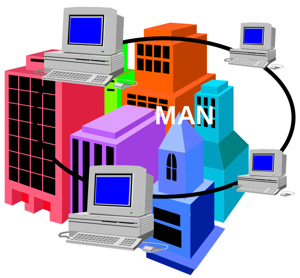
Metropolitan Area Networks

- Bridge larger distances than a LAN, usage e.g. within the city range or on a campus.
- Only one or two cables, no switching elements. Thus a simple network design is achieved.
- All computers are attached to a broadcast medium.
- Distinction between LAN and MAN: The utilization of a clock pulse, geographical distance.



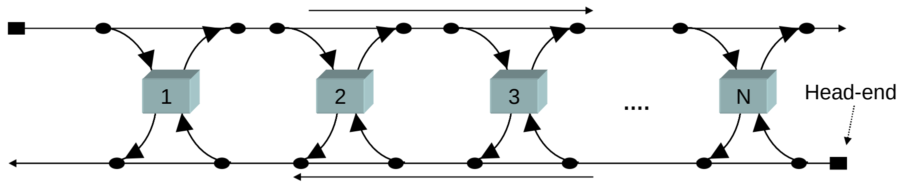
Examples:

- **Distributed Queue Dual Bus** (DQDB)
- Gigabit Ethernet

Distributed Queue Dual Bus (DQDB)

Basic principle:

- *Two* unidirectional busses (simple cables) are attached to all computers:

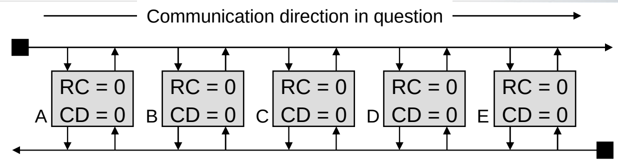


- Each bus is responsible for the communication into one direction
- Each bus has a head-end, which controls all transmission activities: a constant flow of slots of size 53 byte is produced each 125µs.
- Utilizable data field of each slot: 48 byte
- Two substantial protocol bits: *Busy* for marking a slot as occupied, *Request* for the registration of a slot inquiry
- Expansion to 100 km permissible
- Data rates up to 150 MBit/s (optical fiber; with coaxial cables only 44 MBit/s)

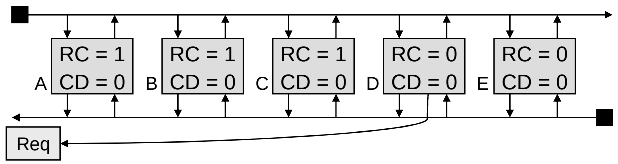
DQDB - Transmission principle

- During a transmission the sending station must know whether the receiver is on the left or the right side.
- Before starting a transmission in one direction, a slot has to be reserved. This is made by sending a reservation request in the opposite direction.
- Simulation of a FIFO queue in order to consider stations in the order of their communication requests:
  - Each station manages two counters: *RC* (Request Counter) and *CD* (Countdown Counter)
  - RC counts the number of transmission wishes of downward located stations, which arrived before the own transmission wish.
  - CD serves as auxiliary counter. If a station wants to send, it generates an inquiry setting a special *Request bit* in a slot in opposite direction. The current value of RC is copied into CD (the station may occupy only the RC+1st cell).
  - RC is set to 0 and counts the number of further coming communication wishes. With each free slot passing in communication direction, CD is counted down by one. If CD = 0, the station may send. If it has now a new communication wish, it must again wait for RC slots.

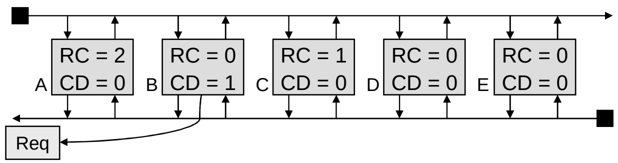
DQDB - Example



1. System is in the initial state. All counters are set to zero.

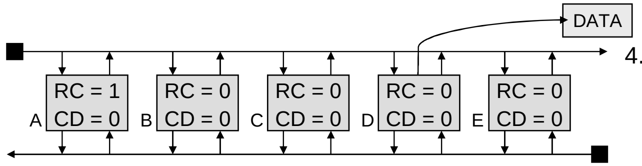


2. D wants to initiate a communication. In the counter direction, a *Req* is dispatched. The stations on the way increase *RC* by 1.

