Master Course
Computer Networks
IN2097

Prof. Dr.-Ing. Georg Carle
Christian Grothoff, Ph.D.
Stephan Günther

Chair for Network Architectures and Services
Department of Computer Science
Technische Universität München
http://www.net.in.tum.de

- Lectures
  - No lecture this week Friday 18.1.2013

  ⇨ time for you to work on the project

Connection-Oriented Networking

Connection-Oriented Network Issues

- Network Service Model

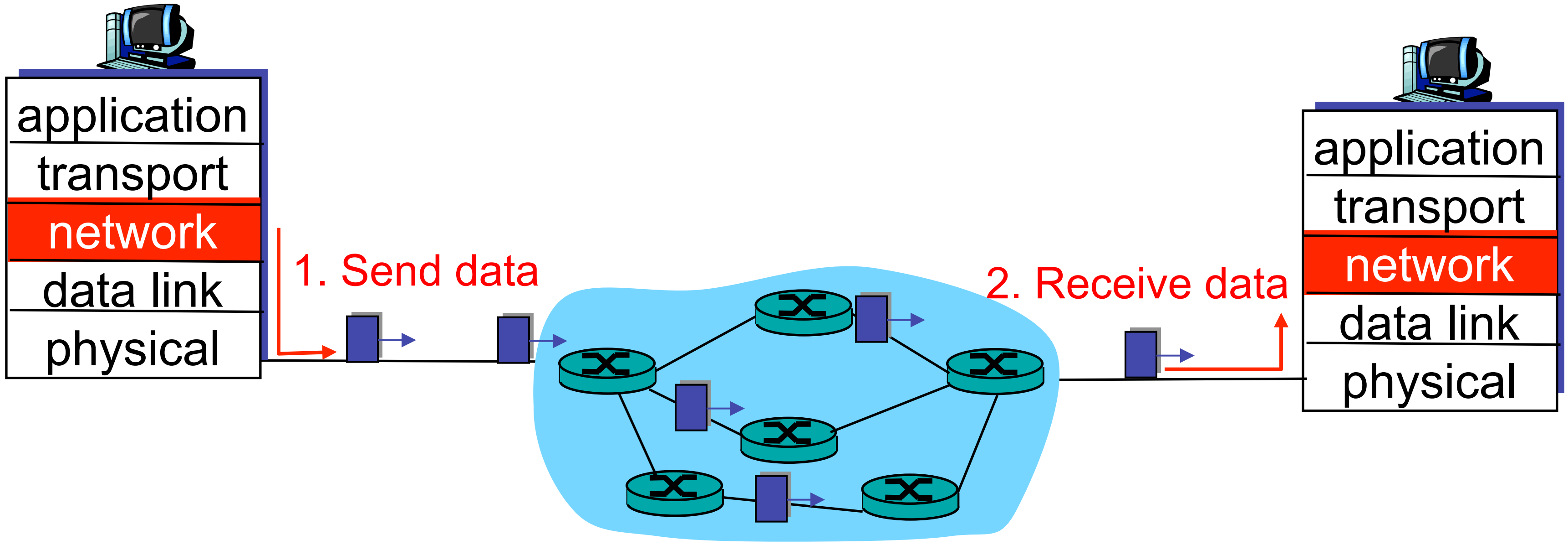
- Virtual Circuits
  - Addresses vs. labels
  - Address lookup vs. label lookup

- Connection / flow state in nodes

- Quality-of-Service (QoS) properties for flows

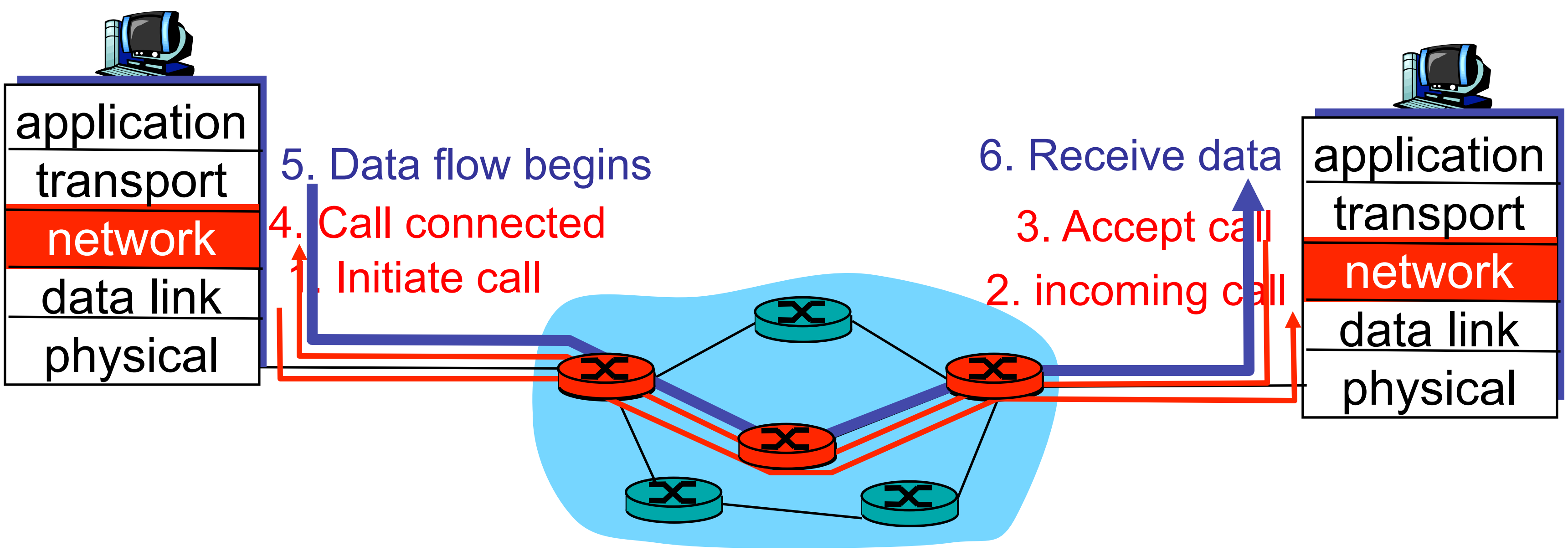
Datagram networks

- no call setup at network layer
- routers: no state about end-to-end connections
  - no network-level concept of "connection"
- packets forwarded using destination host address
  - packets between same source-dest pair may take different paths



Virtual Circuits: Signaling Protocols

- used to setup, maintain teardown VC
- used in X.25, frame-relay, ATM



Datagram or VC network: why?

