Routing & Forwarding:
Logical View of a Router

Control Plane (Routing Processor)

routing information

routing agent (daemon)

routing table

update

lookup

forwarding table

update

switching fabric

input links

Data Plane (Forwarding Engine)

input interfaces (ports)

output interfaces (port)
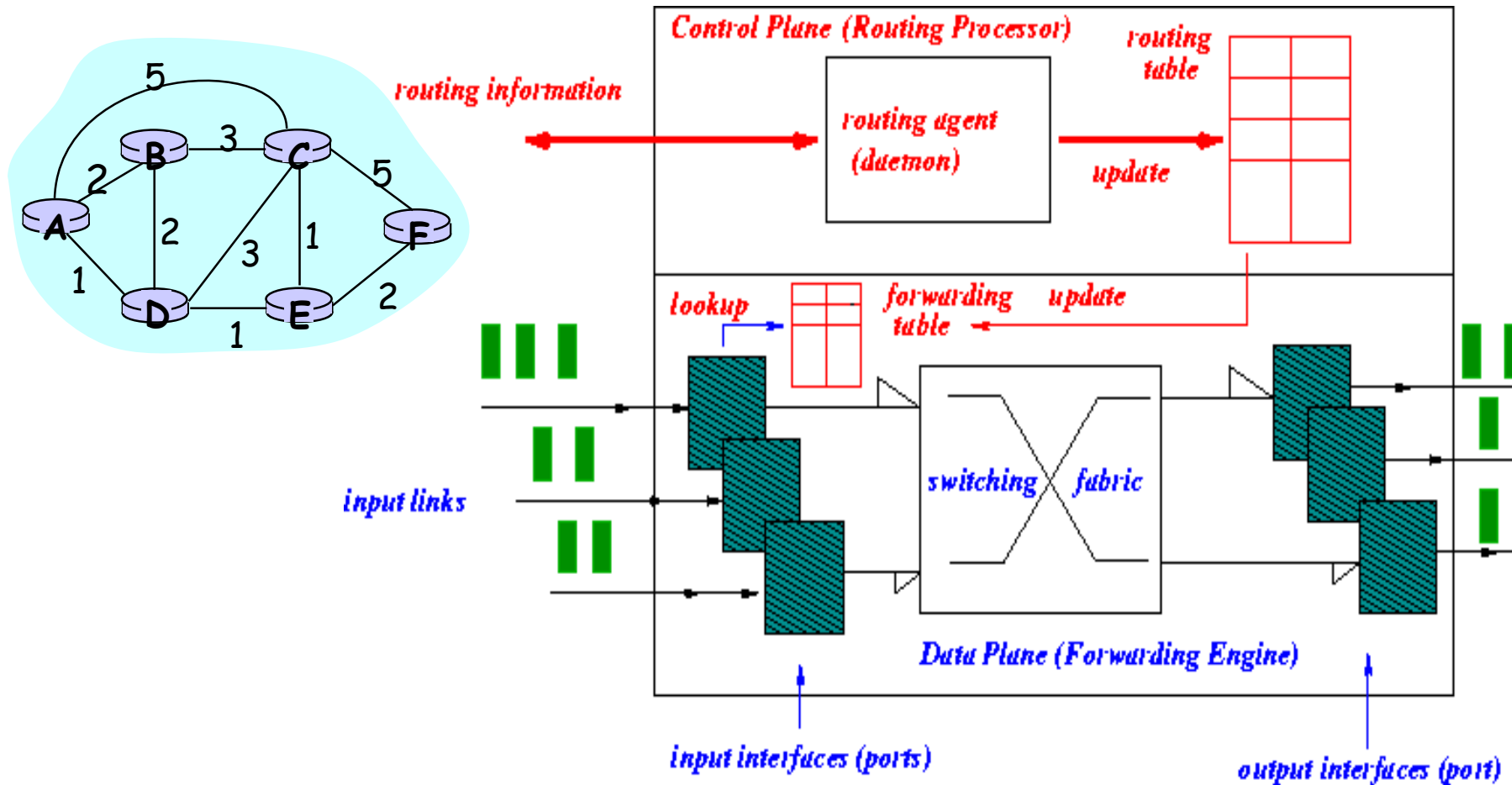
IP Forwarding & IP/ICMP Protocol

