Transmission techniques and multiplexing hierarchies

Switching Technology S38.165
http://www.netlab.hut.fi/opetus/s38165

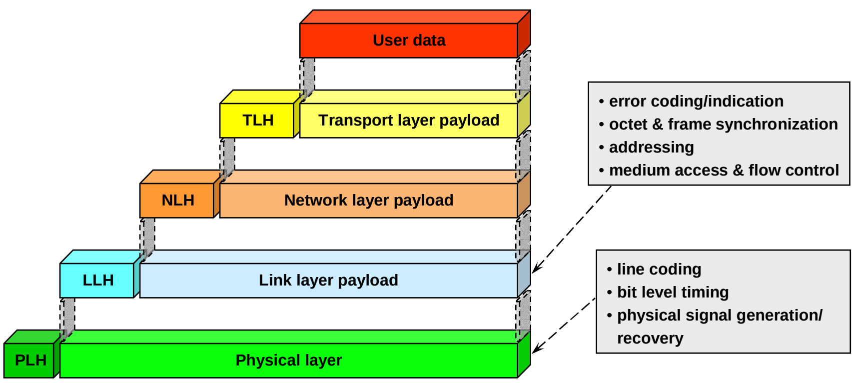
Transmission techniques and multiplexing hierarchies

- Transmission of data signals
- Timing and synchronization
- Transmission techniques and multiplexing
  - PDH
  - ATM
  - IP/Ethernet
  - SDH/SONET
  - OTN
  - GFP

Transmission of data signals

- Encapsulation of user data into layered protocol structure
- Physical and link layers implement functionality that have relevance to switching
  - multiplexing of transport signals (channels/connections)
  - medium access and flow control
  - error indication and recovery
  - bit, octet and frame level timing/synchronization
  - line coding (for spectrum manipulation and timing extraction)

Encapsulation of user data



Synchronization of transmitted data

- Successful transmission of data requires bit, octet, frame and packet level synchronism
- Synchronous systems (e.g. PDH and SDH) transfer additional information (embedded into transmitted line signal) for accurate recovery of clock signals
- Asynchronous systems (e.g. Ethernet) transfer additional bit patterns to synchronize receiver logic

Timing accuracy

- Inaccuracy of frequency classified in telecom networks to
  - jitter (short term changes in frequency > 10 Hz)
  - wander (< 10 Hz fluctuation)
  - long term frequency shift (drift or skew)
- To maintain required timing accuracy network nodes are connected to a hierarchical synchronization network
  - Universal Time Coordinated (UTC): error in the order of 10^{-13}
  - Error of Primary Reference Clock (PRC) of the telecom network 10^{-11}

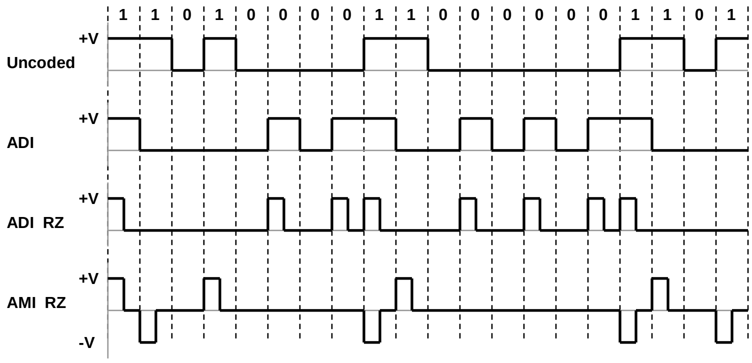
Timing accuracy (cont.)

- Inaccuracy of clock frequency causes
  - degraded quality of received signal
  - bit errors in regeneration
  - slips: in PDH networks a frame is duplicated or lost due to timing difference between the sender and receiver
- Based on applied synchronization method, networks are divided into
  - fully synchronous networks (e.g. SDH)
  - plesiochronous networks (e.g. PDH), sub-networks have nominally the same clock frequency but are not synchronized to each other
  - mixed networks

Methods for bit level timing

- To obtain bit level synchronism receiver clocks must be synchronized to incoming signal
- Incoming signal must include transitions to keep receiver's clock recovery circuitry in synchronism
- Methods to introduce line signal transitions
  - Line coding
  - Block coding
  - Scrambling

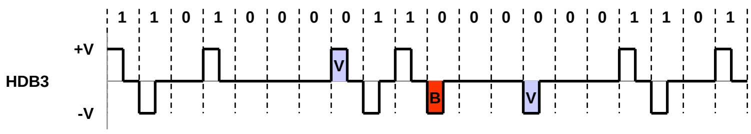
Line coding



ADI - Alternate Digit Inversion
ADI RZ - Alternate Digit Inversion Return to Zero
AMI RZ - Alternate Mark Inversion Return to Zero

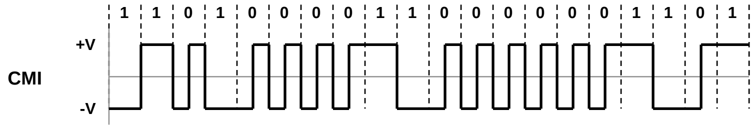
Line coding (cont.)

- ADI, ADI RZ and codes alike introduce DC balance shift
  => clock recovery becomes difficult
- AMI and AMI RZ introduces DC balance, but lacks effective ability to introduce signal transitions
- HDB3 (**High Density Bipolar 3**) code, used in PDH systems, guarantees a signal transition at least every fourth bit
  - 0000 coded by 000V when there is an odd number of pulses since the last violation (V) pulse
  - 0000 coded by B00V when there is an even number of pulses since the last violation pulse



Line coding (cont.)