Internet (datagram)

- data exchange among computers
  - "elastic" service, no strict timing req.
- "smart" end systems (computers)
  - can adapt, perform control, error recovery
  - simple inside network, complexity at "edge"
- many link types
  - different characteristics
  - uniform service difficult

ATM (VC)

- evolved from telephony
- human conversation:
  - strict timing, reliability requirements
  - need for guaranteed service
- "dumb" end systems
  - telephones
  - complexity inside network

Network service model

Q: What *service model* for "channel" transporting datagrams from sender to receiver?

Example services for individual datagrams:

- guaranteed delivery
- guaranteed delivery with less than 40 msec delay

Example services for a flow of datagrams:

- in-order datagram delivery
- guaranteed minimum bandwidth to flow
- restrictions on changes in inter-packet spacing

Network layer service models

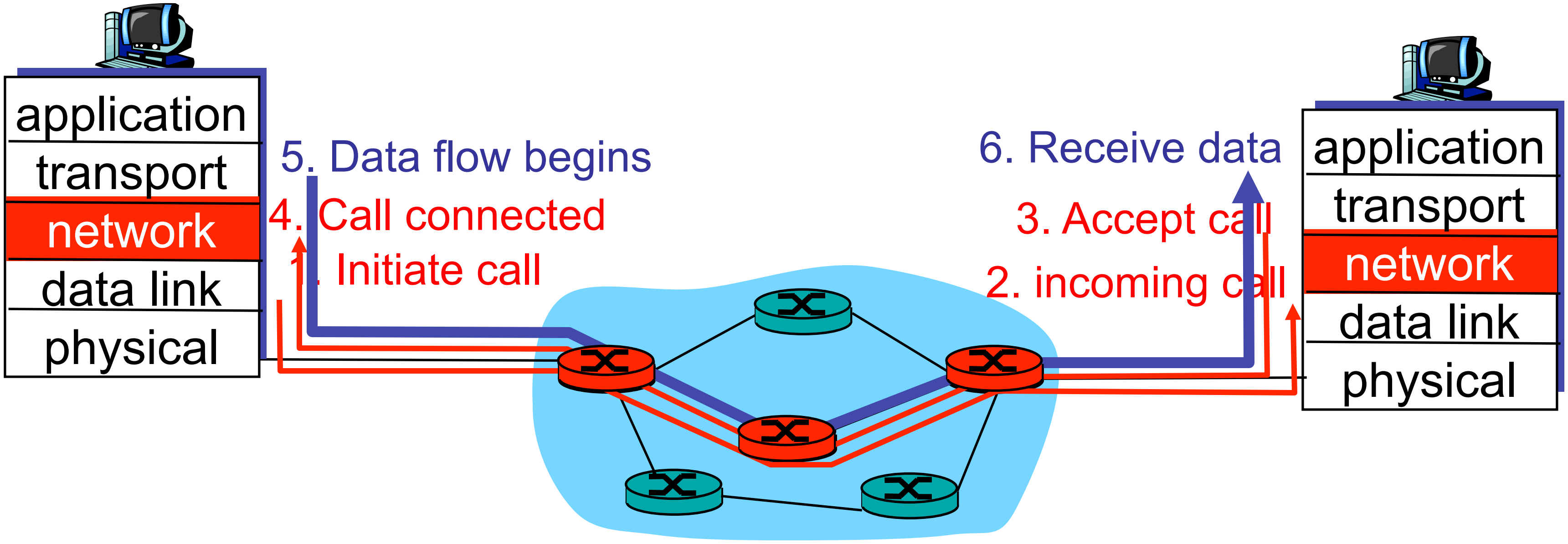
Network Architecture	Service Model	Guarantees ? Bandwidth	Loss	Order	Timing	Congestion feedback
Internet	best effort	none	no	no	no	no (inferred via loss)
ATM	CBR	constant rate	yes	yes	yes	no congestion
ATM	VBR	guaranteed rate	yes	yes	yes	no congestion
ATM	ABR	guaranteed minimum	no	yes	no	yes
ATM	UBR	none	no	yes	no	no

Connection-Oriented Networks - Connection Setup

- in addition to routing and forwarding, *connection-setup* is 3rd important function in some network architectures:
  - ATM, frame relay, X.25
- before datagrams flow, two end hosts and intervening switches/ routers establish virtual connection
  - switches/routers get involved
- network vs transport layer connection service:
  - network: between two hosts (may also involve intervening switches/routers in case of VCs)
  - transport: between two processes

Virtual circuits: signaling protocols

- used to setup, maintain teardown VC
- used in ATM, frame-relay, X.25
- not used in today's Internet



Virtual circuits

"source-to-destination path behaves much like telephone circuit"

