Computer Networks

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Call for presentation

- Tentative topics:
  - 1. Introduction to 4G/5G techniques
  - 2. Social Network Analysis
  - 3. Most Popular Apps in Android/IOS
  - 4. Location-based service (LBS)
  - 5. Mobile Cloud Computing
  - 6. Software Defined Network (SDN)
  - 7. Other topics proposed by yourself
- Confirm: before Oct 17
- Present: Oct 31 or Nov 5
- 10-15 minutes for each presentation

What we learned last weeks

- Link layer services
  - Link access, Framing, Error detection, Flow control, etc.
- Bridges and Layer-2 switch
- LAN
  - Token ring
  - Ethernet
  - WLAN

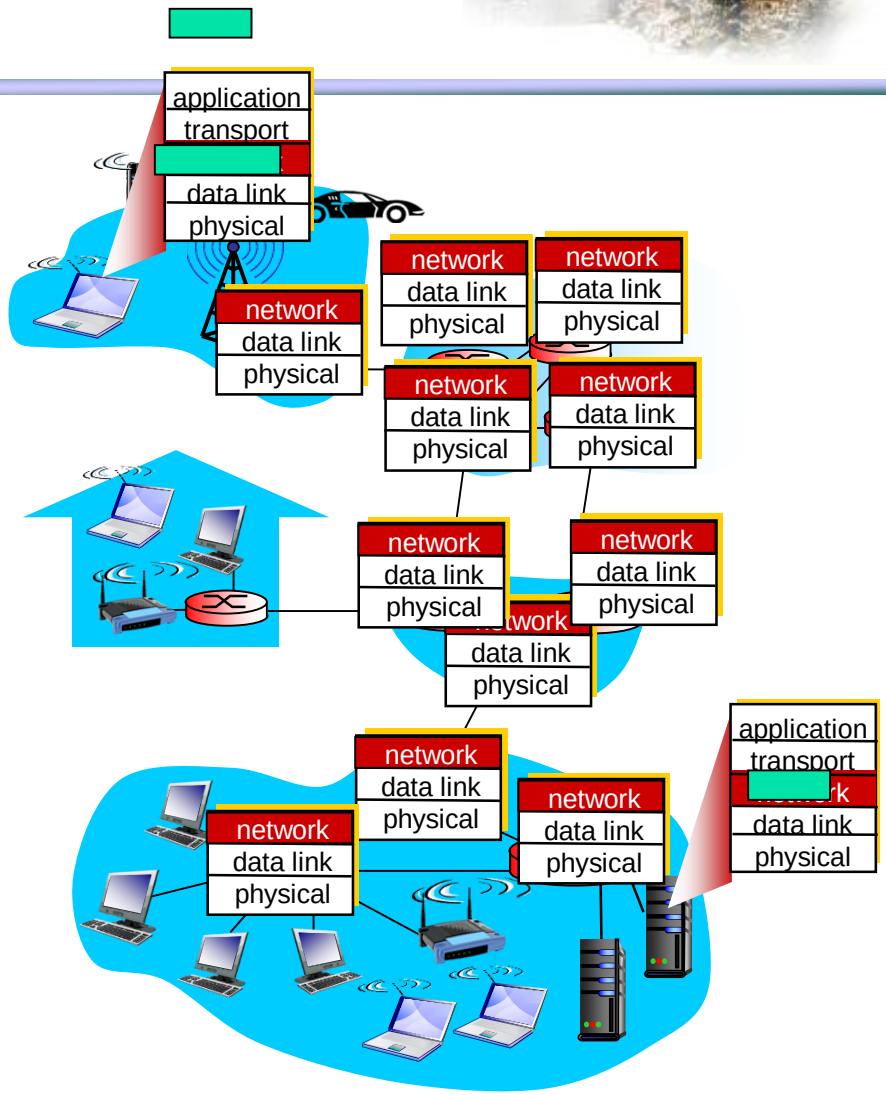
Chapter 3. Packet Switching Networks

- Network Layer Functions
- Virtual Circuit and Datagram Networks
- ATM and Cell Switching
- X.25 and Frame Relay
- Routing

Network Layer Functions

Network Layer

- transport segment from sending to receiving host
- on sending side encapsulates segments into datagrams
- on receiving side, delivers segments to transport layer
- network layer protocols in *every* host, router
- router examines header fields in all IP datagrams passing through it



Two Key Network-layer Functions

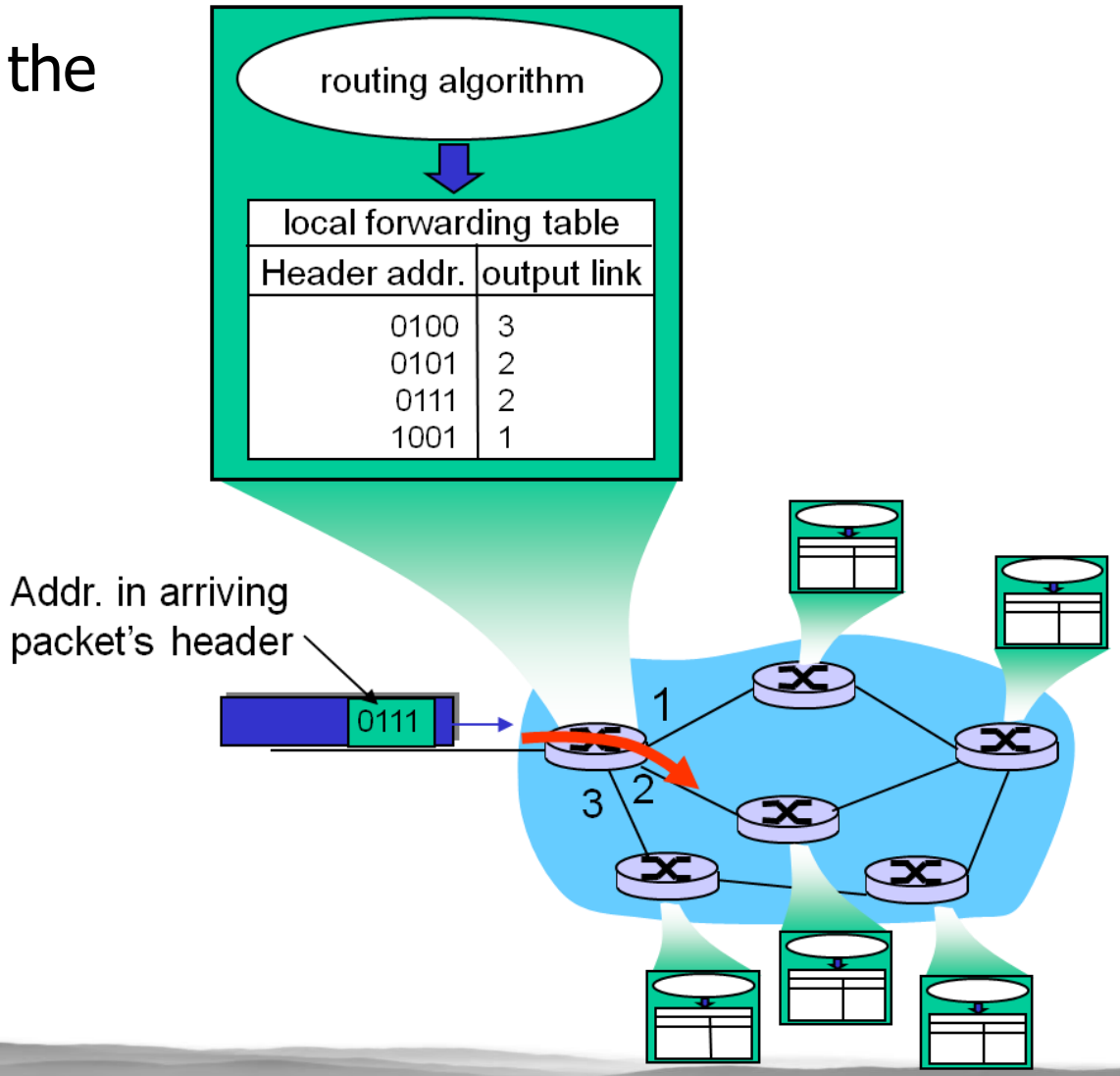
- OSI network-layer functions:
- Switching / Routing
  - Determine route taken by packets from source to destination (multiple nodes)
  - Shortest path from source to destination
  - Routing algorithms
- Forwarding
  - Move packets from input to designated output determined by switching (single node)
  - Error handling, queuing and scheduling

analogy: Trip Planning

- *routing:* planning the route from Nanjing to Shanghai (e.g., Nanjing-Wuxi-Suzhou-Shanghai)
- *forwarding:* getting through single city (e.g., entering and leaving Suzhou Station)