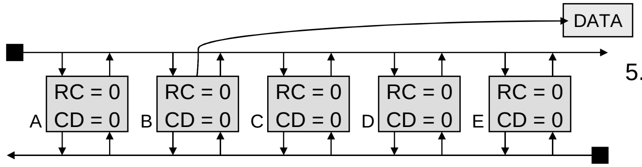


3. B also wants to use the bus. A increases *RC* by 1, B copies *RC* into *CD*.

DQDB - Example



4. The head-end of the communication bus produces slots. Each station counts down *RC* by one with each passing cell, stations with *CD* > 0 count down *CD*. Station D wants to send and has *CD* = 0, by this it has sending permission.



5. With the next slot, station B has a *CD* = 0 and may send.

DQDB never became generally accepted, since short time later ATM was introduced.

Wide Area Networks

- Bridging of any distance
- Usually for covering of a country or a continent
- Topology normally is irregular due to orientation to current needs. Therefore not the shared access to a medium is the core idea, but the thought “how to achieve the fast and reliable transmission of as much data as possible over a long distance”.
- Usually quite complex interconnections of sub-networks which are owned by different operators
- No broadcast, but point-to-point connections
- Range: several 1000 km

Examples:

- Asynchronous Transfer Mode, ATM
- Synchronous Digital Hierarchy, SDH

Transmission Technologies for WANs

Point-to-Point Links

- Provision of a single WAN connection from a customer to a remote network
- Example: telephone lines. Usually communication resources are leased from the provider.
- Accounting bases on the leased capacity and the distance to the receiver.

Circuit Switching

- A connection is established when required, communication resources are reserved exclusively. After the communication process, the resources are released.
- Example: Integrated Services Digital Network, ISDN

Packet Switching

- “Enhancement” of the “Circuit Switching” and the Point-to-Point links.
- Shared usage of the resources of one provider by several users, i.e. one physical connection is used by several virtual resources.
- Shared usage reduces costs

Packet Switching

Packet Switching today is the most common communication technology in WANs. The provider of communication resources provides virtual connections (virtual circuits, circuit switching) between remote stations/networks, the data are transferred in the form of packets.

Examples: Frame Relay, ATM, OSI X.25

Two types of Virtual Circuits:

- *Switched Virtual Circuits* (SVCs)

  Useful for senders with sporadic transmission wishes. A virtual connection is established, data are being transferred, after the transmission the connection is terminated and the ressources are being released.

- *Permanent Virtual Circuits* (PVCs)

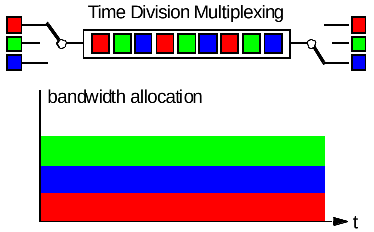
  Useful for senders which need to transfer data permanently. The connection is established permanently, there exists only the phase of the data transfer.

ATM for the Integration of Data and Telecommunication

Telecommunication:

Primary goal: Telephony

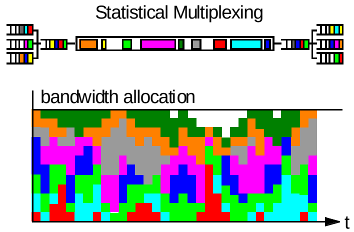
- Circuit-switched
- Firm dispatching of resources
- Performance guarantees
- Unused resources are lost
- Small end-to-end delay



Data communication:

Primary goal: Data transfer

- Packet-switched
- Flexible dispatching of resources
- No performance guarantees
- Efficient use of resources
- Variable end-to-end delay

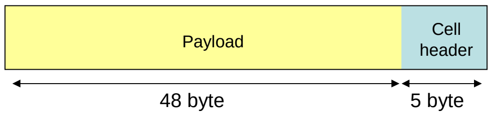


Characteristics of ATM

- ITU-T standard (resp. ATM forum) for *cell transmission*
- Integration of data, speech, and video transmissions
- Combines advantages of:
  - Circuit Switching (granted capacity and constant delay)
  - Packet Switching (flexible and efficient transmission)
- *Cell-based Multiplexing* and *Switching technology*
- *Connection-oriented* communication: virtual connections are established
- Guarantee of *quality criteria* for the desired connection (bandwidth, delay,…). For doing so, resources are being reserved in the switches.
- no flow control and error handling
- Supports PVCs, SVCs and connection-less transmission
- Data rates: 34, 155 or 622 (optical fiber) MBit/s