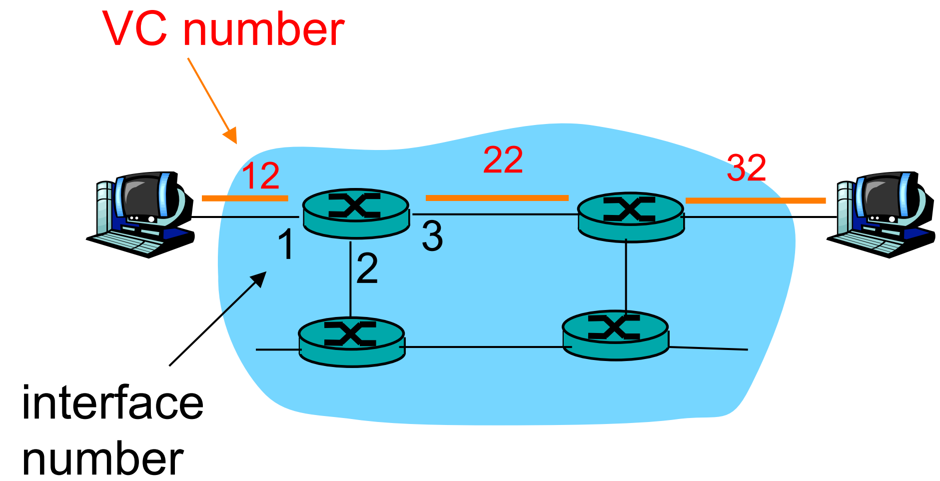
- performance-wise
- network actions along source-to-destination path

- call setup, teardown for each call *before* data can flow
- each packet carries VC identifier (not destination host address)
- *every* router on source-to-destination path maintains "state" for each passing connection
- link, router resources (bandwidth, buffers) may be *allocated* to VC (dedicated resources = predictable service)

VC implementation

- VC consists of:
  - path from source to destination
  - VC numbers, one number for each link along path
  - entries in forwarding tables in routers along path
- packet belonging to VC carries VC number (rather than destination address)
- VC number can be changed on each link
  - New VC number comes from forwarding table

Forwarding table



Forwarding table in northwest router:

Incoming interface	Incoming VC #	Outgoing interface	Outgoing VC #
1	12	3	22
2	63	1	18
3	7	2	17
1	97	3	87
…	…	…	…

Routers maintain connection state information!

Maintaining Network State

state: information *stored* in network nodes by network protocols

- stored in multiple nodes
- often associated with end-system generated call or session
- updated when network “conditions” change
- examples:
  - ATM switches maintain lists of VCs: bandwidth allocations, VCI/VPI input-output mappings
  - RSVP routers maintain lists of upstream sender IDs, downstream receiver reservations

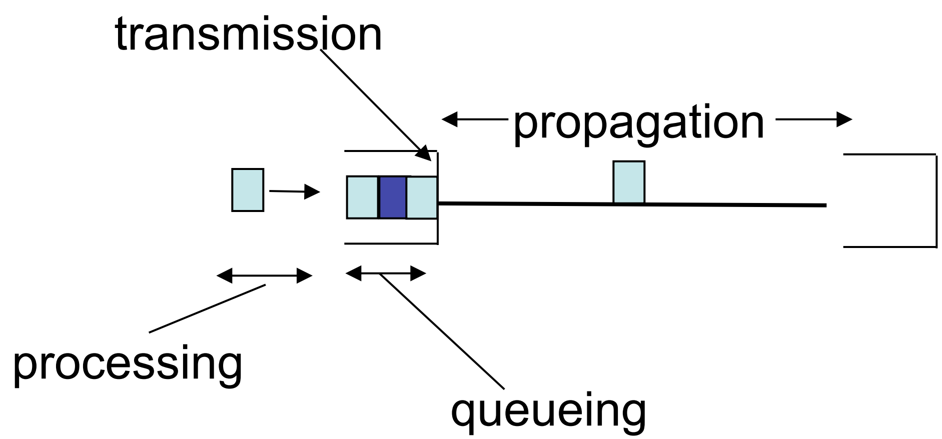
QoS: Sources of packet delay

1. Processing delay:
   - Sending: prepare data for being transmitted
   - Receiving: interrupt handling

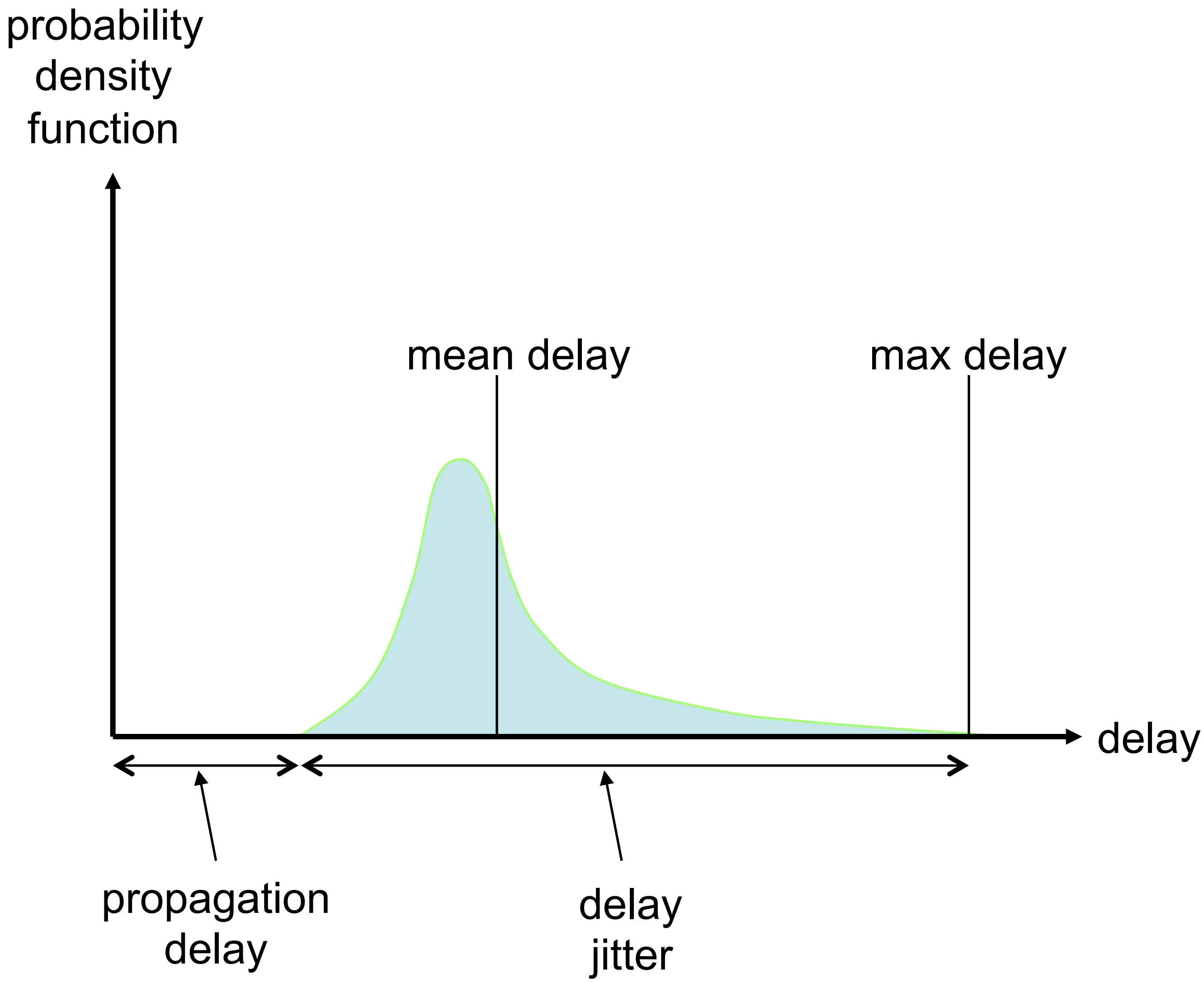
2. Queueing delay
   - time waiting at output link for transmission

