CNL
Communications & Networking
Laboratory

# ECE 462 – Data and Computer Communications

# Lecture 24-25: Internet Protocol Overview


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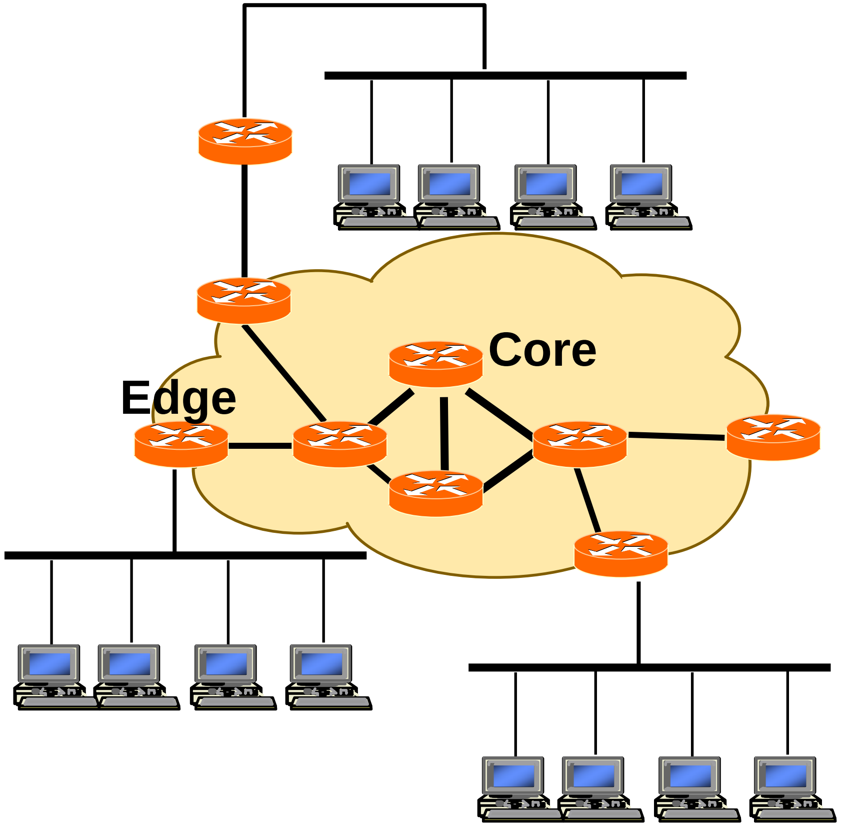
# Outline

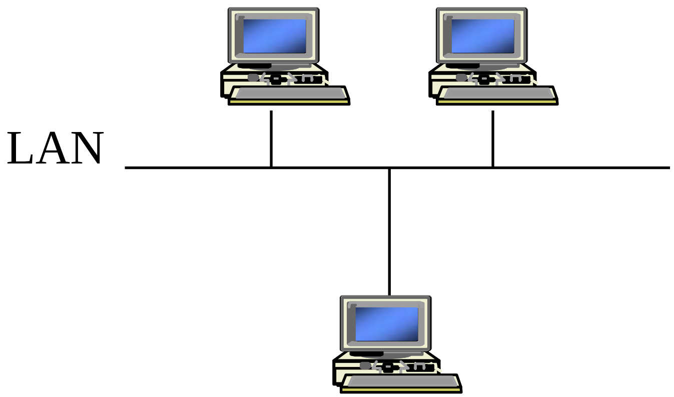
- Internetworking
- Network layer functions
- CL vs. CO
- Routing
- Addressing
- Summary

# Internetworking Terms

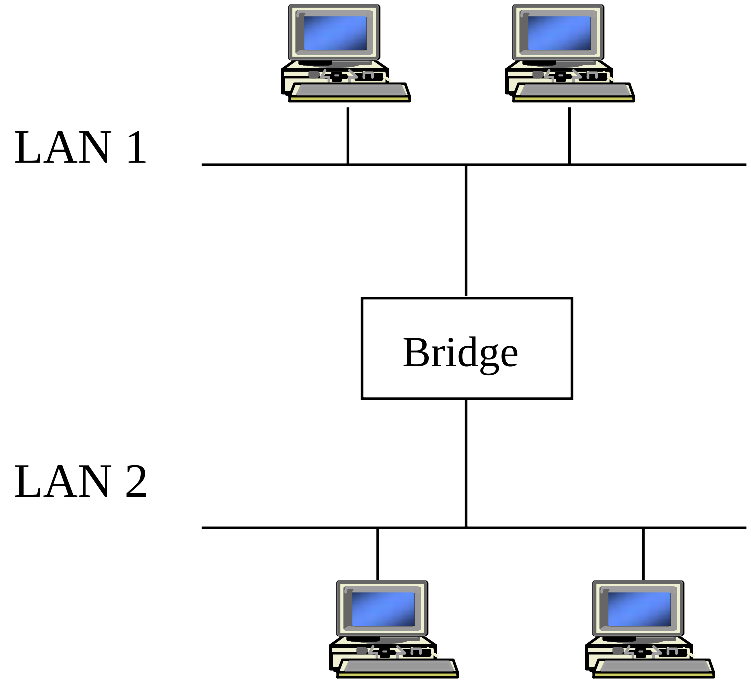
- Internet
- Intranet
- End System (ES)
- Intermediate System (IS)
- Edge Router
- Core Router
- Internet Service Provider (ISP)



# LANs and Bridges



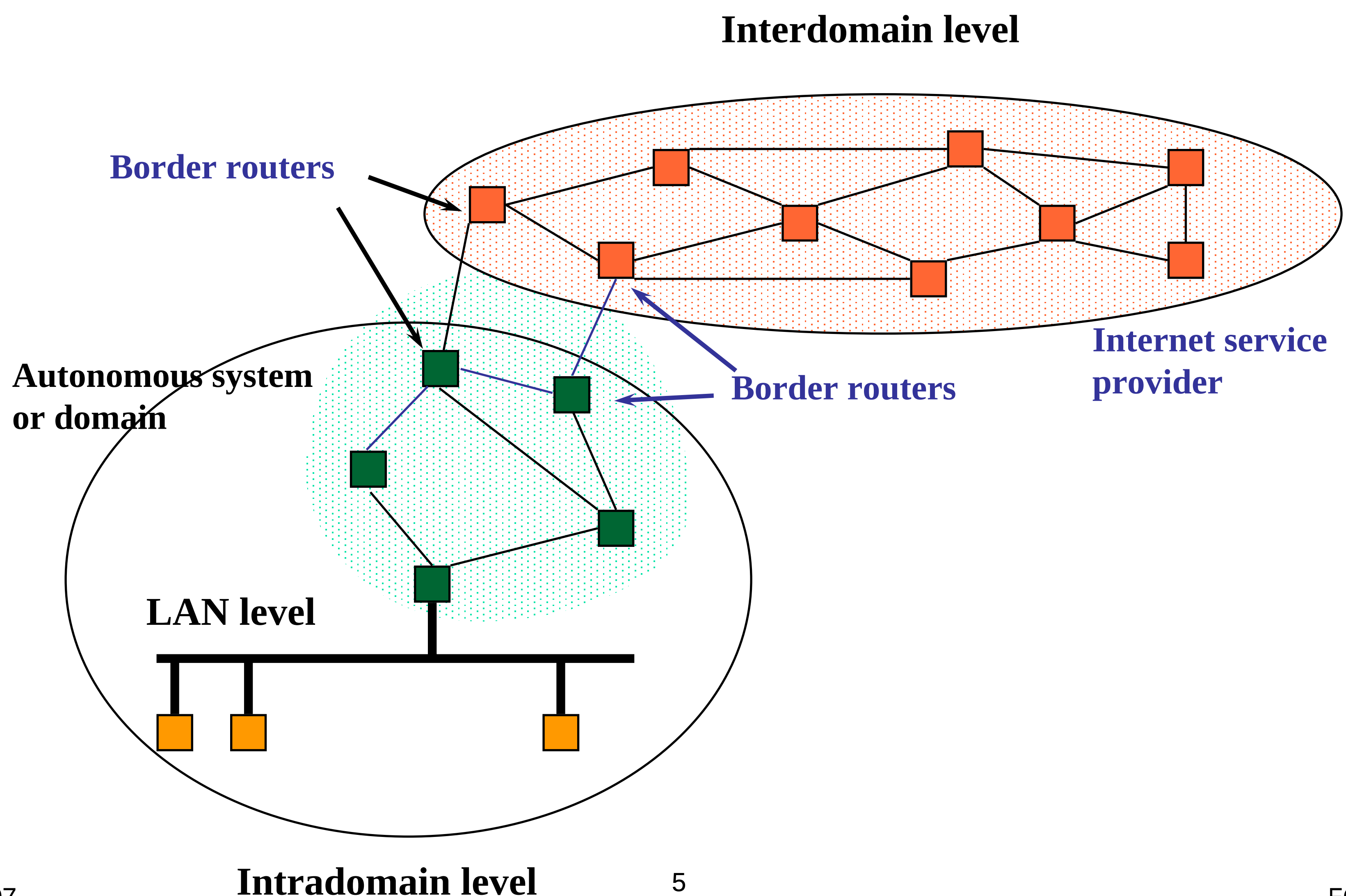

- Each PC is connected to the Ethernet LAN by an interface board (NIC) with a physical address




- A bridge allows packet exchange between two LANs
  - It converts the format of the packet

Figure 7.5

# The Internet



# UUNET’s Network

# Internet Protocol (IP) in Context

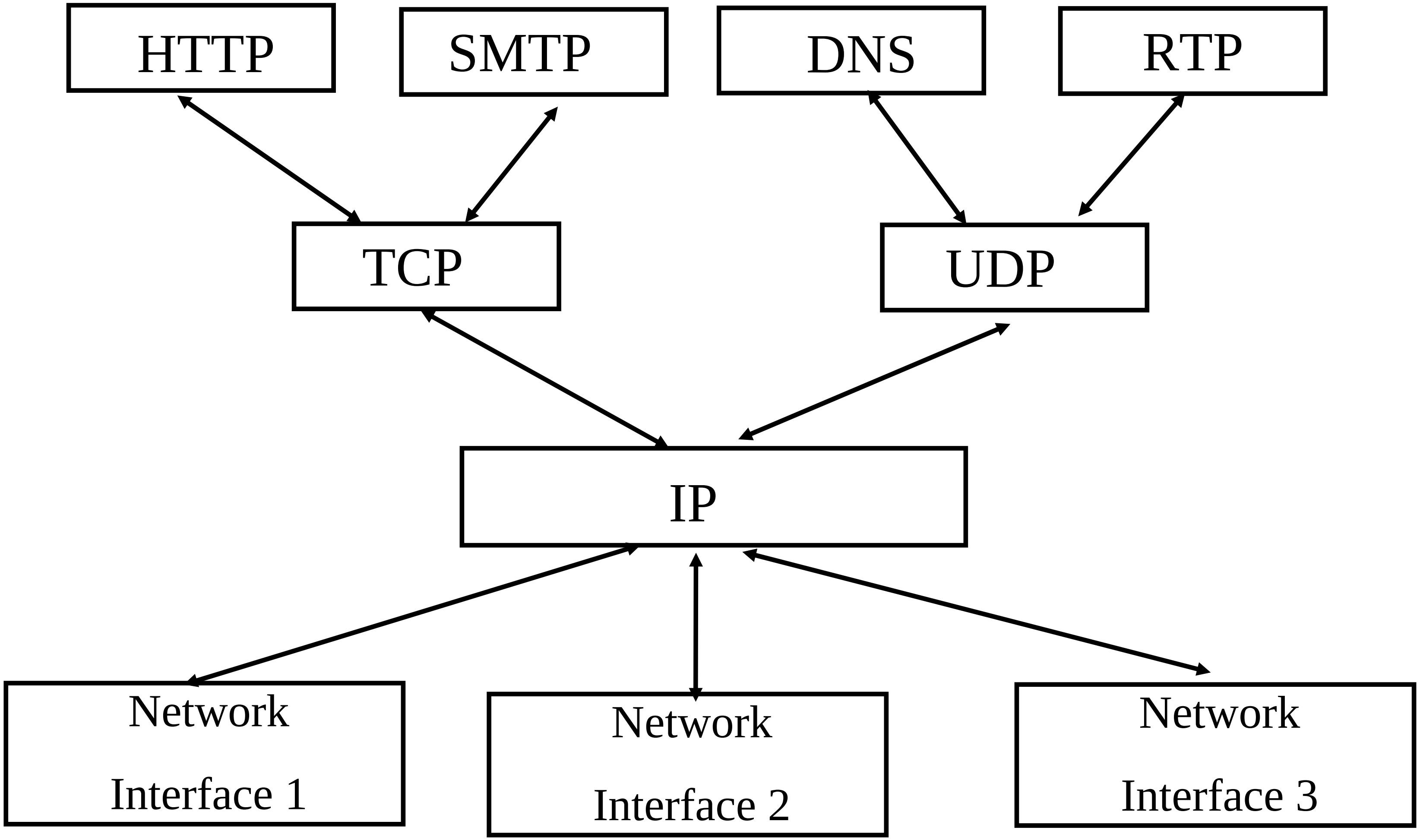
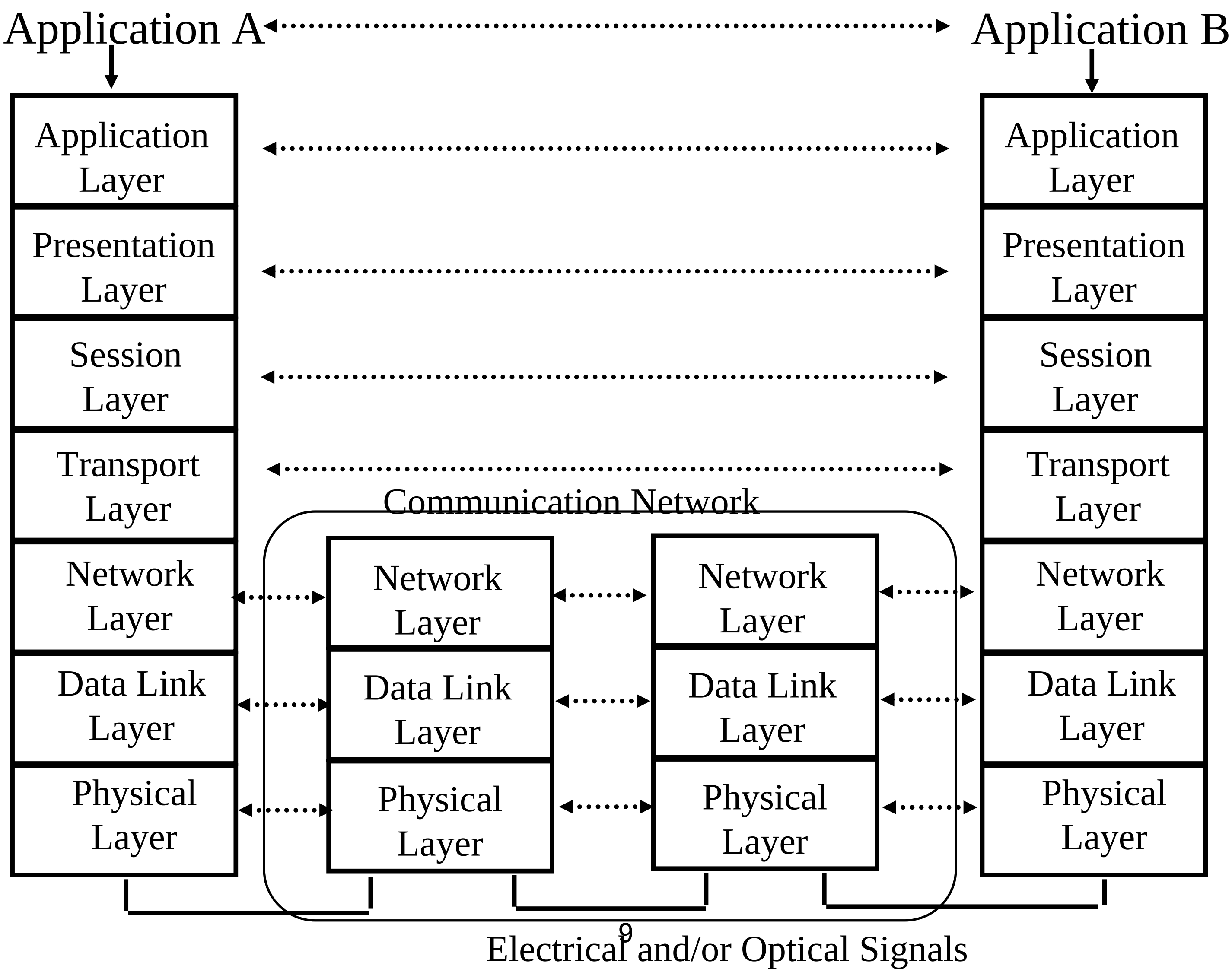



