, scrambled PES payload
- In practice, only TS-level scrambling is used
  - PES-level scrambling is technically much more difficult
    - scrambling is performed on multiplexed TS
    - ETR 289 specifies sub-scrambling of 184-byte super-blocks
    - PES packet boundaries not aligned on crypto-period boundaries
  - PES-level scrambling is never used in practice

EMM & ECM tables

- CA-private in DVB-defined range
  - ETSI ETR 289 defines the range of private CA table ids

    0x80 – 0x81 : ECM

    0x82 – 0x8F : « CA private »
  - defined as « short sections »

    no versioning

    each section is an independent new table
- Typical usage
  - 0x80 and 0x81 alternating with crypto periods

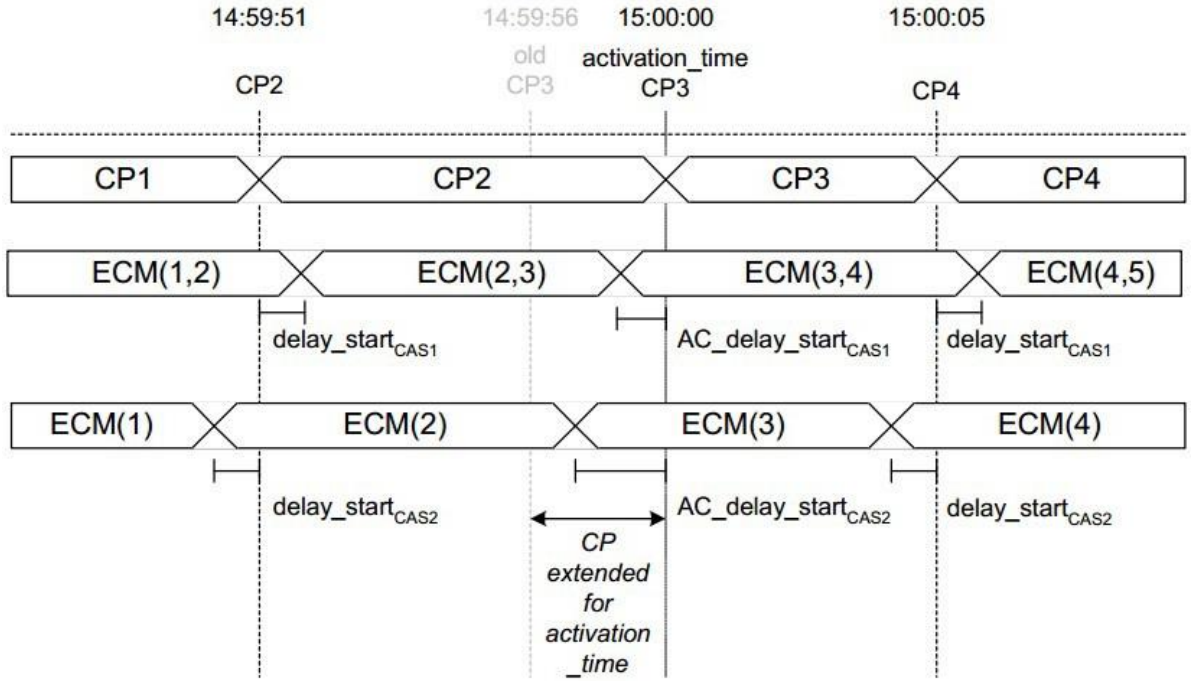
    ECM table id change used as trigger by CA software to submit ECM to smartcard or TEE ECM table id and CP number do not necessarily have the same parity
  - 0x82 – 0x8F used for EMM's