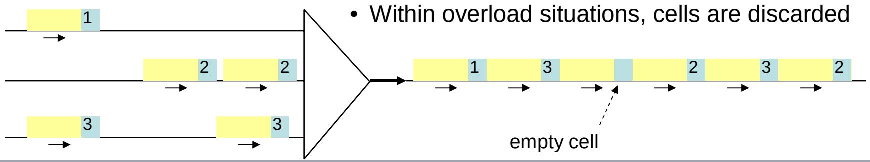
ATM Cells

- No packet switching, but *cell switching*: like time division multiplexing, but without reserved time slots
- Firm cell size: 53 byte



Cell multiplexing on an ATM connection:

- Asynchronous time multiplexing of several virtual connections
- Continuous cell stream
- Unused cells are sent empty
- Within overload situations, cells are discarded



Cell Size: Transmission of Speech

Coding audio: **Pulse-code modulation (PCM)**

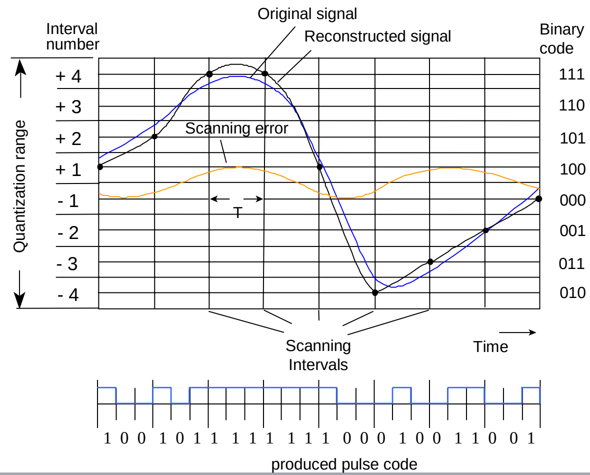
- Transformation of analogous into digital signals
- regular scanning of the analogous signal
- ***Scanning theorem (Nyquist):***

  Scanning rate ≥ 2 * cutoff frequency of the original signal

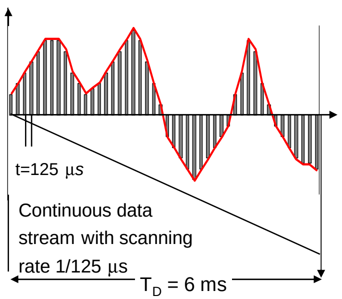
  Cutoff frequency of a telephone: 3.4 kHz

  ⇒ scanning rate of 8000 Hz
- Each value is quantized with 8 bits (i.e. a little bit rounded).
- A speech data stream therefore has a data rate of 8 bits * 8000 s^{-1} = 64 kBit/s

Example (simplification: Quantization with 3 bits)



Cell Size within ATM



Problem:

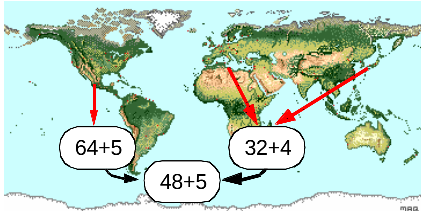
Delay of the cell stream for speech is 6 ms:

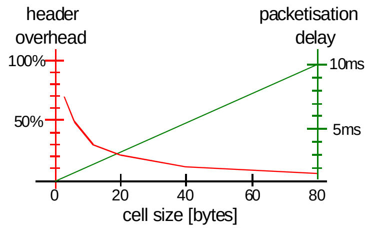
48 samples with 8 bits each
= 48 byte
= Payload for an ATM cell

⇒ Larger cells would cause too large delays during speech transmission

⇒ Smaller cells produce too much overhead for "normal" data (relationship Header/Payload)

i.e. *48 byte is a compromise*.