- When bit rates increase (> 100 Mbit/s) jitter requirements become tighter and signal transitions should occur more frequently than in HDB3 coding
- CMI (Coded Mark Inversion) coding was introduced for electronic differential links and for optical links
- CMI doubles bit rate on transmission link -> higher bit rate implies larger bandwidth and shortened transmission distance



Block coding

- Entire blocks of *n* bits are replaced by other blocks of *m* bits (*m* > *n*)
- *nBmB* block codes are usually applied on optical links by using on-off keying
- Block coding adds variety of "1"s and "0"s to obtain better clock synchronism and reduced jitter
- Redundancy in block codes (in the form of extra combinations) enables error recovery to a certain extent
- When *m*>*n* the coded line signal requires larger bandwidth than the original signal
- Examples: 4B5B (FDDI), 5B6B (E3 optical links) and 8B10B (GbE)

Coding examples

4B5B coding

Input word	Output word	Other output words
0 0 0 0	1 1 1 1 0	0 0 0 0 0 Quiet line symbol
0 0 0 1	0 1 0 0 1	1 1 1 1 1 Idle symbol
0 0 1 0	1 0 1 0 0	0 0 1 0 0 Halt line symbol
0 0 1 1	1 0 1 0 1	1 1 0 0 0 Start symbol
0 1 0 0	0 1 0 1 0	1 0 0 0 1 Start symbol
0 1 0 1	0 1 0 1 1	0 1 1 0 1 End symbol
0 1 1 0	0 1 1 1 0	0 0 1 1 1 Reset symbol
0 1 1 1	0 1 1 1 1	1 1 0 0 1 Set Symbol
1 0 0 0	1 0 0 1 0	0 0 0 0 1 Invalid
1 0 0 1	1 0 0 1 1	0 0 0 1 0 Invalid
1 0 1 0	1 0 1 1 0	0 0 0 1 1 Invalid
1 0 1 1	1 0 1 1 1	0 0 1 0 1 Invalid
1 1 0 0	1 1 0 1 0	0 0 1 1 0 Invalid
1 1 0 1	1 1 0 1 1	0 1 0 0 0 Invalid
1 1 1 0	1 1 1 0 0	0 1 1 0 0 Invalid
1 1 1 1	1 1 1 0 1	1 0 0 0 0 Invalid

5B6B coding

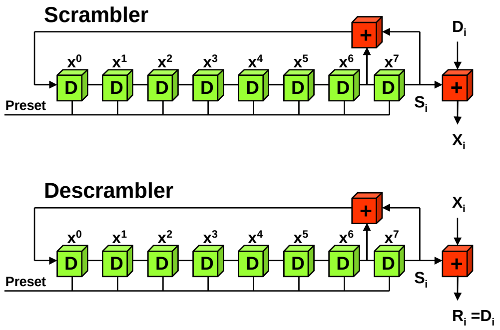
Input word	Output word
0 0 0 0 0	1 0 1 0 1 1
0 0 0 0 1	1 0 1 0 1 0
0 0 0 1 0	1 0 1 0 0 1
0 0 0 1 1	1 1 1 0 0 0
...	...
1 1 1 0 0	0 1 0 0 1 1
1 1 1 0 1	0 1 0 1 1 1
1 1 1 1 0	0 1 1 0 1 1
1 1 1 1 1	0 1 1 1 0 0

Scrambling

- Data signal is changed bit by bit according to a separate repetitive sequence (to avoid long sequences of “1”s or “0”s)
- Steps of the sequence give information on how to handle bits in the signal being coded
- A scrambler consists of a feedback shift register described by a polynomial **($x^N + \dots + x^m + \dots + x^k + \dots + x + 1$)**
- Polynomial specifies from where in the shift register feedback is taken
- Output bit rate is the same as the input bit rate
- Scrambling is not as effective as line coding

Scrambler example

SDH/STM-1 uses x^7+x^6+1 polynomial



$X_i = S_i \oplus D_i$

$R_i = S_i \oplus X_i$
$= S_i \oplus (S_i \oplus D_i) = D_i$

Methods for octet and frame level timing

- Frame alignment bit pattern
- Start of frame signal
- Use of frame check sequence

Frame alignment sequence

- Data frames carry special frame alignment bit patterns to obtain octet and frame level synchronism
- Data bits scrambled to avoid misalignment
- Used in networks that utilize synchronous transmission, e.g. in PDH, SDH and OTN
- Examples
  - PDH E1 frames carry bit sequence 0011011 in every other frame (even frames)
  - SDH and OTN frames carry a six octet alignment sequence (hexadecimal form: F6 F6 F6 28 28 28) in every frame

Start of frame signal

- Data frames carry special bit patterns to synchronize receiver logic
- False synchronism avoided for example by inserting additional bits into data streams
- Used in synchronous and asynchronous networks, e.g., Ethernet and HDLC
- Examples
  - Ethernet frames are preceded by a 7-octet preamble field (10101010) followed by a start-of-frame delimiter octet (10101011)
  - HDLC frames are preceded by a flag byte (0111 1110)

Frame check sequence

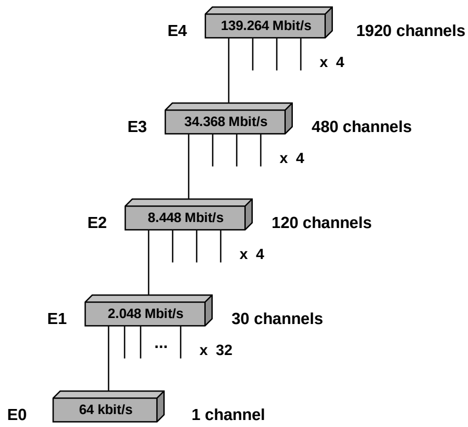
- Data frames carry no special bit patterns for synchronization
- Synchronization is based on the use of error indication and correction fields
  - CRC (Cyclic Redundancy Check) calculation
- Used in bit synchronous networks such as ATM and GFP (Generic Framing Procedures)
- Example
  - ATM cells streams can be synchronized to HEC (Header Error Control) field, which is calculated across ATM cell header