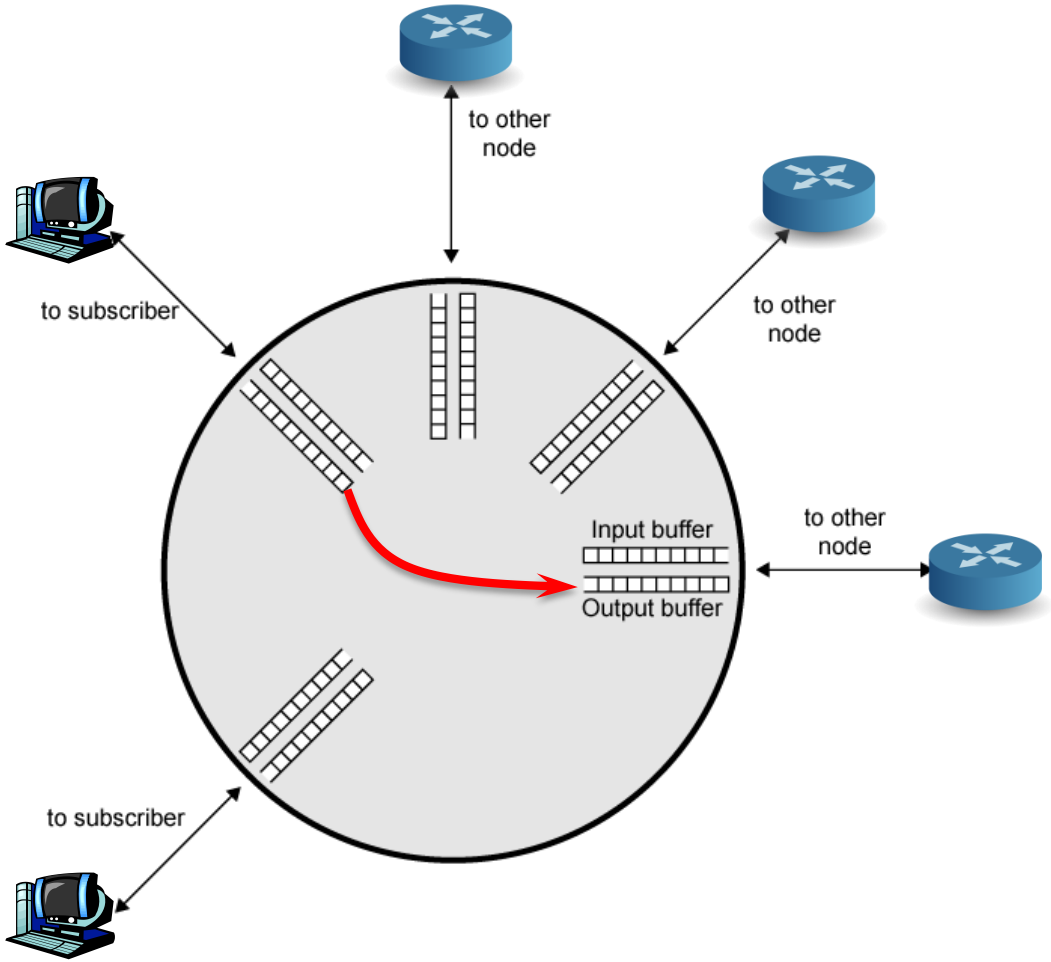
Switch Functions

- Routing determines the forwarding table



Forwarding Functions

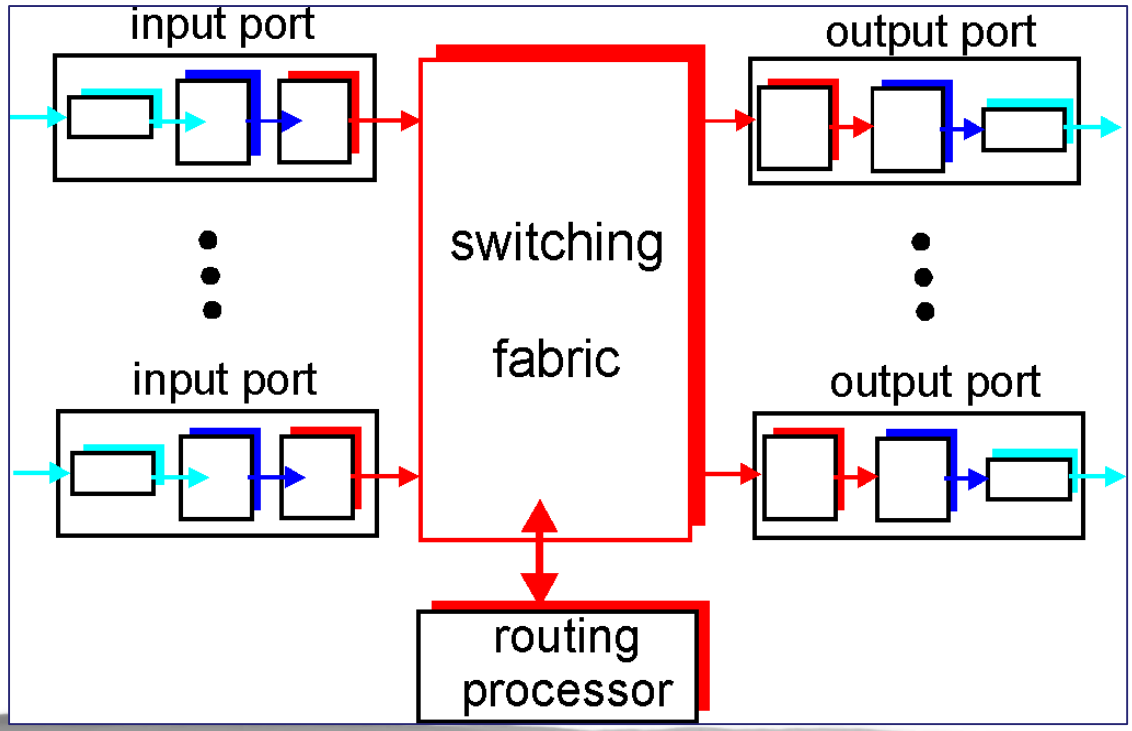
- Queuing and scheduling
  - Host to Switch
  - Switch to Host
  - Switch to Switch



Inside a Switch

Two key switch functions:

- Run routing algorithms/protocol
- Forwarding packets from incoming to outgoing link



Connection setup

- 3rd important function in *some* network architectures:
  - ATM, frame relay, X.25
- Before datagrams flow, two end hosts *and* intervening routers establish virtual connection
  - Routers get involved
- Network vs transport layer connection service:
  - *network:* between two hosts (may also involve intervening routers in case of VCs)
  - *transport:* between two processes

Network Service Model

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

- Network service model
  - Service model for "channel" transporting packets from sender to receiver
  - Called Quality of Service from host perspective

Example services for individual packets

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

Example services for a flow of packets

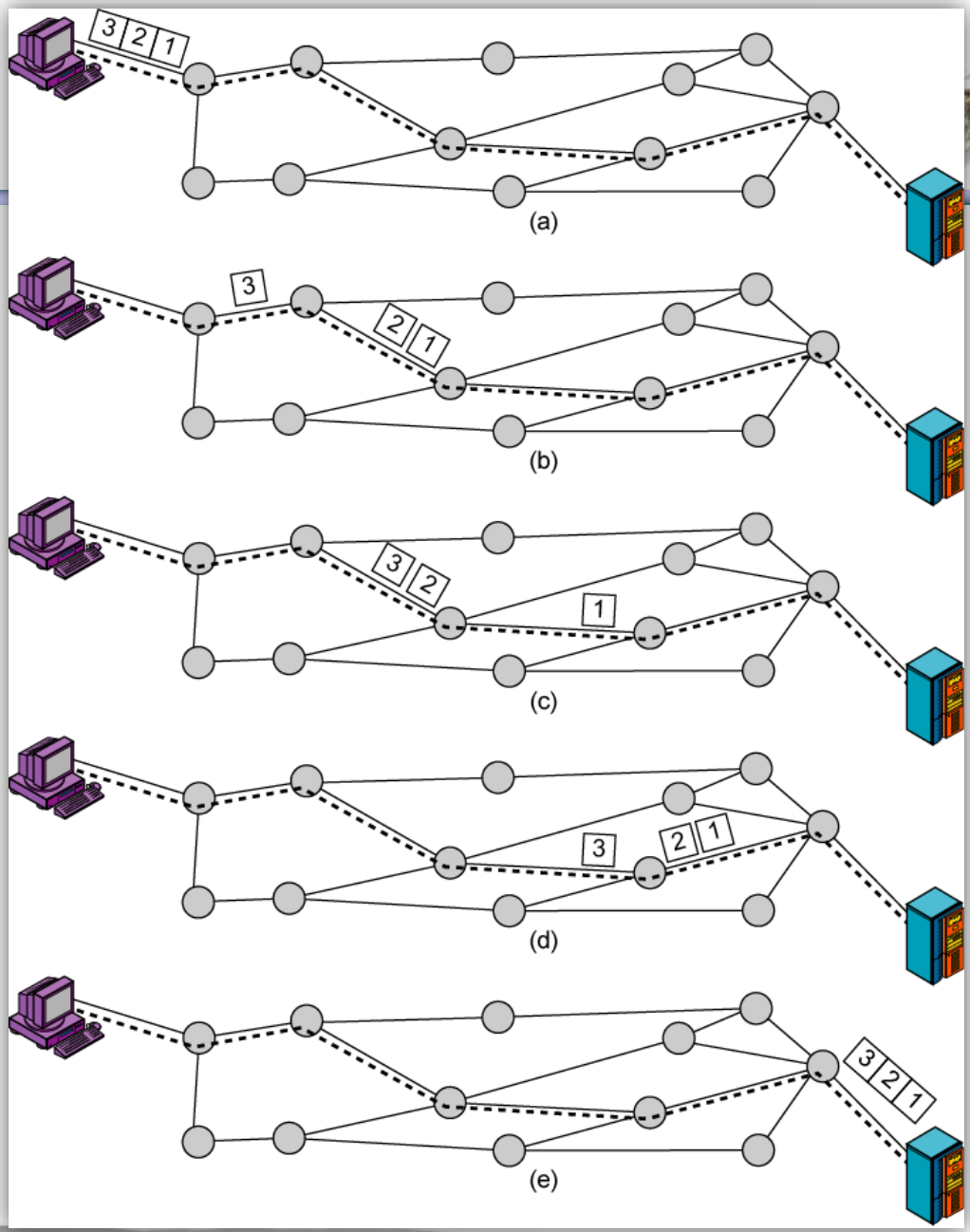
- In-order packet delivery
- Guaranteed minimum bandwidth to flow
- Restrictions on changes in inter-packet spacing