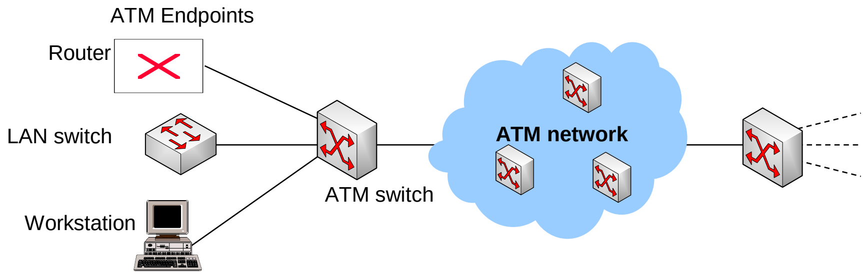




ATM Network

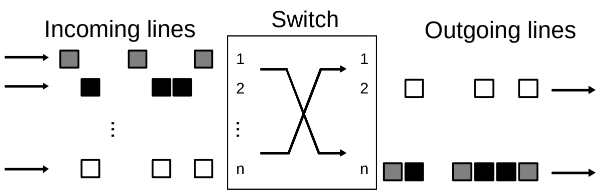
Two types of components:

- *ATM Switch*
  Dispatching of cells through the network by switches. The cell headers of incoming cells are read and an update of the information is made. Afterwards, the cells are switched to the destination.
- *ATM Endpoint*
  Contains an ATM network interface adapter to connect different networks with the ATM network.



ATM Switching

- Before the start of the communication a virtual connection has to established. The switches are responsible for the forwarding of arriving cells on the correct outgoing lines. For this purpose a switch has a *switching table*.



Switching Table

In	Old Header	Out	New Header
1	a	n	a
2	c	n	d
⋮	⋮	⋮	⋮
n	b	2	e

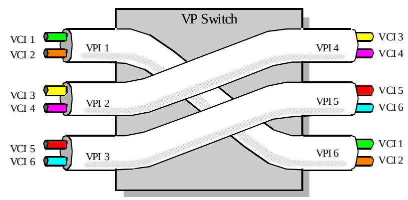
- The header information, which are used in the switching table, are *VPI* (*Virtual Path Identifier*) and *VCI* (*Virtual Channel Identifier*).
- If a connection is being established via ATM, VPI and VCI are assigned to the sender. Each switch on the route fills in to where it should forward cells with this information.

Path and Channel Concept of ATM

- Physical connections "contain" **Virtual Paths** (VPs, a group of connections)
- VPs "contain" **Virtual Channels** (VCs, logical channels)
- VPI and VCI only have local significance and can be changed by the switches.
- Distinction between VPI and VCI introduces a hierarchy on the path identifiers. Thus: Reduction of the size of the switching tables.

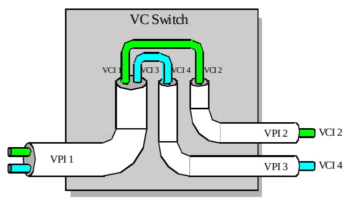
There are 2 types of switches in the ATM network:

Virtual Path Switching



VP-SWITCH

Virtual Channel Switching



VP/VC-SWITCH

Structure of ATM cells

Two header formats:

- Communication between switches and endpoints: *User-Network Interface* (UNI)
- Communication between two switches: *Network-Network Interface* (NNI)

GFC - Generic Flow Control

Only with UNI, for local control of the transmission of data into the network. Typically unused. With NNI these bits are used to increase the VPI field.

Bit	8	7	6	5	4	3	2	1
Byte 1	GFC/VPI				VPI			
Byte 2	VPI							
Byte 3	VCI							
Byte 4					PTI			CLP
Byte 5	HEC							

PTI - Payload Type Identifier

Describes content of the data part, e.g. user data or different control data

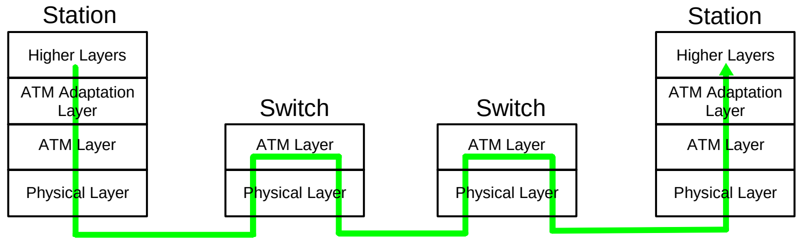
CLP - Cell Loss Priority

If the bit is 1, the cell can be discarded within overload situations.

HEC - Header Error Control

CRC for the first 4 bytes; single bit errors can be corrected.

