Internet Multicast Routing

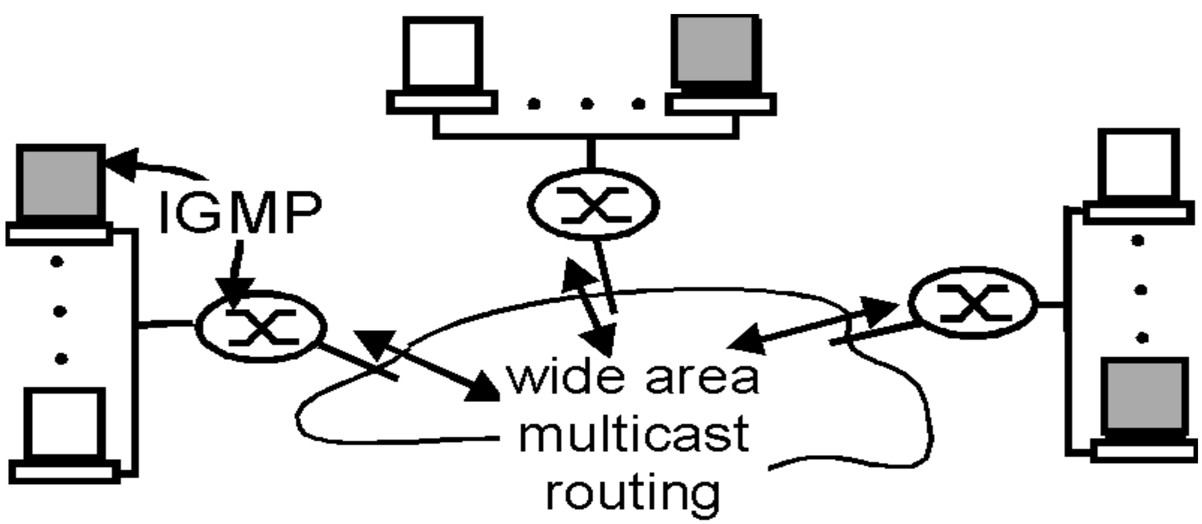
- group addressing
  - class D IP addresses

1110	Multicast Group ID
	⟵ 28 bits ⟶

- link layer multicast
- two protocol functions
  - group management
    - IGMP
  - route establishment
    - DVMRP, MOSPF, CBT, PIM

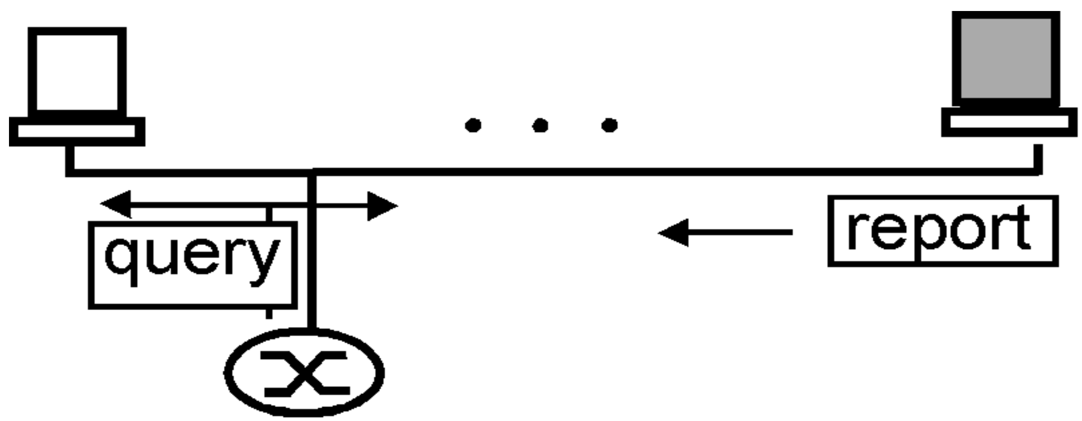
Joining a mcast group: two-step process

- ***local:*** host informs local mcast router of desire to join group: IGMP
- ***wide area:*** local router interacts with other routers to receive mcast packet flow
  - many protocols (e.g., DVMRP, MOSPF, PIM)