Virtual Circuit and Datagram Networks

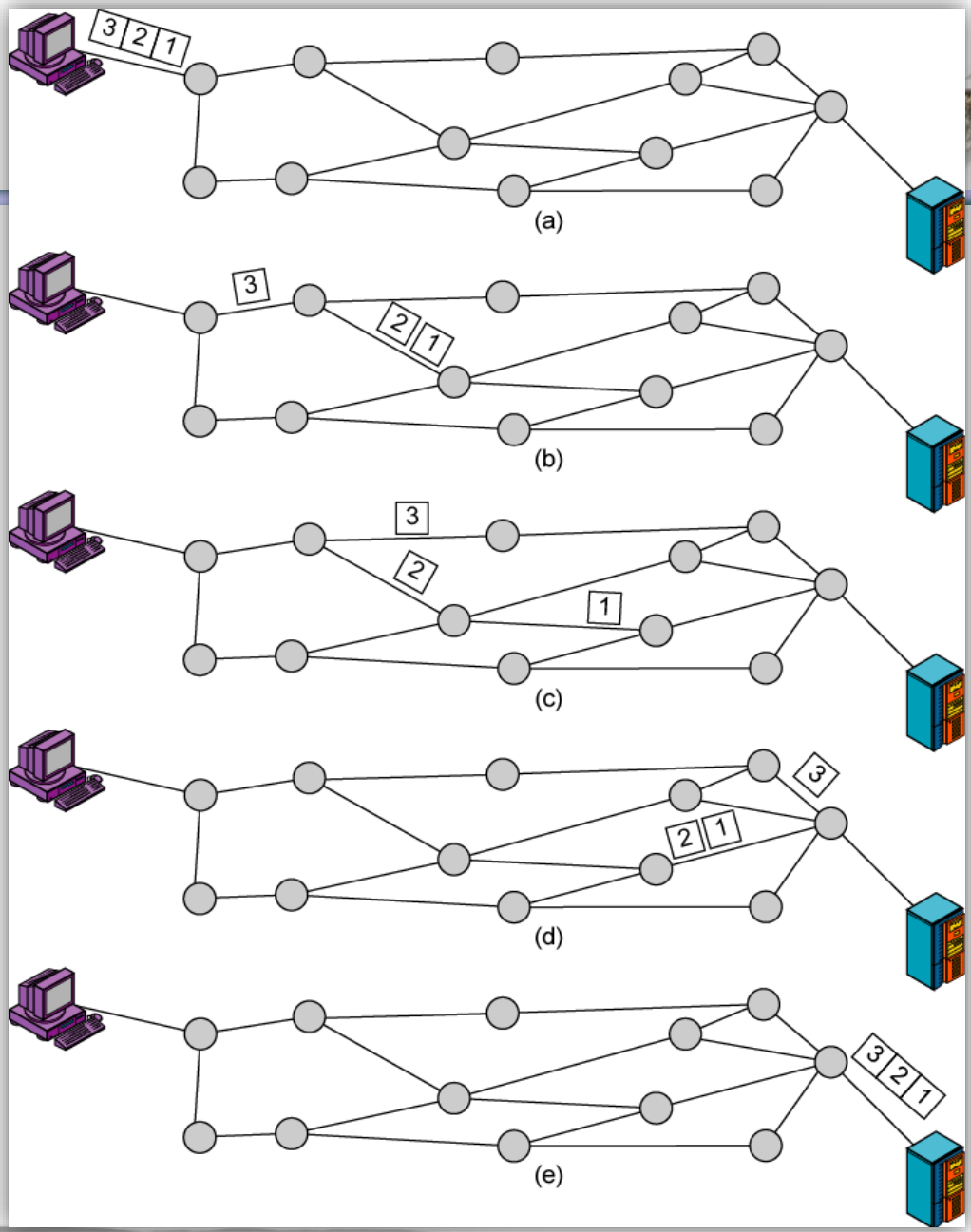
Virtual Circuit and Datagram Networks

- Virtual circuit networks
  - Network service provided on flow of packets
  - VC network provides network-layer connection oriented service
- Datagram networks
  - Network service provided on singular packet
  - Datagram network provides network-layer connectionless service

Routing in Virtual Circuit



Routing in Datagram Nets



Virtual Circuit Networks

- Connection setup, teardown for each flow of packets
- Each packet carries VC identifier (not destination host address)

- Every switch on source-destination path maintains "state" for each passing connection
- Link, switch resources (bandwidth, buffers) may be allocated to VC
  - Dedicated resources = predictable quality of service

Connection Setup

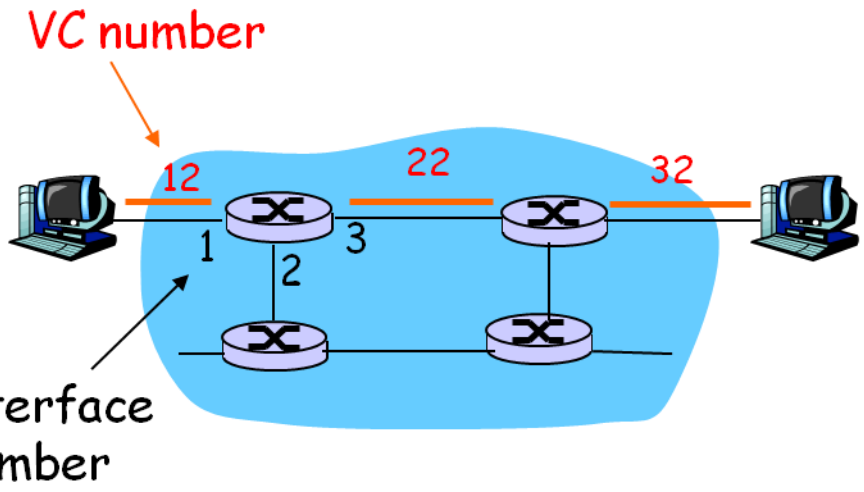
- Essential function for virtual circuit networks
  - E.g. ATM, frame relay, X.25
- Two end hosts and intervening switches pre-establish a path for virtual connection
- Routing is used for finding a suitable (shortest) path

VC Implementation

- A VC consists of
  - Path from source to destination
  - VC numbers, maybe one number for each link along the path
  - Entries in forwarding tables in switches along the path

- Note:
  - Packet belonging to VC carries VC number (rather than addresses)
  - VC number can be changed on each link, forwarding table lists the new VC number

A Forwarding Table for VC



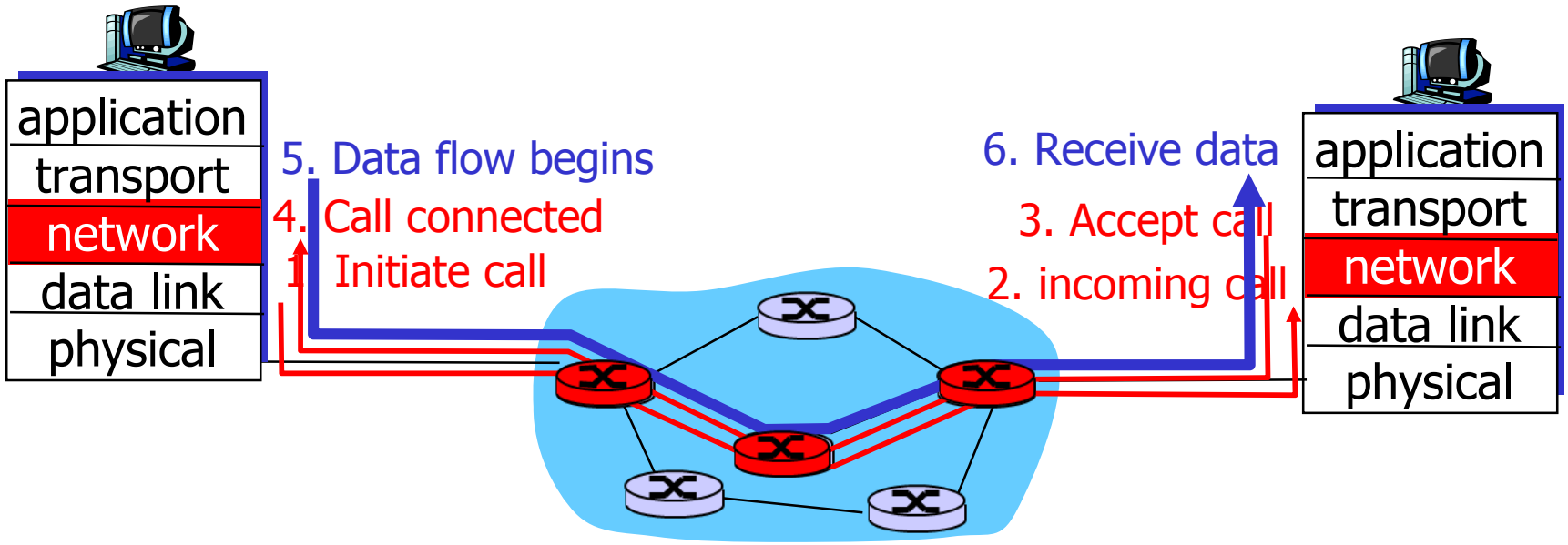
Forwarding table in northwest switch

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

Table entries constitutes state information of a VC

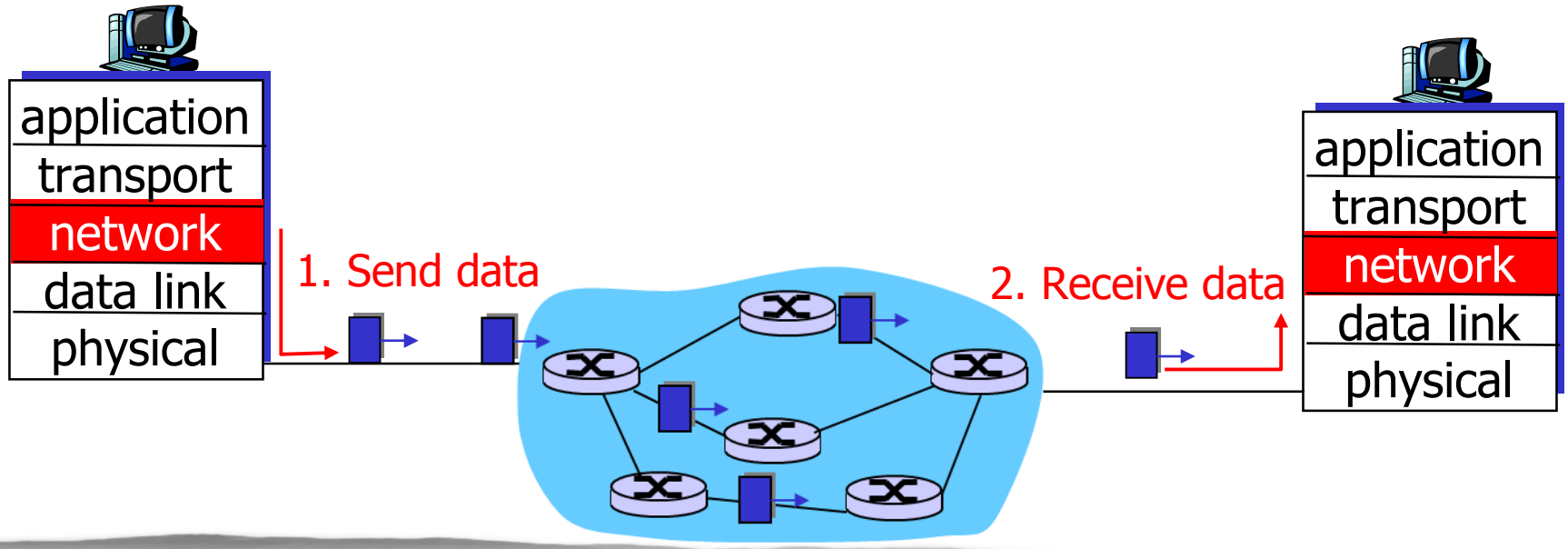
Virtual Circuits: Signaling Protocols

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



Datagram Networks

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



A Forwarding Table for Datagram Networks

- Also called routing table
- May reach 4 billion entries

- The destination address prefix may define a switch address or a subnet address

Dest Address Prefix	Address Mask	Link Interface
11001000 00010111 00010	11111111 11111111 11111000 00000000	0
11001000 00010111 00011000	11111111 11111111 11111111 00000000	1
11001000 00010111 000110	11111111 11111111 11111100 00000000	2
default	*	3

Longest Prefix Matching

Address Prefix	Link Interface
11001000 00010111 00010	0
11001000 00010111 00011000	1
11001000 00010111 00011	2
otherwise	3

Examples

DA: 11001000 00010111 00010110 10100001 Which interface?

