

# Transmission techniques and multiplexing hierarchies

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

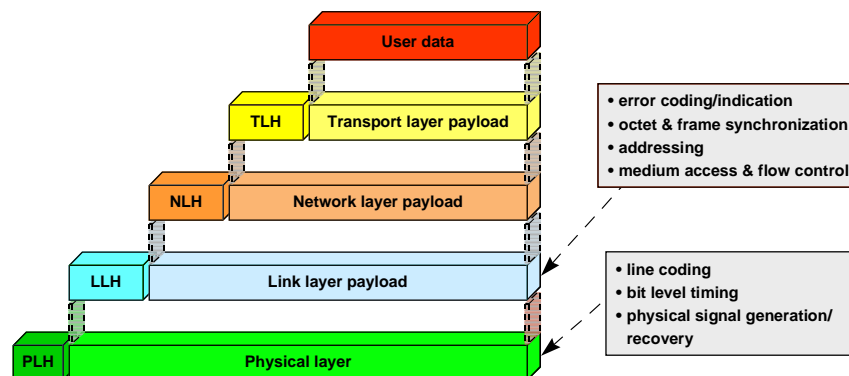
## Transmission techniques and multiplexing hierarchies

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

## 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)

## Transmission of data signals (cont.)



## 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  $10^{-11}$

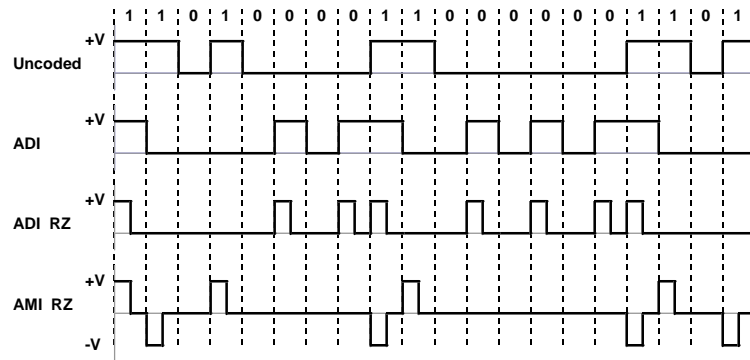
## Timing accuracy (cont.)

- Inaccuracy of clock frequency causes
  - degraded quality of received signal
  - bit errors in regeneration
  - slips: in PDH networks a frame needs to be duplicated or is 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

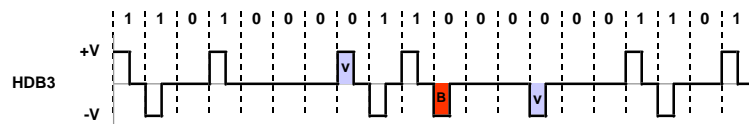
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## Line coding (cont.)

- 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 code, used in PDH systems, guarantees a signal transition at least every fourth bit



HDB3 - High Density Bipolar 3

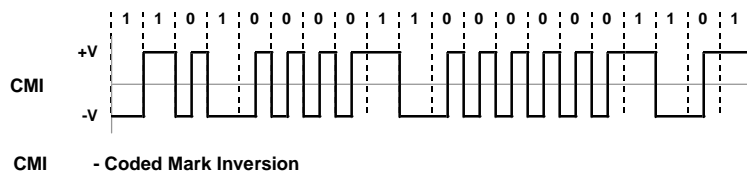
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## Line coding (cont.)

- When bit rates increase ( $> 100$  Mbit/s) jitter requirements become tighter and signal transitions should occur more frequently than in HDB3 coding
- CMI coding was introduced for electronic differential links and for optical links
- CMI doubles bit rate on transmission link  $\rightarrow$  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
0000	11110	00000 Quiet line symbol
0001	01001	11111 Idle symbol
0010	10100	00100 Halt line symbol
0011	10101	11000 Start symbol
0100	01010	10001 Start symbol
0101	01011	01101 End symbol
0110	01110	00111 Reset symbol
0111	01111	11001 Set Symbol
1000	10010	00001 Invalid
1001	10011	00010 Invalid
1010	10110	00011 Invalid
1011	10111	00101 Invalid
1100	11010	00110 Invalid
1101	11011	01000 Invalid
1110	11100	01100 Invalid
1111	11101	10000 Invalid