IGMP: Internet Group Management Protocol

- ***host:*** sends IGMP report when application joins mcast group
  - IP_ADD_MEMBERSHIP socket option
  - host need not explicitly “unjoin” group when leaving
- ***router:*** sends IGMP query at regular intervals
  - host belonging to a mcast group must reply to query



IGMPv1 and v2

IGMPv1

- joining host send IGMP report
- leaving host does nothing
- router periodically polls hosts on subnet using IGMP Query
- hosts respond to Query in a randomized fashion

IGMPv2

- additions:
  - Group Specific Queries
  - Leave Group Message
- host sends Leave Group message if it was the one to respond to most recent query
- router receiving Leave Group msg queries group.

IGMPv3

- unclear status??
- additions:
  - Group-Source Specific Queries, Reports and Leaves
- inclusion/exclusion of sources

Protocol Independent Multicast

Motivation:

- DVMRP good for dense group membership
- need shared/source-based tree flexibility
- independence from unicast routing

Two PIM modes:

- Dense Mode (approx. DVMRP)
- Sparse Mode

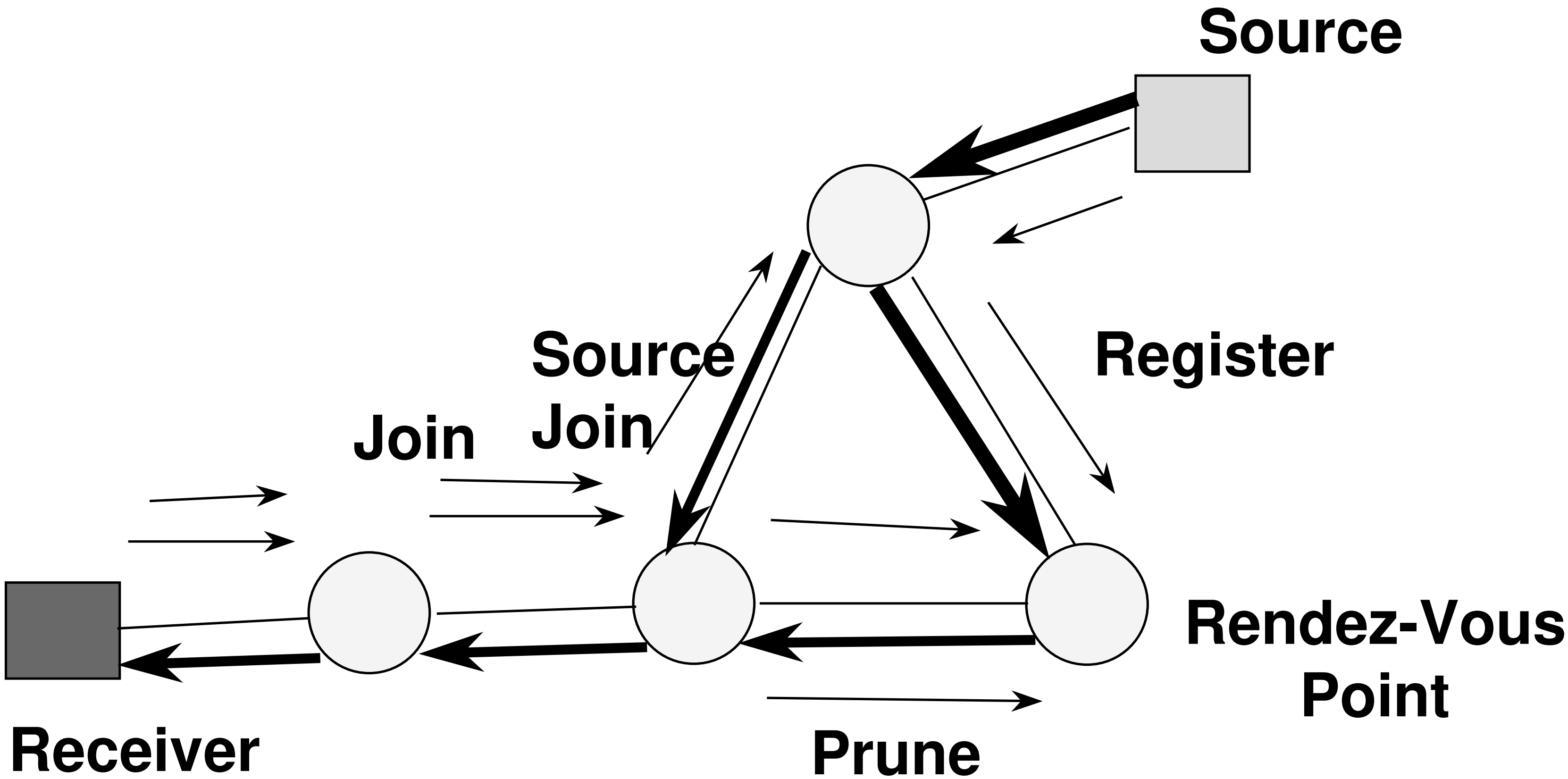
PIM- Dense Mode

- independent from underlying unicast routing
- slight efficiency cost
- contains protocol mechanisms to:
  - detect leaf routers
  - avoid packet duplicates