3. Transmission delay:
   - L=packet length (bits)
   - R=link bandwidth (bps)
   - time to send bits into link = L/R

4. Propagation delay:
   - d = length of physical link
   - s = propagation speed in medium (~2x10^8 m/sec)
   - propagation delay = d/s



QoS: Delay Distributions



QoS Properties of Flows

- Resource reservation for flows
  - routing at connection set-up
  - resource allocation (buffer, bandwidth, CPU)
  - Connection admission control
  - flow policing / shaping (e.g. average rate, burst size limits)
    - – buffer bounds
    - – bandwidth allocation by scheduling
    - – packet size bounds

  ⇨ QoS guarantees possible (latency bounds, ...)

Network Architectures

Link virtualization: ATM

B-ISDN and ATM

- Broadband ISDN (1990)
  - Worldwide consistently build high-performance network
  - Transmission of data, audio, video
  - Standardization via ITU (CCITT)

- ATM (Asynchronous Transfer Mode) was selected as the base technology for B-ISDN
- ATM is part of the ITU specification of B-ISDN
- Additional specifications have been published by the ATM Forum

Introduction

- ATM: **A**synchronous **T**ransfer **M**ode
- Based on standardized protocols
- Integrated technology for multiple services
  - Data
  - Speech / Audio
  - Video
- Usable in LAN and WAN areas
- Highly scalable
- Support for different connection qualities
- Employment of asynchronous time multiplex technologies for flexibility, supporting various transmission bandwidths

Properties

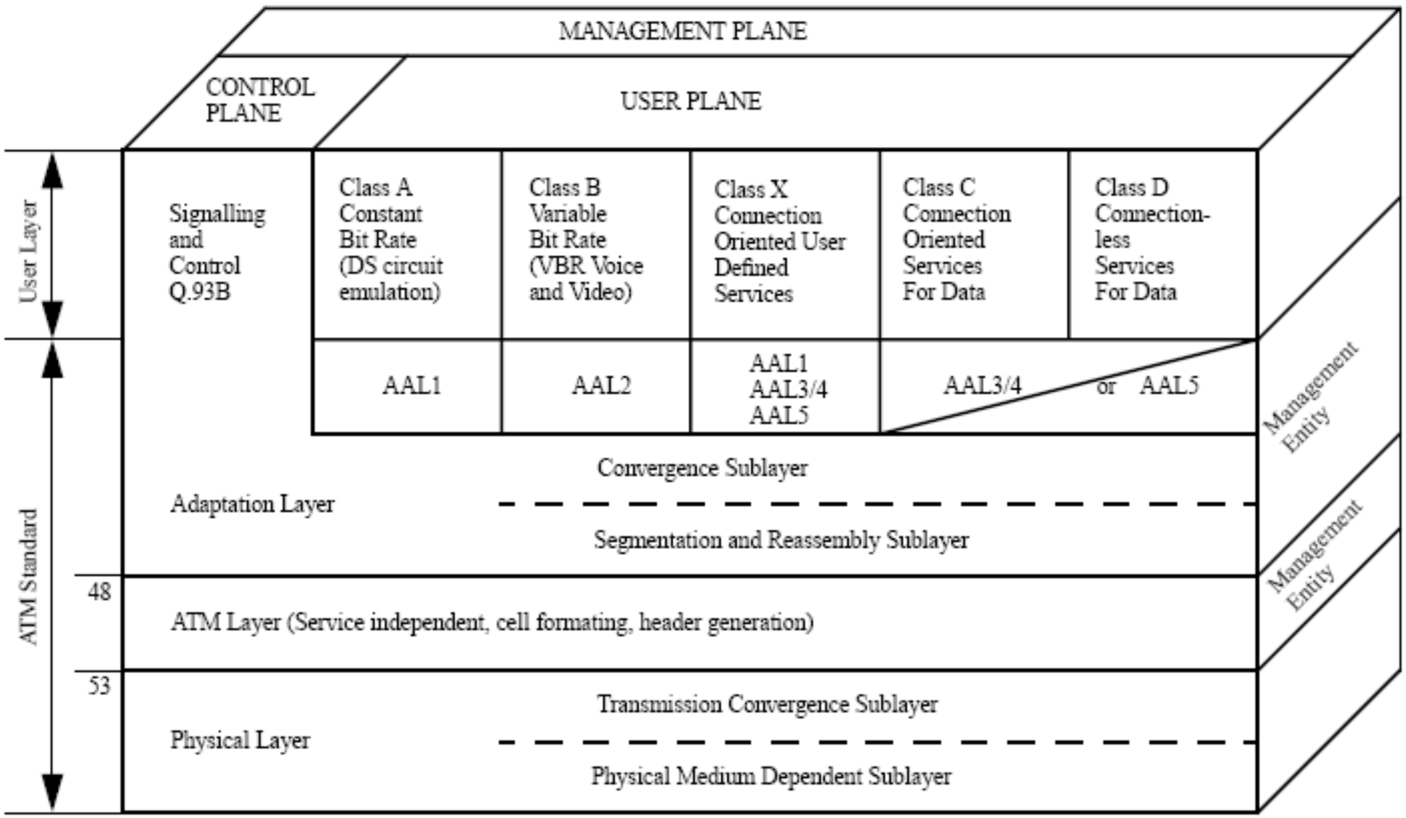
- Data packets of fixed size, named cells
  - ATM cells have a length of 53 byte (5 byte header, 48 byte payload)
  - This allows a high speed processing including massive parallel hardware operations
  - At a payload length of 48 byte, the packetisation delay (time to fill a cell with 64 Kbit/s digitized voice samples)
- Connection oriented
  - point-to-point
  - point-to-multipoint
- Connections may have a fixed (reserved) bandwidth and guaranteed quality of service characteristics
  - Centralized coordination of permissions to send
  - Dedicated bandwidth