    CAS-specific

    typically one table id for each EMM type, easier to filter in STB

Access criteria transition

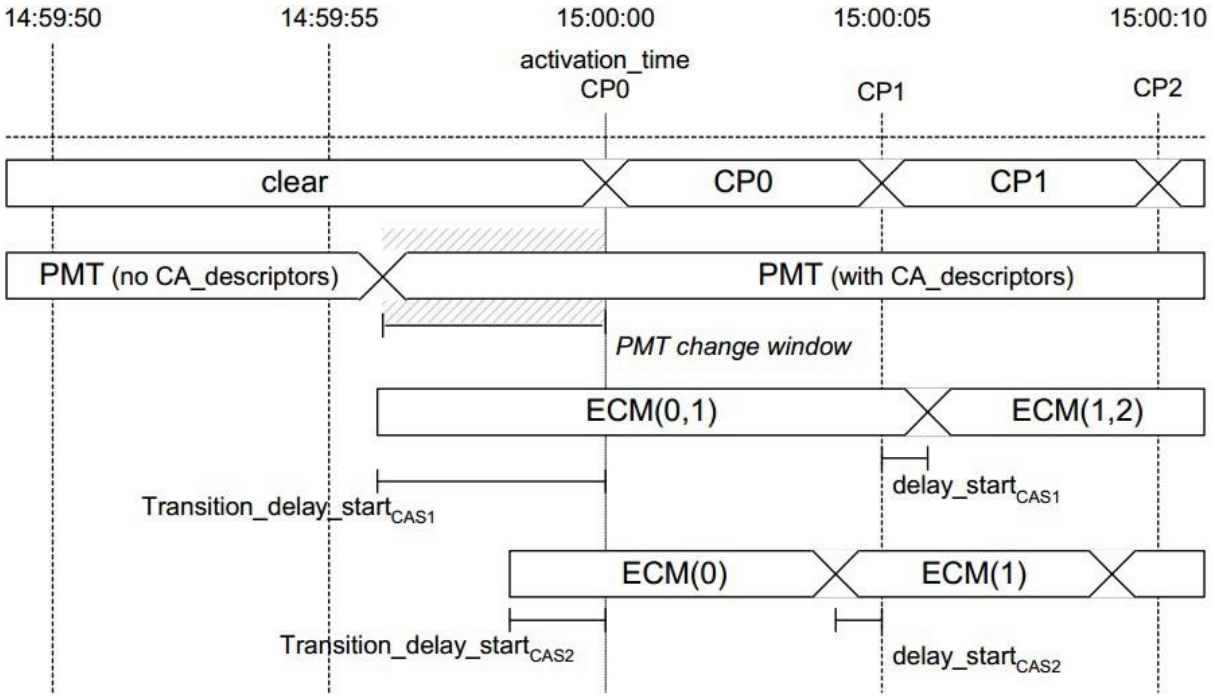
- Use case : restricted event or pay-per-view event transition
- Scenario :
  - the ECMG of each CAS had sent its own timing requirements to SCS
  - SCS synchronizes the generation of the ECM from each CAS



Extracted from DVB standard ETSI TS 103 197

Clear-to-scramble transition

- Use case: PayTV channel with public periods in the clear
- Scenario:
  - the ECMG of each CAS had sent its own timing requirements to SCS
  - SCS synchronizes the generation of the ECM from each CAS



Extracted from DVB standard ETSI TS 103 197

DVB CSA-2

- DVB Common Scrambling Algorithm
  - DVB proprietary algorithm
  - supposed to be « secret »
  - fully described in Wikipedia
  - open-source implementations online (*libdvbcsa*)
- Algorithm
  - 64-bit key (also known as « Control Words » or CW)
  - first pass : block cipher in reverse-CBC mode

    use CW as key block

    size : 64 bits residue

    ignored
  - second pass : stream cipher

    use CW as key and first block as seed (last processed block from reverse-CBC) residue included
  - short payloads (1 to 7 bytes) are not encrypted

    even if *transport_scrambling_control* is non-zero

DVB CSA-2 entropy reduction

- Entering the twilight zone….
- 64-bit key
  - some national regulations from the 90's prohibited 64-bit entropy
  - entropy was artificially reduced to 48 bits

    cw[3] = (cw[0] + cw[1] + cw[2]) mod 256

    cw[7] = (cw[4] + cw[5] + cw[6]) mod 256
  - entropy reduction is no longer required but still often applied
- Operational issues
  - hardware scramblers and descramblers use plain 64-bit keys
  - CWG internally generates 64 random bits
  - where is the entropy reduction applied?

    common chain: CWG? SCS? scrambling

    chain: MUX? scrambler?

    descrambling chain: ECMG? smartcard? CA software in STB? descrambler? who knows if entropy reduction must be applied anyway?