Transport layer: TCP, UDP

Network layer

Routing protocols
- path selection
- RIP, OSPF, BGP

routing table

IP protocol
- addressing conventions
- packet handling conventions

ICMP protocol
- error reporting
- router "signaling"

Data Link layer (Ethernet, WiFi, PPP, …)

Physical Layer (SONET, …)
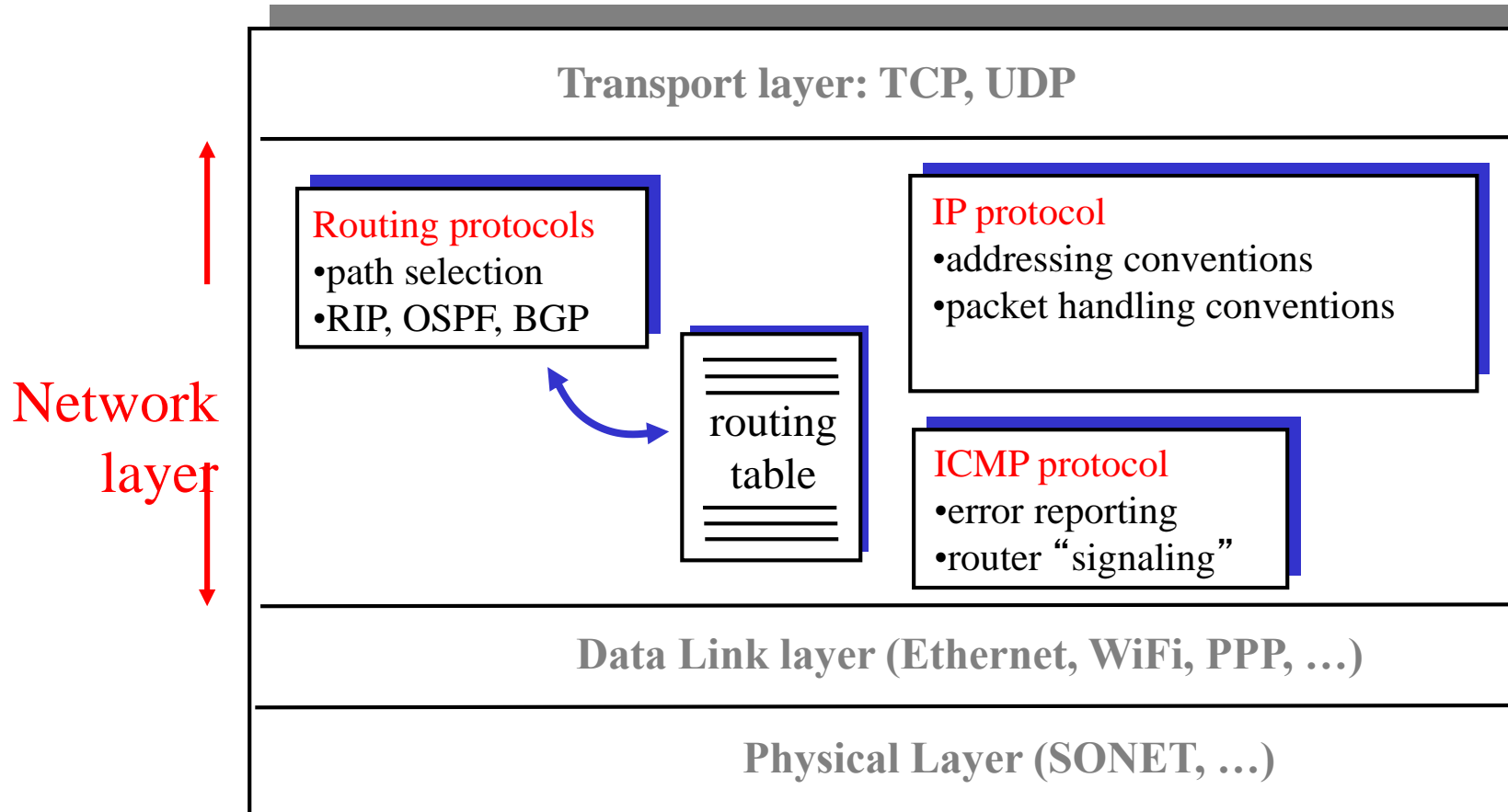
ICMP: Internet Control Message Protocol