Standardization

- ITU-T: **I**nternational **T**elecommunications **U**nion – Telecommunications Standards Section (formerly CCITT) http://www.itu.ch/
- ATM-Forum
  Development of industry standards allowing a fest development of new products
  http://www.atmforum.com/
- ETSI: **E**uropean **T**elecommunications **S**tandards **I**nstitute
  http://www.etsi.fr/
- ANSI: **A**merican **N**ational **S**tandards **I**nstitute
  http://web.ansi.org/

ATM Layer Model

- User plane: information flow between the layers
- Control plane: connection setup, maintenance and termination
- Management plane: meta-signaling and OAM (Operation and Maintenance) information flow



AAL Service Class (Class A / B / C / D)

AAL Type

ATM Layer Service Class (CBR, nrt-VBR, rt-VBR, UBR, ABR)

Physical Layer

- Physical layer
  - maps ATM cells received from the ATM layer to the bit stream required by the physical layer
  - PDH (Plesiochronous Digital Hierarchy)
    - Europe: 2,048 / 8,448 / 34,368 / 139,264 Mbit/s
    - USA: 1,544 / 6,312 / 44,736 / 254,176 Mbit/s
  - SONET (Synchronous Optical NETwork) - USA
    SDH (Synchronous Digital Hierarchy) - Europe
    - OC-3/STM-1 155,520 Mbit/s
    - OC-12/STM-4 622,080 Mbit/s
    - OC-48/STM-16 2,48832 Gbit/s
    - OC-192/STM-64 9,953280 Gbit/s
    - OC-768/STM-256 39,813120 Gbit/s

ATM Layer

- Transport of ATM cells between the communication end points
- Tasks of the user and control plane
  - Connection setup, multiplexing/de-multiplexing and maintaining ATM connections
  - Generation of ATM cell headers (exception: HEC)
  - Negotiation of QoS (Quality of Service) parameters
  - Traffic and overload control
- OAM cells
  - cells of the management plane
- Meta-signalling
  - initial signalling to set up signalling VCs (Virtual Channels)

ATM Cell Format

- 53 Byte
  - 5 Byte Header
  - 48 Byte Payload
    - small payload ⇒ short cell-creation delay for digitized voice
    - halfway between 32 and 64 (compromise!)

Cell at User-to-Network-Interface (UNI)

Bit#	7			4	3			0
	GFC				VPI (8 bit in total)			
	VPI				VCI (16 bit in total)			
	VCI							
	VCI				PT (3 bit)			CLP
	HEC (8 bit)							
	Payload and padding if necessary (48 bytes)							

Cell at Network-to-Network-Interface (NNI)

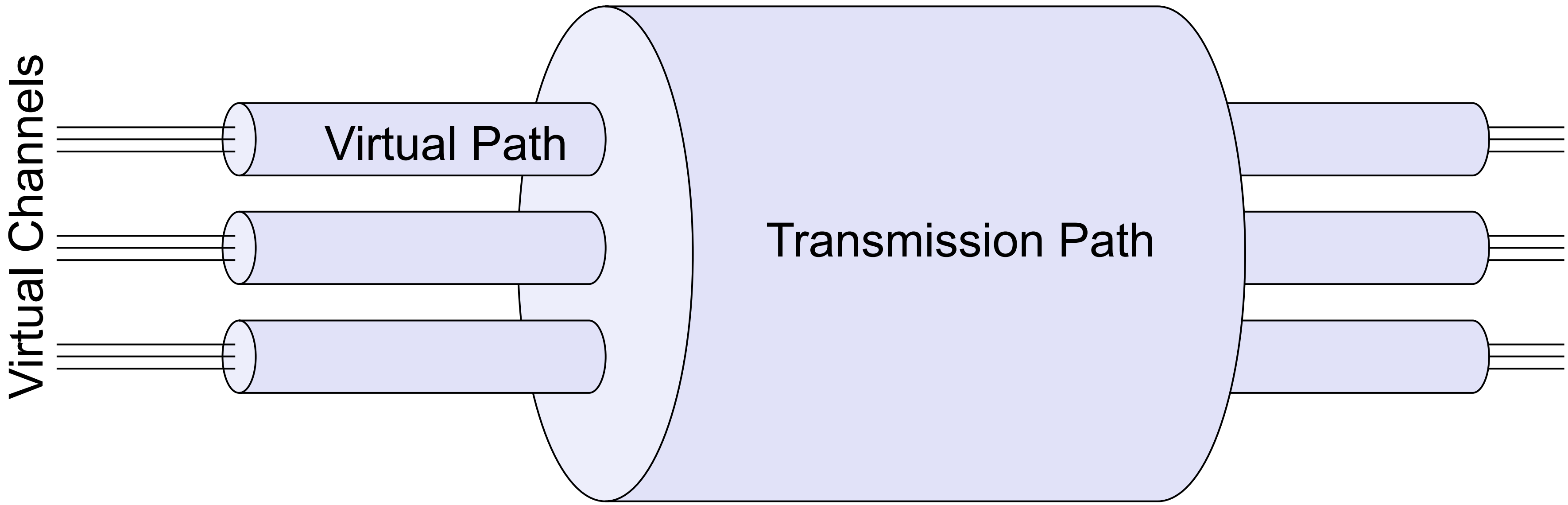
7			4	3			0
VPI (12 bit in total)							
VPI				VCI (16 bit in total)			
VCI							
VCI				PT (3 bit)			CLP
HEC (8 bit)							
Payload and padding if necessary (48 bytes)							