Layers within ATM



Physical Layer

- Transfers ATM cells over the medium
- Generates checksum (sender) and verifies it (receiver); discarding of cells

ATM Layer

- Generate header (sender) and extract contents (receiver), except checksum
- Responsible for connection identifiers (Virtual Path and Virtual Channel Identifier)

ATM Adaptation Layer (AAL)

- Adapts different requirements of higher layer applications to the ATM Layer
- Segments larger messages and reassembles them on the side of the receiver

Service Classes of ATM

Criterion	Service Class			
	A	B	C	D
Data rate	Negotiated maximum cell rate	Maximum and average Cell rate	Dynamic rate adjustment to free resources	"Take what you can get"
Synchronization (source - destination)	Yes		No	
Bit rate	constant	variable		
Connection Mode	Connection-oriented			Connectionless

Applications:

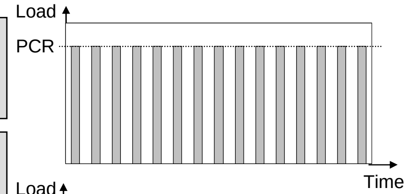
- A, B:
  - Moving pictures
  - Telephony
  - Video conferences
- C, D:
  - Data communication
  - File transfer
  - Mail

Adaptation Layer (AAL):

A	B	C	D
AAL 1	AAL 2	AAL 3	AAL 4
		AAL 5	

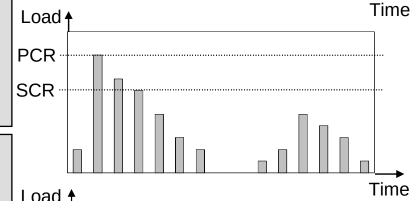
AAL 1: **CBR** - *Constant Bit Rate*, deterministic service

- Characterized by guaranteed fixed bit rate
- Parameter: Peak Cell Rate (PCR)



AAL 2: **VBR** - *Variable Bit Rate* (real time/non real time), statistical service

- Characterized by guaranteed average bit rate. Thus also suited for bursty traffic.
- Parameter: Peak Cell Rate (PCR), Sustainable Cell Rate (SCR), Maximum Burst Size

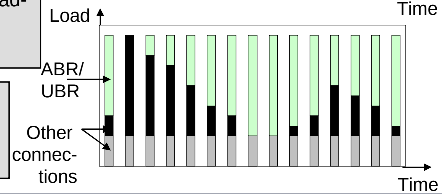


AAL 3: **ABR** - *Available Bit Rate*, load-sensitive service

- Characterized by guaranteed minimum bit rate and load-sensitive, additional bit rate (adaptive adjustment)
- Parameter: Peak Cell Rate, Minimum Cell Rate

AAL 4: **UBR** - *Unspecified Bit Rate*, Best Effort service

- Characterized by no guaranteed bit rate
- Parameter: Peak Cell Rate



Traffic Management

Connection Admission Control
- Reservation of resources during the connection establishment (signaling)
- Comparison between connection parameters and available resources
- Traffic contract between users and ATM network

Usage Parameter Control/Network Parameter Control
- Test on conformity of the cell stream in accordance with the parameters of the traffic contract at the user-network interface or network-network interface
- Generic Cell Rate Algorithm/Leaky Bucket Algorithm

Switch Congestion Control (primary for UBR)
- Selective discarding of cells for the maintenance of performance guarantees in the case of overload

Flow Control for ABR
- Feedback of the network status by resource management cells to the ABR source, for the adjustment of transmission rate and fair dispatching of the capacity

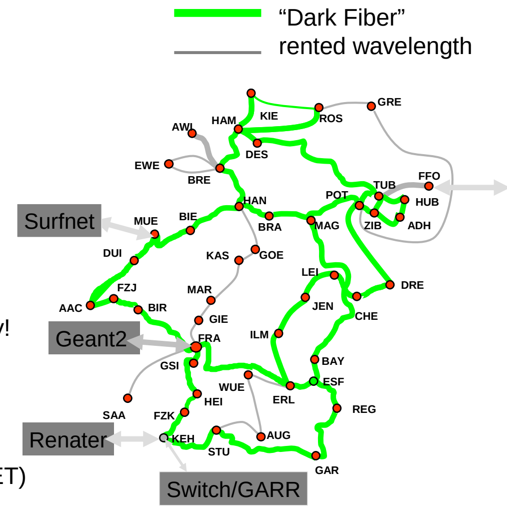
Status of ATM

ATM within LAN:
- Too high cost of the hardware
- Too strong competition by established techniques like Fast Ethernet etc.