DA: 11001000 00010111 00011000 10101010 Which interface?

Longest prefix matching rule: when looking for forwarding table entry for given destination address, use longest address prefix that matches destination address.

Datagram vs. Virtual Circuit

Datagram (Internet)

- Data exchange among computers
  - "Elastic" service, no strict timing
- "Smart" end systems (computers)
  - Can adapt, perform control, error recovery
  - Simple inside network, complexity at "edge"
- Many link types
  - Different characteristics
  - Uniform service difficult

Virtual Circuit (ATM)

- Evolved from telephony
- Human conversation:
  - Strict timing, reliability requirements
  - Need guaranteed service
- "Dumb" end systems
  - Telephones
  - Complexity inside network (switches)
- Link type standardized

ATM and Cell Switching

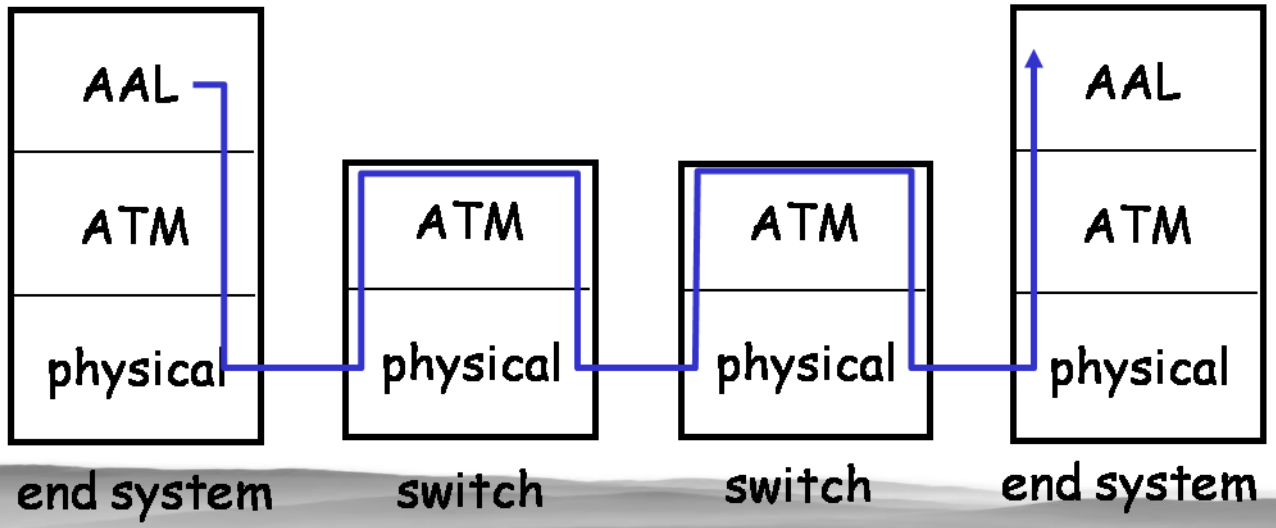
ATM and Cell Switching

- ATM: Asynchronous Transfer Mode
  - 1990's/2000 standard for high-speed Broadband Integrated Service Digital Network (ISDN, 综合业务数字网) architecture
  - 155Mbps to 622 Mbps and higher

- Features
  - Meeting timing/QoS requirements of voice and video, also support "burst" data
  - "Next generation" telephony: technical roots in telephone world
  - Packet-switching (fixed length packets, called "cells") using virtual circuits

ATM Architecture

- Adaptation layer: only at edge of ATM network
  - Data segmentation/reassembly, different service models
  - Roughly analogous to Internet transport layer
- ATM layer: "network" layer
  - Cell switching, routing
- Physical layer: SDH/SONET



ATM Adaptation Layer

- ATM Adaptation Layer (AAL)
  - "Adapts" upper layers (IP or native ATM applications) to ATM layer below
  - Present only in end systems, not in switches
- Different types of AALs
  - AAL1, Constant Bit Rate (CBR), e.g. circuit emulation
  - AAL2, Variable Bit Rate (VBR), e.g. voice and video
  - AAL3/4, Connection-oriented data service, e.g. X.25 and Frame Relay
  - AAL5, Connectionless data service, e.g IP datagram

ATM Services

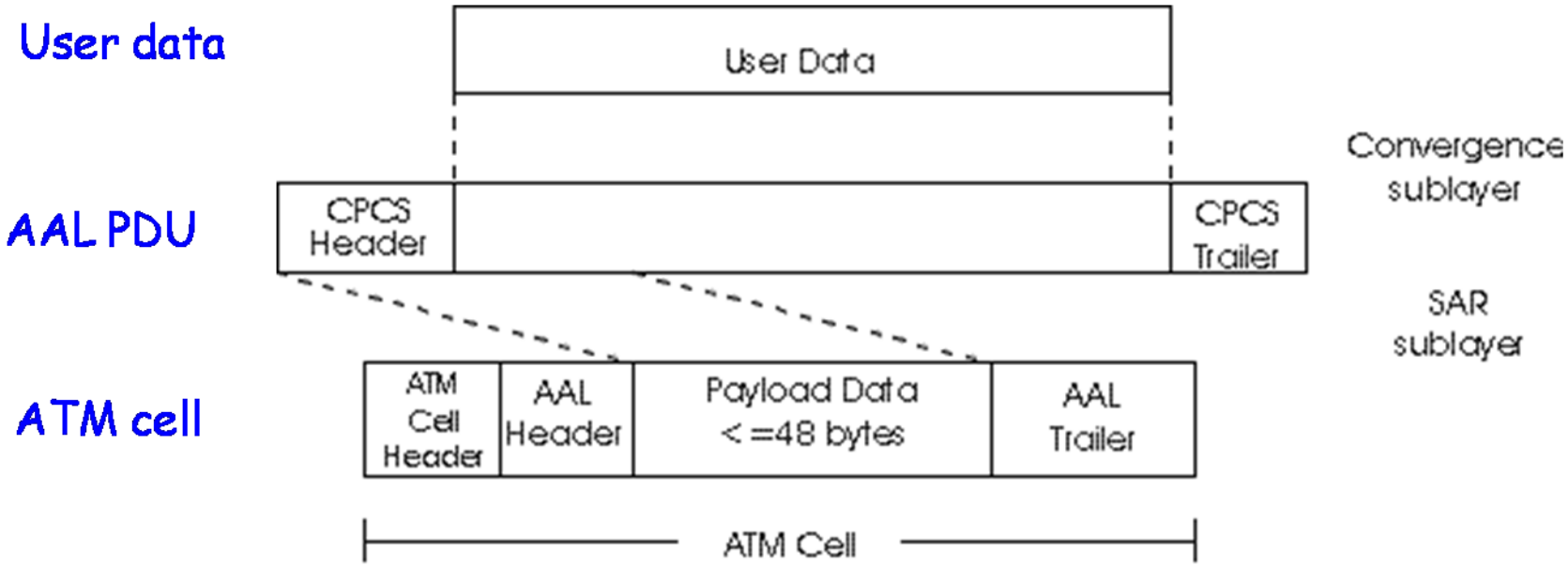
In decreasing priority

- Constant Bit Rate (CBR) and Variable Bit Rate (VBR)
- Available Bit Rate (ABR) and Unspecified Bit Rate (UBR)

Network Architecture	Service Model	Guarantees ?				Congestion feedback
		Bandwidth	Loss	Order	Timing	
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

AAL Frames

- AAL layer frame
  - Header + data + trailer, specific in each AAL type
  - Fragmented across multiple ATM cells

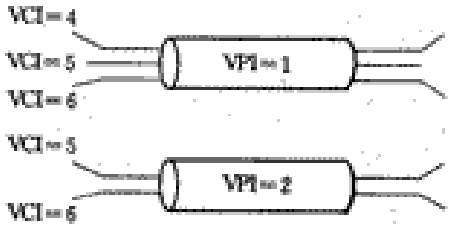


Common Part Convergence Sublayer (CPCS)
Segmentation and Reassembly (SAR)

ATM Layer: Virtual Circuits

- VC transport: cells carried on VC from source to destination
- Permanent VCs (PVC)
  - Long lasting connections
- Switched VCs (SVC)
  - Dynamically set up on per-connection basis
- A VC consists of virtual paths and virtual channels
  - Virtual Path Identifier (VPI) + Virtual Channel Identifier (VCI)