Standards

our essential references

Essential standards

- MPEG
  - ISO 13818-1, MPEG-2 system layer (TS, packetization, PSI)

    transport stream broadcast, blu-ray discs

    program stream DVD
- DVB / ETSI (Europe and more)
  - EN 300 468, DVB service information specifications (signalization)
  - TS 103 197, DVB simulcrypt head-end (CAS head-end)
- ATSC (USA), ISDB (Japan, Brazil)
  - equivalent features as defined in DVB

Obtaining standards documents

- ISO
  https://www.iso.org/standards.html must be purchased
- DVB
  http://www.etsi.org/standards
  direct search : http://www.etsi.org/standards-search
  allocated identifiers : http://www.dvbservices.com/identifiers/
- ITU
  http://www.itu.int/ITU-T/recommendations/
  H.xxx series : http://www.itu.int/rec/T-REC-H/
- IETF
  https://tools.ietf.org/
- NIST
  http://csrc.nist.gov/publications/

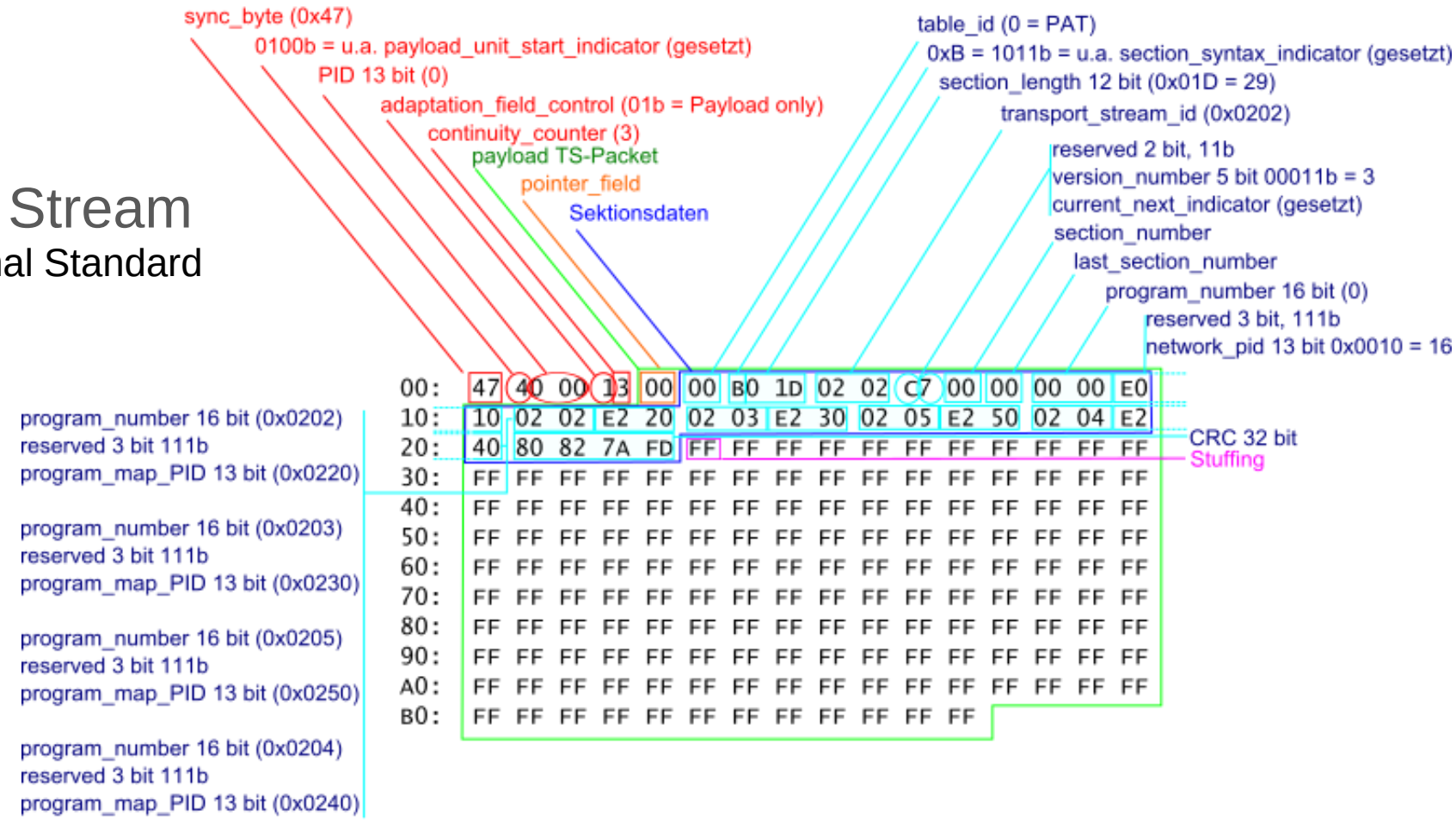
Audio and video standards and nicknames

Origin	Type	ISO / IEC	ITU-T	Nicknames
MPEG-1	Video	11172-2	H.261	MPEG-1 video
MPEG-1	Audio	11172-3		MPEG audio layer 1
MPEG-2	Video	13818-2	H.262	MPEG-2 video
MPEG-2	Audio	13818-3		Layer 2: MPEG audio layer 2 Layer 3: MP3
MPEG-2	Audio	13818-7		AAC (Advanced Audio Coding)
Dolby Digital	Audio			AC-3 (Audio Coding 3)
MPEG-4	Video	14496-2	H.263	DivX, Xvid (codecs)
MPEG-4	Audio	14496-3		HE-AAC, EAAC (High Efficiency, Enhanced AAC)
MPEG-4	Video	14496-10	H.264	AVC (Advanced Video Coding)
MPEG-H	Video	23008-2	H.265	HEVC (High Efficiency Video Coding)
Dolby Digital	Audio			AC-4
MPEG-I	Video	23090-3	H.266	VVC (Versatile Video Coding)