### 5B6B coding

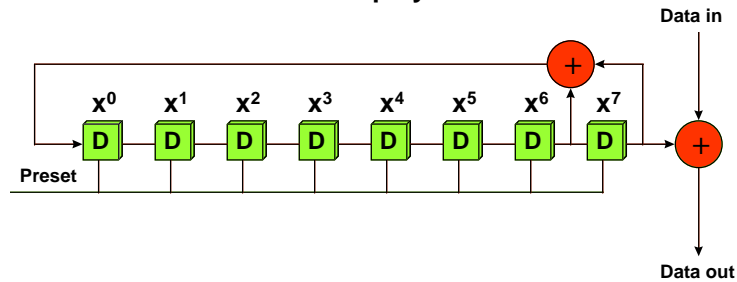
Input word	Output word
00000	101011
00001	101010
00010	101001
00011	111000
...	...
11100	010011
11101	010111
11110	011011
11111	011100

## 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



## 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

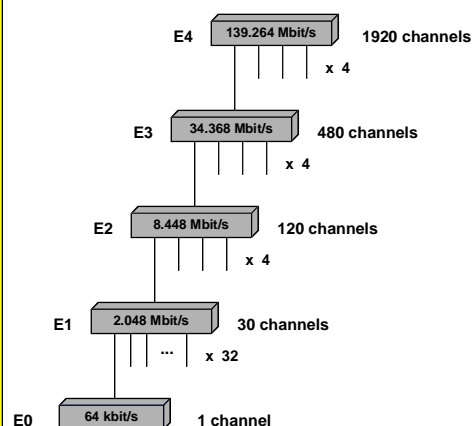
- Data frames carry special bit patterns to synchronize receiver logic
- False synchronism avoided for example by inserting additional bits into data streams
- Used in synchronous and asynchronous networks, e.g., Ethernet and HDLC
- Examples
  - Ethernet frames are preceded by a 7-octet preamble field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

## Frame check sequence

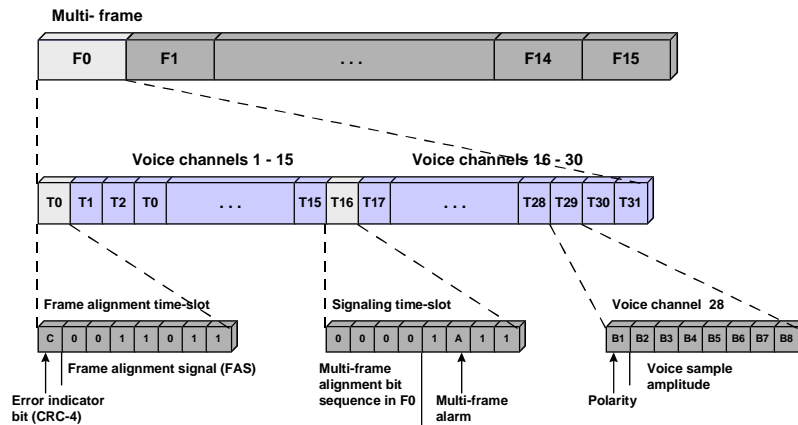
- Data frames carry no special bit patterns for synchronization
- Synchronization is based on the use of error indication and correction fields
  - CRC (Cyclic Redundancy Check) calculation
- Used in bit synchronous networks such as ATM and GFP (Generic Framing Procedures)
- Example
  - ATM cells streams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

## 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  $\mu$  law
  - sample rate 8 kHz (125  $\mu$ s)
- 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 information switching and transmission format in the telecommunication network is PCM 30 (E1)