信元路由信息：
虚通道：由VPI指定，一个VPI包含一组VCI
虚通路：由VCI指定



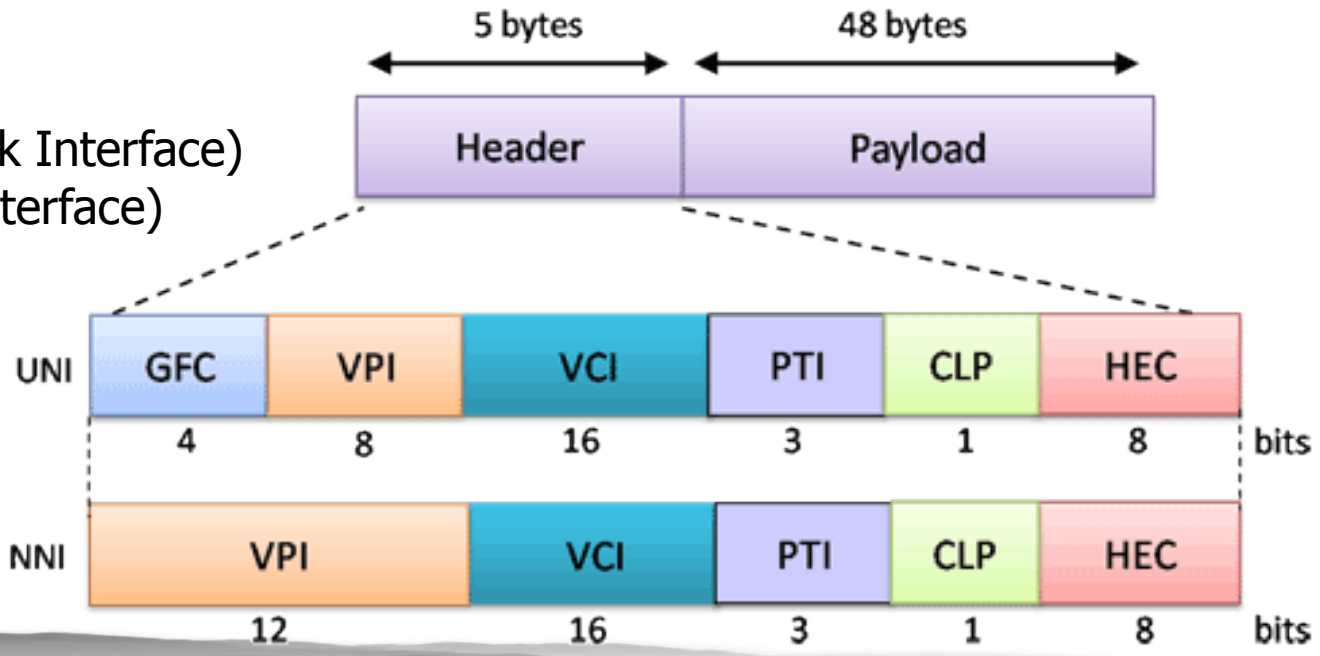
ATM VCs

- Advantages of ATM VC approach
  - QoS performance guarantee for data communication on VC
  - Bandwidth, delay, delay jitter
- Drawbacks of ATM VC approach
  - Inefficient support of Internet datagram traffic
  - One VC for each IP packet: introduces call setup latency and processing overhead
  - Better: one VC for a flow of IP packets

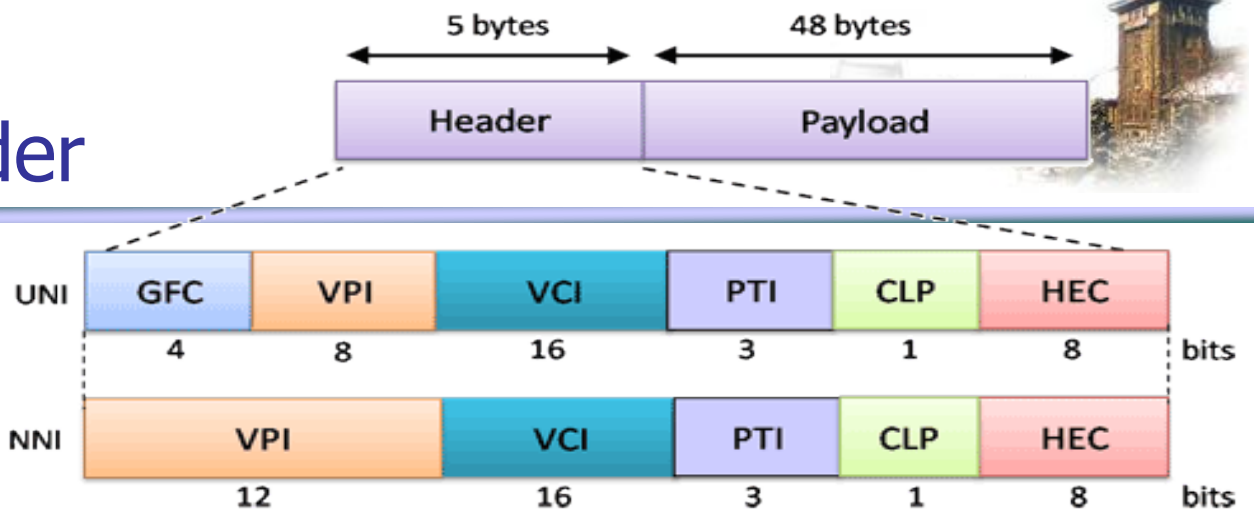
ATM Cells

- 5 octet header + 48 octet payload
- Small payload → short cell-creation delay and switching delay
- 48 = halfway between 32 (Europe) and 64 (North America), a compromise

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



ATM Cell Header



- GFC: Generic Flow Control (一般流量控制)
  - 0 by default, local flow control bits
- VPI/VCI: virtual circuit ID
  - Will change from link to link thru net

VPI（Virtual Path Identifier，虚通道标识符）
VCI（Virtual Connection Identifier，虚通路标识符）

- PT: Payload type
  - E.g. "Operation Administration and Maintenance" cell or data cell

载荷类型，用于指示信息字段的信息是用户信息还是网络信息

- CLP: Cell Loss Priority bit
  - CLP = 1 implies low priority cell, can be discarded if congestion
- HEC: Header Error Checksum (cyclic redundancy check)

ATM Physical Layer

- 2 sublayers
  - Transmission Convergence (TC) sublayer
  - Physical Medium Dependent (PMD) sublayer: depends on physical medium being used

- TC sublayer functions
  - Header checksum generation: 8 bits CRC
  - Cell delineation to signal representation
  - Transmission of idle cells when no data cells to send

传输聚合子层:在发送方,它从ATM层接收信元,组装成特定形式的帧(SONET帧或FDDI数据帧). 在接收方,它从PMD子层提取信元,交付ATM层. 类似于链路层功能
物理介质相关子层：指定物理特性

Physical Medium Dependent Sublayer

- SONET/SDH: transmission frame structure
  - Bit synchronization
  - Bandwidth partitions (TDM)
  - Multiple speeds: OC3 = 155.52 Mbps; OC12 = 622.08 Mbps; OC48 = 2.45 Gbps, OC192 = 9.6 Gbps
- TI/T3: transmission frame structure
  - Low speed line: 1.5 Mbps/ 45 Mbps
- Unstructured: just cells (busy/idle)

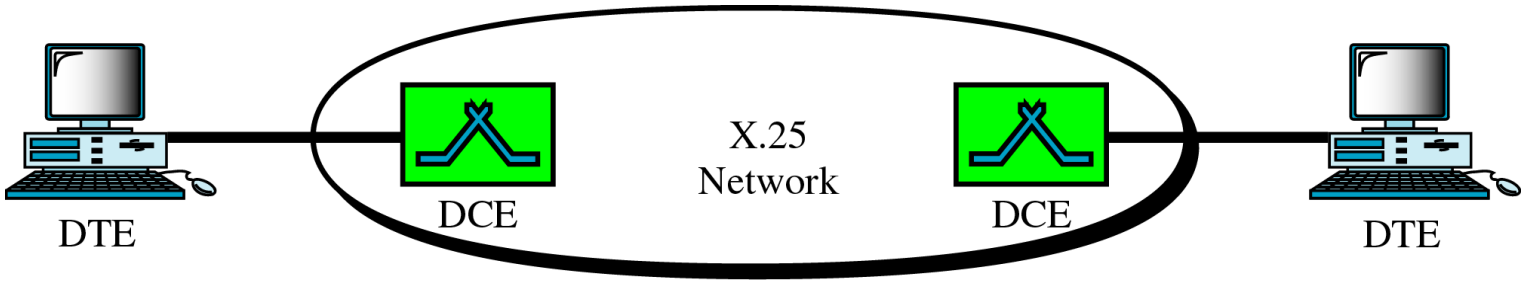
X.25 and Frame Relay

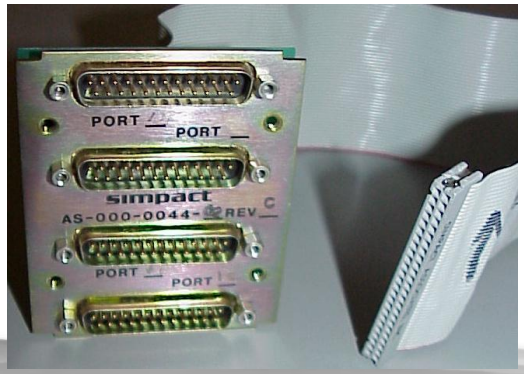
X.25 and Frame Relay

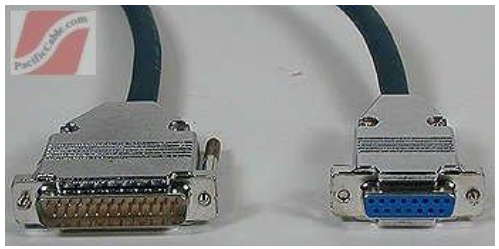
- X.25
  - A packet-switching wide area network developed by ITU-T in 1976
  - Defines how a packet-mode terminal can be connected to a packet network
  - Known as a subscriber network interface (SNI) protocol
- Frame Relay
  - Packet-switching with virtual-circuit technology
  - An enhancement of X.25, due to improved transmission media
  - Interconnect LANs, instead of terminals