Transmission techniques

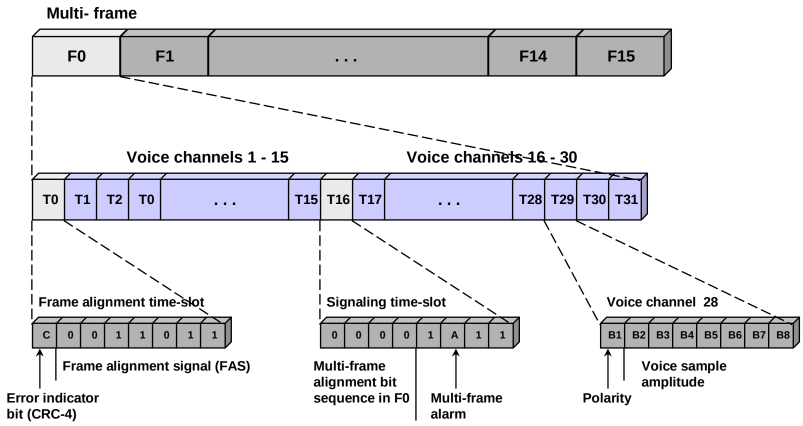
- PDH (Plesiochronous Digital Hierarchy)
- ATM (Asynchronous Transfer Mode)
- IP/Ethernet
- SDH (Synchronous Digital Hierarchy)
- OTN (Optical Transport network)
- GFP (Generic Framing Procedure)

Plesiochronous Digital Hierarchy (PDH)

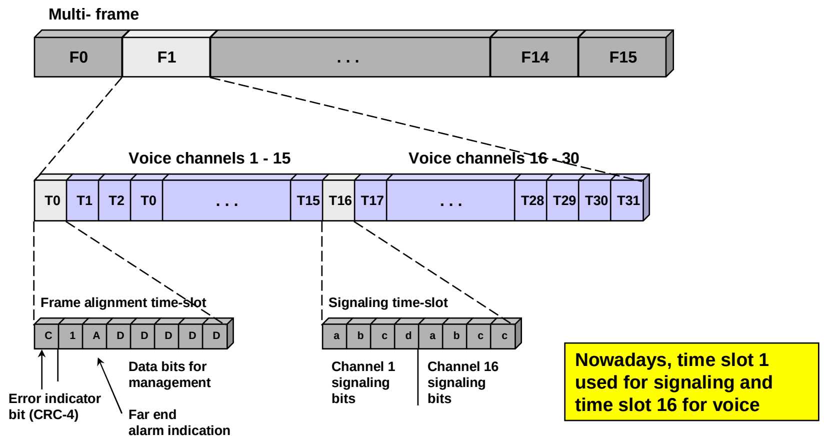
- Transmission technology of digitized telecom network
- Basic channel capacity 64 kbit/s
- Voice information PCM coded
  - 8 bits per sample
  - A or µ law
  - sample rate 8 kHz (125 µs)
- Channel associated signaling (SS7)
- Higher order frames obtained by multiplexing four lower order frames bit by bit and adding some synchr. and management info
- The most common switching and transmission format in the telecommunication network is PCM 30 (E1)



PDH E1-frame structure (even frames)



PDH E1-frame structure (odd frames)



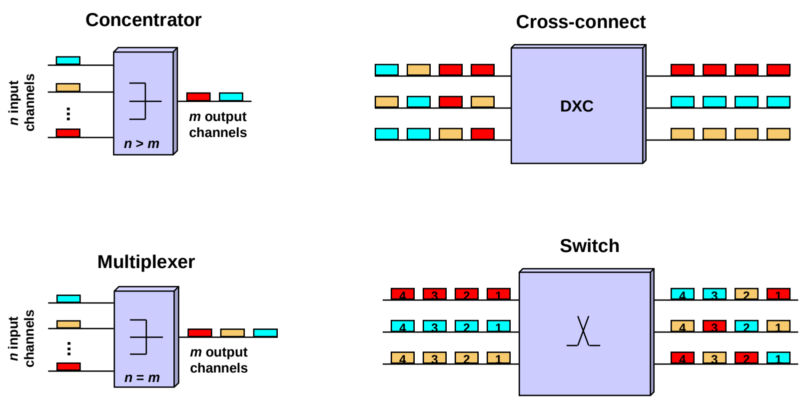
PDH-multiplexing

- Tributaries have the same nominal bit rate, but with a specified, permitted deviation (100 bit/s for 2.048 Mbit/s)
- Plesiochronous = tributaries have almost the same bit rate
- Justification and control bits are used in multiplexed flows
- First order (E1) is octet-interleaved, but higher orders (E2, …) are bit-interleaved

PDH network elements

- **concentrator**
  - *n* channels are multiplexed to a higher capacity link that carries *m* channels (*n* > *m*)
- **multiplexer**
  - *n* channels are multiplexed to a higher capacity link that carries *n* channels
- **cross-connect**
  - static multiplexing/switching of user channels
- **switch**
  - switches incoming TDM/SDM channels to outgoing ones