ATM within WAN:
- often implemented between company locations
- Telecommunication providers prefer **SDH** as transport resp. core networks (better performance for telecommunications, world standard)
- ATM cells can be packed into SDH containers at transition points (encapsulation) resp. unpacked at the receiving network
- ATM was replaced to a large extent by SDH
- ATM is today mostly only offered to users as a service, in order to be able to further use existing devices and mechanisms

Synchronous Digital Hierarchy (SDH)

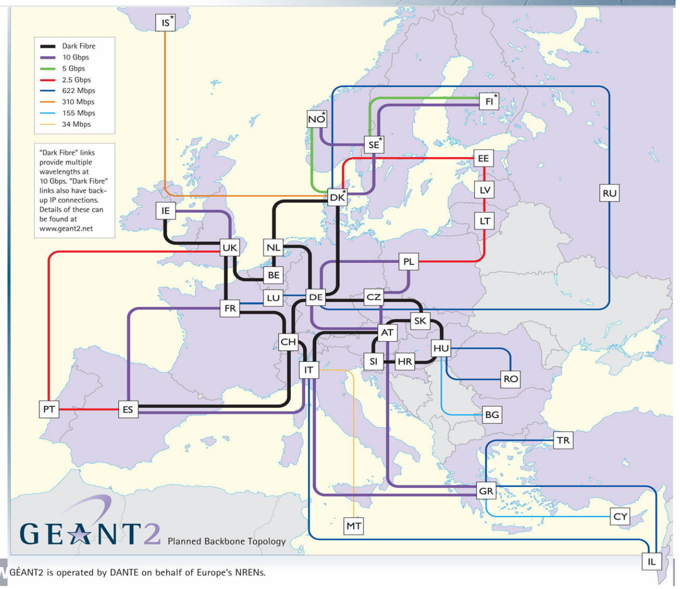
- All modern networks in the public area are using the SDH technology
- Example: the German B-WIN (ATM) was replaced by the G-WIN (Gigabit-Wissenschaftsnetz) on basis of SDH
- Since 2006: X-WIN – complete redesign of topology, additionally integration of DWDM (dense wavelength division multiplexing): up to 160 parallel transmissions over a fiber, giving 1.6 TBit/s capacity!
- Also used within the MAN range (Replaced by Gigabit Ethernet?)
- Analogous technology in the USA: Synchronous Optical Network (SONET)



GÉANT

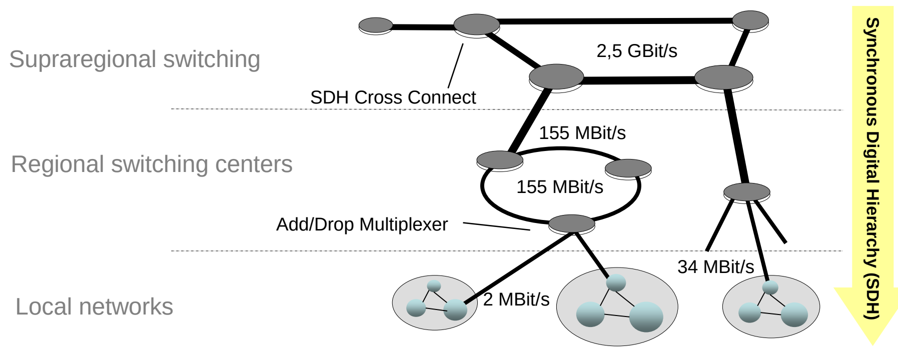
European scientific network GÉANT

- Connects more than 30 countries
- In Germany: connection by a central node in Frankfurt
- Also in Frankfurt and Hamburg: intercontinental connections.