Figure 2.12

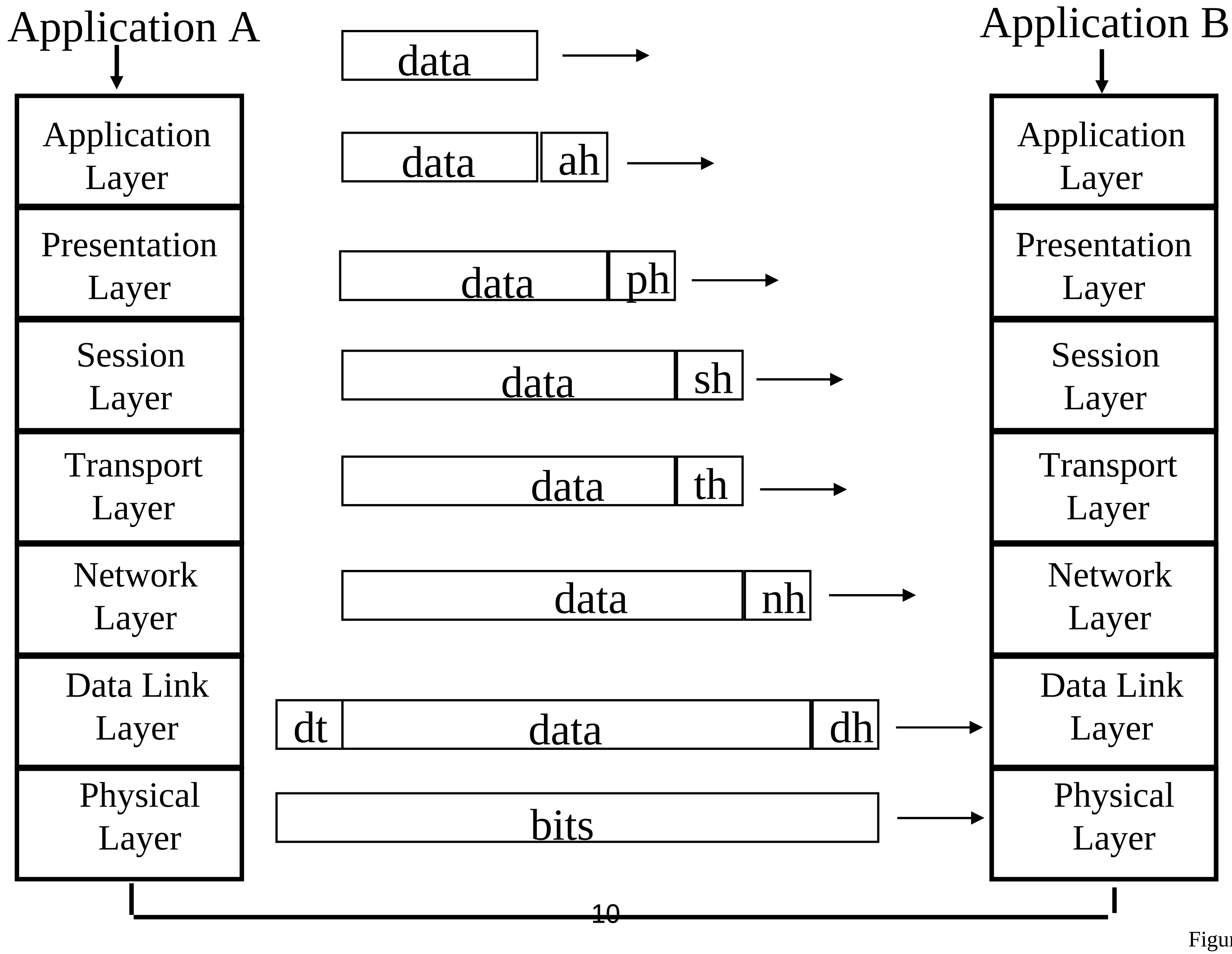
# Internet Protocols

- IP: Internetworking Protocol (Internet Protocol)
- TCP: Transmission Control Protocol
- UDP: User Datagram Protocol
- HTTP: Hypertext Transfer Protocol
- SMTP: Simple Mail Transfer Protocol
- FTP: File Transfer Protocol
- RTP: Real-time Transport Protocol
- DNS: Domain Name System