ATM Cell Format

- ATM header fields
  - GFC
    - Generic Flow Control (default: set to “0000”)
    - only at user-to-network interface (UNI)
  - VPI: Virtual Path Identifier
    - 8 bit at user-to-network interface
    - 12 bit at network-to-network interface (NNI)
  - VCI: Virtual Circuit Identifier - 16 bit
  - PT: Payload Type
    - 1st bit: user data or management
    - 2nd bit: Explicit Forward Congestion Indication
    - 3rd bit: indicates last cell in AAL5 user data
  - CLP: Cell Loss Priority
    - CLP = 1 implies low priority cell, can be discarded
  - HEC: Header Error Checksum (CRC-8)

ATM Connections

- 2 Hierarchies: paths and channels



Properties of ATM Connections

- Start and end at higher layer functions
- Have associated service parameters (e.g. cell loss ratio, latency)
- Negotiation of transmission parameters by signalling before a connection is set up (provision of QoS)
- Preservation of the transmission order
- Unidirectional or bidirectional
- Symmetric or asymmetric bandwidth
- Permanent
  - PVC: Permanent Virtual Channel
- Dynamic
  - SVC: Switched Virtual Channel
  - Signaling: connection setup and tear down
    (Two signalling variants specified by ATM Forum: UNI 3.1, UNI 4.0)
  - Routing Protocols (ATM-Forum: P-NNI)
  - Addressing of end points using E.164 addresses

ATM Layer

Service: transport cells across ATM network

- analogous to IP network layer
- very different services than IP network layer
- possible Quality of Service (QoS) Guarantees

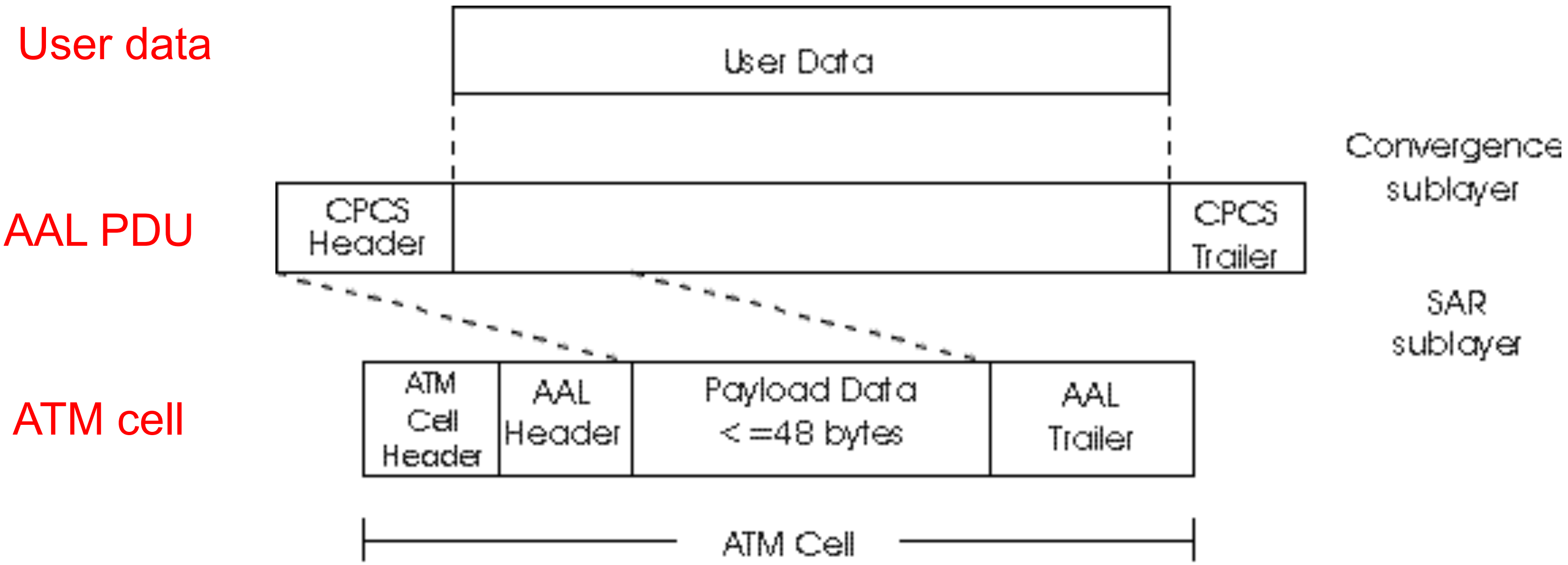
Network Architecture	Service Model	Guarantee: Bandwidth	Guarantee: Loss	Guarantee: Order	Guarantee: Timing	Congestion feedback
Internet	best effort	none	no	no	no	no (inferred via loss)
ATM	CBR	constant rate	yes	yes	yes	no congestion
ATM	VBR	guaranteed rate	yes	yes	yes	no congestion
ATM	ABR	guaranteed minimum	no	yes	no	yes
ATM	UBR	none	no	yes	no	no

CBR: Constant Bit Rate
VBR: Variable Bit Rate
ABR: Arbitrary Bit Rate
UBR: Unspecified Bit Rate

ATM Adaptation Layer (AAL)

Different versions of AAL layers, depending on ATM service class:

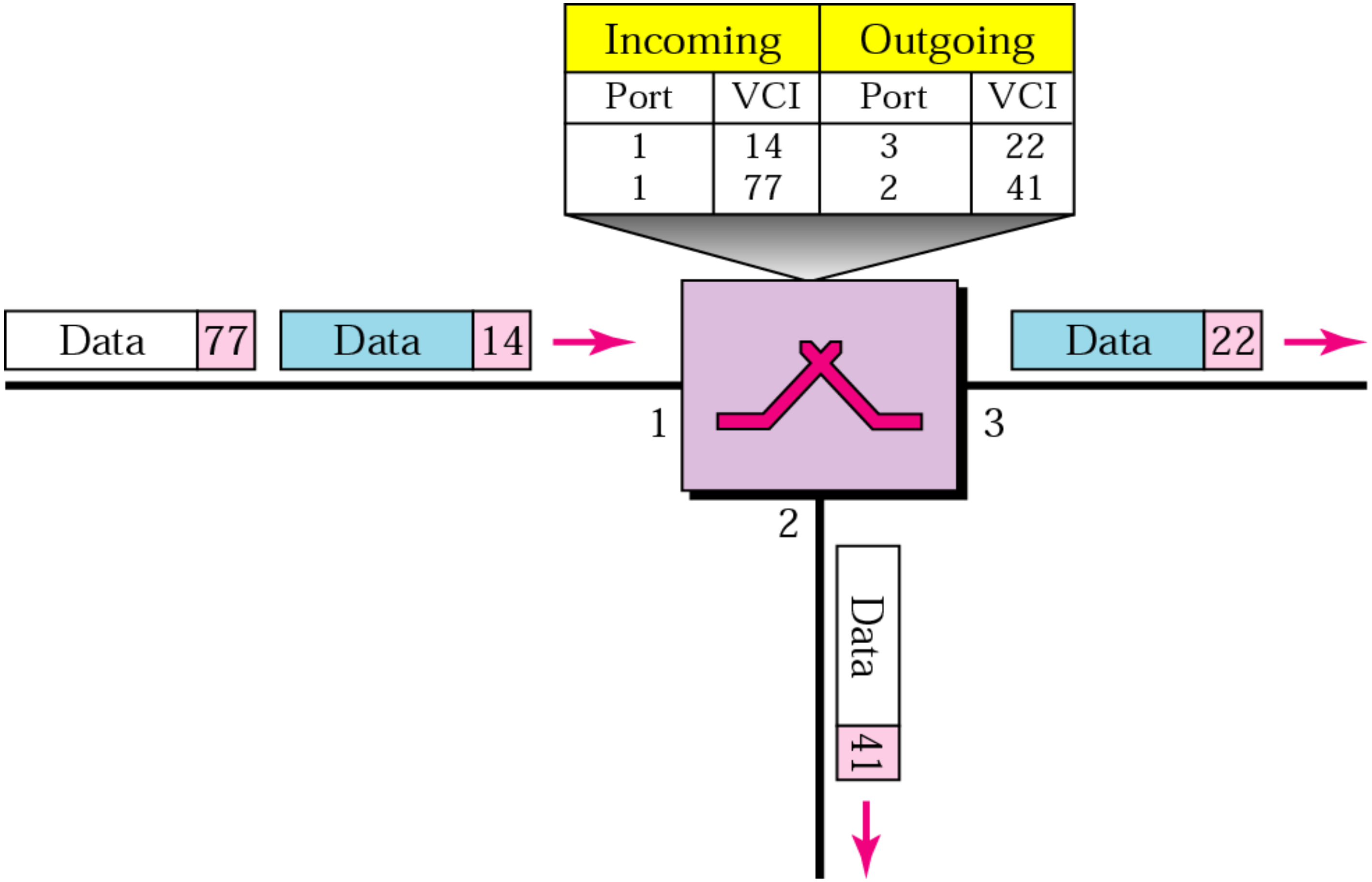
- AAL1: for CBR (Constant Bit Rate) services, e.g. circuit emulation
- AAL2: for VBR (Variable Bit Rate) services, e.g., MPEG video
- AAL5: for data (e.g., IP datagrams)



ATM VCs

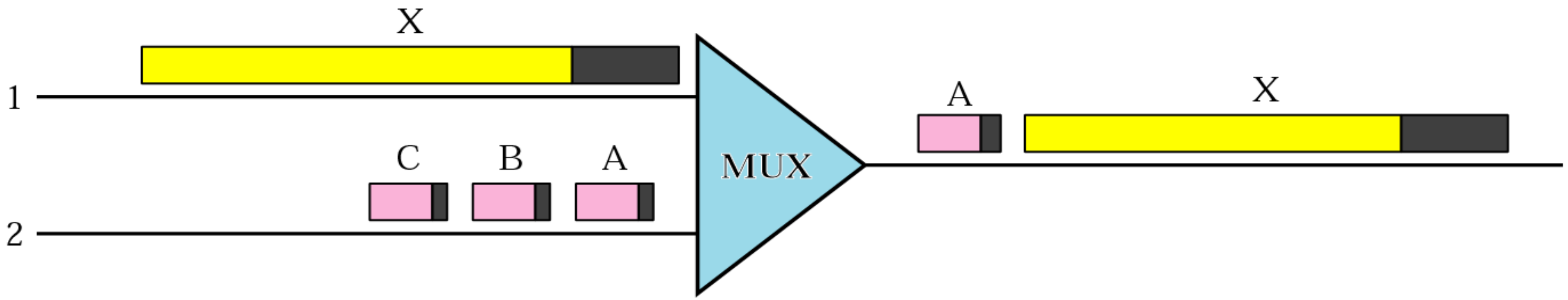
- Advantages of ATM VC approach:
  - QoS performance guarantee for connection mapped to VC (bandwidth, delay, delay jitter)
  - Low per-switch transmission latency
- Drawbacks of ATM VC approach:
  - Inefficient support of datagram traffic
  - one PVC between each source/destination pair does not scale
  - SVC introduces call setup latency, processing overhead for short lived connections