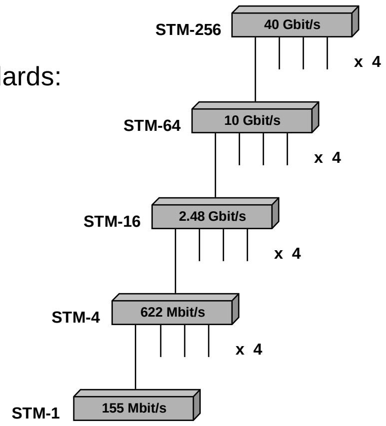
Example PDH network elements



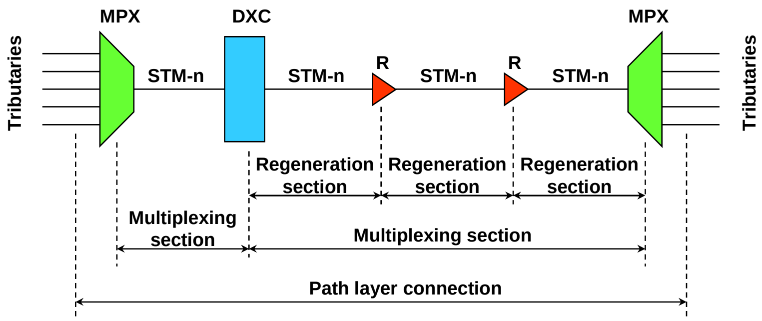
Synchronous digital hierarchy

Major ITU-T SDH standards:
- G.707
- G.783

Notice that each frame transmitted in 125 µs !



SDH reference model



- DXC Digital gross-connect
- MPX Multiplexer
- R Repeater

SDH-multiplexing

- Multiplexing hierarchy for plesiochronous and synchronous tributaries (e.g. E1 and E3)
- Octet-interleaving, no justification bits - tributaries visible and available in the multiplexed SDH flow
- SDH hierarchy divided into two groups:
  - multiplexing level (virtual containers, VCs)
  - line signal level (synchronous transport level, STM)
- Tributaries from E1 (2.048 Mbit/s) to E4 (139.264 Mbit/s) are synchronized (using justification bits if needed) and packed in containers of standardized size
- Control and supervisory information (POH, path overhead) added to containers => virtual container (VC)

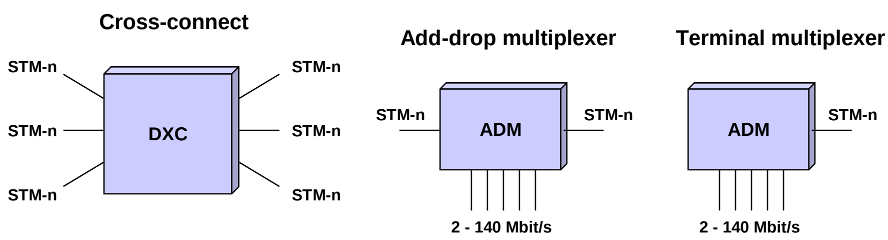
SDH-multiplexing (cont.)

- Different sized VCs for different tributaries (VC-12/E1, VC-3/E3, VC-4/E4)
- Smaller VCs can be packed into a larger VC (+ new POH)
- Section overhead (SOH) added to larger VC => transport module
- Transport module corresponds to line signal (bit flow transferred on the medium)
  - bit rate is 155.52 Mbit/s or its multiples
  - transport modules called STM-N (N = 1, 4, 16, 64, ...)
  - bit rate of STM-N is Nx155.52 Mbit/s
  - duration of a module is 125 μs (= duration of a PDH frame)

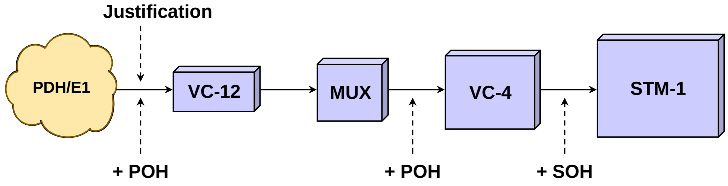
SDH network elements

- regenerator (intermediate repeater, IR)
  - regenerates line signal and may send or receive data via communication channels in RSOH header fields
- multiplexer
  - terminal multiplexer multiplexes/demultiplexes PDH and SDH tributaries to/from a common STM-n
  - add-drop multiplexer adds or drops tributaries to/from a common STM-n
- digital cross-connect
  - used for rearrangement of connections to meet variations of capacity or for protection switching
  - connections set up and released by operator

Example SDH network elements



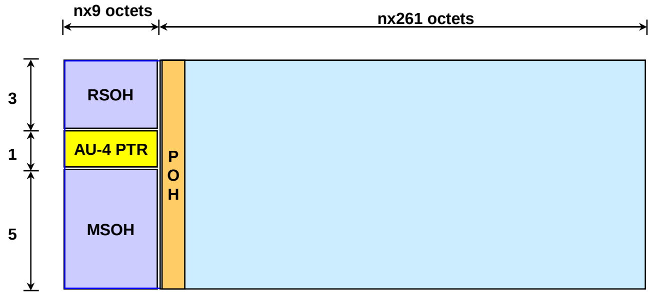
Generation of STM-1 frame



STM-*n* frame

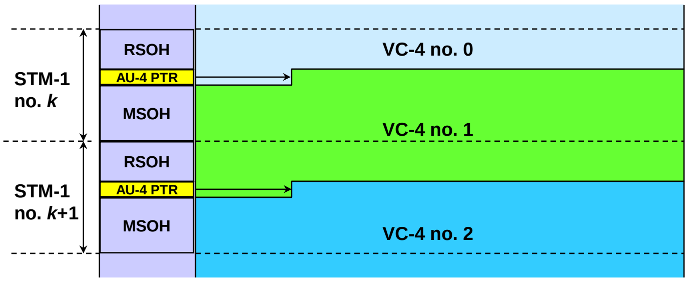
Three main fields:

- Regeneration and multiplexer section overhead (RSOH and MSOH)
- Payload and path overhead (POH)
- AU (administrative) pointer specifies where payload (VC-4 or VC-3) starts



Synchronization of payload

- Position of each octet in a STM frame (or VC frame) has a number
- AU pointer contains position number of the octet in which VC starts
- Lower order VC included as part of a higher order VC (e.g. VC-12 as part of VC-4)