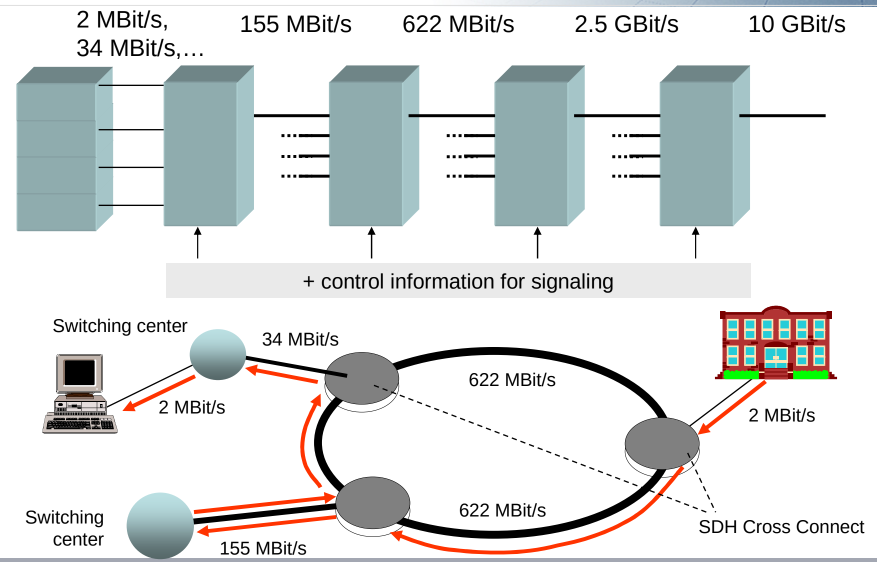


SDH Structure

- SDH realizes higher data rates than ATM (at the moment up to about 40 GBit/s)
- Flexible capacity utilization and high reliability
- Structure: arbitrary topology, meshed networks with a switching hierarchy (exemplarily 3 levels):



Multiplexing within SDH



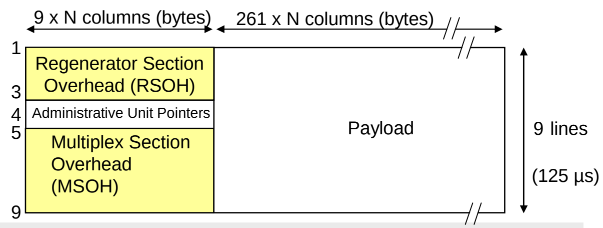
Characteristics of SDH

- World-wide standardized bit rates on the hierarchy levels
- Synchronized, centrally clocked network
- Multiplexing of data streams is made byte by byte, simple multiplex pattern
- Suitability for speech transmission:
  since on each hierarchy level four data streams are mixed byte by byte and a hierarchy level has four times the data rate of the lower level, everyone of these mixed data streams has the same data rate as on the lower level. Thus the data experience a constant delay.
- Direct access to signals by cross connects without repeated demultiplexing
- Short delays in inserting and extracting signals
- Additional control bytes for network management, service and quality control,…
- Substantial characteristic: ***Container*** for the transport of information

SDH Transport Module (Frame)

Synchronous Transport Module (STM-N, N=1,4,16, 64)

STM-1 structure:
- 9 lines with 270 bytes each.
- Basis data rate of 155 MBit/s.



Administrative Unit Pointers
- permit the direct access to components of the Payload

Section Overhead
- **RSOH**: Contains information concerning the route between two repeaters or a repeater and a multiplexer
- **MSOH**: Contains information concerning the route between two multiplexers without consideration of the repeaters in between.

Payload
- Contains the utilizable data as well as further control data

Creation of a STM

- Utilizable data are packed into a **container**.
- A distinction of the containers is made by size: C-1 to C-4
- Payload data are adapted if necessary by padding to the container size
- As additional information to the utilizable data, for a connection further bytes are added for controlling the data flow of a container over several multiplexers:

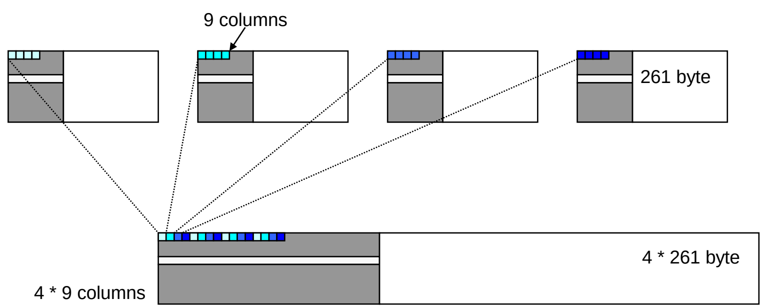
  Path Overhead (POH)
  - Control of single sections of the transmission path
  - Change over to alternative routes in case of an error
  - Monitoring and recording of the transmission quality
  - Realization of communication channels for maintenance
- By adding the POH bytes, a container becomes a **Virtual container**