Virtual Circuit Switching

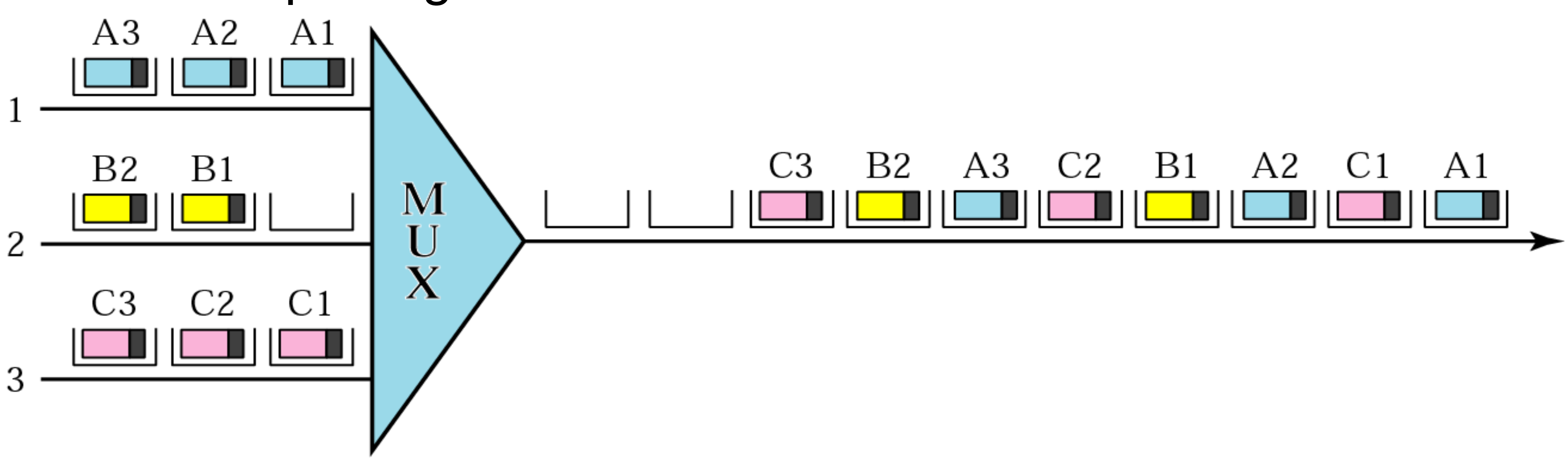


Multiplexing of Variable vs. Fixed Size Packets

- Multiplexing of variable size packets

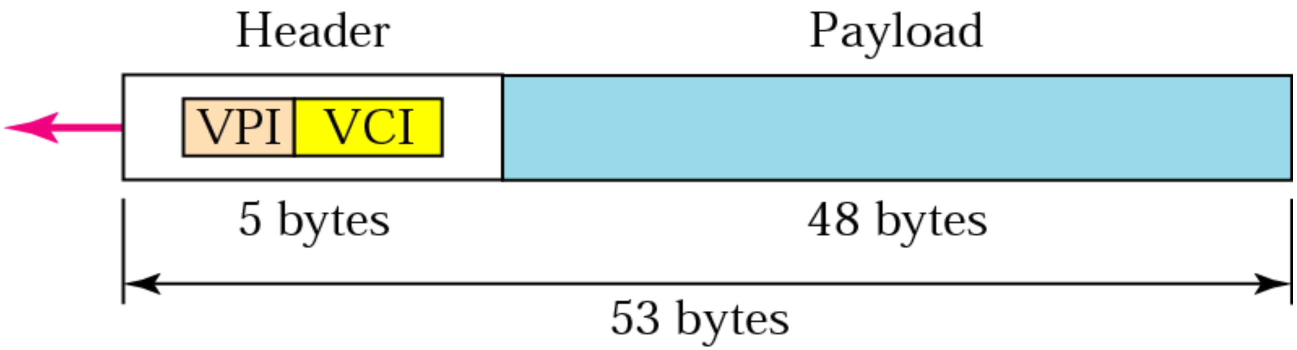


- ATM Multiplexing

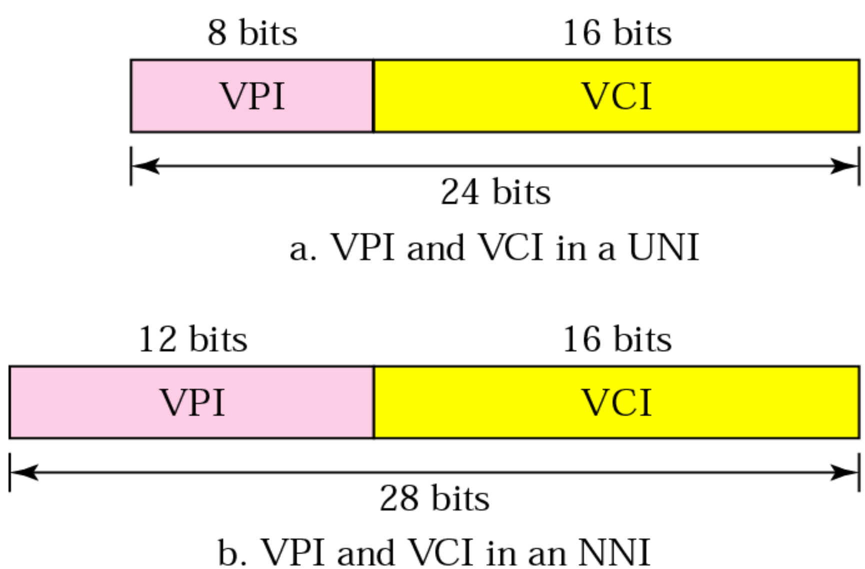


ATM Identifiers

- ATM Cell



- Virtual Path Identifiers and Virtual Channel Identifiers



(UNI: User-to-Network-Interface
NNI: Network-to-Network-Interface)

ATM Virtual Connections