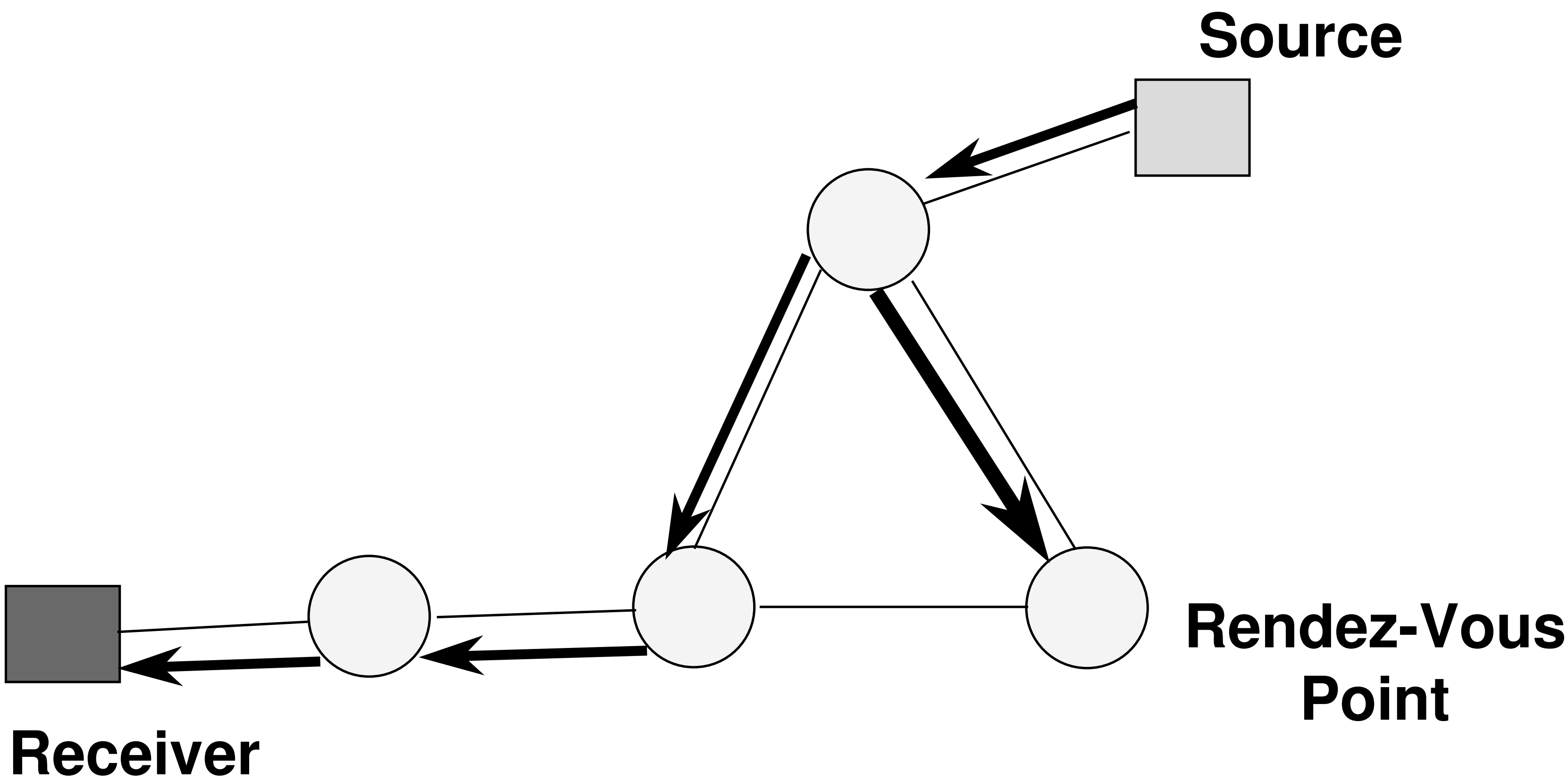
PIM - Sparse Mode

- Rendezvous Point (Core):
  receivers meet sources
- reception through RP connection = Shared Tree
- establish path to source = Source-Based Tree

PIM - Sparse Mode



PIM - Sparse Mode



Border Gateway Multicast Routing Protocol (BGMRP)

- a protocol for inter-domain multicast routing
- bi-directional shared tree for inter-domain routing
- cores (RPs) associated with domains
- receiver domains can utilize choice of protocol

ICMP: Internet Message Control Protocol

- used to communicate network-level error conditions and info to IP/TCP/UDP protocols or user processes
- often considered part of IP, but
- ICMP message sent within IP datagram
- IP demultiplexes up to ICMP using IP protocol field
- ICMP message contains IP header and first 8 bytes of IP contents that causes ICMP mesage to be generated

