Communication Systems
Wide-Area Network (WAN) / ATM

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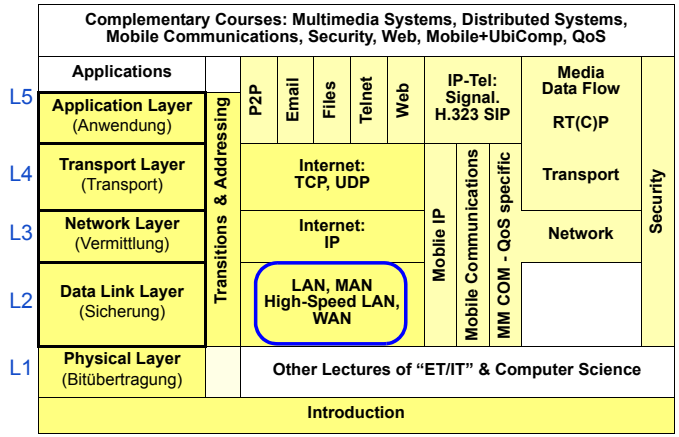
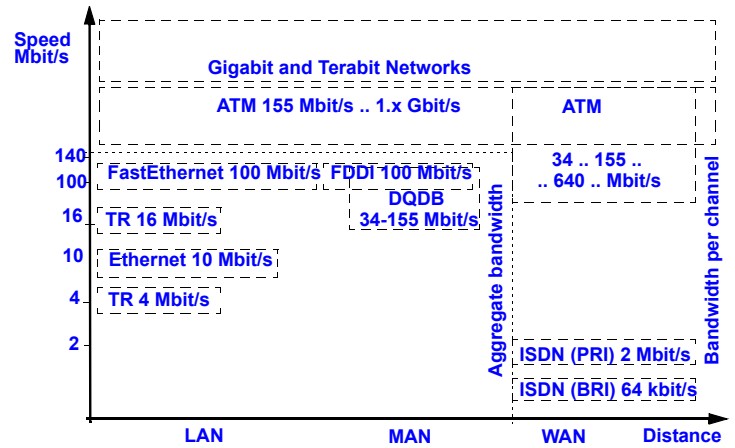
Scope



Overview

WANs and Other Networks



1. Characteristics of WANs

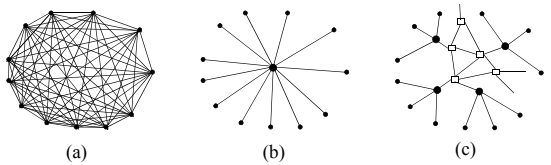
Range
- international, worldwide, nationwide
- generally from approx. 100 km onwards, but also in private/commercial buildings PABX (Private Automatic Branch Exchange)

Transfer Rates
- from 9.600 kbps up to several Gigabit per second

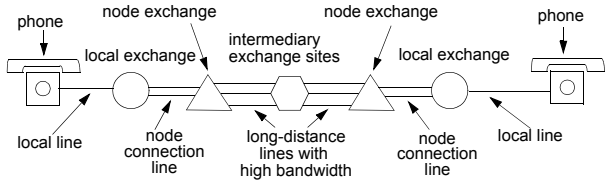
Typical use of WANs
- traditionally: services of telephone companies (telephone, fax, ...)
  - telecommunication networks usually have been service specific
    - Plain Old Telephone Service (POTS) with voice
    - cable TV, radio with audio/video or audio
- increasingly integrated data services (Internet: CSCW, WWW, E-Mail, ...)
- still small carrier network for distributed services such as radio, TV, ...

Traditional differences to computer networks
- circuit vs. packet switching
- low (kbps) vs. high data rates (Gbit/s)
- high (10^{-6}) vs. low (10^{-10}) bit error probabilities
- addressing patterns
- protocols

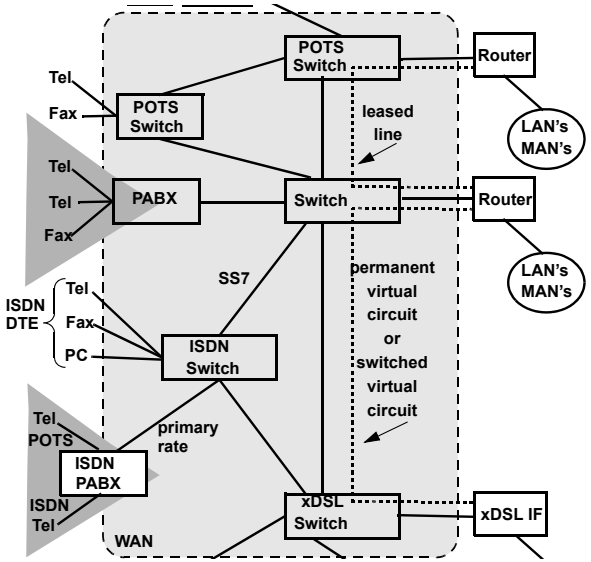
Characteristics of WANs (2)