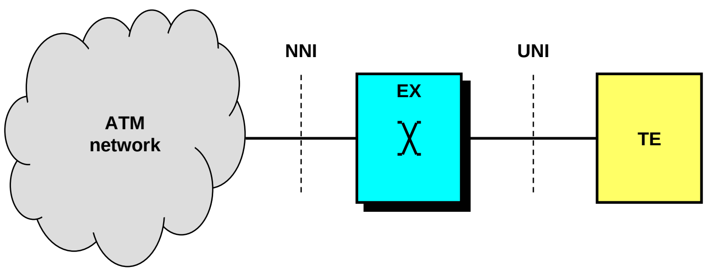
ATM concept in summary

- **cell**
  - 53 octets
- **routing/switching**
  - based on VPI and VCI
- **adaptation**
  - processing of user data into ATM cells
- **error control**
  - cell header checking and discarding
- **flow control**
  - no flow control
  - input rate control
- **congestion control**
  - cell discarded (two priorities)

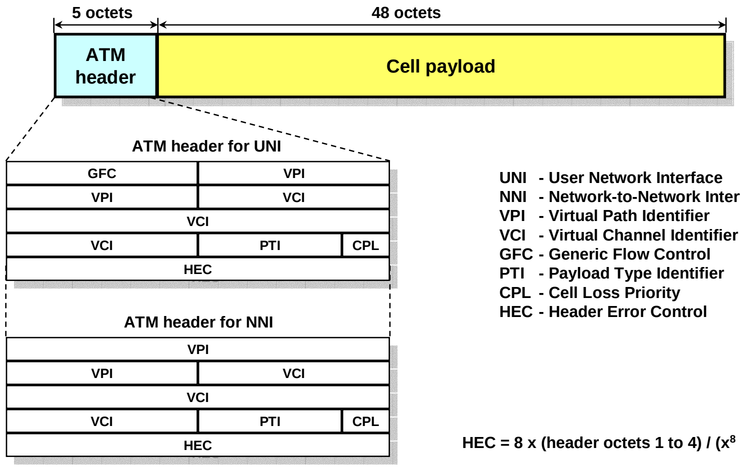
ATM protocol reference model

AAL		Convergence sublayer (CS)
		Segmentation and reassembly (SAR)
ATM		Generic flow control VPI/VCI translation Multiplexing and demultiplexing of cells
Phys	TC	Cell rate decoupling HEC header sequence generation/verification Cell delineation Transmission frame adaptation Transmission frame generation/recovery
	PM	Timing Physical medium

Reference interfaces



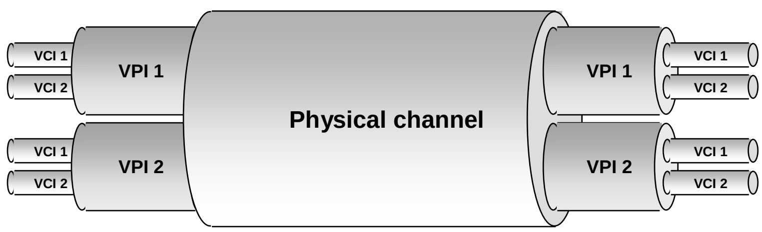
ATM cell structure



UNI - User Network Interface
NNI - Network-to-Network Interface
VPI - Virtual Path Identifier
VCI - Virtual Channel Identifier
GFC - Generic Flow Control
PTI - Payload Type Identifier
CPL - Cell Loss Priority
HEC - Header Error Control

HEC = 8 x (header octets 1 to 4) / (x^8 + x^2 + x + 1)

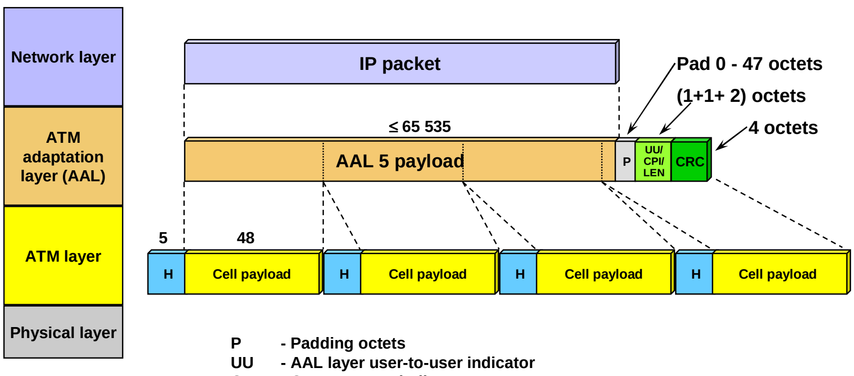
ATM connection types



Physical layers for ATM

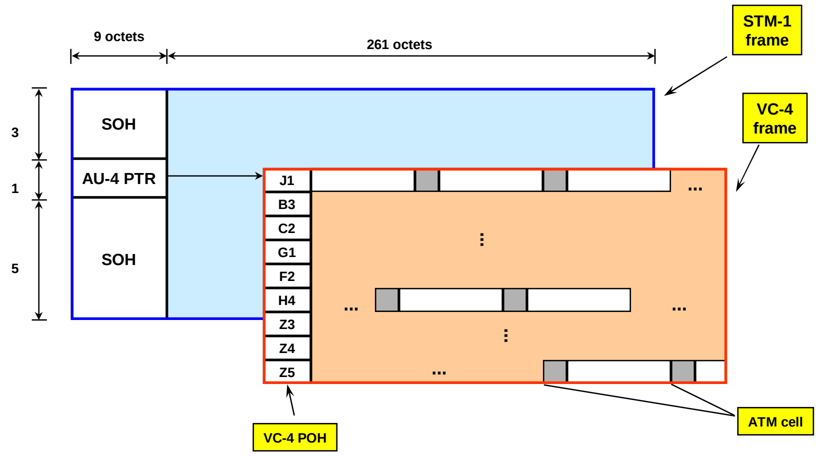
- **SDH** (Synchronous Digital Hierarchy)
  - STM-1 155 Mbit/s
  - STM-4 622 Mbit/s
  - STM-16 2.4 Gbit/s
- **PDH** (Plesiochronous Digital Hierarchy)
  - E1 2 Mbit/s
  - E3 34 Mbit/s
  - E4 140 Mbit/s
- TAXI 100 Mbit/s and IBM 25 Mbit/s
- Cell based interface
  - uses standard bit rates and physical level interfaces (e.g. E1, STM-1 or STM-4)
  - HEC used for framing