## PDH E1-frame structure (even frames)

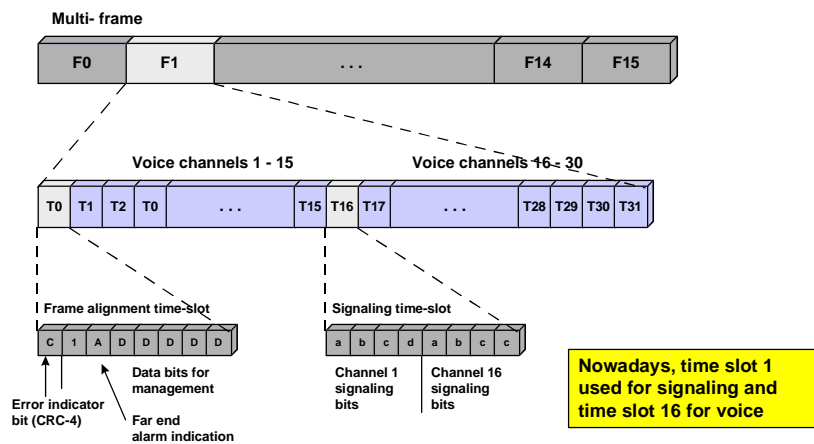


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## PDH E1-frame structure (odd frames)



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## CRC-4 multi-frame format

CRC-4 calculation ensures, that the frame alignment function can not lock into a user signal of (x0011011)

PDH standards/ITU-T

- G.703
- G.704
- G.706
- G.711

Sub-multi-frame	Frame	Time-slot 0							
		Bit 1	Bit 2	Bit 3	Bit 4	Bit 5	Bit 6	Bit 7	Bit 8
SMF #1	0	c1	0	0	1	1	0	1	1
	1	0	1	A	Sa4	Sa5	Sa6	Sa7	Sa8
	2	c2	0	0	1	1	0	1	1
	3	0	1	A	Sa4	Sa5	Sa6	Sa7	Sa8
	4	c3	0	0	1	1	0	1	1
	5	1	1	A	Sa4	Sa5	Sa6	Sa7	Sa8
	6	c4	0	0	1	1	0	1	1
	7	0	1	A	Sa4	Sa5	Sa6	Sa7	Sa8
SMF #2	8	c1	0	0	1	1	0	1	1
	9	1	1	A	Sa4	Sa5	Sa6	Sa7	Sa8
	10	c2	0	0	1	1	0	1	1
	11	1	1	A	Sa4	Sa5	Sa6	Sa7	Sa8
	12	c3	0	0	1	1	0	1	1
	13	E	1	A	Sa4	Sa5	Sa6	Sa7	Sa8
	14	c4	0	0	1	1	0	1	1
	15	E	1	A	Sa4	Sa5	Sa6	Sa7	Sa8

Sub-frame #1 (SMF #1):

Sa: Spare bit reserved for national use

A: Remote Alarm (FAS) indication

Frame alignment signal: 0011011

CRC-4 Frame Alignment Signal: 001011

CRC multi-frame not aligned with MFAS TS16

Sub-frame #2 (SMF #2):

E: CRC-4 error indication used by

receiving equipment

C1, C2, C3, C4: CRC-4 bits

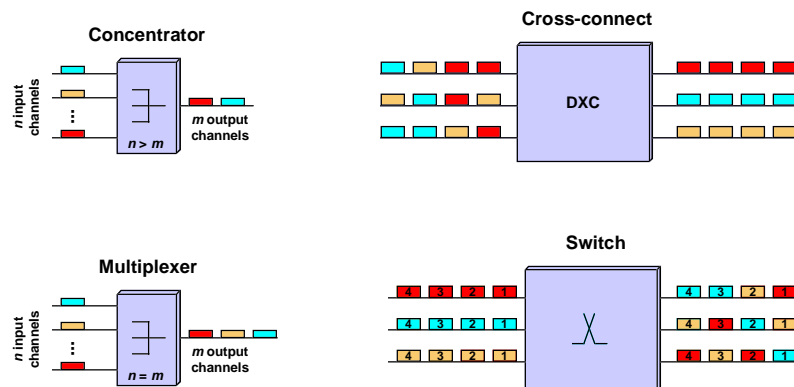
## Multiplexing/PDH

- 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 flow
- First order is octet-interleaved, but higher orders are bit-interleaved