Multi level, highly redundant hierarchy (DTAG)
- telephone ($27 \cdot 10^6$)
- local exchange (6 200)
- node exchange (417)
- main exchange (56)
- central exchange (8)



Characteristics of WANs (3)



2. B-ISDN: Introduction

ISDN AND PREDECESSOR (Plain Old Telephone Service POTS)
- relatively low data transfer rates, with the following features missing:
  - TV distribution
  - AV – Retrieval
  - efficient communication channels for data communication
  - efficient channels for communicating audio and video information

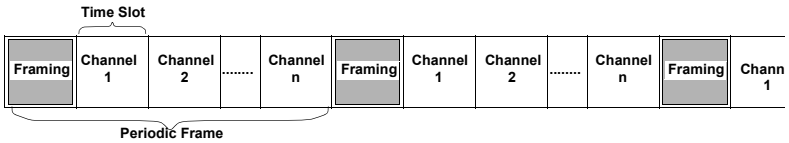
⇒ **Broadband Requirements ISDN (B-ISDN)**

- flexible, service- UNspecific network
- high data rates
- efficient resource usage (for all services)
- more cost-efficient than in the past (incl. maintenance, operating)

B-ISDN: First Attempt

STM (Synchronous Transfer Mode):

- **Based on time division multiplexing**



Disadvantages:

- **Fixed data rates**
- **Fixed bandwidth for connections**

⇒ **development discontinued**

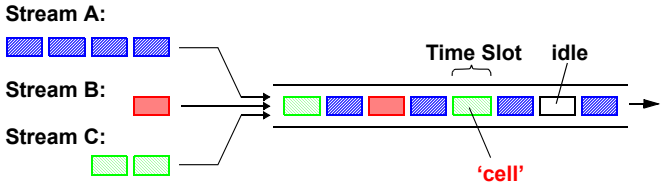
⇒ **ATM instead**

Asynchronous Transfer Mode

Strategic B-ISDN direction since 1988

Technology:

- **Fast „cell“ switching**
- **Variable bandwidth channel assignment**



Asynchronous refers to multiplexing of data (ITU-T recommendation I.113):

" ... it is asynchronous in the sense that the recurrence of cells containing information from an individual user is not necessarily periodic."

3. ATM: Design Decisions & Concepts

TDM: retain Time Division Multiplexing, but

- **time slot allotted to channel**
  - by header, and
  - **NOT** specified by relative position
- **thereby**
  - enabling the free selection of a channel's bandwidth
  - no bandwidth wastage among VBR channels

OBJECTIVE: simple, efficient protocol

Therefore: ATM network

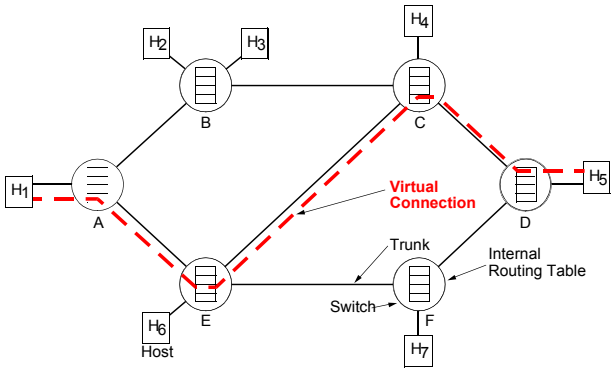
- **no error treatment**
- **no flow control**
- **connection-oriented at the lowest level**
- **cells**
  - packets but with small, fixed length
- **packet headers provide limited functionality only**

ATM Concepts: Virtual Connection

Virtual connection for requirements more favourable than

- **circuit switching or**
- **pure packet switching with datagrams**

Example of a virtual connection:

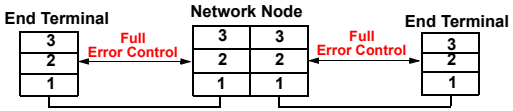


ATM Concepts: Error Treatment

Take very low error rates of fiber optics into account

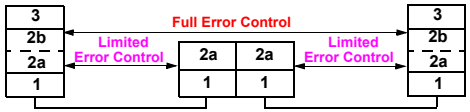
1. **traditionally, channels had significant error rates**