Transport of data in ATM cells

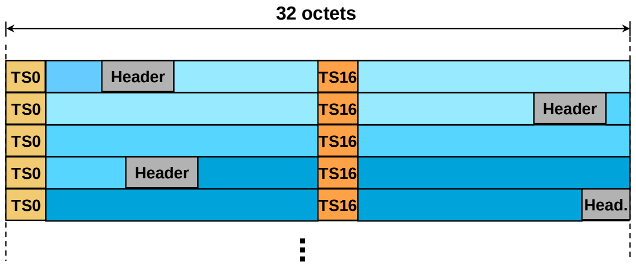


P - Padding octets
UU - AAL layer user-to-user indicator
CPI - Common part indicator
LEN - Length indicator

ATM cell encapsulation / SDH



ATM cell encapsulation / PDH (E1)

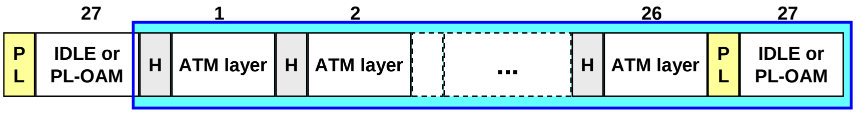


TS0
- frame alignment
- F3 OAM functions
  - loss of frame alignment
  - performance monitoring
  - transmission of FERF and LOC
  - performance reporting

TS16
- reserved for signaling

Cell based interface

Frame structure for cell base interfaces:



- **PL cells processed on physical layer (not on ATM layer)**
- **IDLE cell for cell rate adaptation**
- **PL-OAM cells carry physical level OAM information (regenerator (F1) and transmission path (F3) level messages)**
- **PL cell identified by a pre-defined header**
  - **00000000 00000000 0000000 00000001 (IDLE cell)**
  - **00000000 00000000 0000000 00001001 (phys. layer OAM)**
  - **xxxx0000 00000000 0000000 0000xxxx (reserved for phys. layer)**

H = ATM cell Header, PL = Physical Layer, OAM = Operation Administration and Maintenance

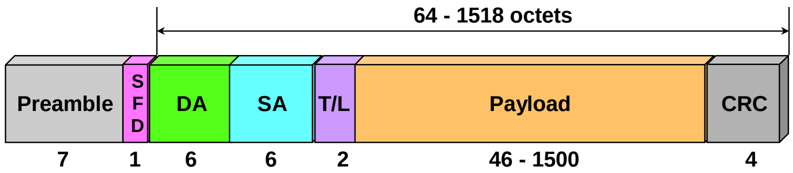
ATM network elements

- Gross-connect
  - switching of virtual paths (VPs)
  - VP paths are statically connected
- Switch
  - switching of virtual channel (VCs)
  - VC paths are dynamically or statically connected
- DSLAM (Digital Subscriber Line Access Multiplexer)
  - concentrates a larger number of sub-scriber lines to a common higher capacity link
  - aggregated capacity of subscriber lines surpasses that of the common link

Ethernet

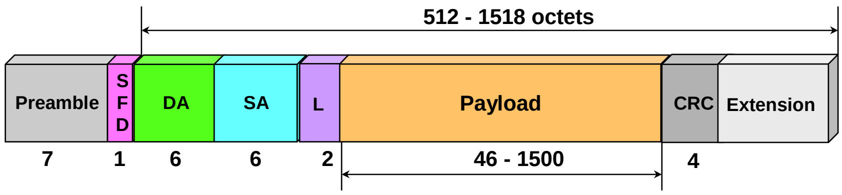
- Originally a link layer protocol for LANs (10 and 100 MbE)
- Upgrade of link speeds
  => optical versions 1GbE and 10 GbE
  => suggested for long haul transmission
- No connections - each data terminal (DTE) sends data when ready - MAC is based on CSMA/CD
- Synchronization
  - line coding, preamble pattern and start-of-frame delimiter
  - Manchester code for 10 MbE, 8B6T for 100 MbE, 8B10B for GbE

Ethernet frame



Preamble - AA AA AA AA AA AA AA (Hex)
SFD - Start of Frame Delimiter AB (Hex)
DA - Destination Address
SA - Source Address
T/L - Type (RFC894, Ethernet) or Length (RFC1042, IEEE 802.3) indicator
CRC - Cyclic Redundance Check
Inter-frame gap 12 octets (9,6 µs /10 MbE)

1GbE frame



Preamble - AA AA AA AA AA AA AA (Hex)
SFD - Start of Frame Delimiter AB (Hex)
DA - Destination Address
SA - Source Address
T/L - Type (RFC894, Ethernet) or Length (RFC1042, IEEE 802.3) indicator
CRC - Cyclic Redundancy Check
Inter-frame gap 12 octets (96 ns /1 GbE)
Extension - for padding short frames to be 512 octets long