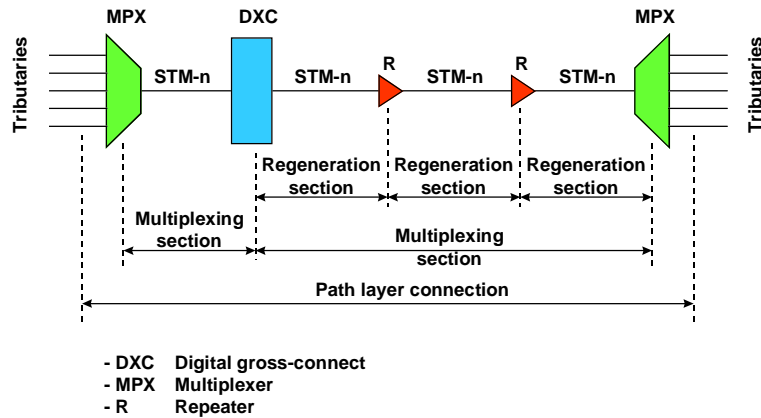
## PDH network elements

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

## Example PDH network elements



## SDH reference model



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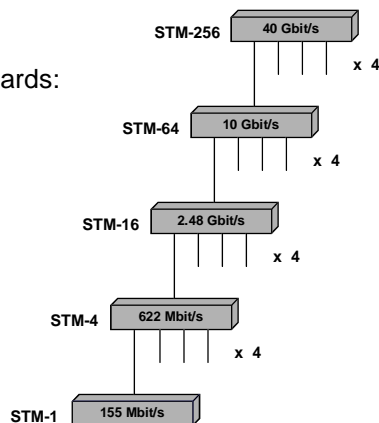
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## Synchronous digital hierarchy

Major ITU-T SDH standards:

- G.707
- G.783



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## Multiplexing/SDH

- 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)

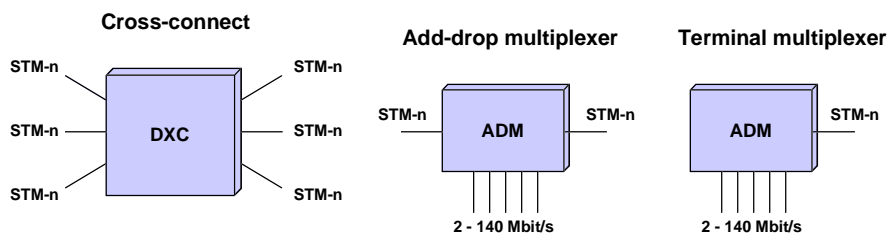
## Multiplexing/SDH (cont.)

- 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 multiples of it
  - transport modules called STM-N (N = 1, 4, 16, 64, ...)
  - bit rate of STM-N is  $N \times 155.52$  Mbit/s
  - duration of a module is 125  $\mu$ s (= duration of a PDH frame)

## SDH network elements

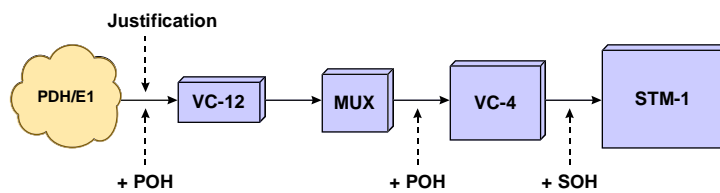
- regenerator (intermediate repeater, IR)
  - regenerates line signal and may send or receive data via communication channels in RSOH header fields
- multiplexer
  - terminal multiplexer multiplexes/demultiplexes PDH and SDH tributaries to/from a common STM-n
  - add-drop multiplexer adds or drops tributaries 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





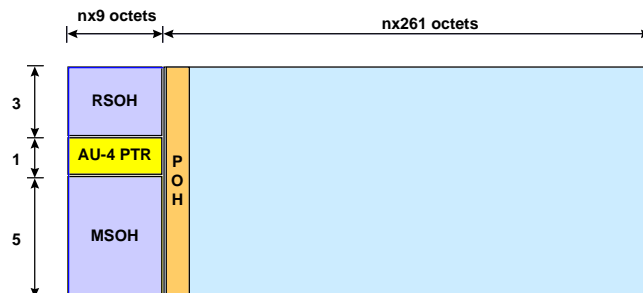
## Generation of STM-1 frame



## STM-*n* frame

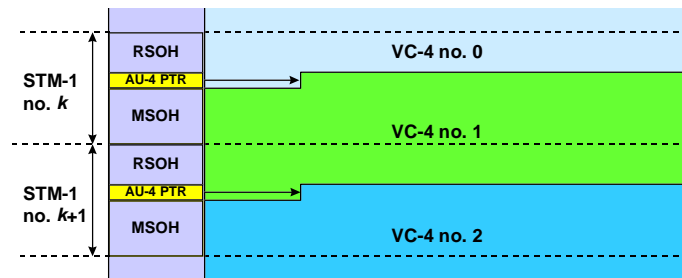
### Three main fields:

- 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)



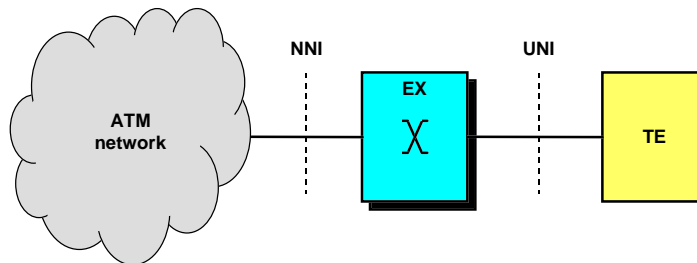
## ATM concept in summary

- **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)

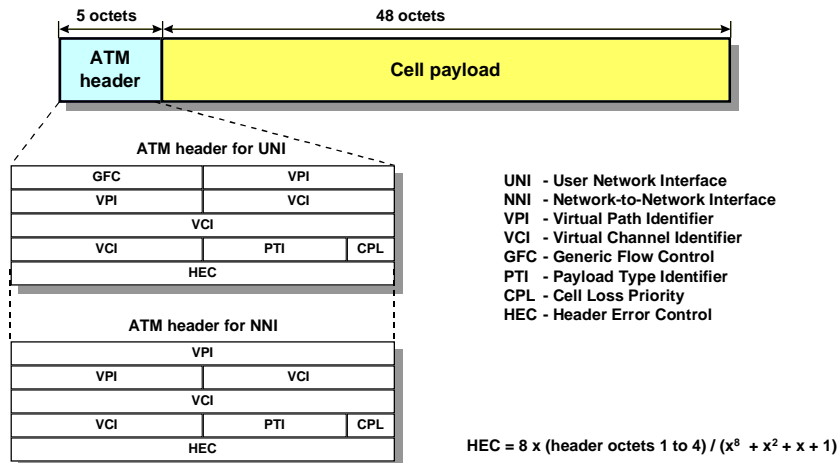
## ATM protocol reference model

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



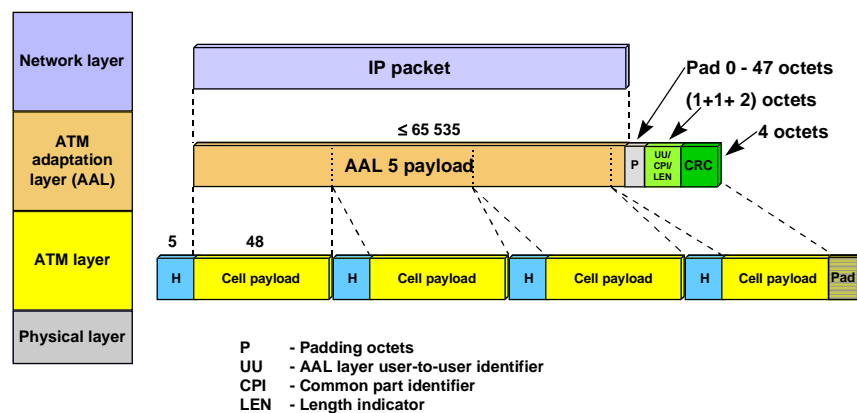
## ATM connection types



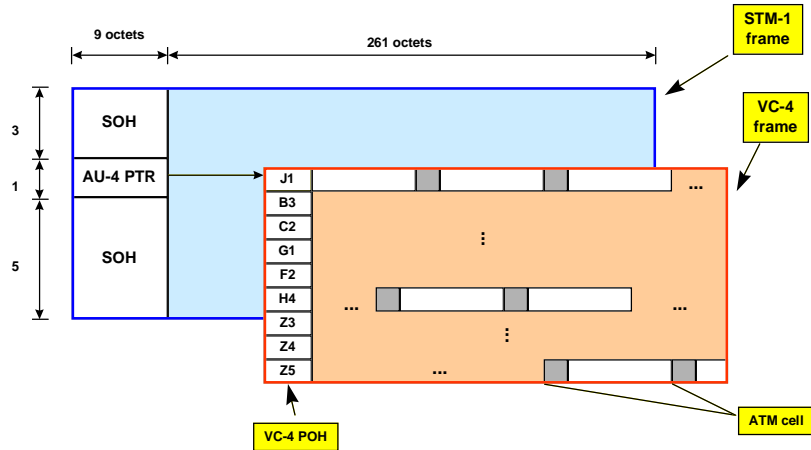
## Physical layers for ATM

- **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 phys. level interfaces (e.g. E1, STM-1 or STM-4)
  - HEC used for framing

## Transport of data in ATM cells



## ATM cell encapsulation / SDH

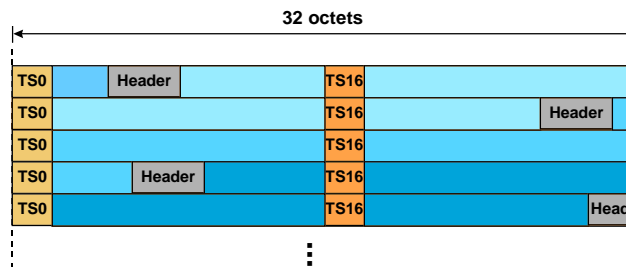


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## ATM cell encapsulation / PDH (E1)