X.25

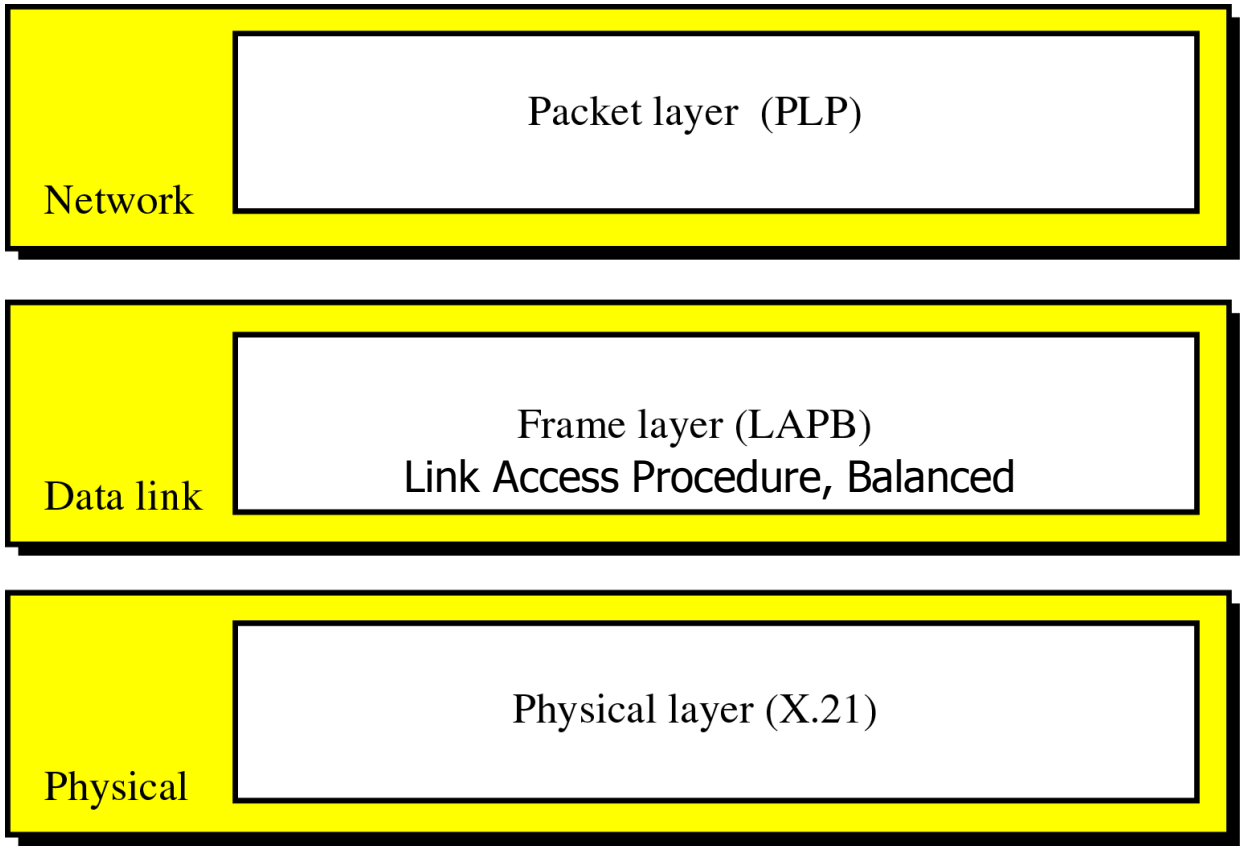
- Defines how a user's DTE (Data Terminal Equipment) communicates with DCEs (Data Communications Equipments) in a packet switching network
- Defines how packets are sent thru the virtual circuit established between DTEs







X.25 Layers



PLP: Packet Layer Protocol

The Physical Layer

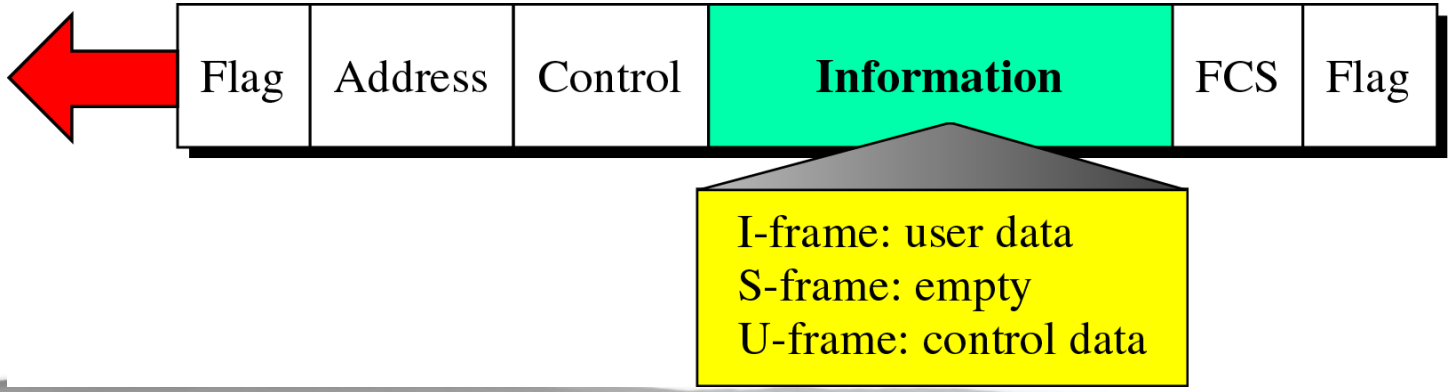
- Specify the physical interface between DTE and DCE
- Signaling on the link that connected the X.25 network

- Can provide synchronous data transmission at rates from 100 kbps to 10 Mbps
- Capable of running full-duplex data transmissions

Frame Layer

- Link access procedure, balanced (LAPB) protocol
  - Reliable data transfer: error and flow control
  - Link Setup; Packet Transfer; Link Disconnect

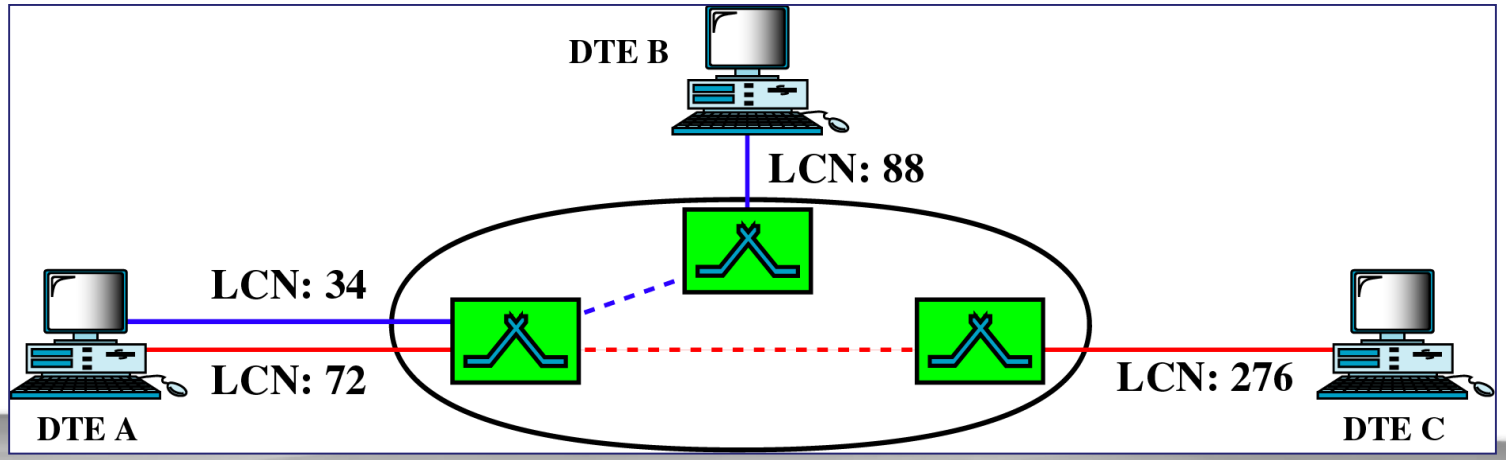
- 3 types of frames
  - I-Frames: data frame
  - S-Frames: flow and error control
  - U-Frames: setup and disconnect links between DTE and DCE



Packet Layer

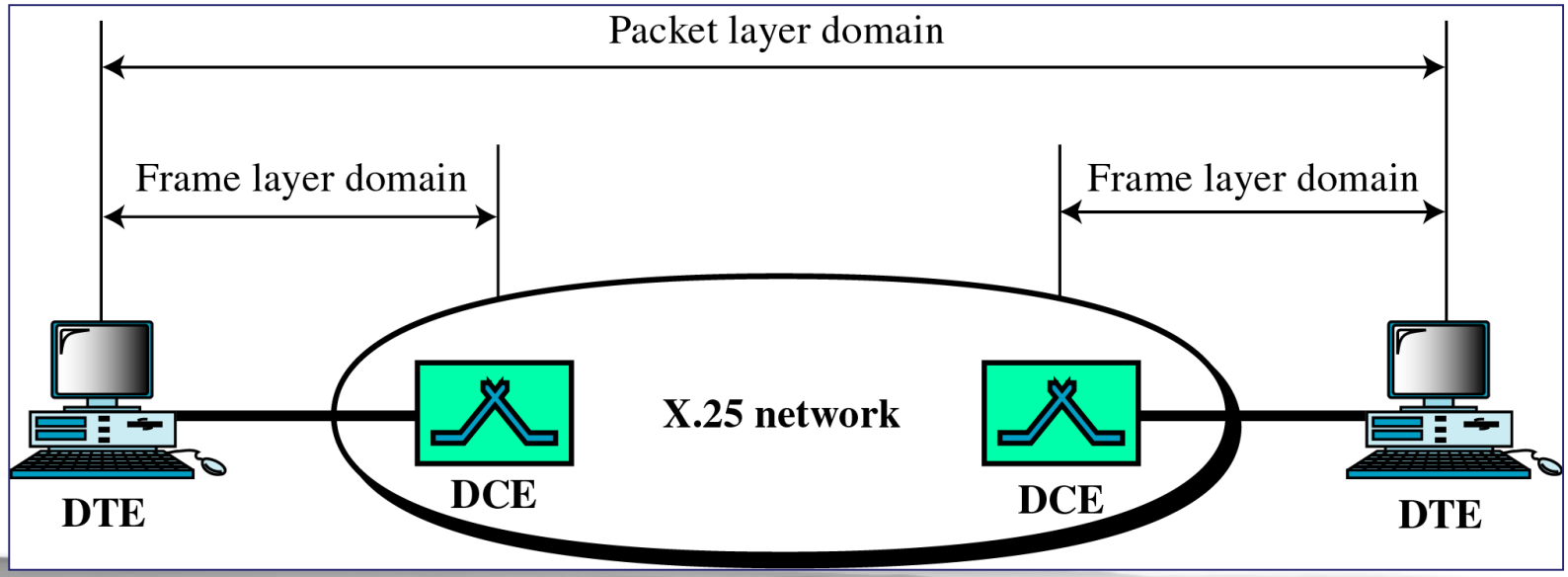
- Packet Layer Protocol (PLP)
  - Establish connection, transfer data, and terminate connection between 2 DTEs
  - Create virtual circuits and negotiate network services between DTEs

- Virtual circuits in X.25
  - 2 types: permanent VC, switched VC
  - Identified by logical channel number (LCN)



Connection Events in X.25

- Setup links between DCE and DTE pairs
- Establish VC between DTEs
- Transfer data
- Release the VC
- Disconnect the links