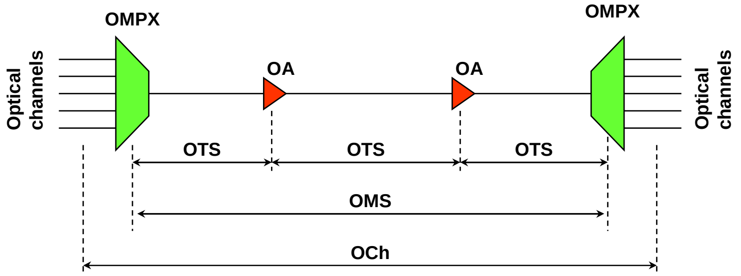
Ethernet network elements

- **Repeater**
  - interconnects LAN segments on physical layer
  - regenerates all signals received from one segment and forwards them onto the next
- **Bridge**
  - interconnects LAN segments on link layer (MAC)
  - all received frames are buffered and error free ones are forwarded to another segment (if they are addressed to it)
- **Hub and switch**
  - hub connects DTEs with two twisted pair links in a star topology and repeats received signal from any input to all output links
  - switch is an intelligent hub, which learns MAC addresses of DTEs and is capable of directing received frames only to addressed ports

Optical transport network

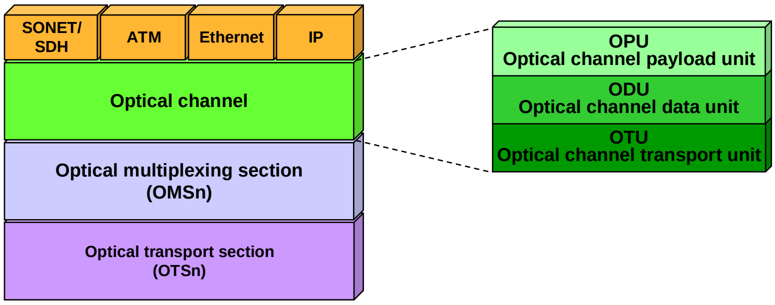
- Optical Transport Network (OTN) being developed by ITU-T (G.709) specifies interfaces for optical networks
- Goal to gather for the transmission needs of today's wide range of digital services and to assist network evolution to higher bandwidths and improved network performance
- OTN builds on SDH and introduces some refinements:
  - management of optical channels in optical domain
  - FEC to improve error performance and allow longer link spans
  - provides means to manage optical channels end-to-end in optical domain (i.e. no O/E/O conversions)
  - interconnections scale from a single wavelength to multiple ones

OTN reference model



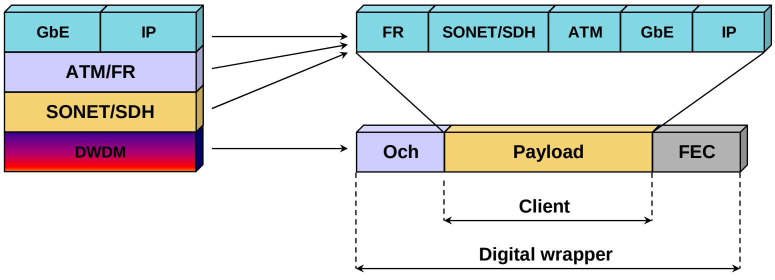
- OCh Optical Channel
- OA Optical Amplifier
- OMS Optical Multiplexing Section
- OMPX Optical Multiplexer
- OTS Optical Transport Section

OTN layers and OCh sub-layers

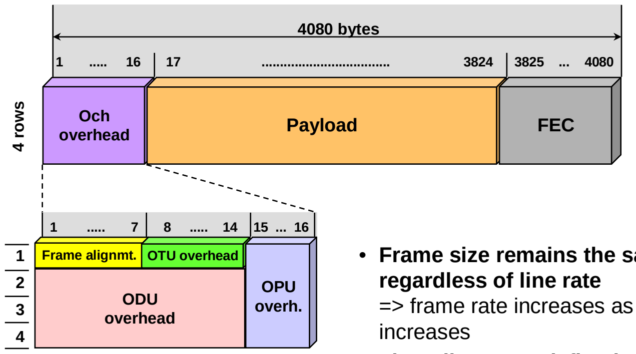


OTN frame structure

- **Three main fields**
  - Optical channel overhead
  - Payload
  - Forward error indication field



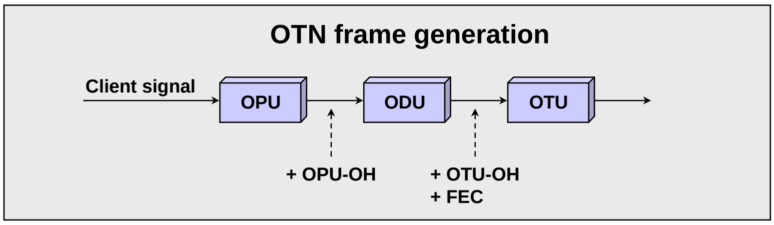
OTN frame structure (cont.)

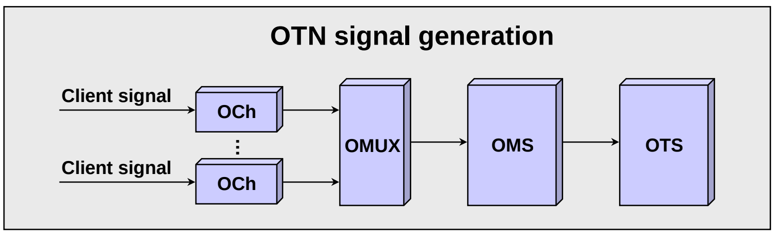


OTU - Optical transport unit
ODU - Optical data unit
OPU - Optical payload unit
FEC - Forward error correction

- **Frame size remains the same (4x4080) regardless of line rate**
  => frame rate increases as line rate increases
- **Three line rates defined:**
  - OTU1 2.666 Gbit/s
  - OTU2 10.709 Gbit/s
  - OTU3 43.014 Gbit/s

Generation of OTN frame and signal





OTN network elements

- **optical amplifier**
  - amplifies optical line signal
- **optical multiplexer**
  - multiplexes optical wavelengths to OMS signal
  - add-drop multiplexer adds or drops wavelengths to/from a common OMS
- **optical cross-connect**
  - used to direct optical wavelengths (channels) from an OMS to another
  - connections set up and released by operator
- **optical switches ?**
  - when technology becomes available optical switches will be used for switching of data packets in optical domain