# Review 1- The OSI Architecture



# Review 2- The OSI Architecture



# Review 3

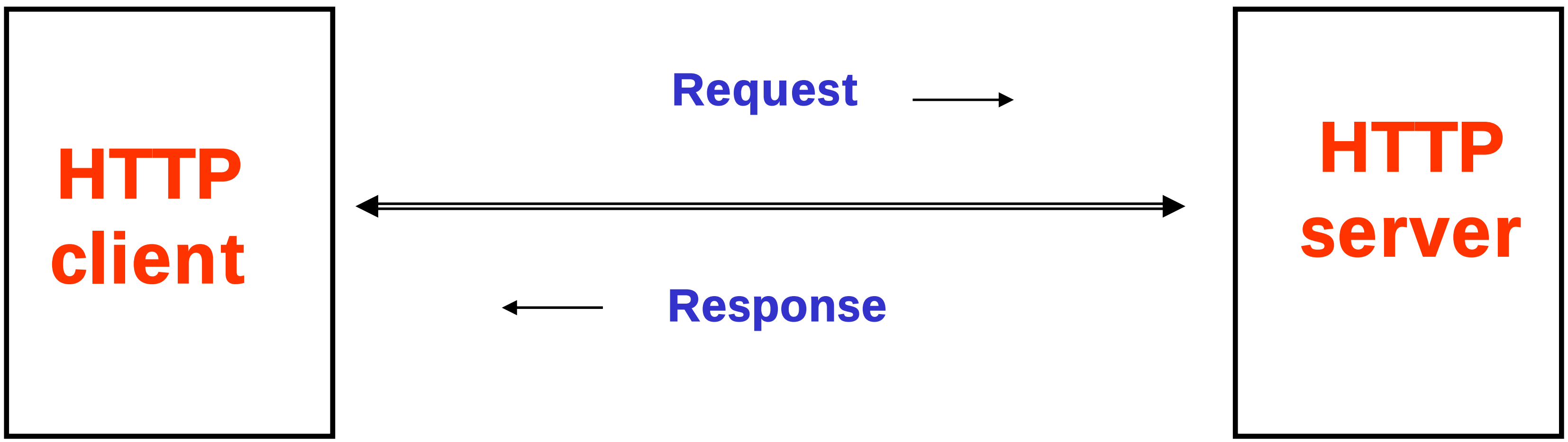



Figure 2.1

# Review 4

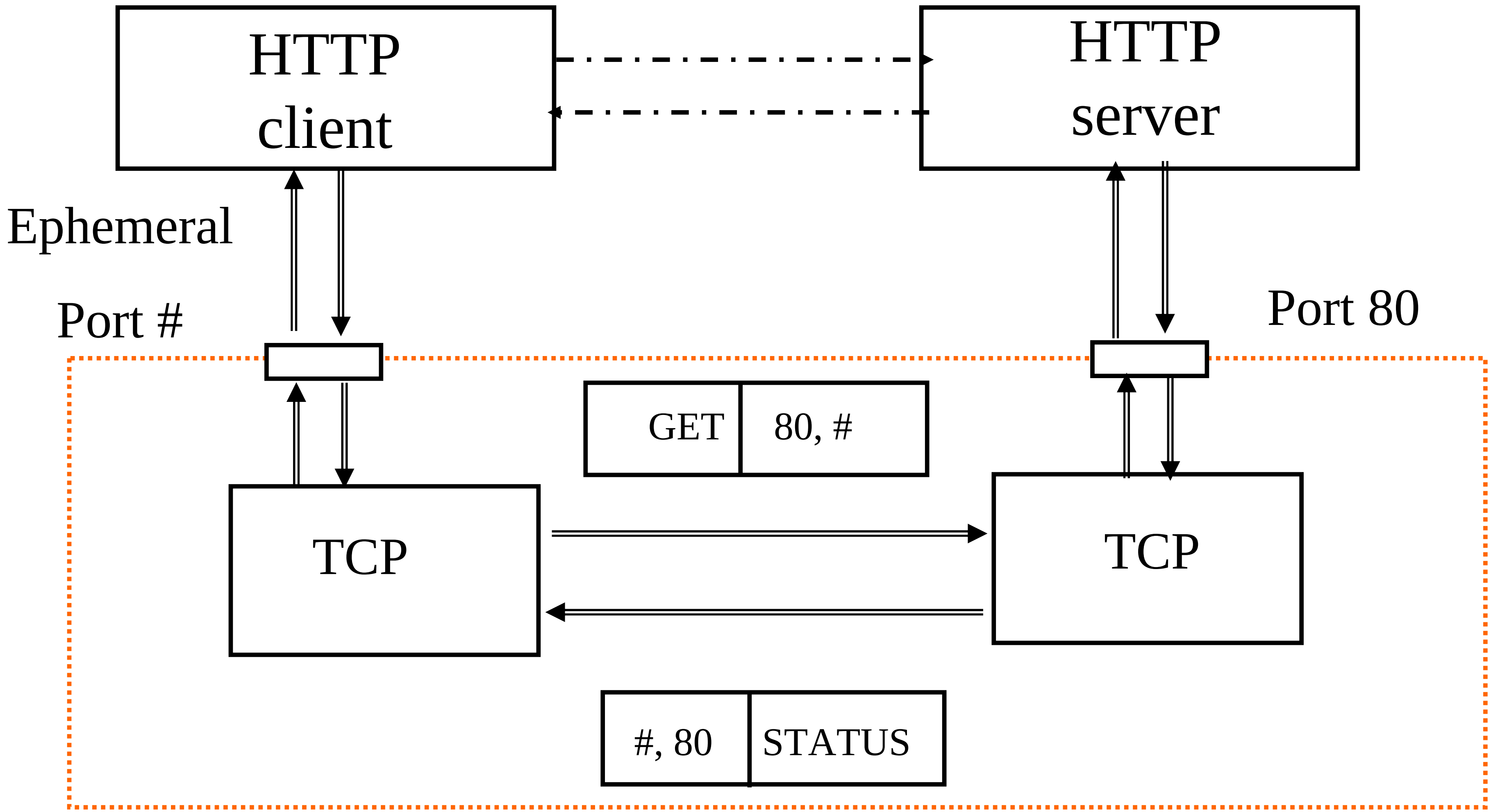



Figure 2.2

# Review 5

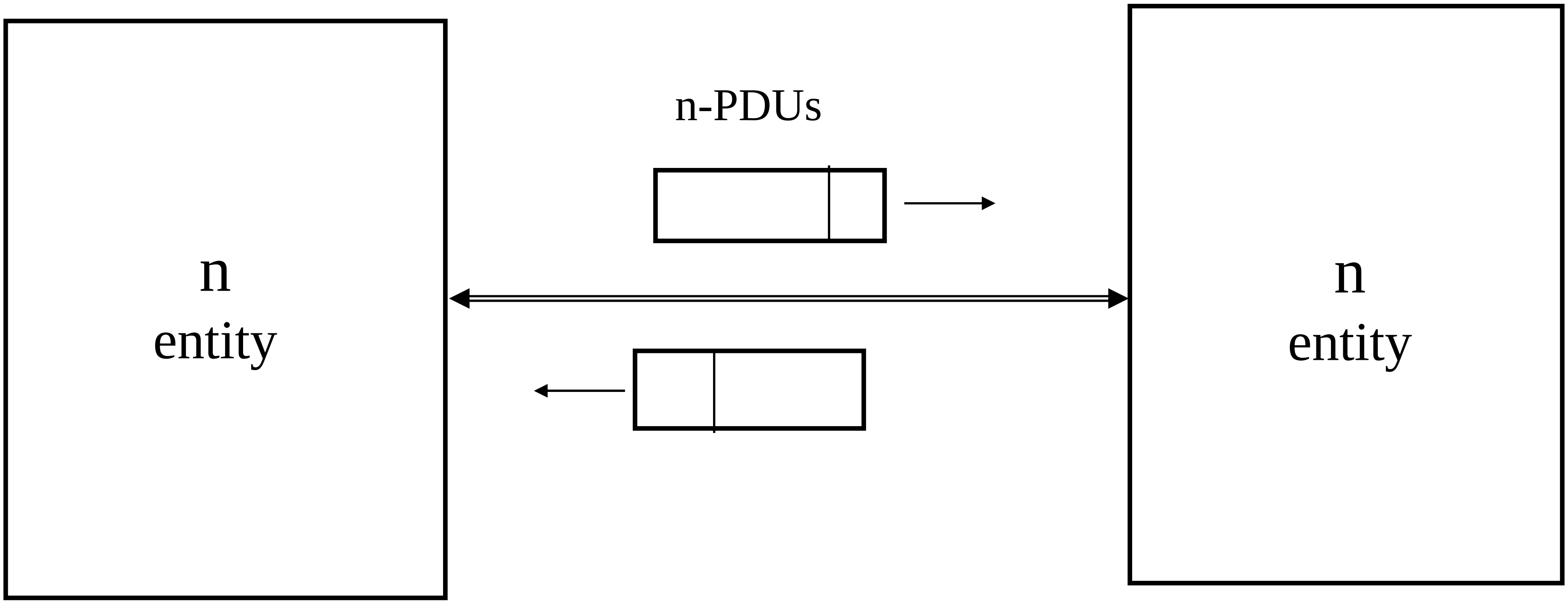
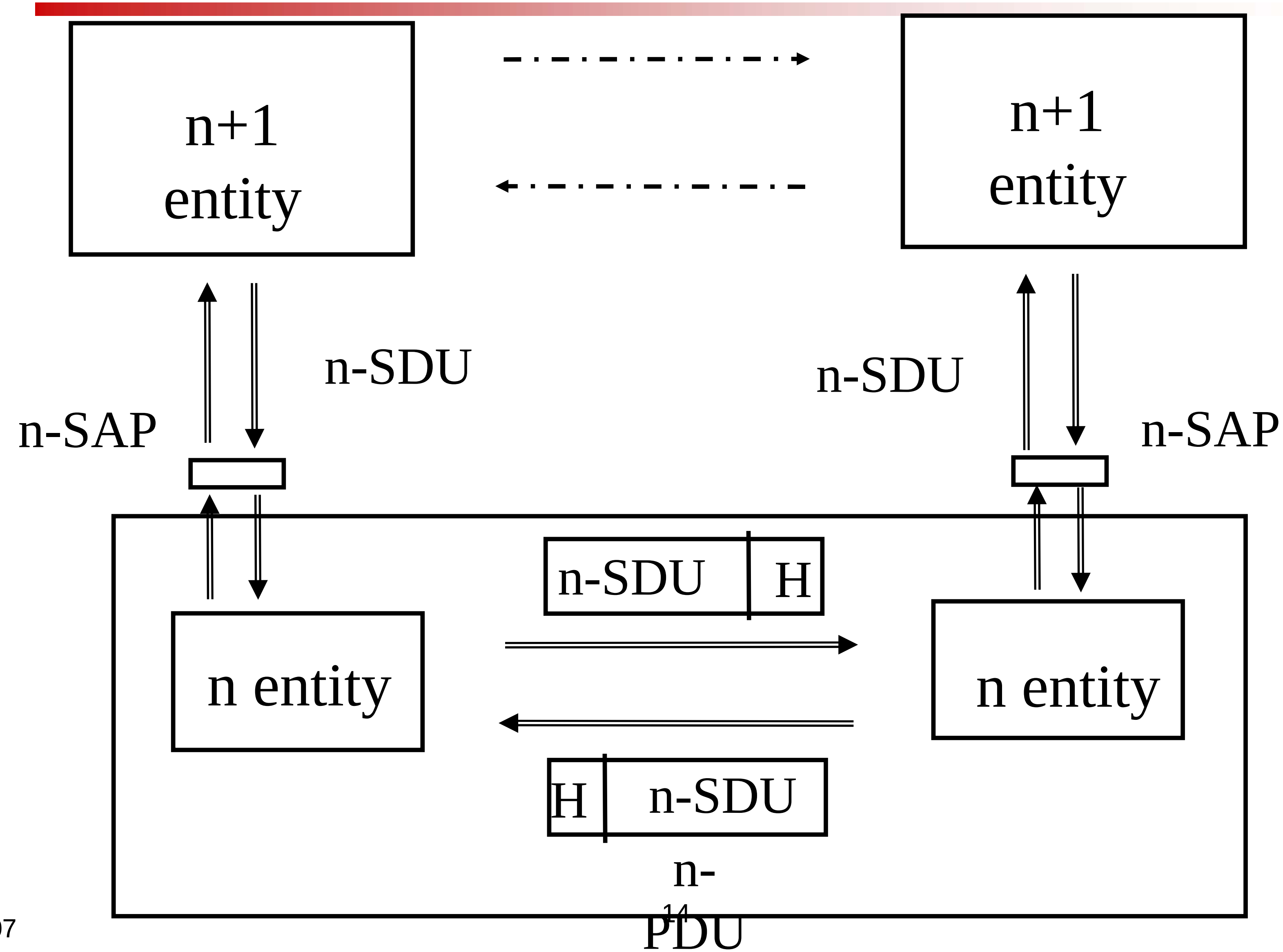


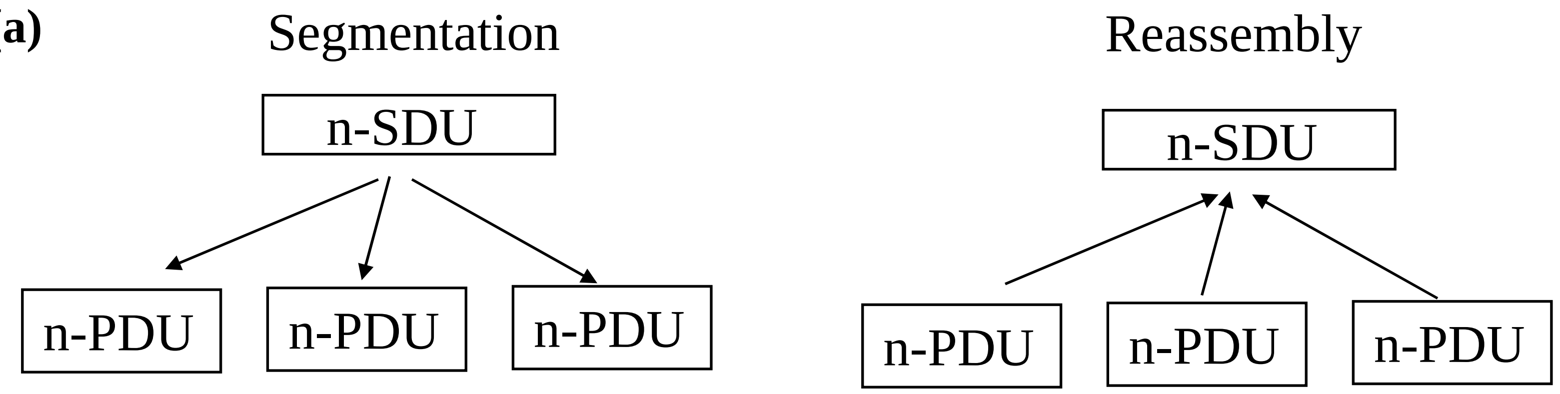

Figure 2.5

# Review 6

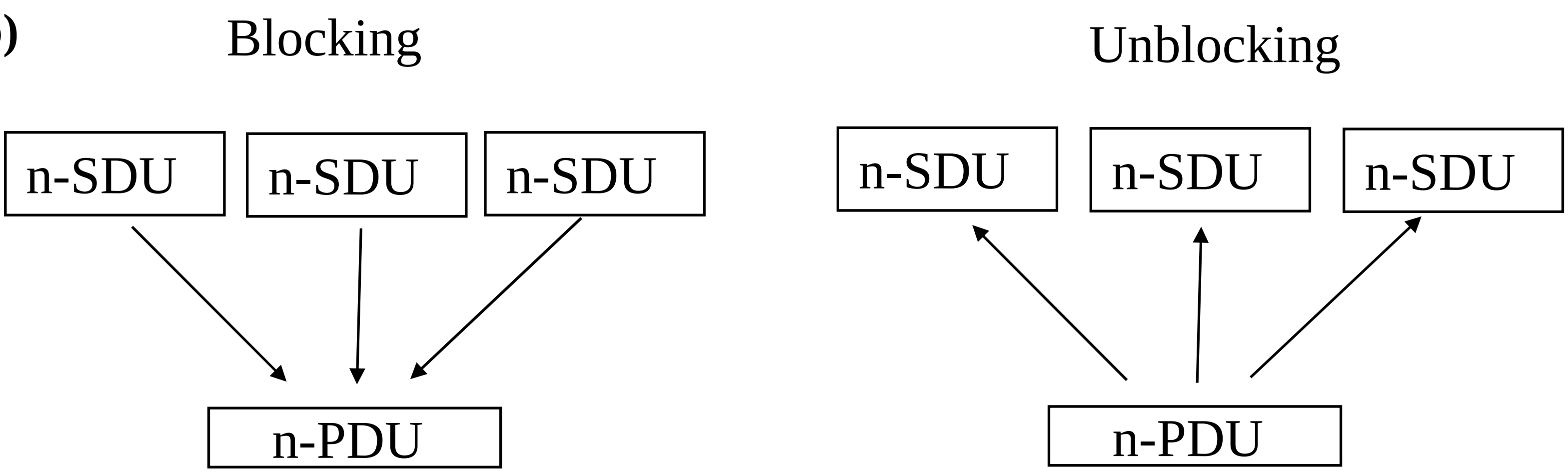

n+1
entity
n+1
entity
n-SDU
n-SDU
n-SAP
n-SAP
n-SDU
H
n entity
n entity
H
n-SDU
n-
PDU

# Review 7

(a)

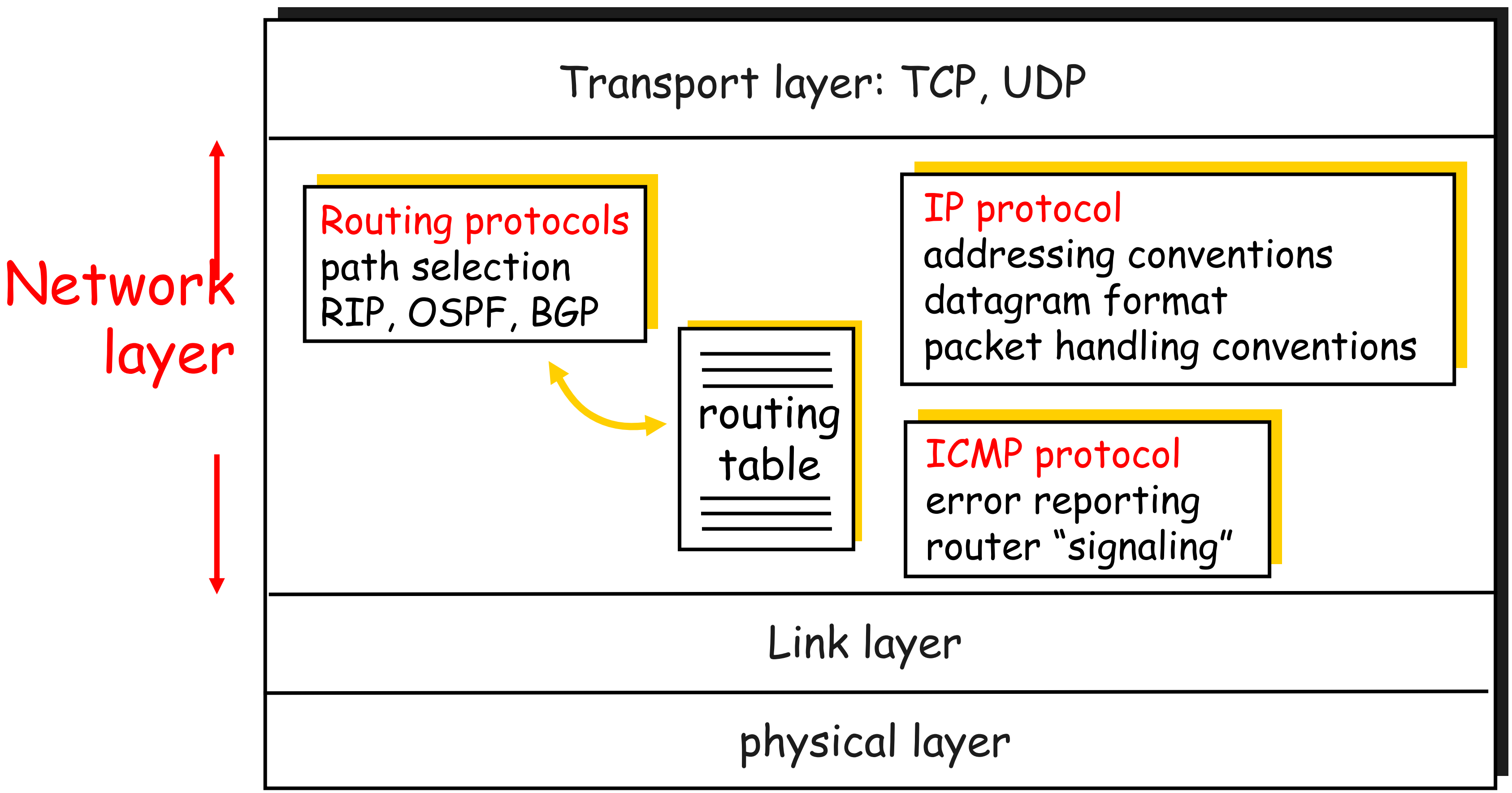

Segmentation
n-SDU
n-PDU
n-PDU
n-PDU
Reassembly
n-SDU
n-PDU
n-PDU
n-PDU

(b)