ICMP Packet Types

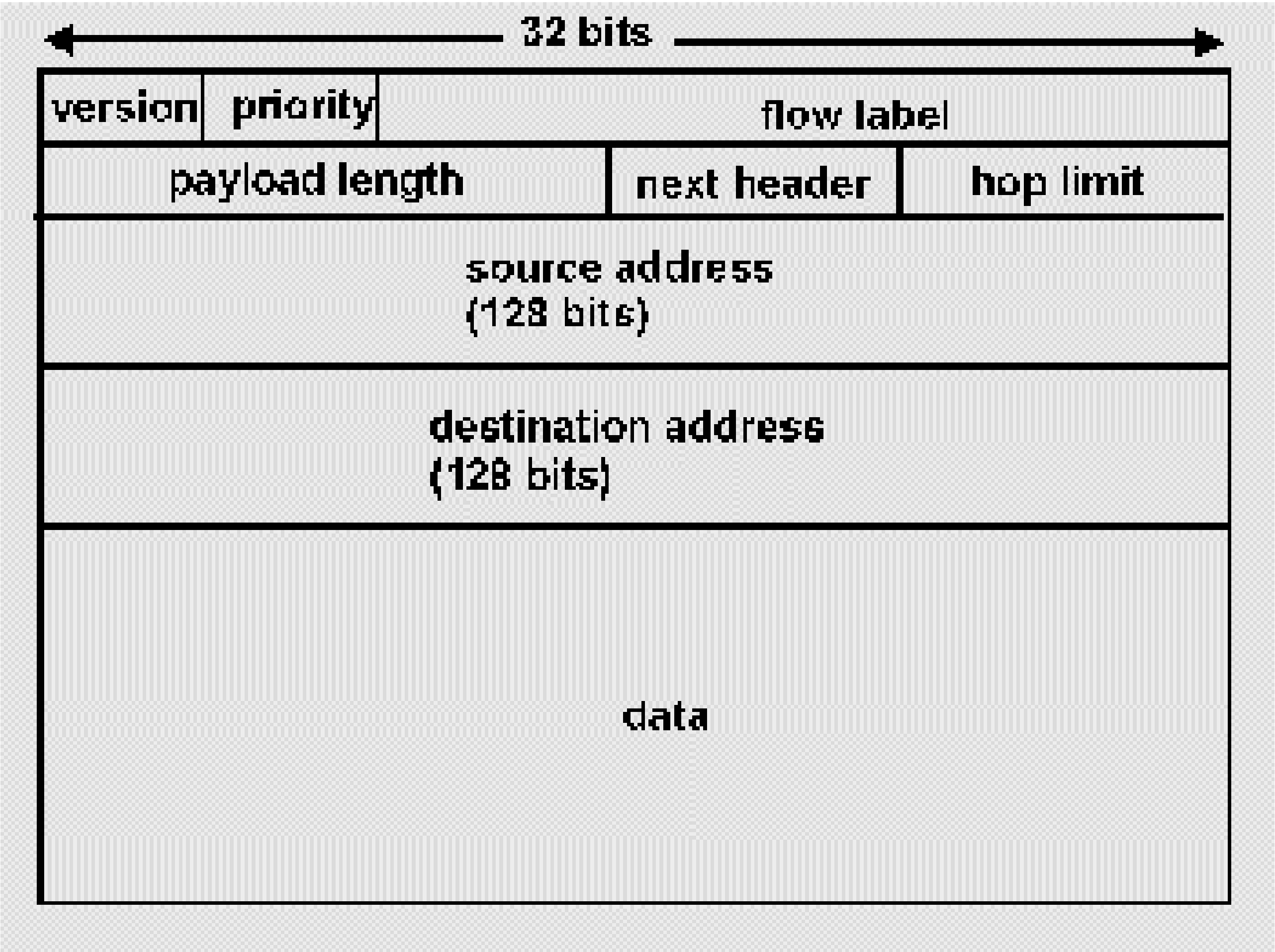
IPv6: next generation IP

Changes to Ipv4:

- 128 bit addresses (so we don't run out of IP addresses)
- header simplification (faster processing)
- more support for type of service
  - priorities
  - flow identifier: identifiy packets in a connection
- security

Notes:

- no fragmentation in network
  - packet too big generates ICMP error to source
  - source fragmentation via extension header
- no checksum (already done at transport and data link layer)


32 bits
version
priority
flow label
payload length
next header
hop limit
source address
(128 bits)
destination address
(128 bits)
data