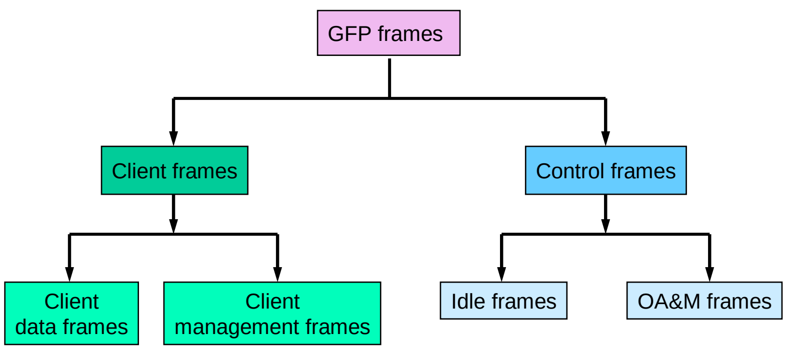
Generic Framing Procedure (GFP)

- **Recently standardized traffic adaptation mechanism especially for transporting block-coded and packet-oriented data**
- **Standardized by ITU-T (G.7041) and ANSI (T1.105.02) (the only standard supported by both organizations)**
- **Developed to overcome data transport inefficiencies of existing ATM, POS, etc. technologies**
- **Operates over byte-synchronous communications channels (e.g. SDH/SONET and OTN)**
- **Supports both fixed and variable length data frames**
- **Generalizes error-control-based frame delineation scheme (successfully employed in ATM)**
  - **relies on payload length and error control check for frame boundary delineation**

GFP (cont.)

- **Two frame types: client and control frames**
  - client frames include client data frames and client management frames
  - control frames used for OAM purposes
- **Multiple transport modes (coexistent in the same channel) possible**
  - Frame-mapped GFP for packet data, e.g. PPP, IP, MPLS and Ethernet)
  - Transparent-mapped GFP for delay sensitive traffic (storage area networks), e.g. Fiber Channel, FICON and ESCON

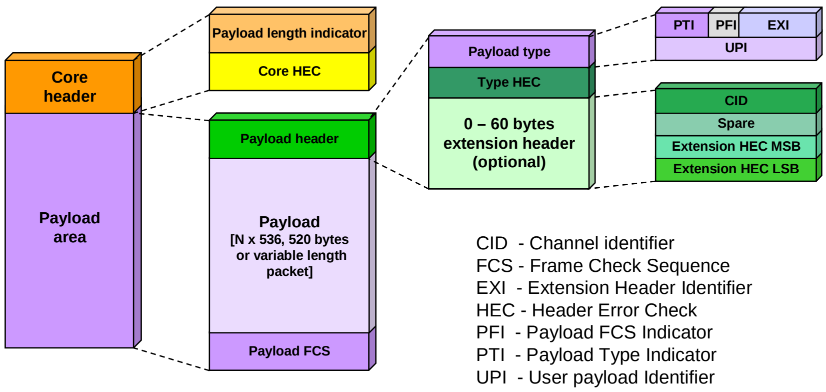
GFP frame types



GFP client data frame

- Composed of a frame header and payload
- Core header intended for data link management
  - payload length indicator (PLI, 2 octets), HEC (CRC-16, 2 octets)
- Payload field divided into payload header, payload and optional FCS (CRC-32) sub-fields
- Payload header includes:
  - payload type (2 octets) and type HEC (2 octets) sub-fields
  - optional 0 - 60 octets of extension header
- Payload:
  - variable length (0 - 65 535 octets, including payload header and FCS) for frame mapping mode (GFP-F) - frame multiplexing
  - fixed size Nx[536, 520] for transparent mapping mode (GFP-T) - no frame multiplexing

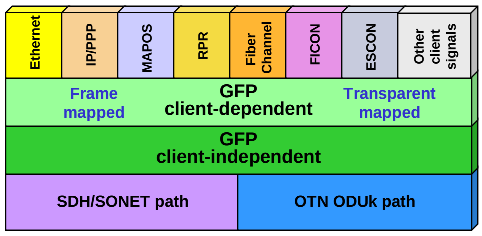
GFP frame structure



CID - Channel identifier
FCS - Frame Check Sequence
EXI - Extension Header Identifier
HEC - Header Error Check
PFI - Payload FCS Indicator
PTI - Payload Type Indicator
UPI - User payload Identifier

Source: IEEE Communications Magazine, May 2002

GFP relationship to client signals and transport paths

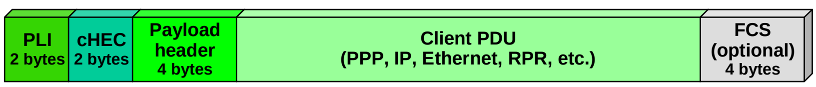


ESCON - Enterprise System CONnection
FICON - Fiber CONnection
IP/PPP - IP over Point-to-Point Protocol
MAPOS - Multiple Access Protocol over SONET/SDH
RPR - Resilient Packet Ring

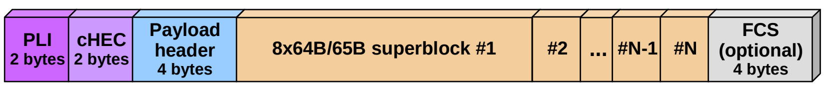
Source: IEEE Communications Magazine, May 2002

Adapting traffic via GFP-F and GFP-T

GFP-F frame



GFP-T frame



FCS - Frame Check Sequence
cHEC - Core Header Error Control
PDU - Packet Data Unit
PLI - Payload Length Indicator

GFP-T frame mapping