Blocking
n-SDU
n-SDU
n-SDU
n-PDU
Unblocking
n-SDU
n-SDU
n-SDU
n-PDU

# The Internet Network layer

**Host, router network layer functions:**

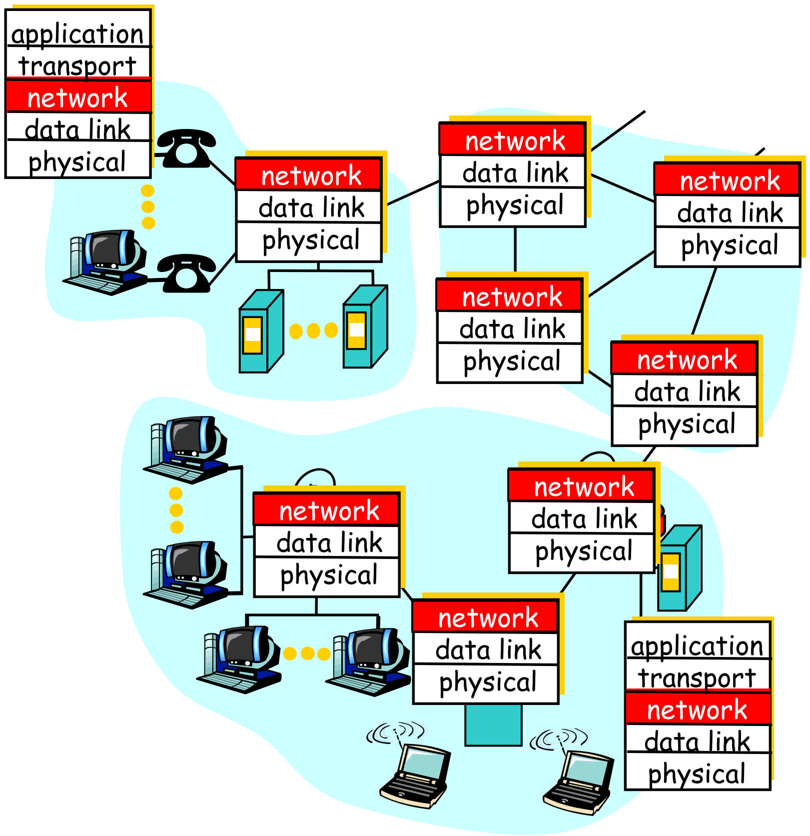


# Network Layer Functions

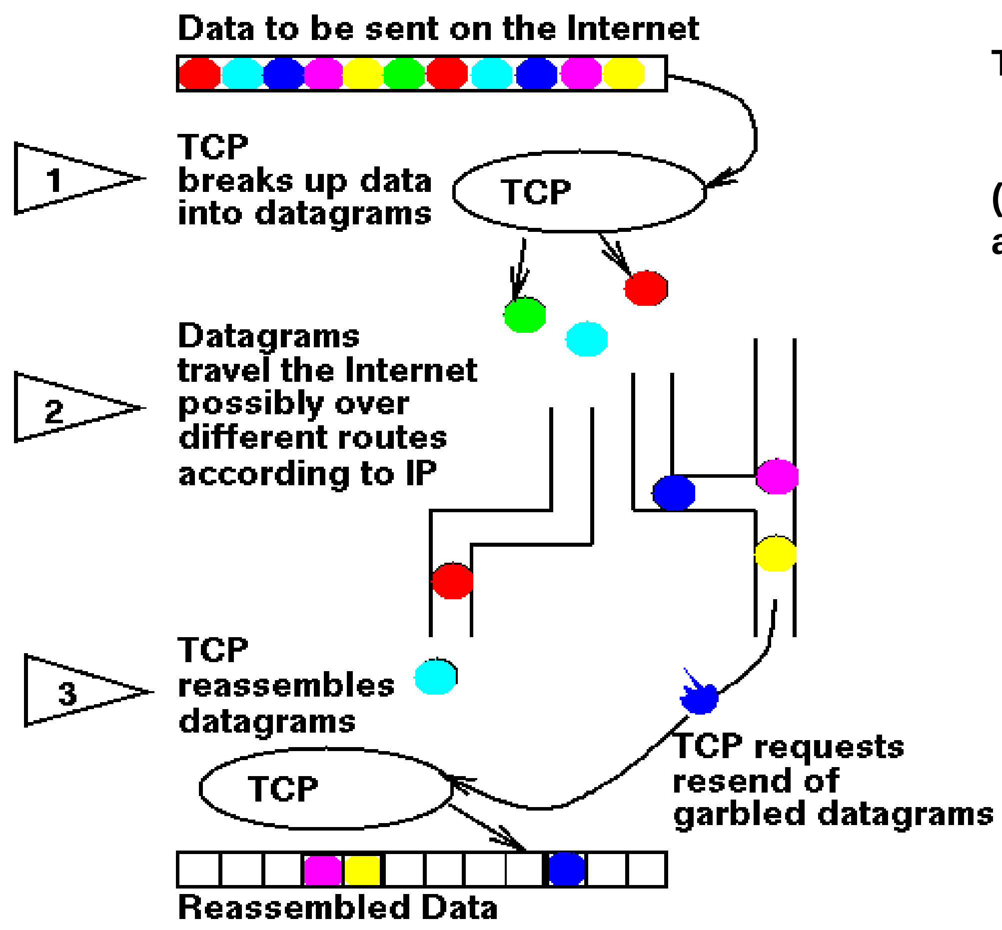
- Transport packet from sending to receiving hosts
- Network layer protocols in *every* host, router

Three important functions:

- ***path determination:*** route taken by packets from source to dest. *Routing algorithms*
- ***switching:*** move packets from router's input to appropriate router output
- ***call setup:*** some network architectures require router call setup along path before data flows



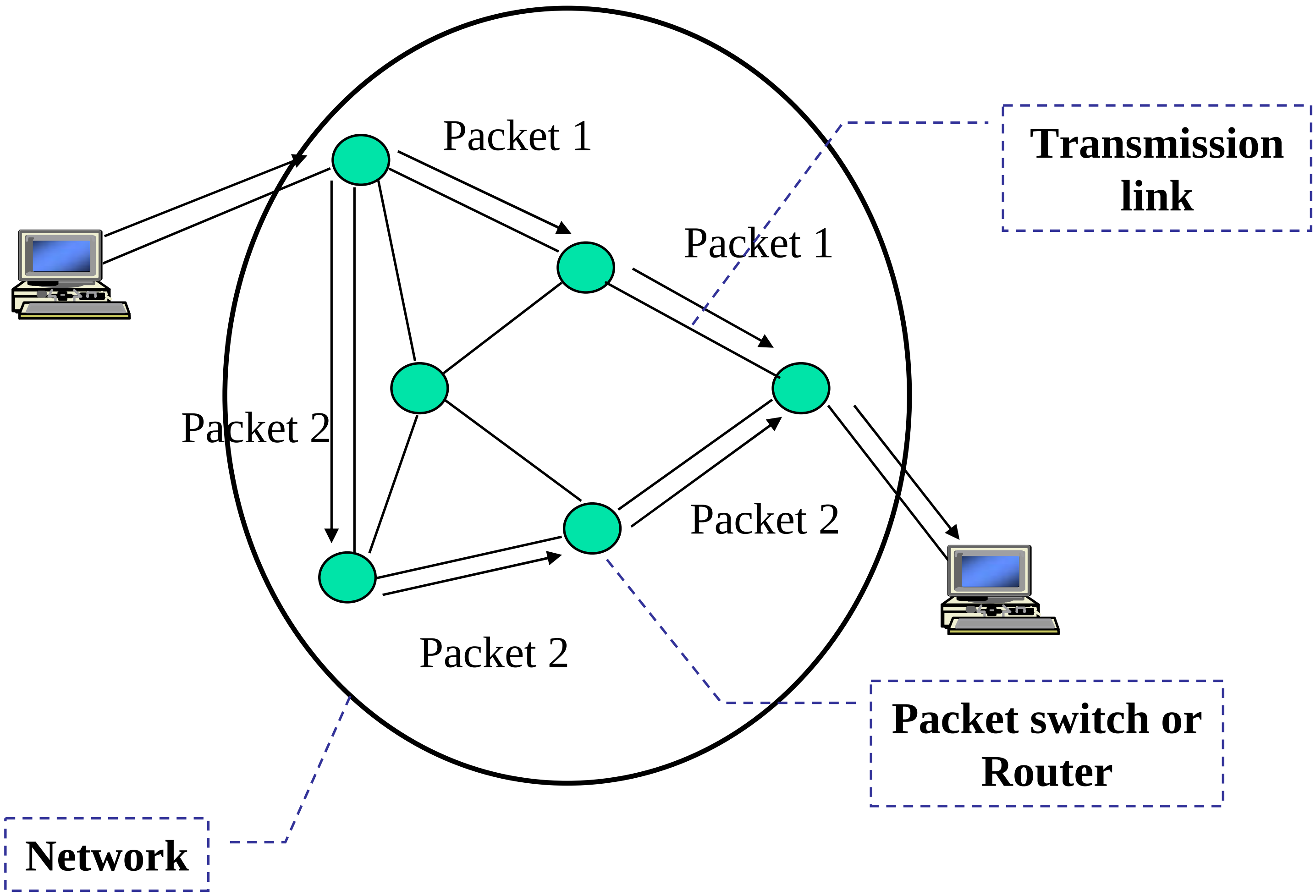
# IP Packet Forwarding



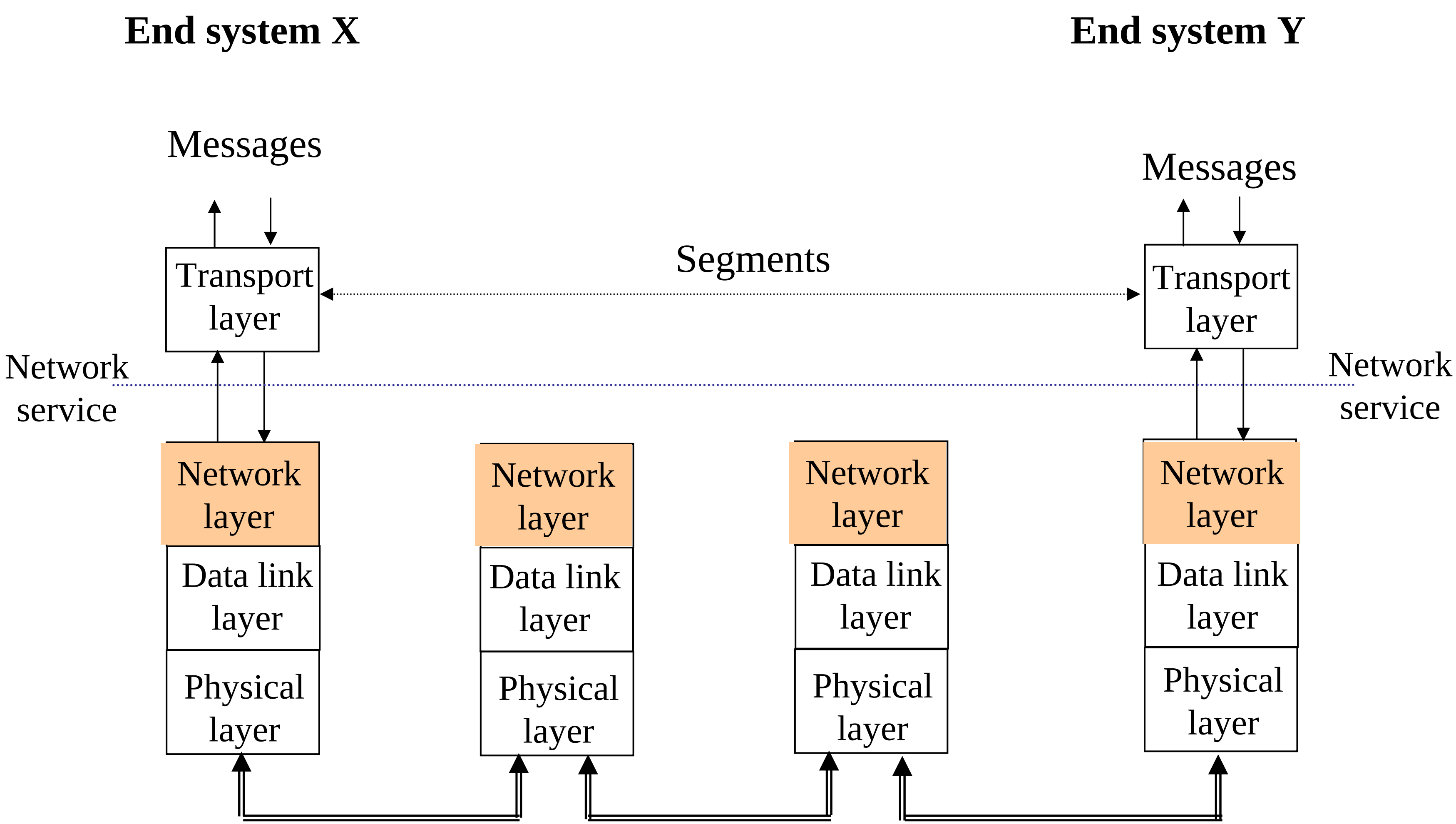

TCP = TRANSMISSION
CONTROL
PROTOCOL
(Breaks messages into packets and reassembles them)

IP = INTERNET
PROTOCOL
(Moves packets around the Internet)