**TS0**

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

**TS16**

- reserved for signaling

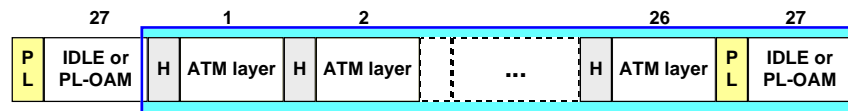
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## Cell based interface

**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 00000000 00000001 (IDLE cell)
  - 00000000 00000000 00000000 00001001 (phys. layer OAM)
  - xxxx0000 00000000 00000000 0000xxxx (reserved for phys. layer)

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

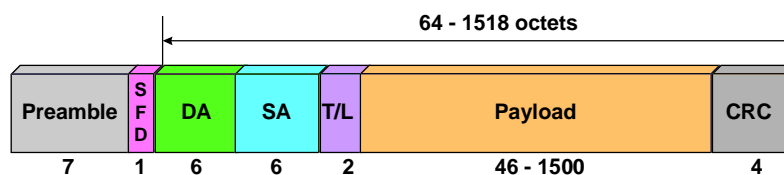
## ATM network elements

- 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, 8B9B for GbE

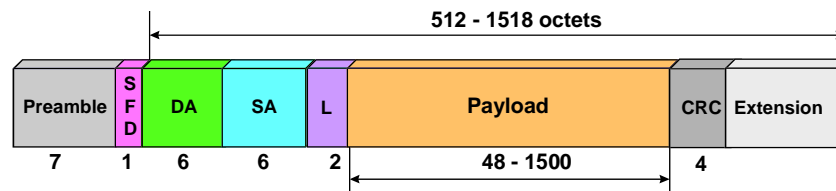
## Ethernet frame



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  $\mu$ s /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