- used by hosts & routers to communicate network-level information
  - error reporting: unreachable host, network, port, protocol
  - echo request/reply (used by ping)
- network-layer "above" IP:
  - ICMP msgs carried in IP datagrams
- ICMP message: type, code plus first 8 bytes of IP datagram causing error

| Type	Code	description
0	0	echo reply (ping)
3	0	dest. network unreachable
3	1	dest host unreachable
3	2	dest protocol unreachable
3	3	dest port unreachable
3	6	dest network unknown
3	7	dest host unknown
4	0	source quench (congestion control - not used)
8	0	echo request (ping)
9	0	route advertisement
10	0	router discovery
11	0	TTL expired
12	0	bad IP header

Traceroute and ICMP

- source sends series of UDP segments to destination
  - first set has TTL =1
  - second set has TTL=2, etc.
  - unlikely port number
- when datagram in *n*th set arrives to nth router:
  - router discards datagram and sends source ICMP message (type 11, code 0)
  - ICMP message include name of router & IP address

- when ICMP message arrives, source records RTTs

stopping criteria:
- UDP segment eventually arrives at destination host
- destination returns ICMP "port unreachable" message (type 3, code 3)
- source stops

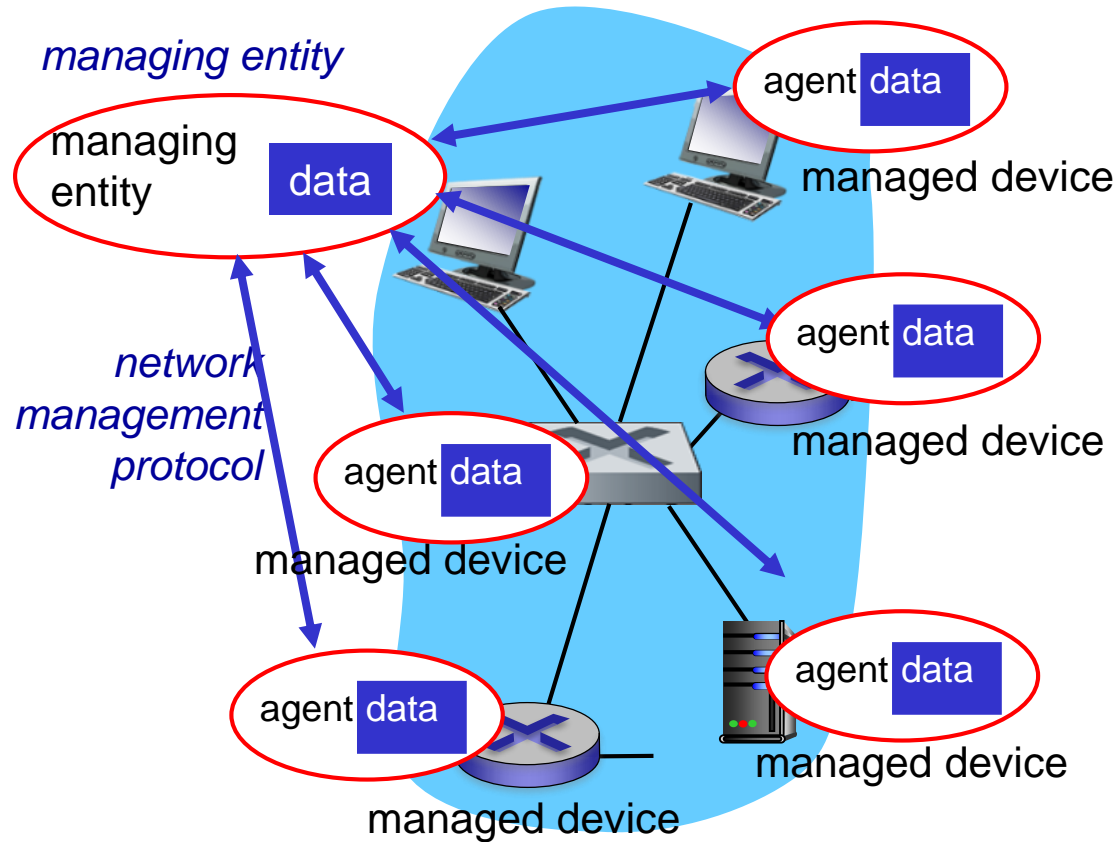3 probes   3 probes

3 probes
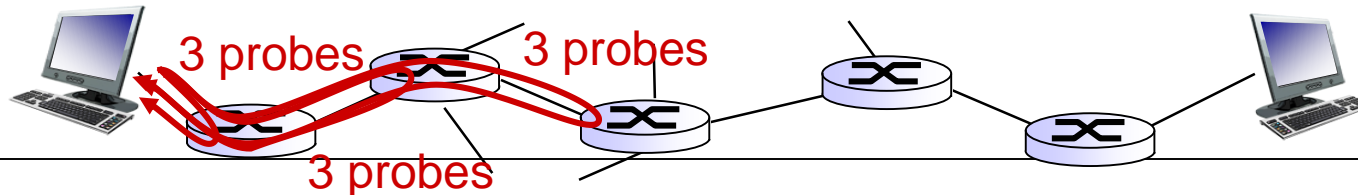
What is Network Management?

- autonomous systems (aka "network"): 1000s of interacting hardware/software components
- other complex systems requiring monitoring, control:
  - jet airplane
  - nuclear power plant
  - others?
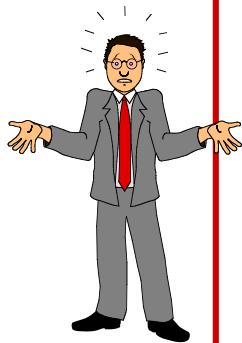
"Network management includes the deployment, integration and coordination of the hardware, software, and human elements to monitor, test, poll, configure, analyze, evaluate, and control the network and element resources to meet the real-time, operational performance, and Quality of Service requirements at a reasonable cost."

Infrastructure for Network Management

definitions:

managing entity

managing entity

data

network management protocol

agent data

managed device

agent data

managed device

agent data

managed device

agent data

managed device

agent data

managed device

managed devices contain *managed objects* whose data is gathered into a *Management Information Base (MIB)*