Transitioning from IPv4 to IPv6

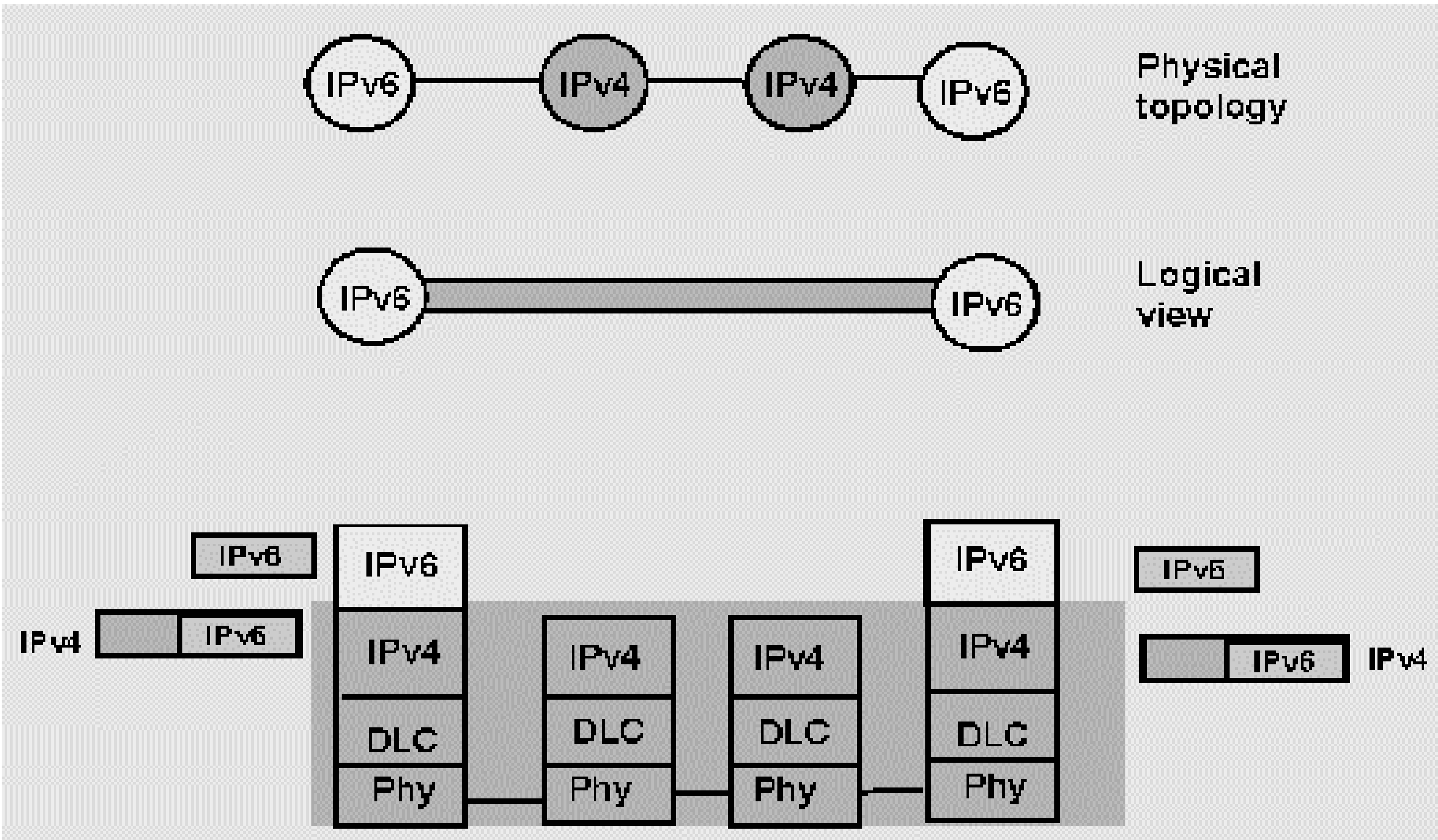
Internet too big for "flag day":

- can't turn off all IP routers, install IPv6 and reboot
- IPv4 nodes will be legacy
- IPv6 nodes can route IPv4 packets
- IPv4 nodes cannot route IPv6 packets

Tunneling

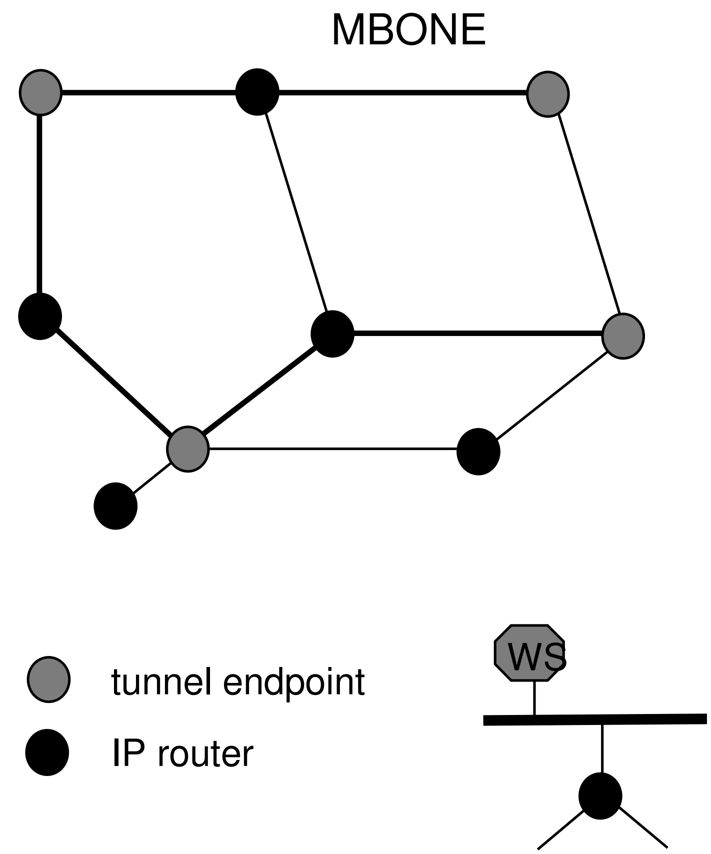
- source and destination speak network protocol X
- physically intermediate nodes speak network protocol Y
  - source takes protocol X packet, sticks it inside (encapsulates) protocol Y packet
  - intermediate nodes route using protocol Y
  - destination receives packet using protocol Y, removes protocol X packet
- *network between source and destination looks like a single link to protocol X*