Creation of a STM

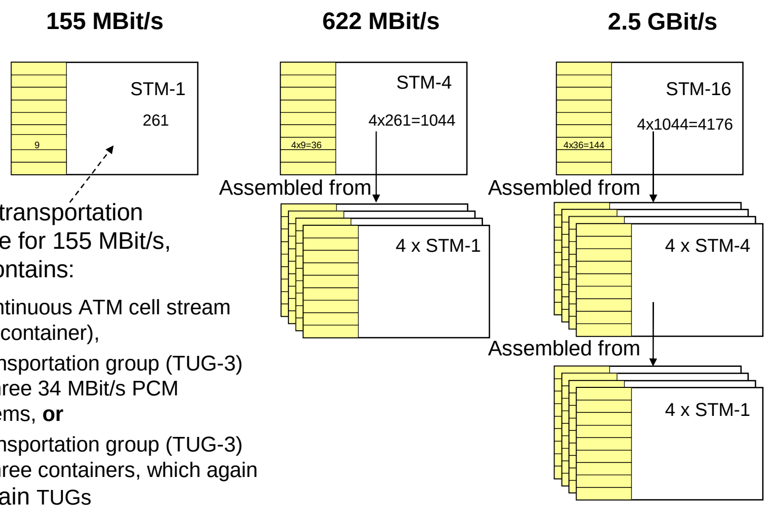
- If several containers are transferred in a STM payload, these are multiplexed byte by byte in **Tributary Unit Groups**.
- By adding an Administrative Unit Pointer, the Tributary Unit Group becomes an **Administrative Unit** (AU).
- Then the SOH bytes are supplemented, the SDH frame is complete. RSOH and MSOH contain for example bits for
  - Frame synchronization
  - Error detection (parity bit)
  - STM-1 identificators in larger transportation modules
  - Control of alternative paths
  - Service channels
  - … and some bits for future use.

SDH Hierarchy

- Higher hierarchy levels assembling STM-1 modules
- Higher data rates are assembled by multiplexing the contained signals byte by byte
- Each byte has a data rate suitable by 64 KBit/s, for the transmission of speech data (telephony)
- Except STM-1, only transmission over optical fiber is specified



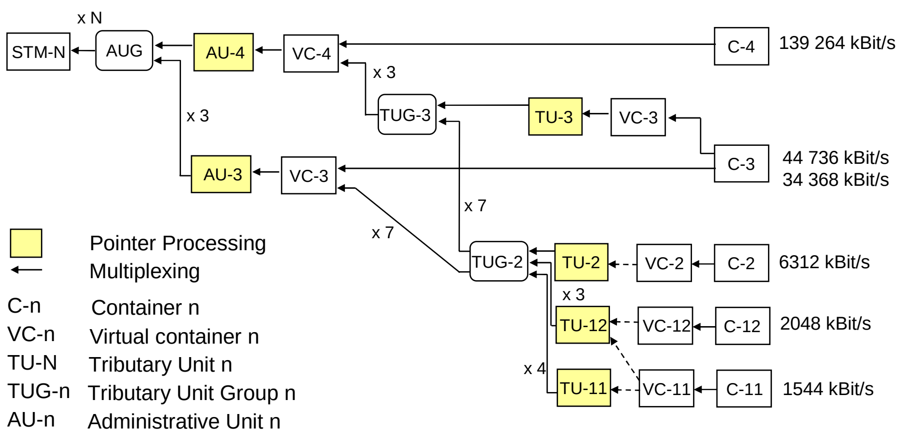
SDH Hierarchy



Basis transportation module for 155 MBit/s, e.g. contains:

- a continuous ATM cell stream (C-4 container),
- a transportation group (TUG-3) for three 34 MBit/s PCM systems, **or**
- a transportation group (TUG-3) for three containers, which again contain TUGs

SDH Multiplex Structure



(yellow box)	Pointer Processing
←	Multiplexing
C-n	Container n
VC-n	Virtual container n
TU-N	Tributary Unit n
TUG-n	Tributary Unit Group n
AU-n	Administrative Unit n
AUG	Administrative Unit Group
STM-N	Synchronous Transport Module N