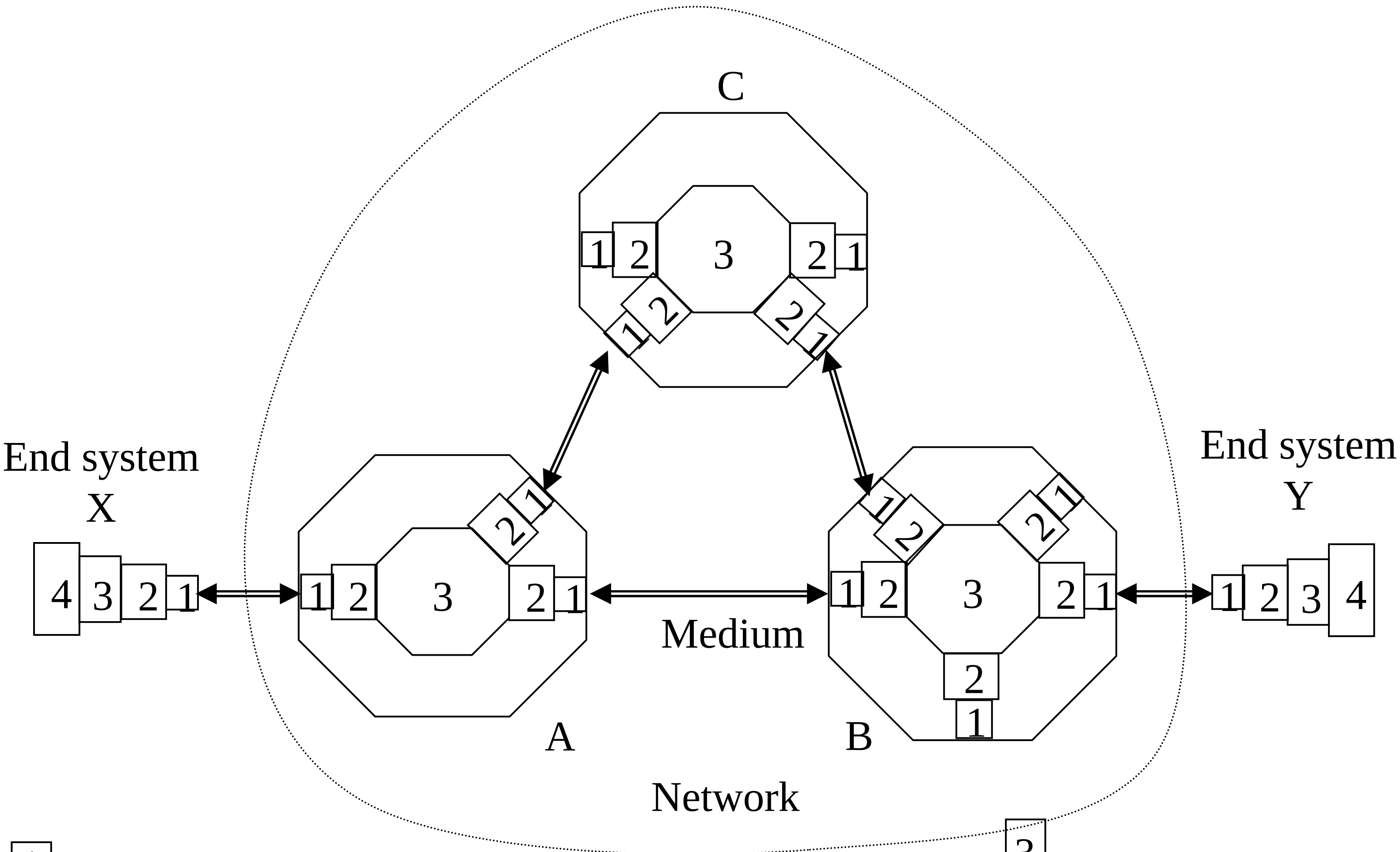
# Connectionless Packet Forwarding



# The Network Layer



# The Network Layer Operation




1 Physical layer entity

2 Data link layer entity

3 Network layer entity

3 Network layer entity

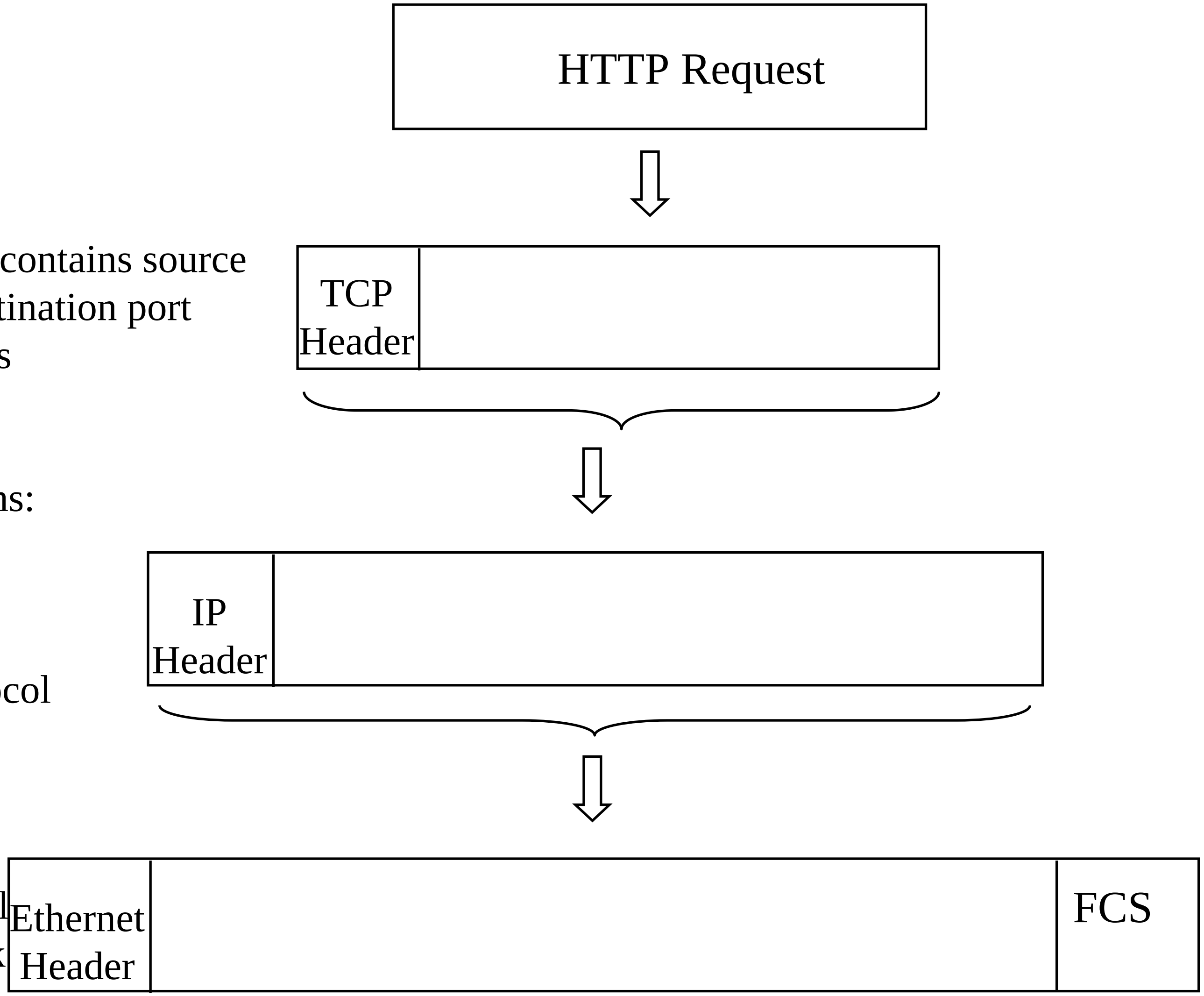
4 Transport layer entity

# PDU Operation

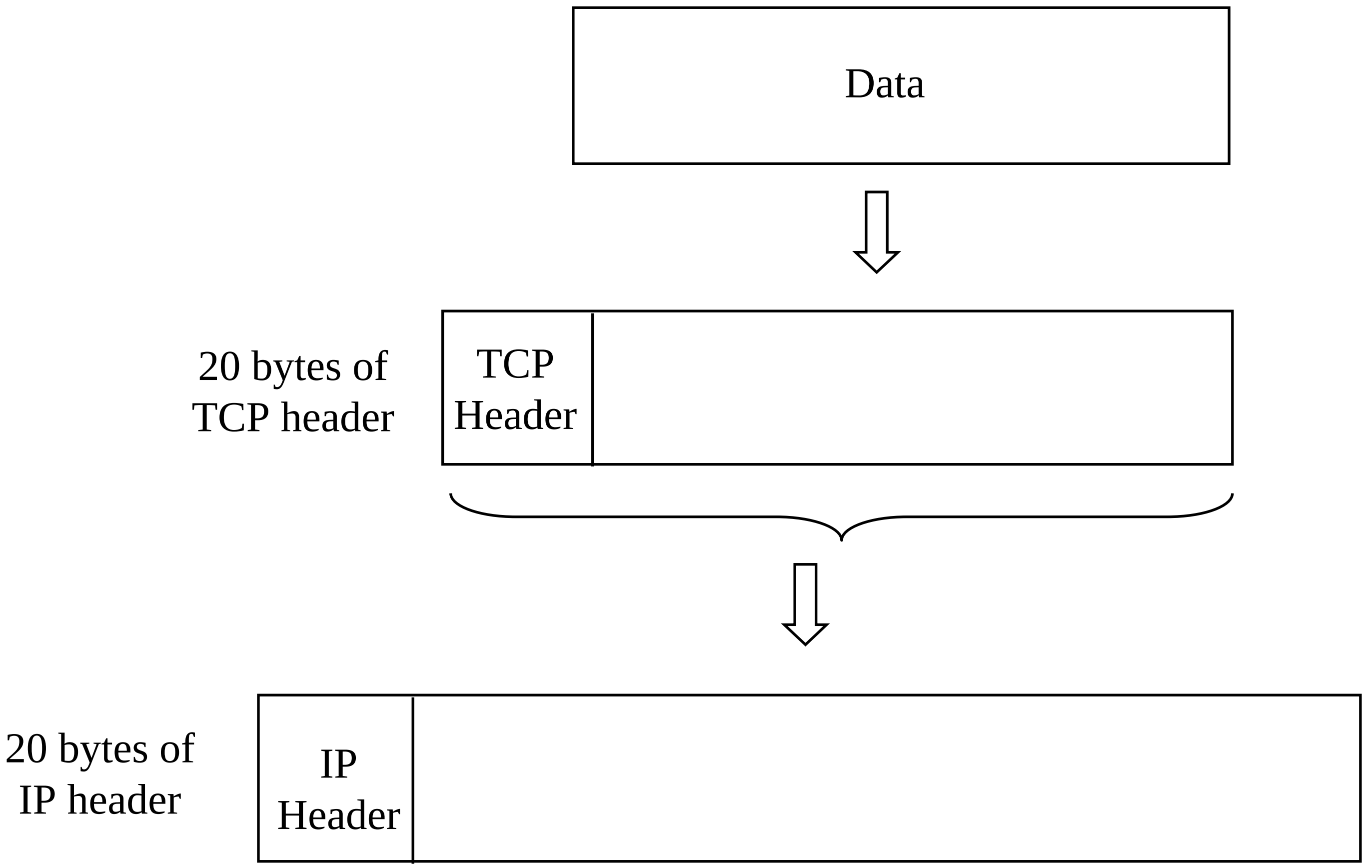
Header contains source and destination port numbers

Header contains:
source and
destination IP
addresses;
transport protocol
type

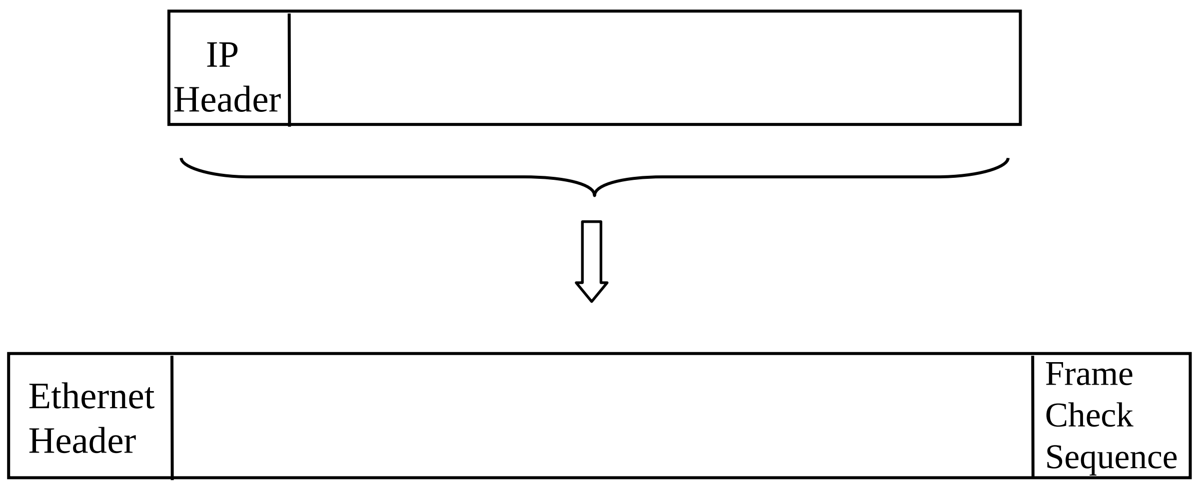
Header contains:
source and
destination physical
addresses;  network
protocol type



# PDU Operation

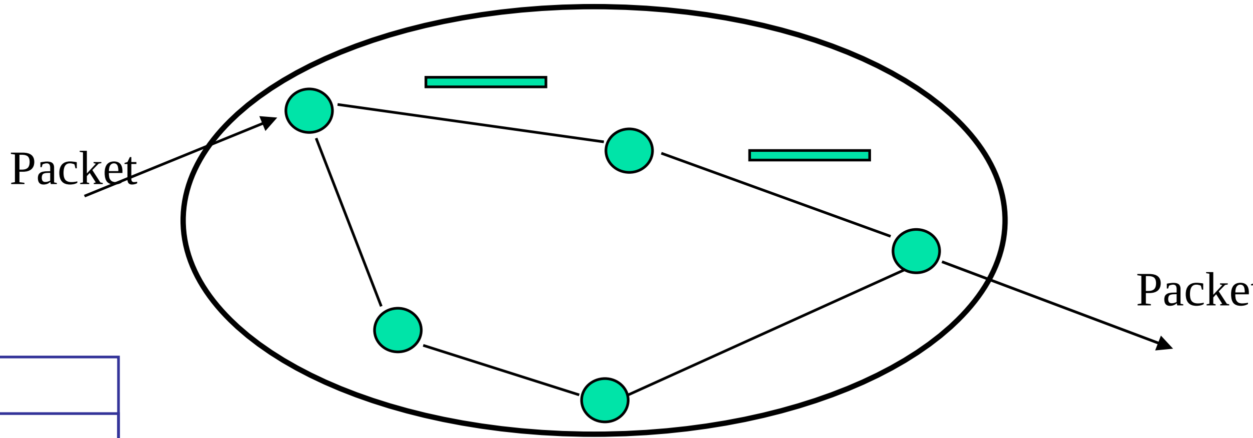


# PDU Operation



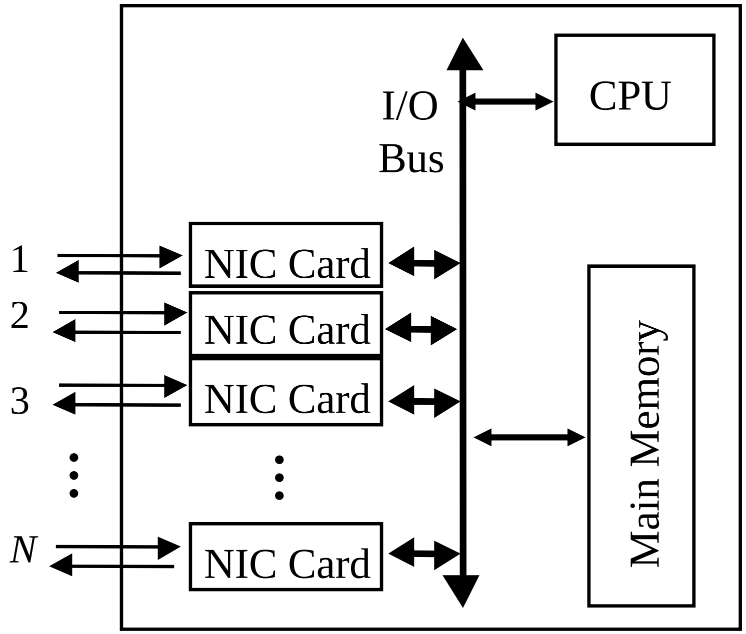

Header contains
source and destination
physical addresses;
network protocol type

# How Packets Are Routed




| Destination address | Output port |
|---|---|
| | |
| 0785 | 7 |
| | |
| 1345 | 12 |
| | |
| 1566 | 6 |
| | |
| 2458 | 12 |
| | |