SNMP Protocol

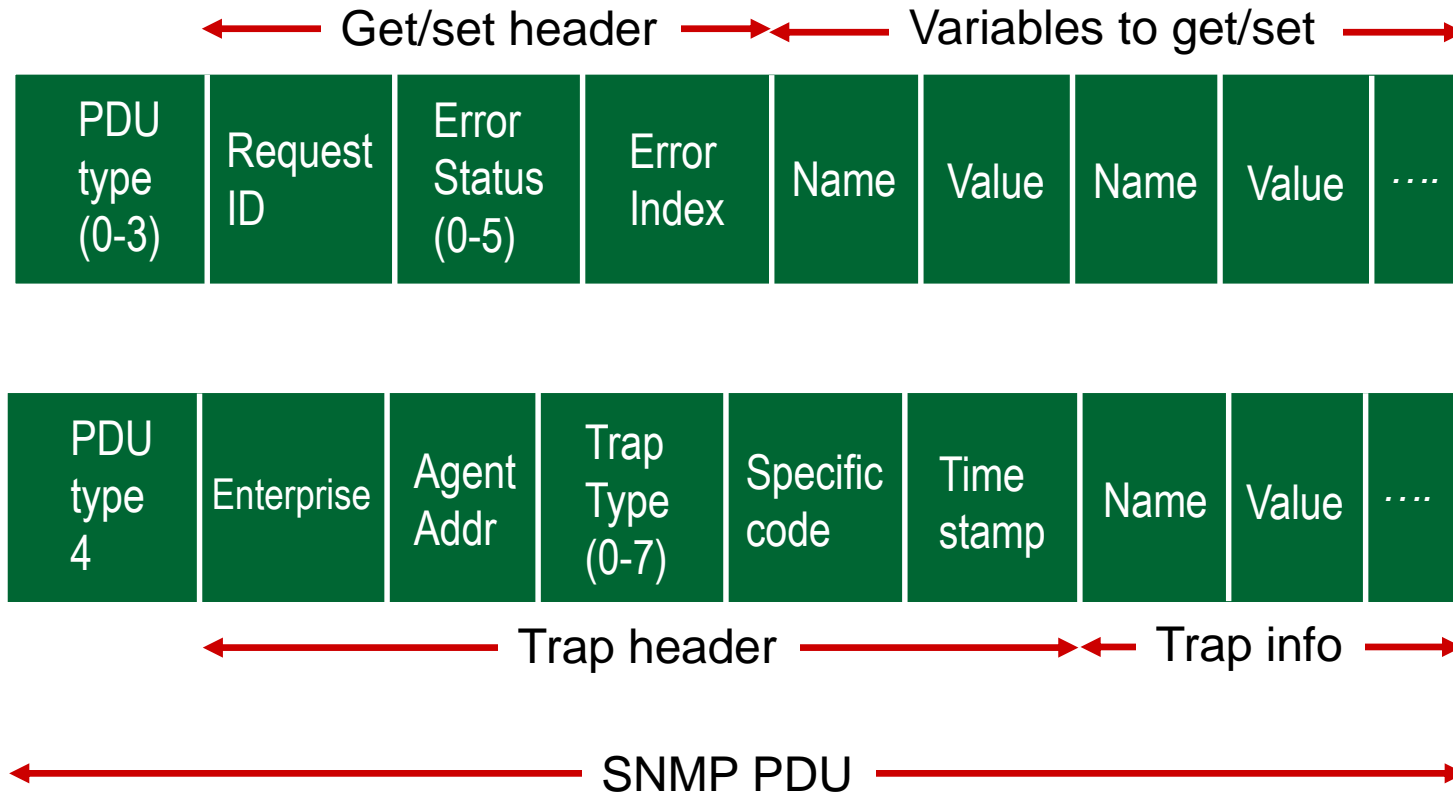Two ways to convey MIB info, commands:

request/response mode

trap mode
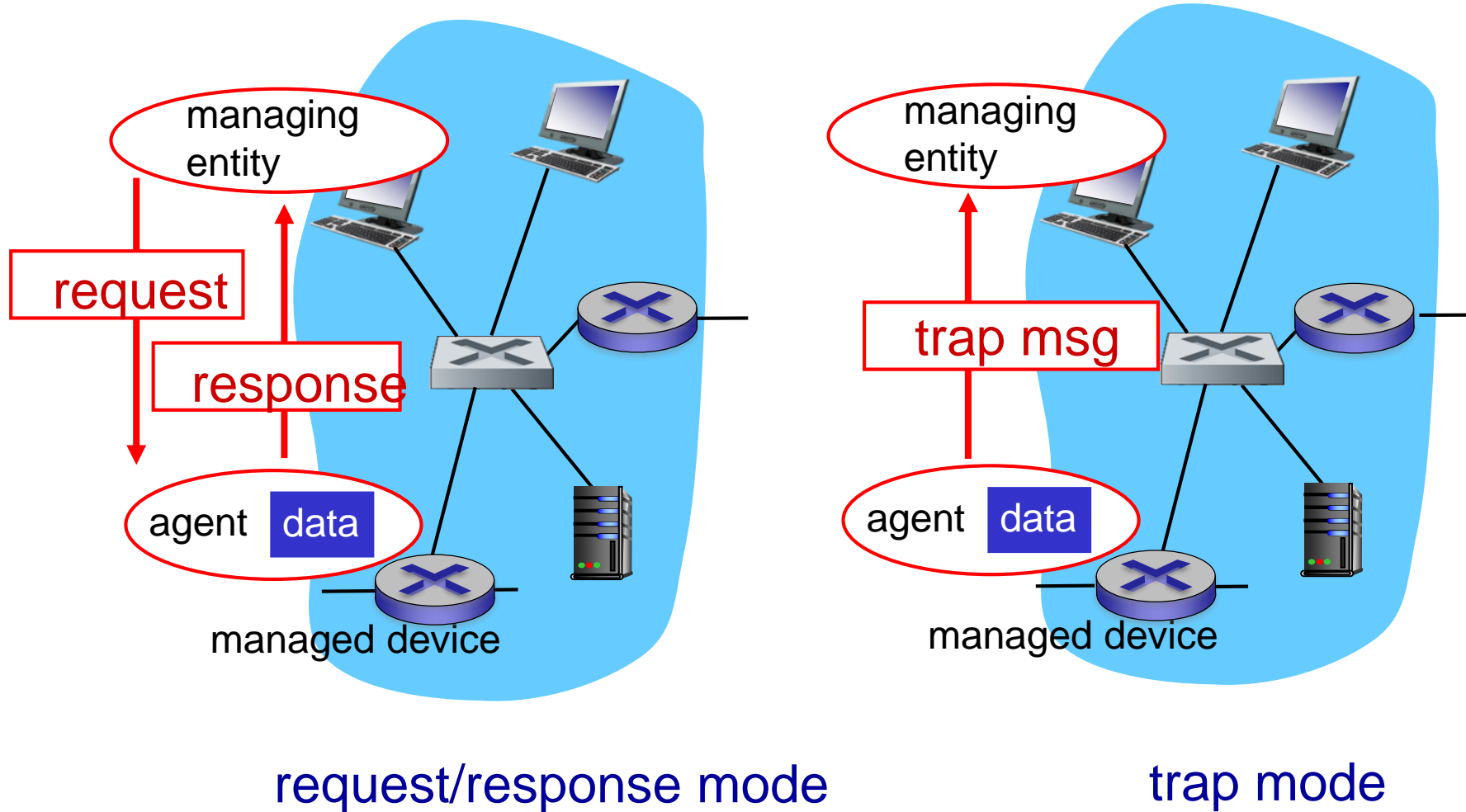
SNMP Protocol: Message Types

Message type	Function
GetRequest GetNextRequest GetBulkRequest	manager-to-agent: "get me data" (data instance, next data in list, block of data)
InformRequest	manager-to-manager: here's MIB value
SetRequest	manager-to-agent: set MIB value
Response	Agent-to-manager: value, response to Request
Trap	Agent-to-manager: inform manager of exceptional event

SNMP Protocol: Message Formats

← Get/set header → ← Variables to get/set →

PDU type (0-3)	Request ID	Error Status (0-5)	Error Index	Name	Value	Name	Value	....

PDU type 4	Enterprise	Agent Addr	Trap Type (0-7)	Specific code	Time stamp	Name	Value	....

← Trap header → ← Trap info →

← SNMP PDU →

More on network management: see earlier editions of textbook!

Network Layer Summary

- Network Layer Functions and Service Models
  - Addressing, Routing and Forwarding
  - Virtual Circuit vs. Datagram; *Programmable* Data Plane via SDN
  - *Distributed* vs. *Centralized* Control Plane
- IP Addressing Scheme: CIDR; DHCP
- IP Forwarding and IP Protocol
  - IP Datagram Forwarding Model: dest. in same net vs. diff. net
  - IPv4: Datagram Format, IP Fragmentation, …; IPv6
- Network Layer Routing
  - Fundamental Issues
  - Two Basic *Distributed* Algorithms: LS and DV
  - Routing in the Internet: Intra-AS vs. Inter-AS routing
    - Intra-AS: RIP and OSPF (*distributed* routing protocols)
    - Inter-AS: BGP and Policy Routing
- Openflow switches, SDN Controllers & Centralized Control Plane
- ICMP & SNMP