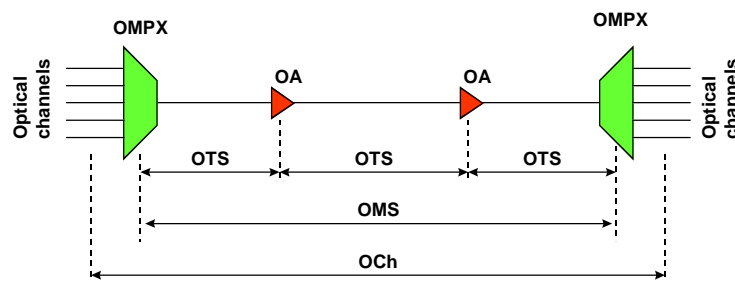
## Ethernet network elements

- **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

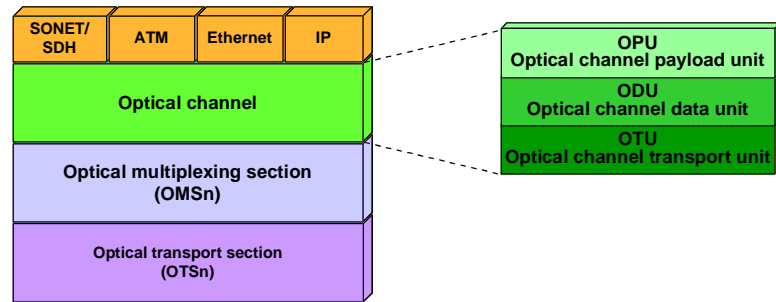
- Optical Transport Network (OTN) being developed by ITU-T (G.709) specifies interfaces for optical networks
- Goal to gather for the transmission needs of today's wide range of digital services and to assist network evolution to higher bandwidths and improved network performance
- OTN builds on SDH 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

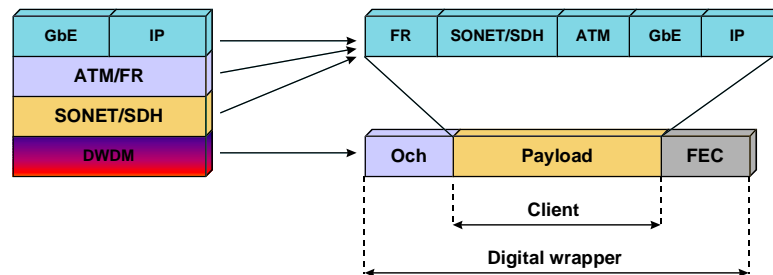
## OTN layers and OCh sub-layers



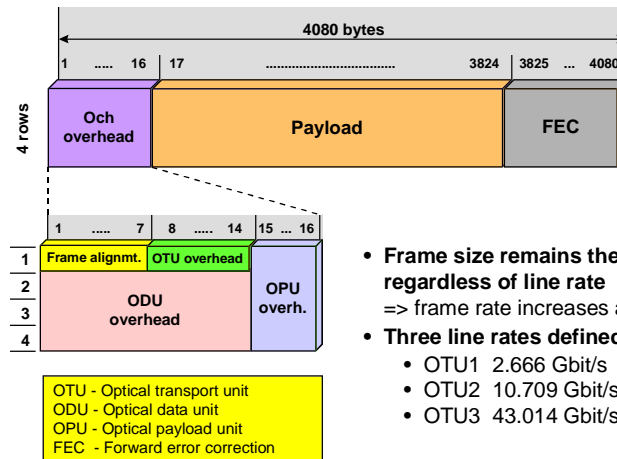
## OTN frame structure

### • Three main fields

- Optical channel overhead
- Payload
- Forward error indication field

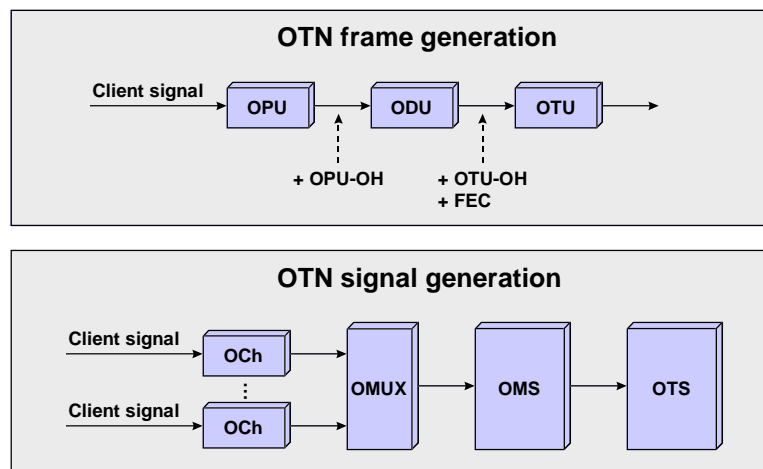


## OTN frame structure



- 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