MPEG-2 Transport Stream

ISO/IEC 13818-1 International Standard

Beispiel eines TS-Pakets



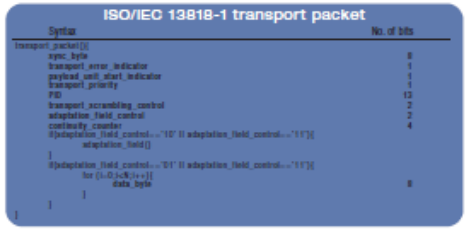
MPEG-2 Transport Stream

ISO/IEC 13818-1 International Standard

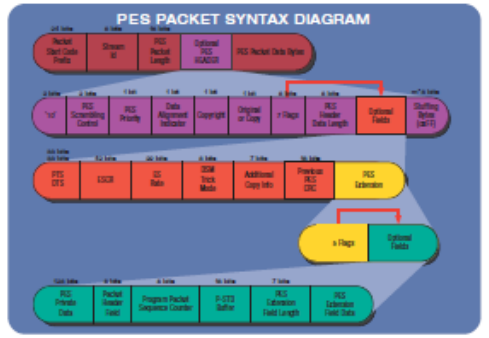
Service Information (SI) in DVB Systems

ETSI EN 300 468 International Standard

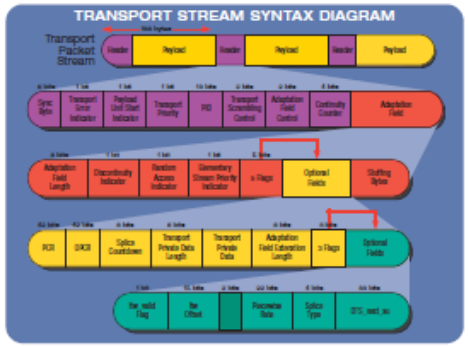
ISO/IEC 13818-1 transport packet



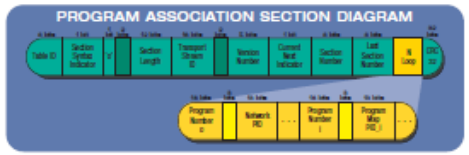
PES PACKET SYNTAX DIAGRAM



TRANSPORT STREAM SYNTAX DIAGRAM

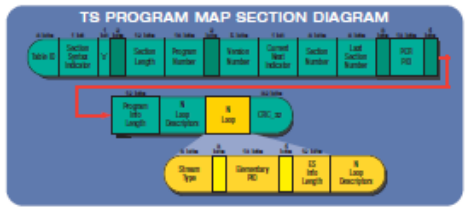


PROGRAM ASSOCIATION SECTION DIAGRAM

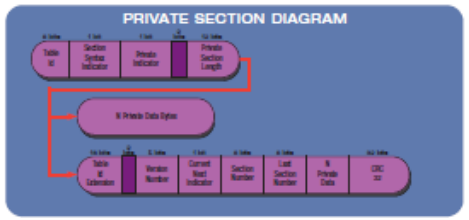


CONDITIONAL ACCESS SECTION DIAGRAM

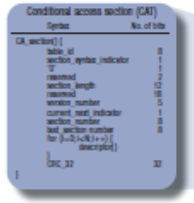
TS PROGRAM MAP SECTION DIAGRAM



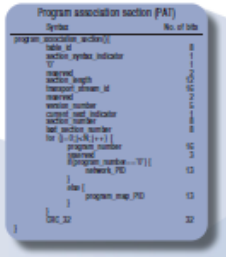
PRIVATE SECTION DIAGRAM



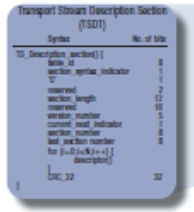
Conditional access section (CAT)



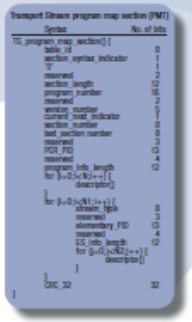
Program association section (PAT)



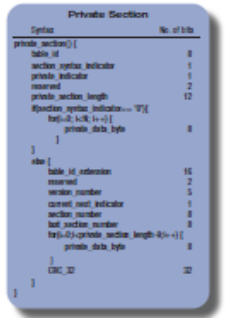
Transport Stream Description Section (TSDT)



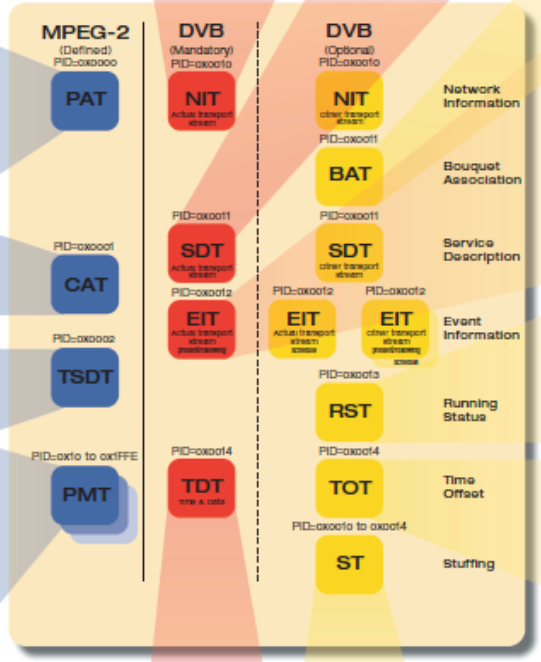
Transport Stream program map section (PMT)