⇒ **HDLC: error correction at link level**



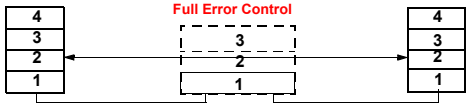
2. **improved technology, less errors**

⇒ **Frame Relay: only some functions at link level**



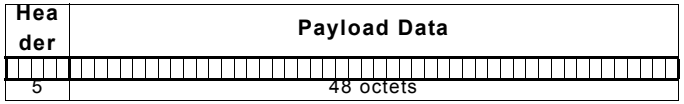
3. **very low error rate, very low delays**

⇒ **ATM: error correction (of data) only at the outer network edges**



ATM Concepts: Cell

53 Byte ATM cell



Cell length
- **USA favored: 64 Bytes**
- **Europe favored: 32 Bytes**
- **48 Bytes compromise**

Tradeoff
- **short cells**
  - better for voice, because
    - low end-to-end delay (packeting delay)
- **long cells**
  - good for traditional data, because
    - reduced header overhead
    - less segmentation/reassembling

ATM: Reference Model

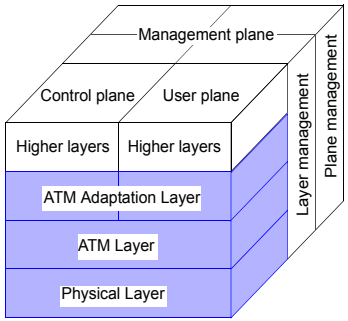
Physical Layer:
- **for various media and wide range of bandwidth defined: 25 Mbit/s … 2 Gbit/s**

ATM Layer:
- **Multiplexing and switching of cells**

ATM Adaption Layer (AAL):
- **Application-oriented services (Segmentation & reassembly, …)**

User Plane
- **Data transfer**

Control Plane
- **Signaling (out-of-band) for connection management (setup + control + release)**



Management Plane:
- **Layer Management**
  - Layer specific aspects, e.g., resource management, Operation and Maintenance (OAM)
- **Plane Management**
  - Dealing with common aspects of all planes

ATM: Functions

Layer Management	High layer functions	Higher layers	
	Convergence	CS	AAL
	Segmentation and reassembly	SAR	
	Generic flow control Cell header generation/extraction Cell VPI/VCI translation Cell multiplex and demultiplex	ATM	
	Cell rate decoupling HEC sequence generation/verification Cell delineation Transmission frame adaptation Transmission frame generation/recover	TC	Physical Layer
	Bit timing Physical medium	PM	

AAL: ATM adaptation layer
CS: Convergence sublayer
HEC: Header error control
PM: Physical medium
SAR: Segmentation and reassembly
TC: Transmission convergence
VCI: Virtual channel identifier
VPI: Virtual path identifier

4. ATM Physical Layer

Sub-layers

- **Physical Medium Dependent (PMD) and Transmission Convergence (TC)**
- **(mainly) based on SDH specification and rates**
  - primarily 155 and 622 Mbps
- **however, alternatives have been specified as well (especially as ATM-LANs)**
  - approx. 25 Mbps and approx. 50 Mbps (ATM Forum, because of unshielded twisted pair cable)
  - 100 Mbps (ATM Forum, because of FDDI)

Physical Medium Dependent (PMD): functions

- **offers service, preferably independent from carrier medium i.e., could also use the payload of other networks**
- **bit timing**
- **bit encoding, electrical-optic conversion, ...**

ATM Physical Layer (2)

Multiplex rates

SONET		SDH	Data Rate (Mbps)		
electrical	optical	optical	total	SPE	payload
STS-1	OC-1	-	51.84	50.112	49.536
STS-3	OC-3	STM-1	**155.52**	150.336	**148.608**
STS-9	OC-9	STM-3	466.56	451.008	445.824
STS-12	OC-12	STM-4	**622.08**	601.344	**594.432**
STS-18	OC-18	STM-6	933.12	902.016	981.648
STS-24	OC-24	STM-8	1244.16	1202.688	1188.864
STS-36	OC-36	STM-12	1866.24	1804.032	1783.296
STS-48	OC-48	STM-16	2488.32	2405.376	2377.728

STS: Synchronous Transport Signal

SPE: Synchronous Payload Envelope (payload incl. some additional data)