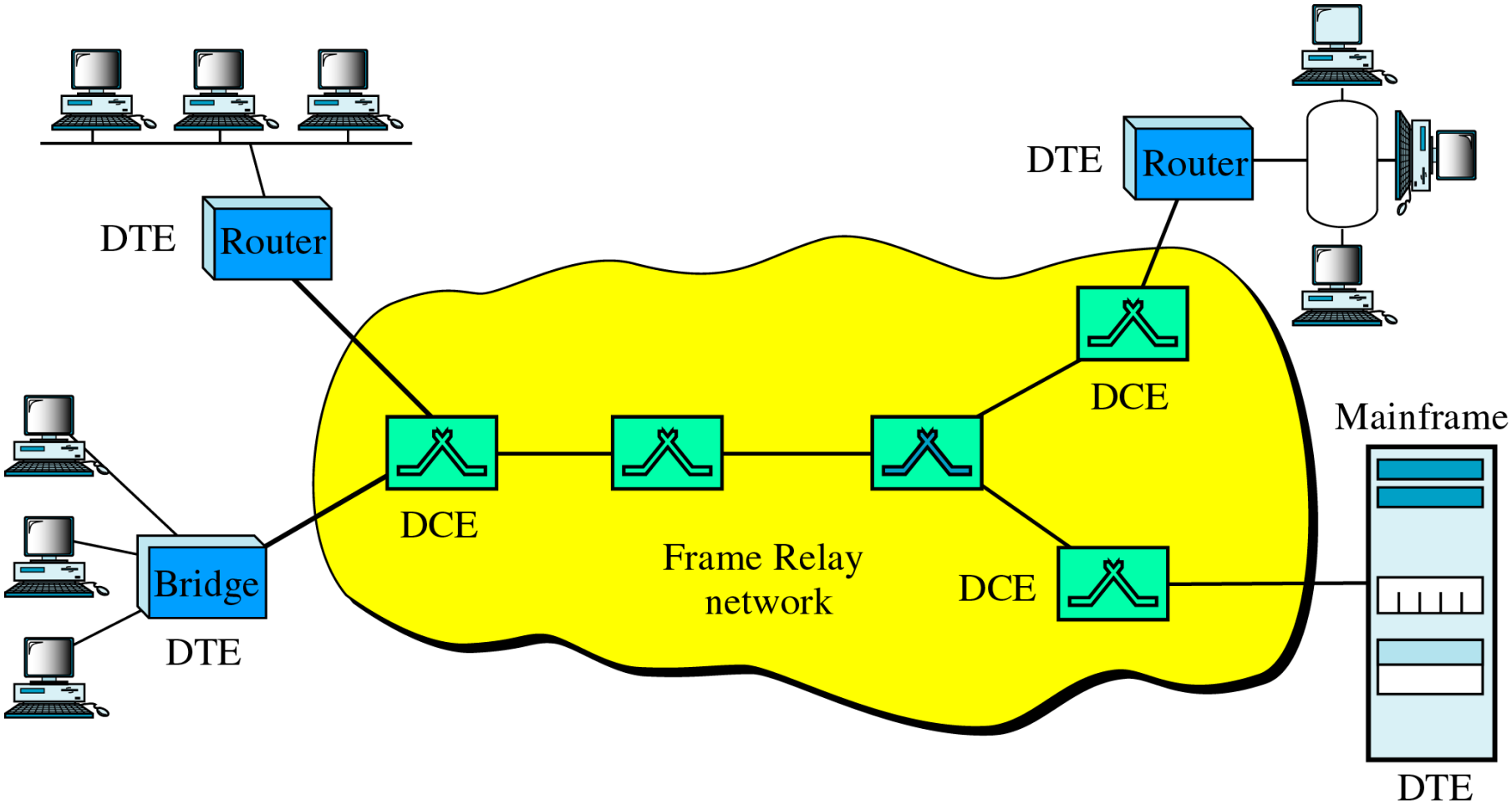


Frame Relay

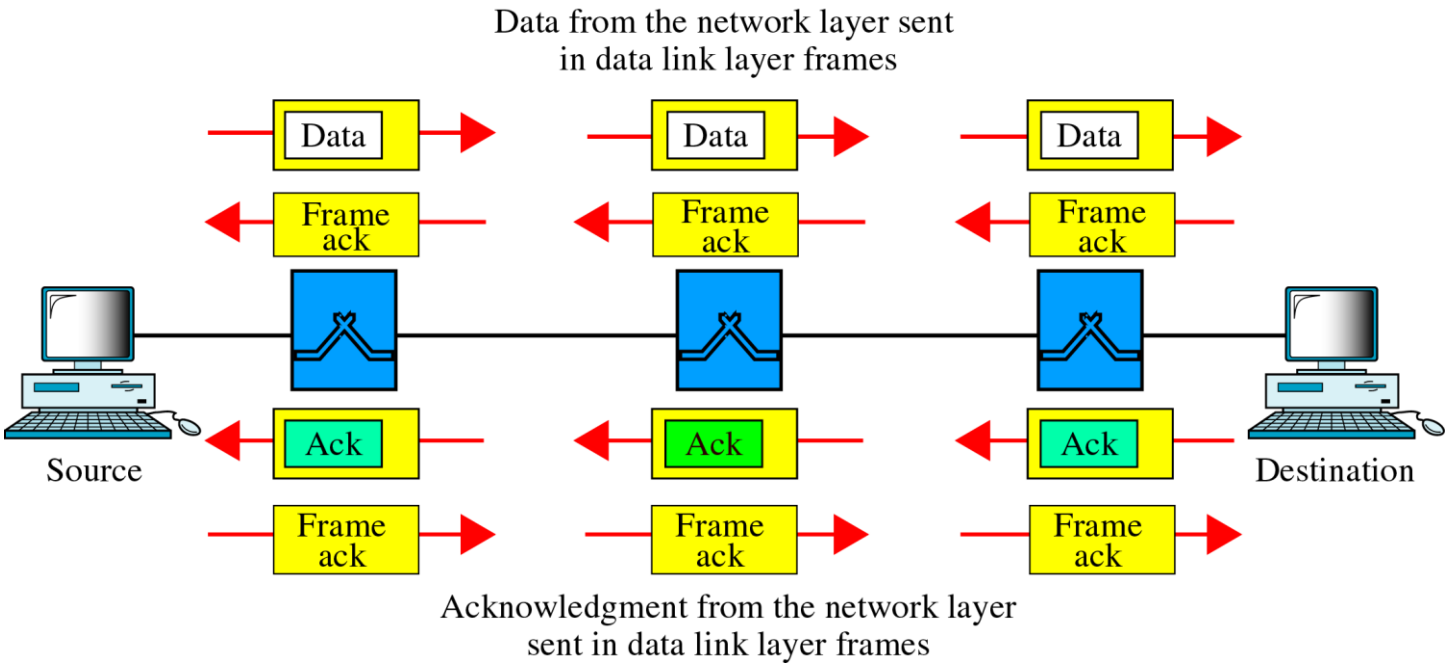
- Improvement of X.25, taking advantage of high-speed new links with lower error-rates
  - Operate only at the Physical and Data link layer
  - Not provide error checking or require ACK in data link layer
- Layers in FR
  - Physical layer, any protocols recognized by ANSI, up to 44.376 Mbps
  - Data link layer, a simplified version of HDLC called core LAPF, no error and flow control fields

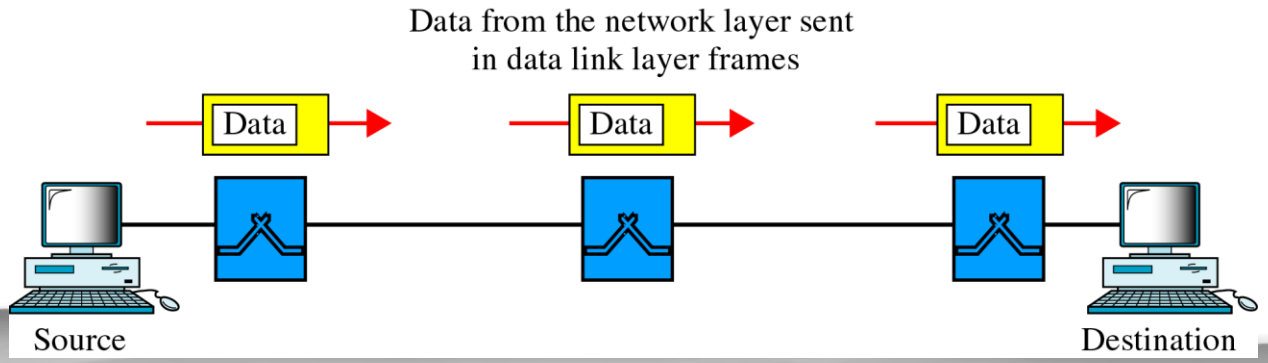
ANSI: American National Standards Institute
LAPF: Link Access Procedure for Frame Mode Services