Tunneling: a pictorial view



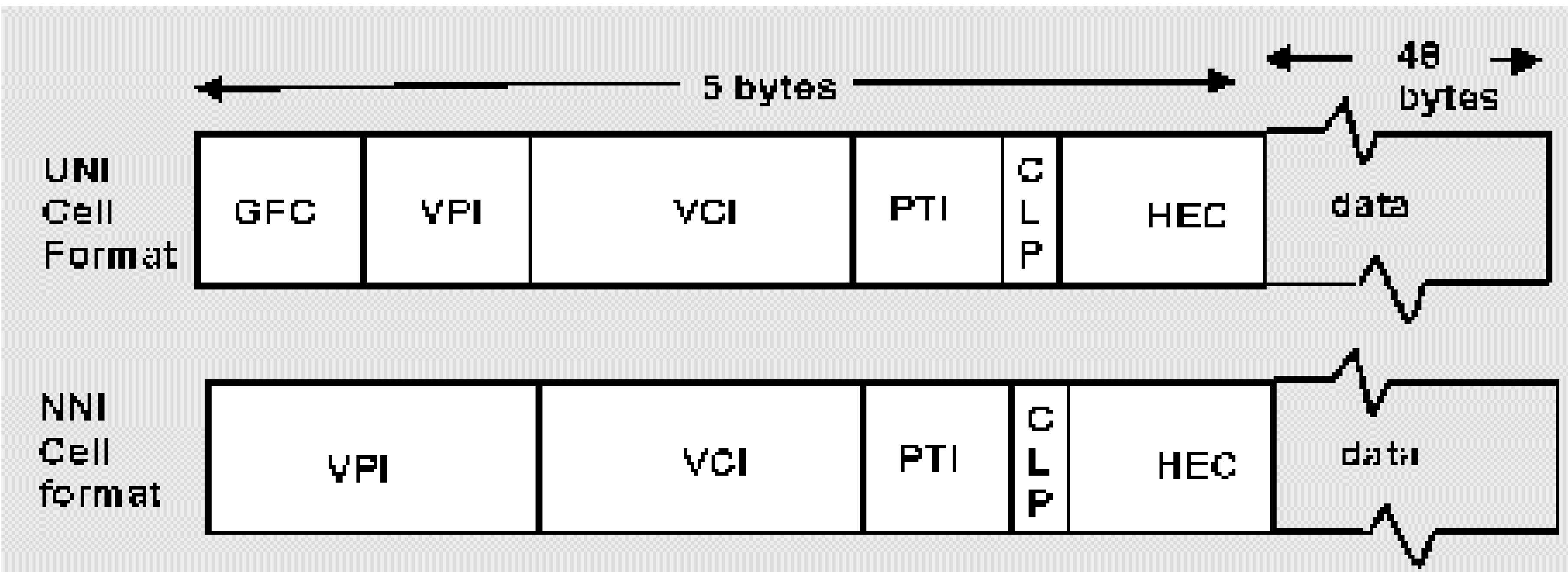
Mbone: Multicast Backbone

- virtual network overlaying Internet
- needed until multicast capable routers deployed **and turned on**
- IP in IP encapsulation
- limited capacity, resilience