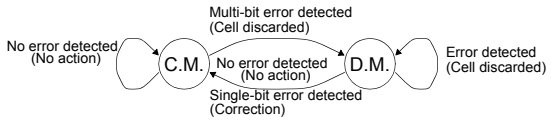
Transmission Convergence (TC)

De-coupling of the cell rate

- **TC sublayer: spacing between physical layer cells: max. 26 cells**
- **if no physical layer OAM cell is available: insert "idle cell"**

Error treatment of the HEC Header (Header Error Control)

- **4 bytes from the header constitute the header data**
- **5th byte contains the error correction**
  - at bit error rate 10^{-8}:
    - probability of cell loss: 10^{-13} (due to error in header has been determined but cannot be corrected)
  - probability for incorrect correction < 10^{-20}
- **Correction/Detection Mode**



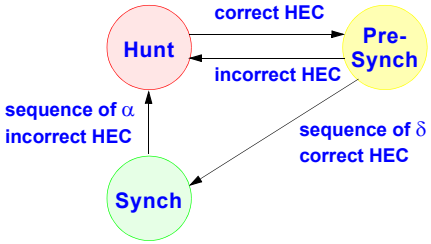
Recognize cell boundaries

Adapt cell flow to transmission frames

Generate/extract transmission frames

Detection of Cell Boundaries

Finite Automata



States

- **Hunt**
  - check incoming data stream bit wise
  - if HEC field has been detected, go to Pre-Synch state
- **Pre-Synch**
  - check incoming data stream cell wise
- **Synch**
  - regular, operational state: synchronized

5. ATM Layer

Purpose:
- Multiplexing and switching of cells (53 bytes each)

Function
- independent from the physical medium
- realization of virtual connections
- multiplexing and demultiplexing of connections (identified via VCIs+VPIs)
- detach/add cell header (during transfer from/to AAL)
- conversion of VCIs at various relay stations
- access flow control (only at network edges (UNI))
- no temporal relationship between different connections
- no error control (ACKs)

Service
- connection-oriented (virtual path, virtual channel)
- unidirectional, but pair can be established in one step
  - point-to-point connection and multicast (point-to-multiple point)
- maintaining the sequence of all cells within a connection

Comparison to OSI / ReferenceModel layer respectively
- L1: since VC with VP corresponds to virtual pipeline ("unreliable bit pipe")
- L3: since capable of end-to-end and routing

ATM: Virtual Connections

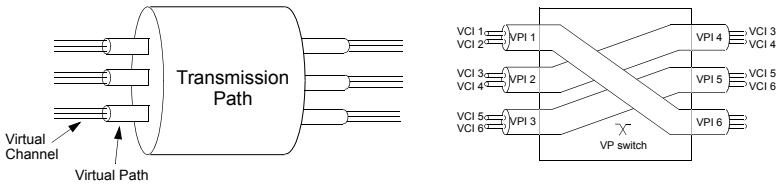
Logical association between the endpoints of a link (individual link)

Characteristics:
- *Unidirectional* data transfer
- Guaranteed *sequential* delivery
- Error detection by HEC and *correction* of single bit errors
- *QoS* characteristics associated with each virtual connection

Virtual Path:
- Route through a network
- Carries various VCs
- In overload situations: discard cells marked as low priority
- VP also has a QoS

Virtual Channel / Virtual Path

2-Level-Hierarchy



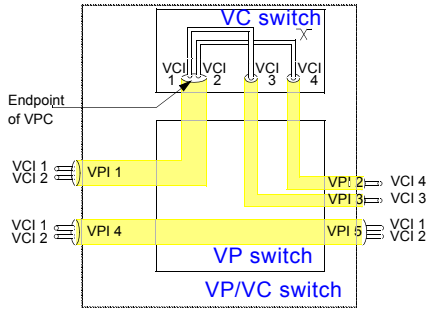
Virtual Path (VP)
- a group of VCs
  - unidirectional, permanent or switched transmission path
- routing is done at VP level (with VPI = VP Identifier)
  - all VCs of a VP follow the same physical path
  - reducing the routing effort
  - rerouting virtual connection groups
- implementing private networks
- connections established faster
- resource reservations independent from the number of connections

VP Crossconnect: control, management, no signaling

Virtual Channel / Virtual Path (2)

Virtual Channel (VC)
- unidirectional communication connection
- VC Identifier (VCI)
- if VP is left open: connections are established more quickly