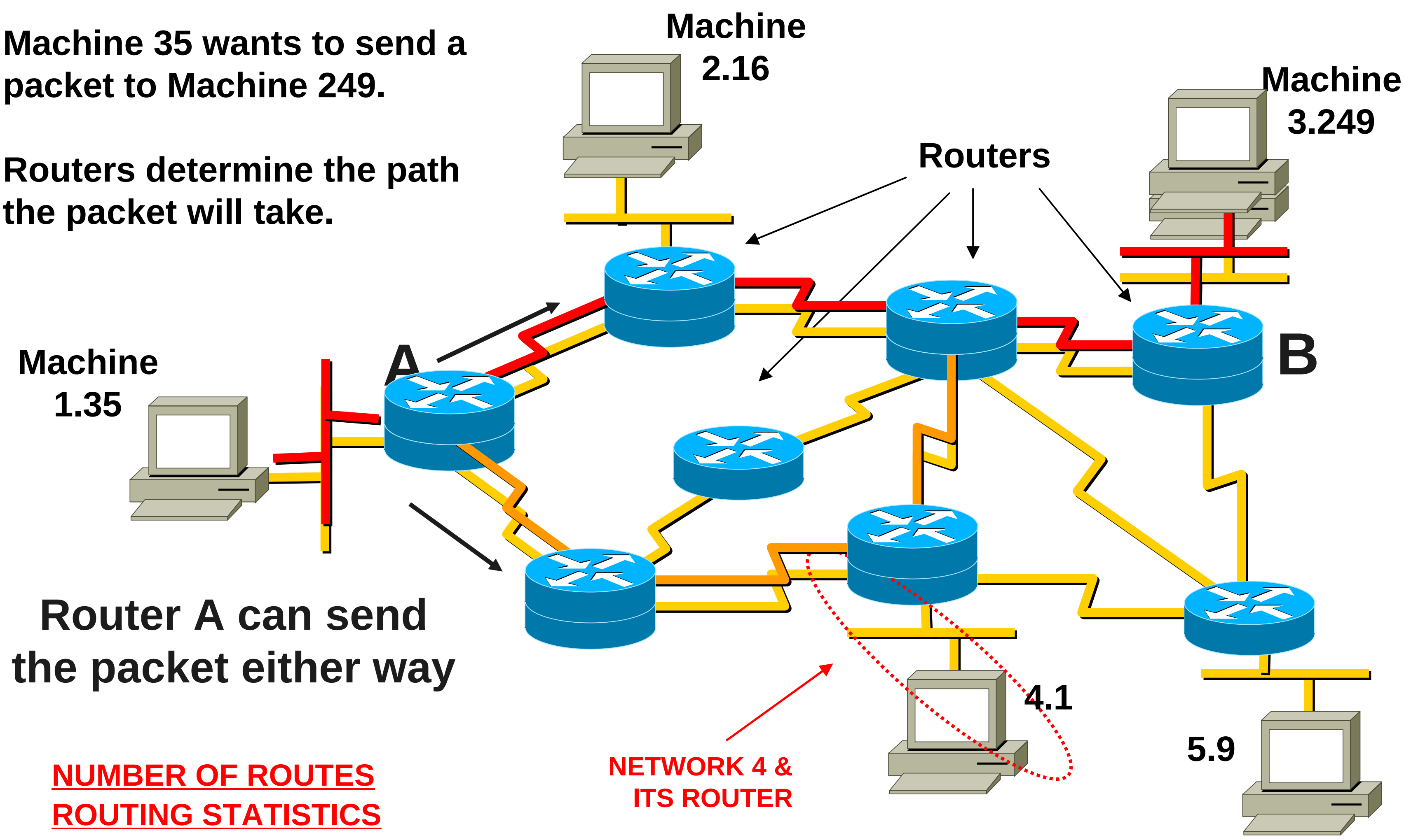
# Ports or Network Interface Cards



# Routing

Machine 35 wants to send a packet to Machine 249.

Routers determine the path the packet will take.



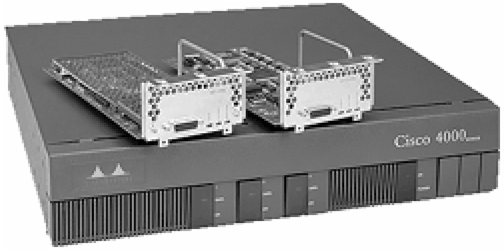

Router A can send the packet either way

NUMBER OF ROUTES

ROUTING STATISTICS

# Routers

CISCO



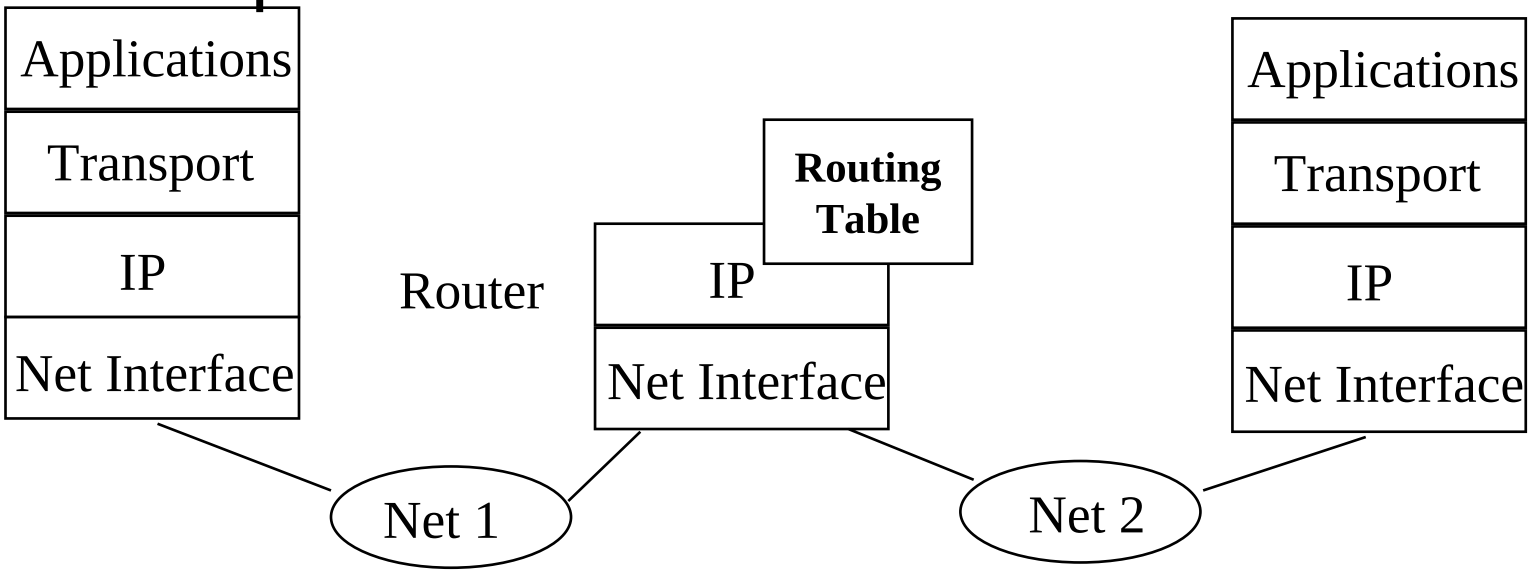
# Routing in the Internet

- The Global Internet consists of Autonomous Systems (AS) interconnected with each other:
  - **Stub AS**: small corporation
  - **Multihomed AS**: large corporation (no transit)
  - **Transit AS**: provider

- Two-level routing:
  - **Intra-AS:** administrator is responsible for choice
  - **Inter-AS:** unique standard

# Routing & Forwarding

- Routing: decision that determines the path
  - next hop, source routing, VC setup
- Forwarding: transfer of packet from input to output



# Creating the Routing Tables

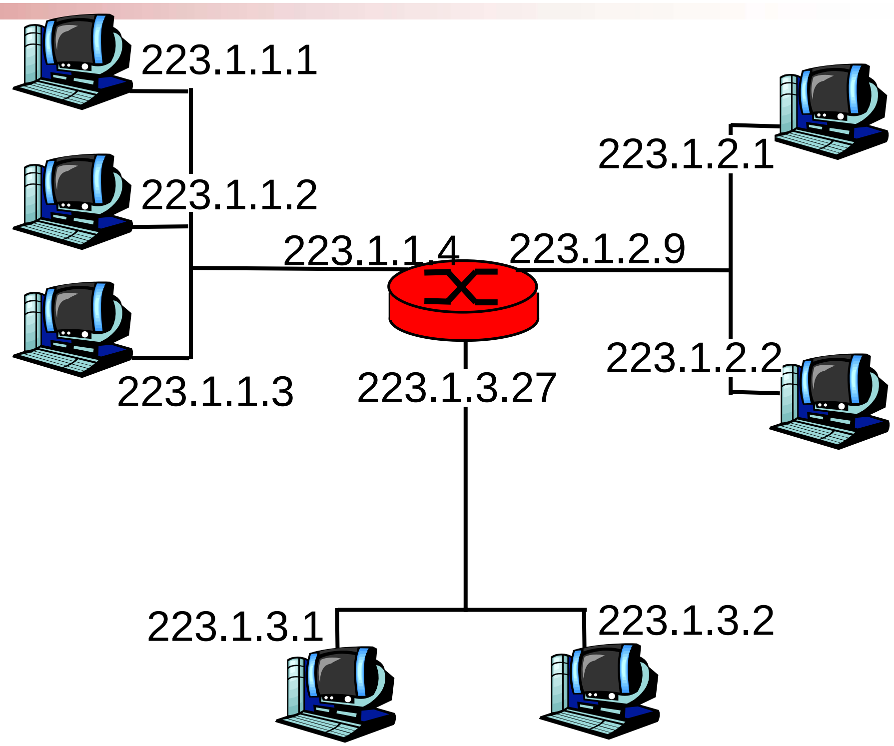
- Need information on state of links
  - link up/down; congested; delay or other metrics
- Need to distribute link state information using a routing protocol
  - what information is exchanged? how often?
  - exchange with neighbors; broadcast or flood
- Need to compute routes based on information
  - single metric;  multiple metric
  - single route; alternate routes

# Design Requirements

- Responsiveness to changes
  - topology or bandwidth changes, congestion
  - rapid convergence of routers to consistent set of routes
  - freedom from persistent loops
- Optimality
  - resource utilization, path length
- Robustness
  - continues working under high load, congestion, faults, equipment failures, incorrect implementations
- Simplicity
  - Efficient software implementation, reasonable processing load

# IP Addressing

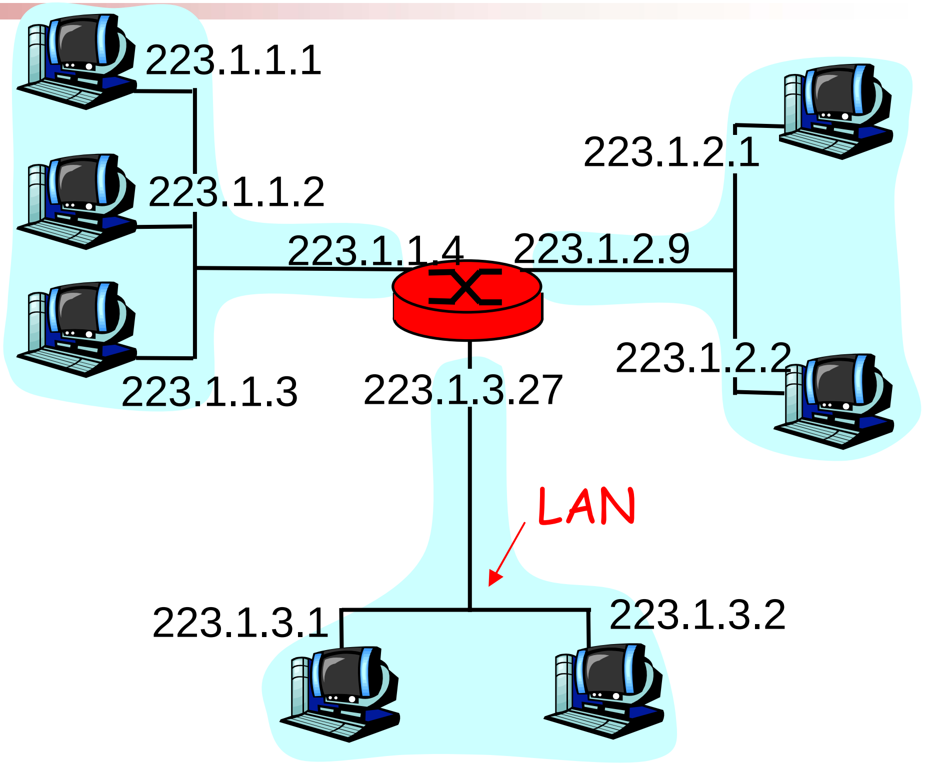
- IP address: 32-bit identifier for host, router *interface*
- *interface:* connection between host, router and physical link
  - router's typically have multiple interfaces
  - host may have multiple interfaces
  - IP addresses associated with interface, not host, router




$$223.1.1.1 = \underbrace{11011111}_{223}\ \underbrace{00000001}_{1}\ \underbrace{00000001}_{1}\ \underbrace{00000001}_{1}$$

# IP Addressing

- IP address:
  - network part (high order bits)
  - host part (low order bits)
- *What's a network ?* (from IP address perspective)
  - device interfaces with same network part of IP address
  - can physically reach each other without intervening router

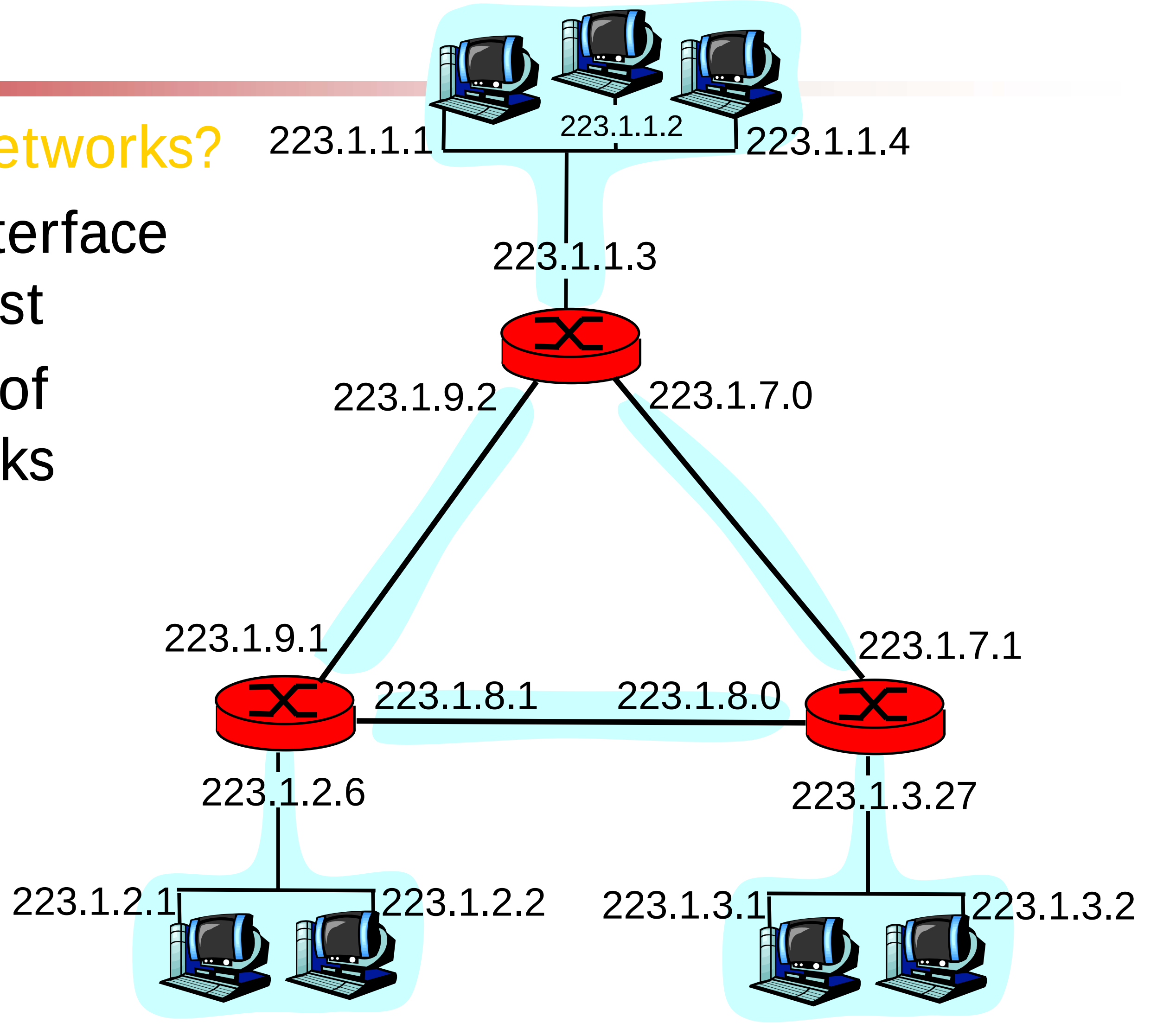



network consisting of 3 IP networks (for IP addresses starting with 223, first 24 bits are network address)