A Frame Relay Network



X.25 vs. Frame Relay

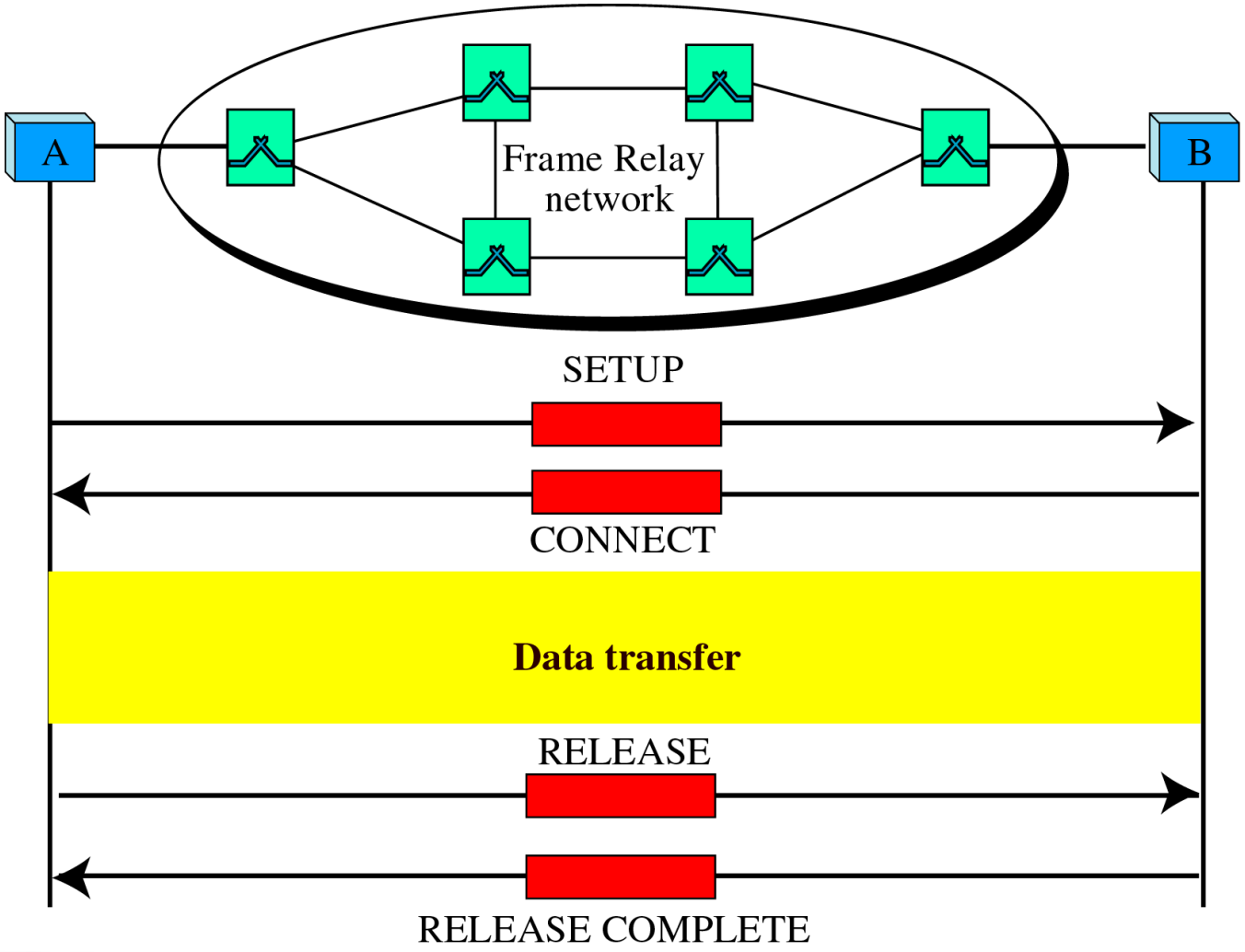




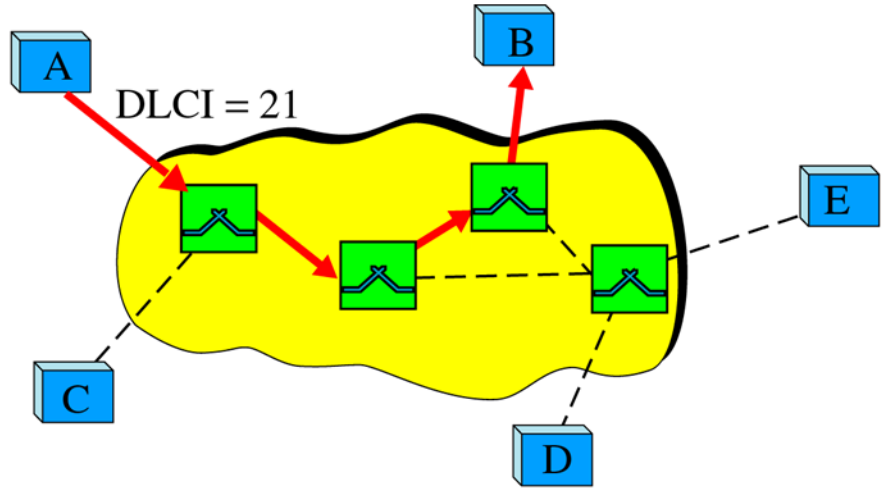
Virtual Circuits in FR

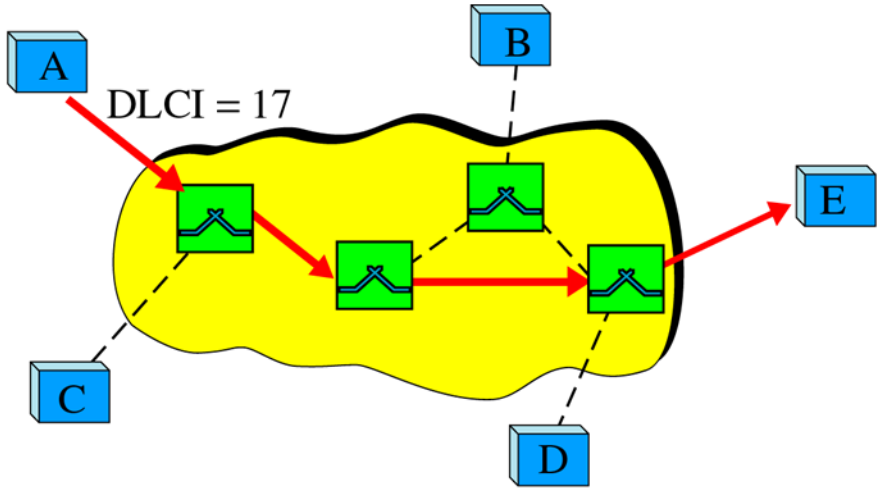
- Also provide PVC and SVC connections
- A VC is identified by a Data Link Connection Identifier (DLCI)
  - 2 DLCIs are given for each end of the connection
- DLCI is assigned to the DTEs when the VC is established
  - Serve as addresses of the DTEs
  - Not changed on DCEs

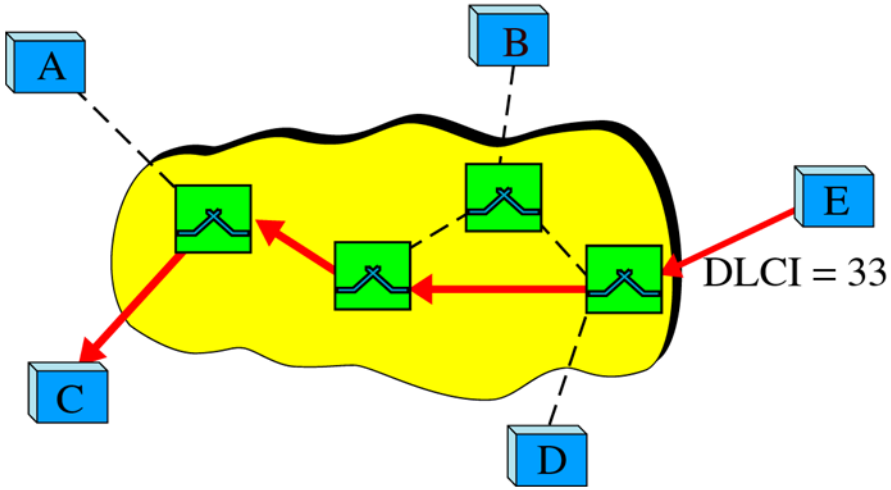
SVC Setup and Release

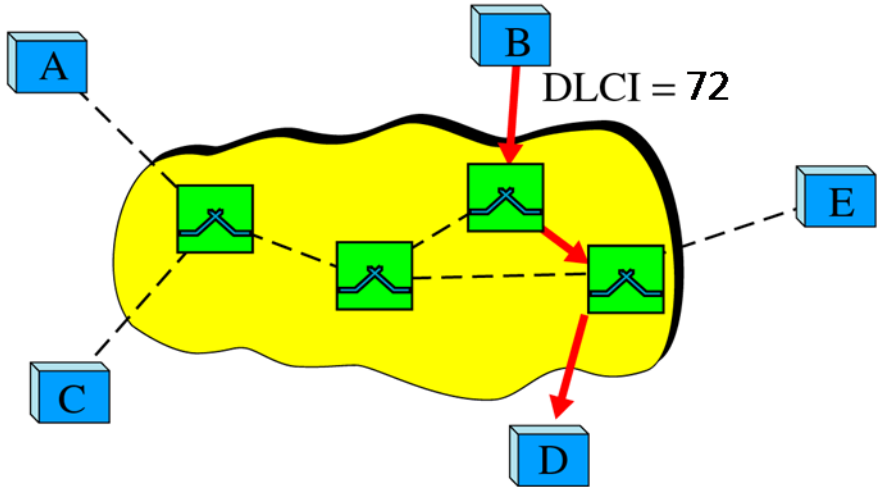


DLCIs in FR Networks



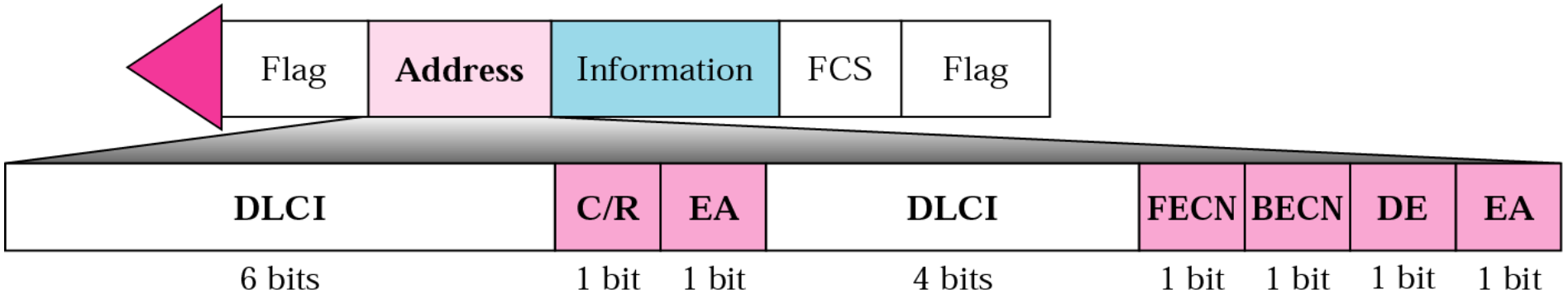






FR Frame Structure

C/R: Command/response
EA: Extended address
FECN: Forward explicit congestion notification
BECN: Backward explicit congestion notification
DE: Discard eligibility
DLCI: Data link connection identifier



Summary

- 网络层基本功能
  - 交换/路由，转发，建立连接
- 虚电路+分组交换
  - ATM（面向连接，信元：固定长度的分组，支持CBR， VBR， ABR，UBR）
  - X.25（面向连接，流控制和错误检测），帧中继（面向连接，无错误控制，无流控制）