VP/VC switch
- switches VCI as well as VPI



Comment
- VP/VC identifier has no end-to-end relevance

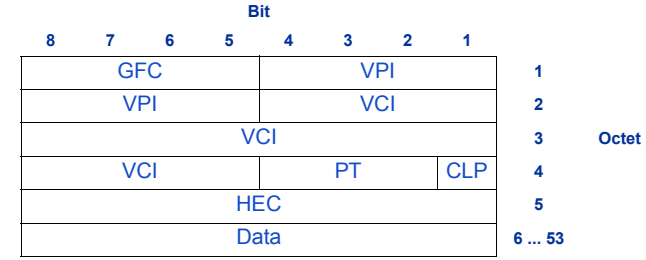
Cell Structure at UNI

User Network Interface (UNI)

- between host (also Customer Premises Equipment CPE) and ATM network

Cell Format

- 5 byte header: Channel / path information, error control
- 48 byte data information (structure depends on traffic class)
  - header cell format (theoretically 256 VPs with 65.536 VCs each)

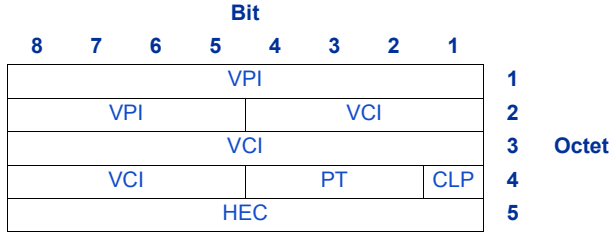


GFC	Generic Flow Control	for flow control host ÷ net
VCI	Virtual Channel Identifier	for routing
VPI	Virtual Path Identifier	(for routing)
PT	Payload Type	for network management
CLP	Cell Loss Probability	for priority
HEC	Header Error Correction	for error treatment

Cell Structure on NNI

Network-Network Interface NNI

- between 2 switching centers
- header cell format



no flow control within the network, i.e. no GFC, instead VPI longer

Connect / Disconnect

ITU Q.2931:

Connect and disconnect for ATM is supported for

- Switched Virtual Connections (SVC)
- Permanent Virtual Connections (PVC)

Out-of-band signaling

- established via a specific connection (Signaling Virtual Channel/Path)
- during connect: also reservation of resources done

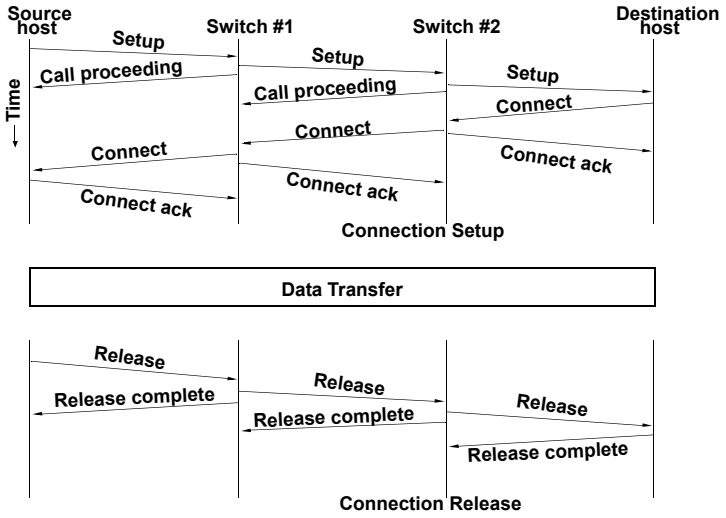
Other possibility

- (permanent) VP established
  reservation of resources for VP
  dynamic establishment of VCs within VP

Message types:

Message	Meaning when sent by host	Meaning when sent by network
SETUP	Please establish a circuit	Incoming call
CALL PROCEEDING	I saw the incoming call	Your call request will be attempted
CONNECT	I accept the incoming call	Your call request was accepted
CONNECT ACK	Thanks for accepting	Thanks for making the call
RELEASE	Please terminate the call	The other side has had enough
RELEASE COMPLETE	Ack for RELEASE	Ack for RELEASE

Connect / Disconnect (2)



6. Layer Management, "Traffic Control" Tasks

Network resource management
- **how VC groups are pooled to VPs**
- **monitor priority assignments**

Connection admission control
- **by information on: source traffic (peak cell rate, average cell rate, burstiness, peak duration, ...)**
- **by information on the service class (AAL or internal classes)**

Monitoring
- **monitoring previously stated features of cell streams**
- **types**
  - UPC Usage Parameter Control (at edge: UNI)
  - NPC Network Parameter Control (internally: NNI)
- **Operation**
  - drop cell
  - mark cell