# IP Addressing

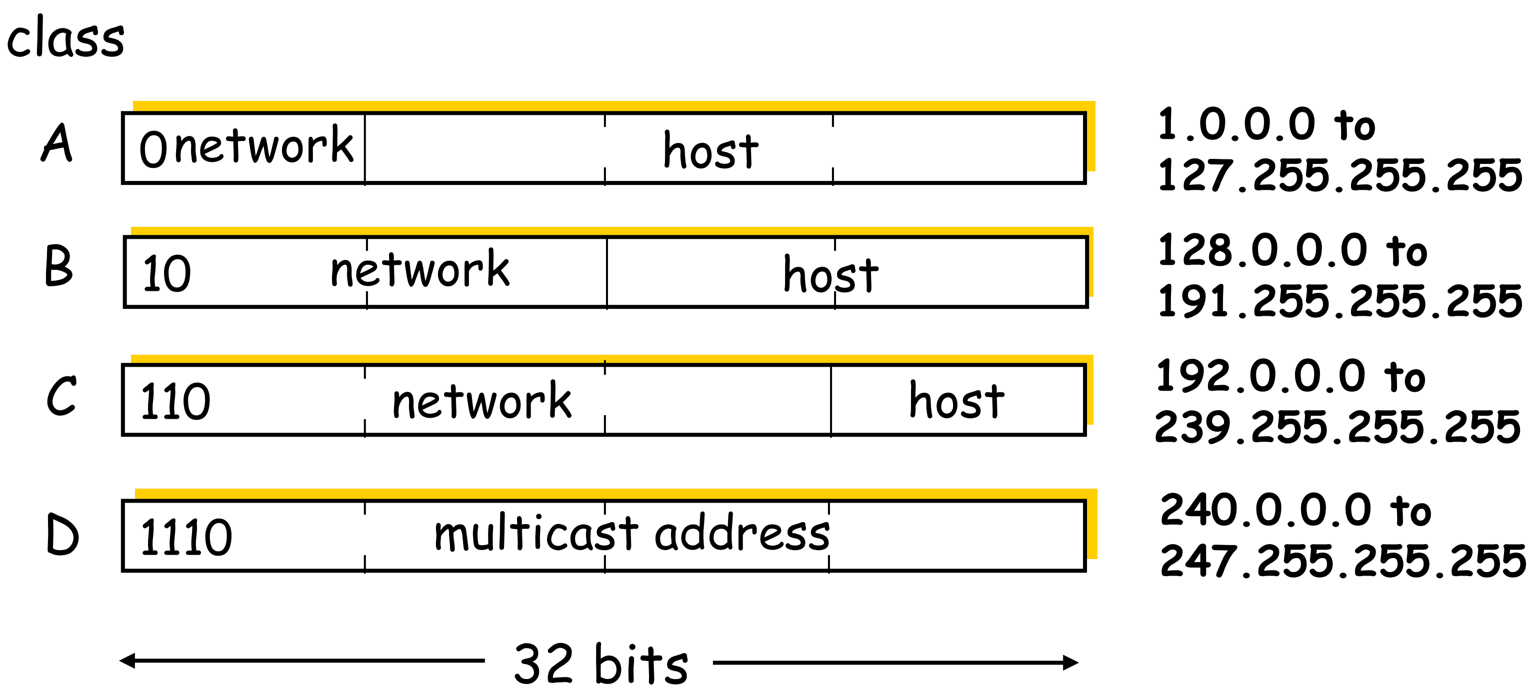
## How to find the networks?

- Detach each interface from router, host
- create “islands of isolated networks




Interconnected system consisting of six networks

# IP Addresses




- There is also Class E with prefix of 1111, reserved for experimentation

# IP Addresses- Detailed

| Bit position: | 0 | 1 | 2 | 3 | 8 | 16 | 31 |
|---|---|---|---|---|---|---|---|
| Class A | 0 | Net ID | | | Host ID | | |
| Class B | 1 | 0 | Net ID | | | Host ID | |
| Class C | 1 | 1 | 0 | Net ID | | | Host ID |
| Class D | 1 | 1 | 1 | 0 | Multicast address | | |
| Class E | 1 | 1 | 1 | 1 | Reserved for experiments | | |

<table>
<tr><th>0</th><th>4</th><th>8</th><th>16</th><th>19</th><th>24</th><th>31</th></tr>
<tr><td>Version</td><td>IHL</td><td>Type of Service</td><td colspan="4">Total Length</td></tr>
<tr><td colspan="3">Identification</td><td>Flags</td><td colspan="3">Fragment Offset</td></tr>
<tr><td colspan="2">Time to Live</td><td>Protocol</td><td colspan="4">Header Checksum</td></tr>
<tr><td colspan="7">Source IP Address</td></tr>
<tr><td colspan="7">Destination IP Address</td></tr>
<tr><td colspan="5">Options</td><td colspan="2">Padding</td></tr>
</table>

Figure 8.4

# IP Header Format

- Version (4 bits)
- Internet header length (4 bits): in 32-bit words
  - Min header is 5 words or 20 bytes
- Type of service (8 bits): Reliability, precedence, delay, and throughput
- Total length (16 bits): header + data in bytes
  - Total must be less than 64 kB
- Identifier (16 bits): Helps uniquely identify the datagram during its life for a given source, destination address

# IP Header Format (Cont'd)

- Flags (3 bits): More flag - used for
  - Fragmentation
  - No-fragmentation
  - Reserved
- Fragment offset (13 bits): In units of 8 bytes
- Time to live (8 bits): Specified in router hops
- Protocol (8 bits): Next level protocol to receive the data
- Header checksum (16 bits): 1's complement sum of all 16-bit words in the header

# IP Header Format (Cont'd)

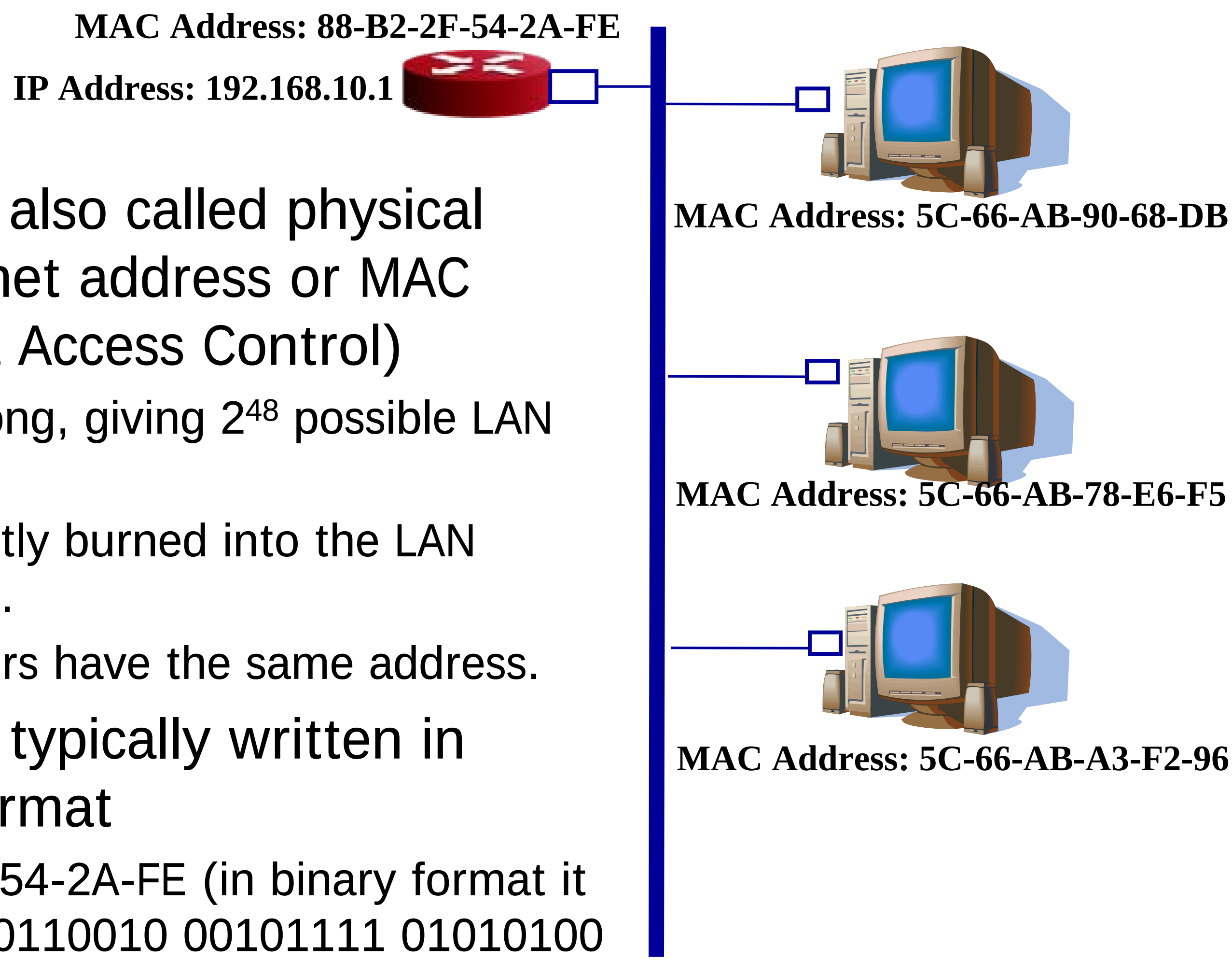
- Source Address (32 bits): Original source
  - Does not change along the path.
- Destination Address (32 bits): Final destination
  - Does not change along the path
- Options (variable): Security, source route, record route, stream id (used for voice) for reserved resources, timestamp recording
- Padding (variable): Makes header length a multiple of 4
- Data (variable): Data + header < 65,535 bytes

# IP Protocol Numbers

- 0 Reserved
- 1 ICMP (Internet Control Message Protocol)
- 2 IGMP (Internet Group Management Protocol)
- 4 ST (Stream Protocol)
- 5 TCP (Transmission Control Protocol)
- 8 EGP (Exterior Gateway Protocol)
- 9 IGP (Interior Gateway Protocol)
- 17 UDP (User Datagram Protocol)

# Putting them all together

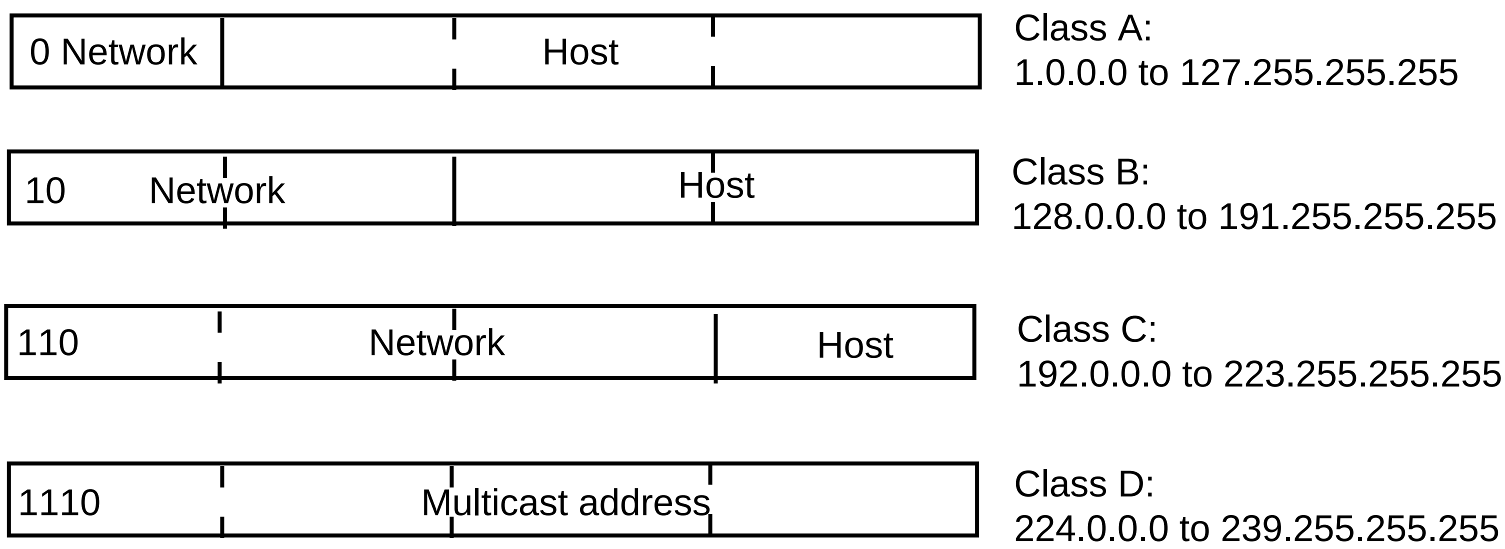
# LAN Addresses




- LAN Address is also called physical address, Ethernet address or MAC address (Media Access Control)
  - It is six-byte long, giving $2^{48}$ possible LAN addresses.
  - It is permanently burned into the LAN adapter's ROM.
  - No two adapters have the same address.
- LAN Address is typically written in hexadecimal format
  - E.g. 88-B2-2F-54-2A-FE (in binary format it is 10001000 10110010 00101111 01010100 00101010 11111110)