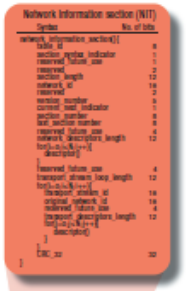
Private Section



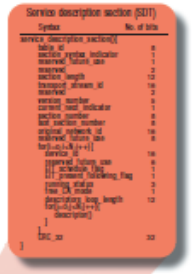
MPEG-2 / DVB (Defined) / DVB (Optional)



Network Information section (NIT)

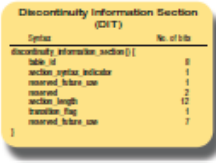


Service description section (SDT)

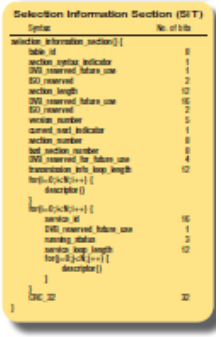


Bouquet association section (BAT)

Discontinuity Information Section (DIT)

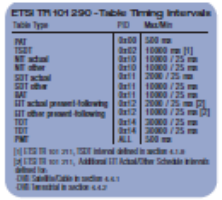


Selection Information Section (SIT)



Event Information Section (EIT)

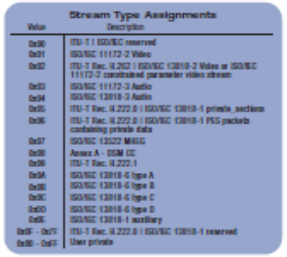
ETSI TR 101 290 - Table Timing Intervals



Running status section (RST)

Time offset section (TOT)

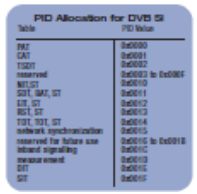
Stream Type Assignments



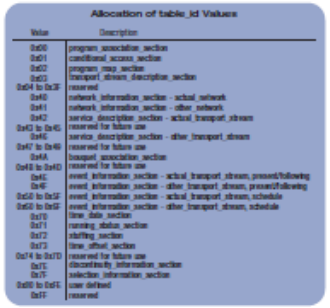
Time and date section (TOT)

Stuffing section (ST)

PID Allocation for DVB SI



Allocation of table_id Values



Abbreviations			WSS Wide Screen Signaling
AC-3 Dolby AC-3 audio coding	DVD Digital Versatile Disc	MPEG Moving Pictures Expert Group	RS Reed-Solomon
(ITU-R Recommendation BS1196 [19])	EBU European Broadcasting Union	NIT Network Information Table	RST Running Status Table
BAT Bouquet Association Table	EIT Event Information Table	NVOD Near Video On Demand	SeF Scale Factor
BCD Binary Coded Decimal	EMM Entitlement Management Message	PAT Program Association Table	SDT Service Description Table
bslbf bit string, left bit first	EPG Electronic ProgramGuide	PDC ProgramDelivery Control	SI Service Information
CA Conditional Access	ETS European Telecommunication Standard	PID Packet IDentifier	SIT Selection Information Table
CAT Conditional Access Table	FEC Forward Error Correction	PMT Program Map Table	SMI Storage Media Interoperability
CLUT Color Look-Up Table	IEC International Electrotechnical Commission	PSI Program Specific Information	ST Stuffing Table
CRC Cyclic Redundancy Check	IRD Integrated Receiver Decoder	PSTN Public Switched Telephone Network	TDT Time and Date Table
DAB Digital Audio Broadcasting	ISO International Organization for Standardization	QAM Quadrature Amplitude Modulation	TOT Time Offset Table
DIT Discontinuity Information Table	LSB Least Significant Bit	QPSK Quaternary Phase Shift Keying	TPS Transmission Parameter Signaling
DVB Digital Video Broadcasting	MJD Modified Julian Date	rpchof remainder polynomial coefficients, highest order first	TS Transport Stream
VBI Vertical Blanking Interval	VPS Video Program System	uimsbf unsigned integer most significant bit first	UTC Universal Time, Co-ordinated