"Traffic Control" Tasks (2)

Traffic Shaping
- **traffic characteristics adjusted according to network/system**
- **objective: increased throughput while maintaining guarantees**

Congestion Control
- **avoid congestion situations**
- **usually by procedures based on rates**
  - certain rates (cells per time slot) are permitted
  - for predefined timeframe (not necessarily per cell)
  - **"GENERIC CELL RATE ALGORITHM":**
    - checks cell rate (changes cell stream)
    - no traffic shaping
  - (also as traffic shaping)
    - token bucket procedure
- **react accordingly during congestion**

Quality of Service

Quality of Service (QoS)
- **negotiate externally and guarantee QoS**
- **quantify internally, comply with negotiated terms, handle exceptions**

„Traffic contract" for a virtual circuit between customer and network:
- **Traffic to be offered: What is the load generated by the source?**
- **Service agreed upon: What service quality can network provide for the load?**
- **Compliance requirements: How strict must the contract be fulfilled?**

Single parameters
- **types**
  - call control, e.g.
    - time for connect, disconnect
    - probability of call being refused
  - information transfer: e.g.
    - cell transit time, cell loss rate
- **Call Acceptance Control (CAC) decides during call acceptance if compliant with QoS**
- **control done during data transmission (compliance with QoS)**
  - Usage Parameter Control at the UNI (in the application)
  - Network Parameter Control at the NNI

ATM Service Classes

QoS quality management via service classes

supports or suited for	CBR	RT-VBR	NRT-VBR	ABR	UBR
Background	similar to POTS data with CBR encoding	data with VBR encoding	delay important, but Jitter tolerable	for burst with known required bandwidth	for classical data traffic
Bandwidth Guarantee	yes			optional	-
Real-time Data Traffic	yes, that means a.o. cell transit time and fluctuations limited		-		
Bursty Data Traffic	-		yes		
Comment	cell loss rate limited			feedback rates to application	
Application Example	dedicated line PCM audio-data (dialog)	MPEG video-data (live)	electronic mail	reading of interactive documents (WWW)	IP LAN coupling

CBR **Constant Bit Rate**
RT-VBR **Variable Bit Rate (Real Time)**
NRT-VBR **Variable Bit Rate (Non-Real Time)**
ABR **Available Bit Rate**
UBR **Unspecified Bit Rate**

Traffic Descriptor and Quality of Service

Quality of Service important because of real-time traffic

During connect a contract is negotiated between network and both service users (three party negotiation)

Contract contains the following parts

1. **Traffic Descriptor**
   - customized for each direction
   - payload
2. **Quality of Service**
   - a multitude of parameters
   - for each parameter:
     worst case (i.e. acceptable minimum or maximum)
   - desired value

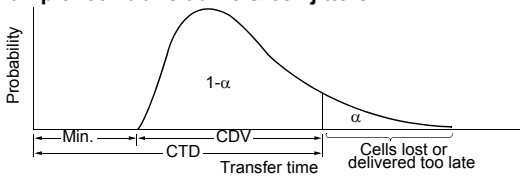
Both components have to be stated in factors that can be quantified

Important Parameters of a Contract

- **layer specific (here ATM layer)**

Parameter	Acronym	Meaning
Peak cell rate	**PCR**	Maximum rate at which cells will be sent
Sustained cell rate	SCR	long-term average cell rate
Minimum cell rate	MCR	minimum acceptable cell rate
Cell delay variation tolerance	**CDVT**	maximum acceptable cell jitter
Cell loss ratio	CLR	Fraction of cells lost or delivered too late
Cell transfer delay	**CTD**	How long delivery takes (mean and maximum)
Cell delay variation	**CDV**	variance in cell delivery times
Cell error rate	CER	Fraction of cells delivered without error
Severely-errored cell block ratio	SECBR	Fraction of blocks garbled
Cell misinsertion rate	CMR	Fraction of cells delivered to wrong destination

Example: cell transit time & cell jitters



α (cell loss rate) normally less than 10^{-10}

Generic Cell Rate Algorithm

Primary objective:
- **ensure that sender complies with traffic descriptor**

Two parameters
- **Peak Cell Rate (PCR)**
- **Cell Delay Variation Tolerance (CDVT or L)**