# IP Addresses

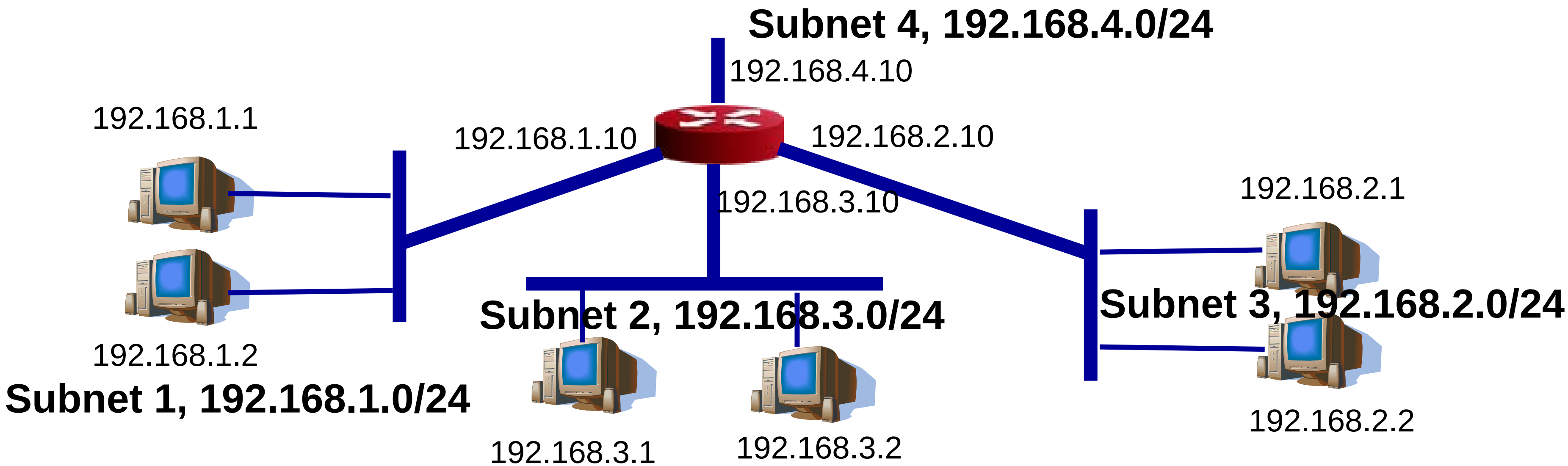
- Each IPv4 Address is 32 bits long, written in dotted decimal notation, e.g. 223.1.1.10
- Original IP Addresses architecture defined four classes of address.
  - **Class A, $2^7$ networks and $2^{24}$ interfaces**
  - **Class B, $2^{14}$ networks and $2^{16}$ interfaces**
  - **Class C, $2^{21}$ networks and $2^8$ interfaces**
  - **Class D, multicast addresses**



# Classless Interdomain Routing (CIDR) Addresses

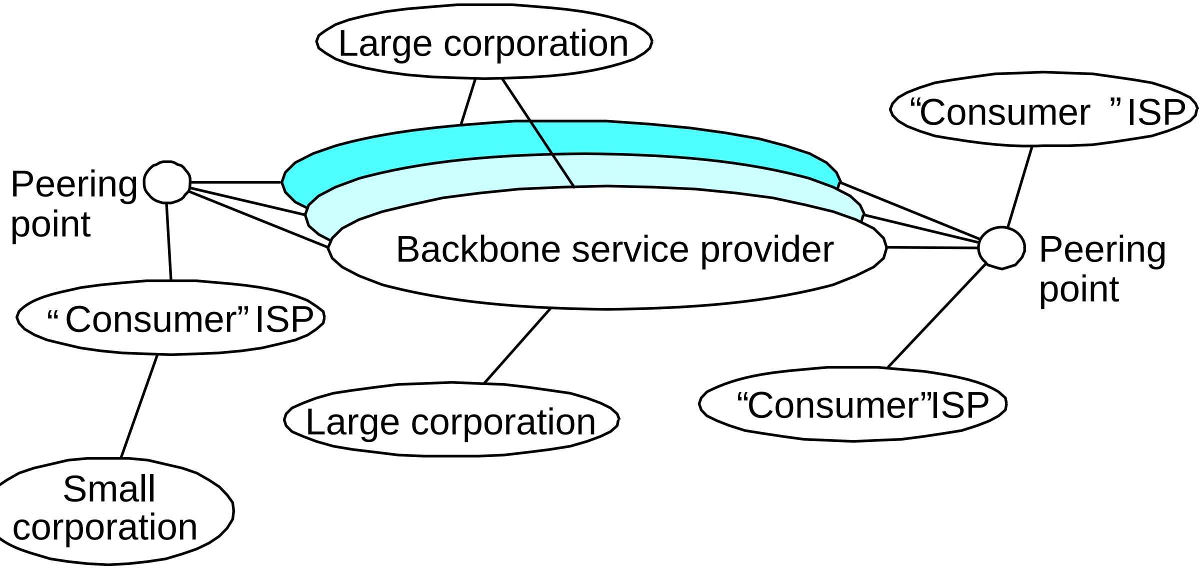
- CIDR network addresses release the constraint that the network part of the address has to be 8, 16 or 24 bits. It has dotted-decimal form a.b.c.d/x, where x indicates the number of the leading bits that constitutes the network part of the address
  - **e.g. 192.168.240.10/20 means the first 20 bits are network address and the rest 12 bits are interface addresses.**
- In practice, an organization can further divide the interface addresses to create its own internal network. This procedure is known as subnetting

# Classless Interdomain Routing (CIDR) Addresses



# Internet Structure

Today



# Subnetting

- Add another level to address/routing hierarchy: *subnet*
- *Subnet masks* define variable partition of host part
- Subnets visible only within site

| Network number | Host number |
|---|---|

Class B address

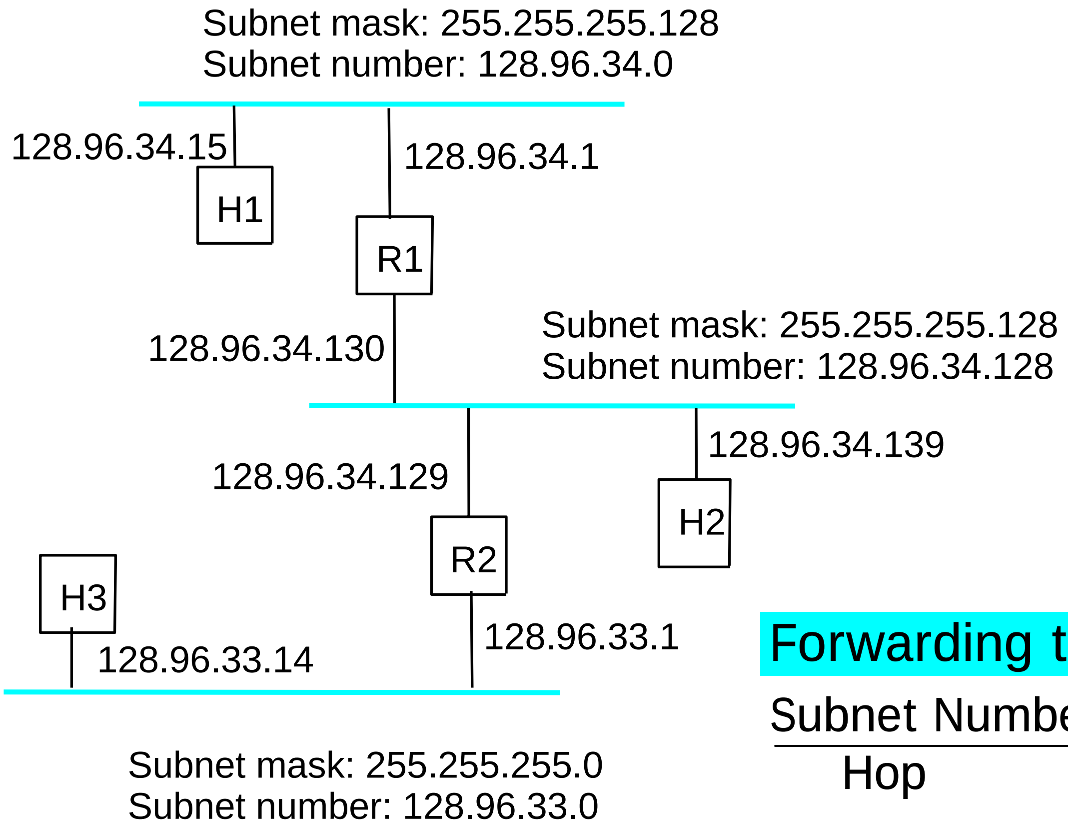
| 111111111111111111111111 | 00000000 |
|---|---|

Subnet mask (255.255.255.0)

| Network number | Subnet ID | Host ID |
|---|---|---|

Subnetted address

# Subnet Example




Forwarding table at router R1

| Subnet Number | Subnet Mask | Next Hop |
|---|---|---|
| 128.96.34.0 | 255.255.255.128 | interface 0 |
| 128.96.34.128 | 255.255.255.128 | interface 1 |
| 128.96.33.0 | 255.255.255.0 | R2 |

# Forwarding Algorithm

```
D = destination IP address
for each entry (SubnetNum, SubnetMask, NextHop)
   D1 = SubnetMask & D
   if D1 = SubnetNum
      if NextHop is an interface
         deliver datagram directly to D
      else
         deliver datagram to NextHop
```

- Use a default router if nothing matches
- Not necessary for all 1s in subnet mask to be contiguous
- Can put multiple subnets on one physical network
- Subnets not visible from the rest of the Internet

# Supernetting

- Assign block of contiguous network numbers to nearby networks
- Called CIDR: Classless Inter-Domain Routing
- Represent blocks with a single pair

  **`(first_network_address, count)`**

- Restrict block sizes to powers of 2
- Use a bit mask (CIDR mask) to identify block size
- All routers must understand CIDR addressing

# Route Propagation

- Know a smarter router
  - hosts know local router
  - local routers know site routers
  - site routers know core router
  - core routers know everything
- Autonomous System (AS)
  - corresponds to an administrative domain
  - examples: University, company, backbone network
  - assign each AS a 16-bit number
- Two-level route propagation hierarchy
  - interior gateway protocol (each AS selects its own)
  - exterior gateway protocol (Internet-wide standard)

# Routing

- Routing Basics
- Distance Vector Routing
- Link State Routing
- Internet Routing Protocols

# Hierarchical Routing

Our routing study thus far - idealization

- all routers identical
- network "flat" ... *not* true in practice

scale: with 50 million destinations:

- can't store all dest's in routing tables!
- routing table exchange would swamp links!

administrative autonomy

- internet = network of networks
- each network admin may want to control routing in its own network

# Hierarchical Routing

- aggregate routers into regions, "autonomous systems" (AS)
- routers in same AS run same routing protocol
  - "inter-AS" routing protocol
  - routers in different AS can run different inter-AS routing protocol

gateway routers

- special routers in AS
- run inter-AS routing protocol with all other routers in AS
- *also* responsible for routing to destinations outside AS
  - run *intra-AS routing* protocol with other gateway routers

# Popular Interior Gateway Protocols

- RIP: Route Information Protocol
  - developed for XNS
  - distributed with Unix
  - distance-vector algorithm
  - based on hop-count
- OSPF: Open Shortest Path First
  - recent Internet standard
  - uses link-state algorithm
  - supports load balancing
  - supports authentication

# EGP: Exterior Gateway Protocol

- Overview
  - designed for tree-structured Internet
  - concerned with  reachability, not optimal routes
- Protocol messages
  - neighbor acquisition: one router requests that another be its peer; peers exchange reachability information
  - neighbor reachability: one router periodically tests if the another is still reachable; exchange HELLO/ACK messages; uses a k-out-of-n rule
  - routing updates: peers periodically exchange their routing tables (distance-vector)

# BGP-4: Border Gateway Protocol

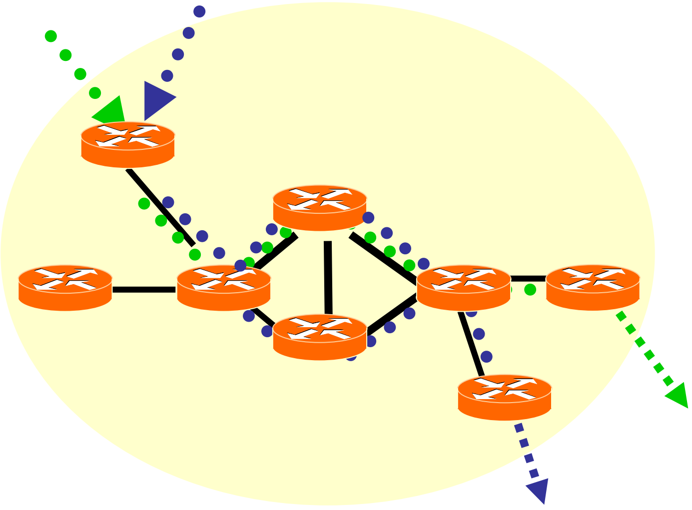
- AS Types
  - stub AS: has a single connection to one other AS
    - carries local traffic only
  - multihomed AS: has connections to more than one AS
    - refuses to carry transit traffic
  - transit AS: has connections to more than one AS
    - carries both transit and local traffic
- Each AS has:
  - one or more border routers
  - one BGP speaker that advertises:
    - local networks
    - other reachable networks (transit AS only)
    - gives path information

# IP Version 6

- Features
  - 128-bit addresses (classless)
  - multicast
  - real-time service
  - authentication and security
  - autoconfiguration
  - end-to-end fragmentation
  - protocol extensions
- Header
  - 40-byte “base” header
  - extension headers (fixed order, mostly fixed length)
    - fragmentation
    - source routing
    - authentication and security
    - other options

# MPLS: A basis for the Next Generation Internet

- MPLS: Multi Protocol Label Switching



# Summary

- IPv4 uses 32-bit addresses organized as network
- prefix and host suffix.
- Four classes of networks: A, B, C, D
- Routers determine next hop using routing tables
- IP provides connectionless unreliable service

# Measurements for Traffic delays across Networks - PING

- **Ping to GMU from the desktop**

```
C:\>ping osf1.gmu.edu

Pinging osf1.gmu.edu [129.174.1.13] with 32 bytes of data:

Reply from 129.174.1.13: bytes=32 time<10ms TTL=62

Reply from 129.174.1.13: bytes=32 time<10ms TTL=62

Reply from 129.174.1.13: bytes=32 time<10ms TTL=62
```

- **Ping to a Network Address from a Router**

```
Router@ail#ping 10.1.7.2

Sending 5, 100-byte ICMP Echos to 10.1.7.2, timeout is 2 seconds:

!!!!!

Success rate is 100 percent (5/5), round-trip min/avg/max = 1/1/4 ms
```