T = 1/PCR ... minimal interval between the arrival of two cells

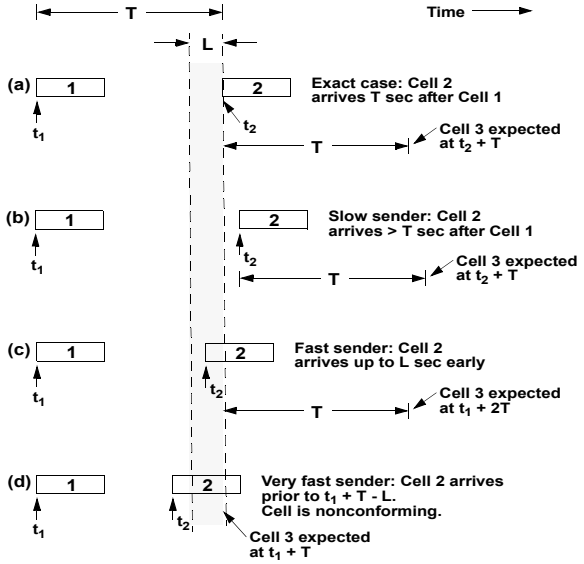
if sender sends exactly with PCR

t_1: arrival of 1st cell
t_1+T: arrival of 2nd cell
t_1+2T: arrival of 3rd cell

Sender can:
- **send with rate R < PCR**
- **also send temporarily with R > PCR; burst length limited by L**

Algorithm
- **cell x is expected by $t_1 + (n-1)\cdot T$**
- **does cell y arrive not earlier than $t_1 + (n-1)\cdot T - L$?**
  yes: will be accepted
  no: will be dropped or assigned a low priority

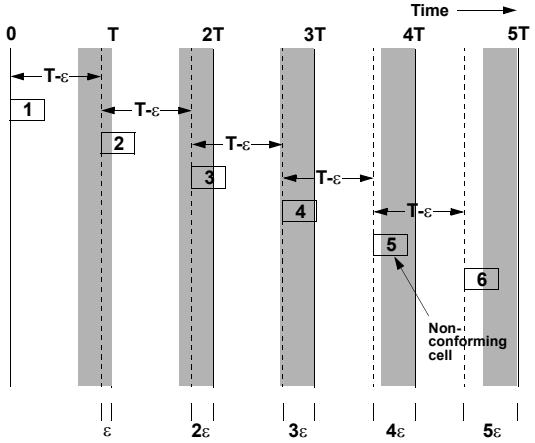
Generic Cell Rate Algorithm: Example (2)



Generic Cell Rate Algorithm (3)

Example:

Sender sends cells within an interval of T - ε, whereby ε = 0.3 · L



Comment: ATM Congestion Control

GCRA by itself cannot prevent congestion in the network

Two additional mechanisms

- **admission control**
  test if an additional connection would have a negative impact on existing connections
- **resource reservation**
  - buffer
  - CPU
  - bandwidth

7. ATM Adaptation Layer (AAL)

Function

- **provide application specific services**
- **segmentation, reassembling**

classes (originally), protocols (today)

Protocol: AAL ...	0	1		2	3/4 5				3/4 5
Timing	empty	fixed	-	fixed	-	fixed	-	fixed	-
Data Rate		steady		variable		steady		variable	
Mode		connection-oriented				connectionless			
Class (old)		A		B	C				D

Timing: **temporal correlation of source + destination (delay, jitter, variances)**

Data rate: **VBR (variable) or CBR (fixed)**

AAL subdivision

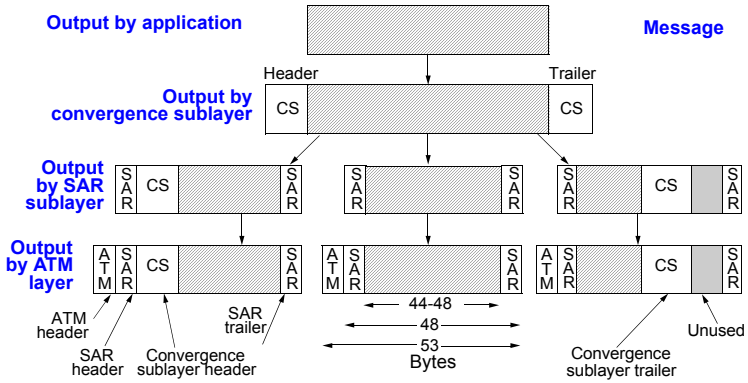
- **Segmentation and Reassembly Sublayer (SAR)**
  - PDU ÷ ATM cells
- **convergence: Convergence Sublayer (CS)**
  - service / protocol dependent
  - error treatment, time relationship (between sender and receiver)

AAL Layers

Packet

- **own header (as part of the ATM cell payload)**
- **thereby reducing the data throughput**

PDUs



AAL 0

Features
- direct access to the ATM layer

Note
- no official AAL type
- but generally known

Overhead
- none

AAL 1

Properties
- simple connection-oriented communication with low end-to-end delay
- example: 64 kbps voice transmission

Segmentation and Reassembly Sublayer (SAR)
- Sequence Number & CS Indication bit (for synchronization)
- SAR header with 4 bit error correction of this header

Convergence Sublayer (CS)
- jitter handling (cell delay variation):
  - buffer
  - exception handling
- general error recognition (loss or faulty cell), information reported to higher layer (no error correction)
- information about time to tune local clock

Overhead
- minimal: 1 byte (SAR PDU header) per 48 bytes in the cell

AAL 2

Features
- data rate normally variable but with fixed end-to-end delay
- example:
  - audio and video data encoded/compressed by VBR (e.g. MPEG-2)

Segmentation and Reassembly Sublayer (SAR)
- identify the position within the packet and the size of the actual data field (e.g. video frame part)

Convergence Sublayer (CS)
- recognize missing cells

Comment:
- standardized, but without field length
- these were removed to disable the standard (standard could not be stopped anymore)
- new standardization for wireless application ...

AAL 3/4

Features
- message mode
  - connectionless
  - LAN to LAN connections
- streaming mode:
  - connection-oriented
  - AAL SDU with fixed length
  - with or without flow control (e.g. with multicasting)

Segmentation and Reassembly Sublayer (SAR)
- actual segmentation and reassembling
- error recognition
- multiplexing of several AAL connections/sessions over an ATM connection

Convergence Sublayer (CS)
- receives data from 1 ... 65.535 bytes
- padding to a multiple of 4

Overhead
- 4 bytes per cell
- 8 bytes per message (message 1 to 65.535 bytes payload)

AAL 5

Simple and Efficient Adaptation Layer (SEAL)
- **suggested by the computer industry**
  - transport of IP packets (RFC 1483 und RFC 1577)
- **variable data amount, no time relationship source-destination**

Convergence Sublayer (CS)
- **4 bytes CRC (much longer than other AALs)**
- **message's length specification (1 to 65.535 bytes)**

Overhead
- **no byte per cell**
- **8 bytes per message (message 1 to 65.535 bytes payload)**

Approach
- **shift effort from SAR to CPCS (no overhead per cell but per CPCS unit)**
- **reduced functionality (no multiplexing from AAL to ATM)**
- **no header information in CPCS**
  - uses one bit from ATM-layer for AAL purposes
  - indicates end of CPCS unit in payload type field of ATM cell header

Payload	Padding	UU	CPI	Length	CRC
0-65535	0-47	1	1	2	4

UU: User-to-User
CPI: common part indicator

8. ATM-LANs

ATM vs. ATM LAN
- **ATM focus**
  - replace public exchange in the backbone range
  - originally up to end systems
- **focus here: LAN with**
  - connectionless traffic
  - other topologies
  - often multicast and broadcast
- **usually used: IP over AAL 5**

Application
- **connecting LANs by ATM paths**
- **implement a LAN with ATM technology**

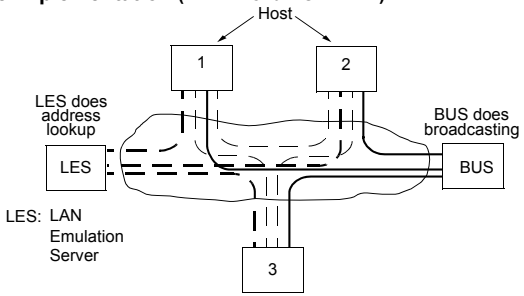
Problems
- **usually connectionless data transfer (ATM is connection-oriented)**
- **multicast and broadcast**
- **mapping of Internet Addresses (IP address) onto ATM addresses**

ATM-LANs (2)

Realized by a multitude of virtual connections
- **function:**
  - each end device has a connection with every other end device
  - i.e., IP packet is sent as an AAL packet
  - virtual connection (permanent or dynamic)
- **but**
  - routing: which IP address via what connection?
  - like multicast and broadcast?

ATM-LANs (3)

One possible implementation (ATM Forums LANE)



- **connection between each pair of end systems (permanent or dynamic)**
- **IP packet is sent within the AAL packet**

Address mapping through LAN EMULATION SERVER (LES)

Broadcast functionality through broadcast server
- **emulates a bus**