Case Study: ATM Network Layer

- ATM: packet (cell) format:
- UNI: user-network interface (host-to-switch)
- NNI: network-network interface (switch-to-switch)



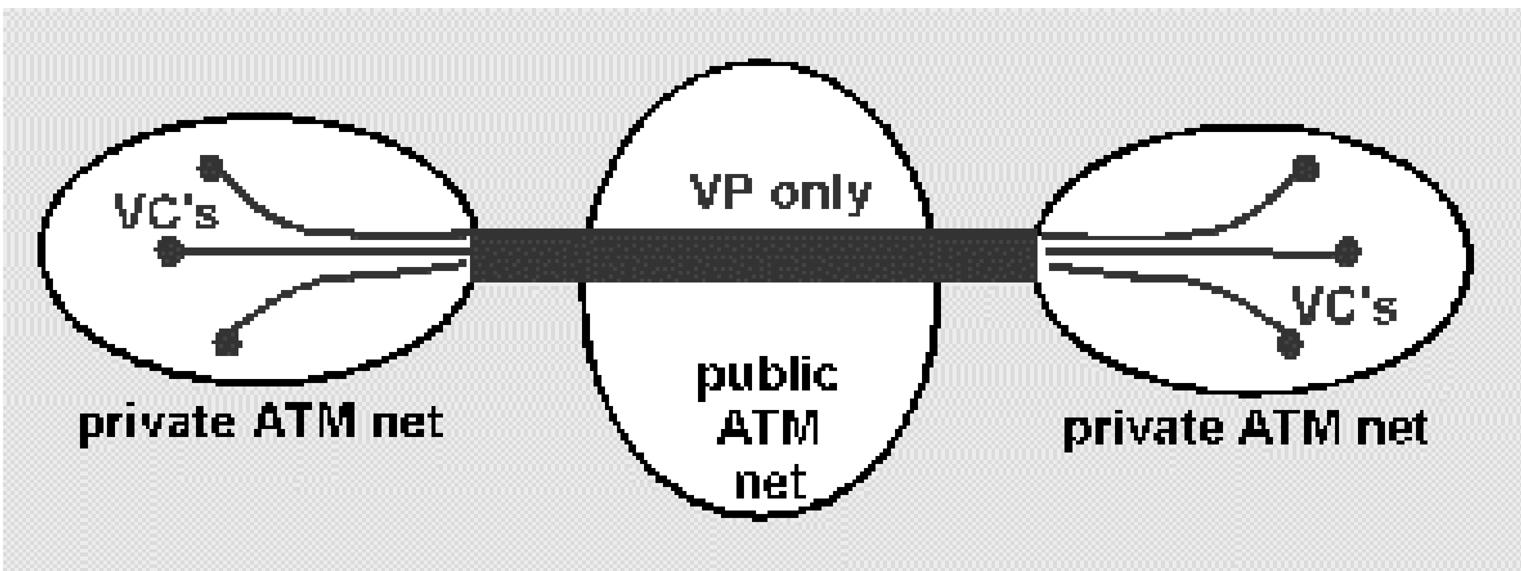
- GFC: generic flow control (unused)
- VPI: virtual path identifier
- VCI: virtual circuit identifier
    - VPI and VCI together a call/connection identifier
- PTI: payload type: 3 bits
    - 111: RM cell (recall RM congestion control)
    - 000: user cell
    - 010: user cell, congestion experienced (recall EFCI)
- CLP: cell loss priority (1 bit)
    - priority bit for discarding
- HEC: header error correction
- DATA: 48 bytes of data

Observations about ATM Cell

- very small
  - reflecting telephony origins
  - 48 bytes a compromise, halfway 64 and 32
- no explicit source/destination address
  - VCI/VPI used instead
  - faster switching (VPI/VCI can index into table)
  - 28 bit VPI/VCI for switching instead of 128 bit IP address in IPv6 (savings)
- fixed length for faster switching
- minimal priority

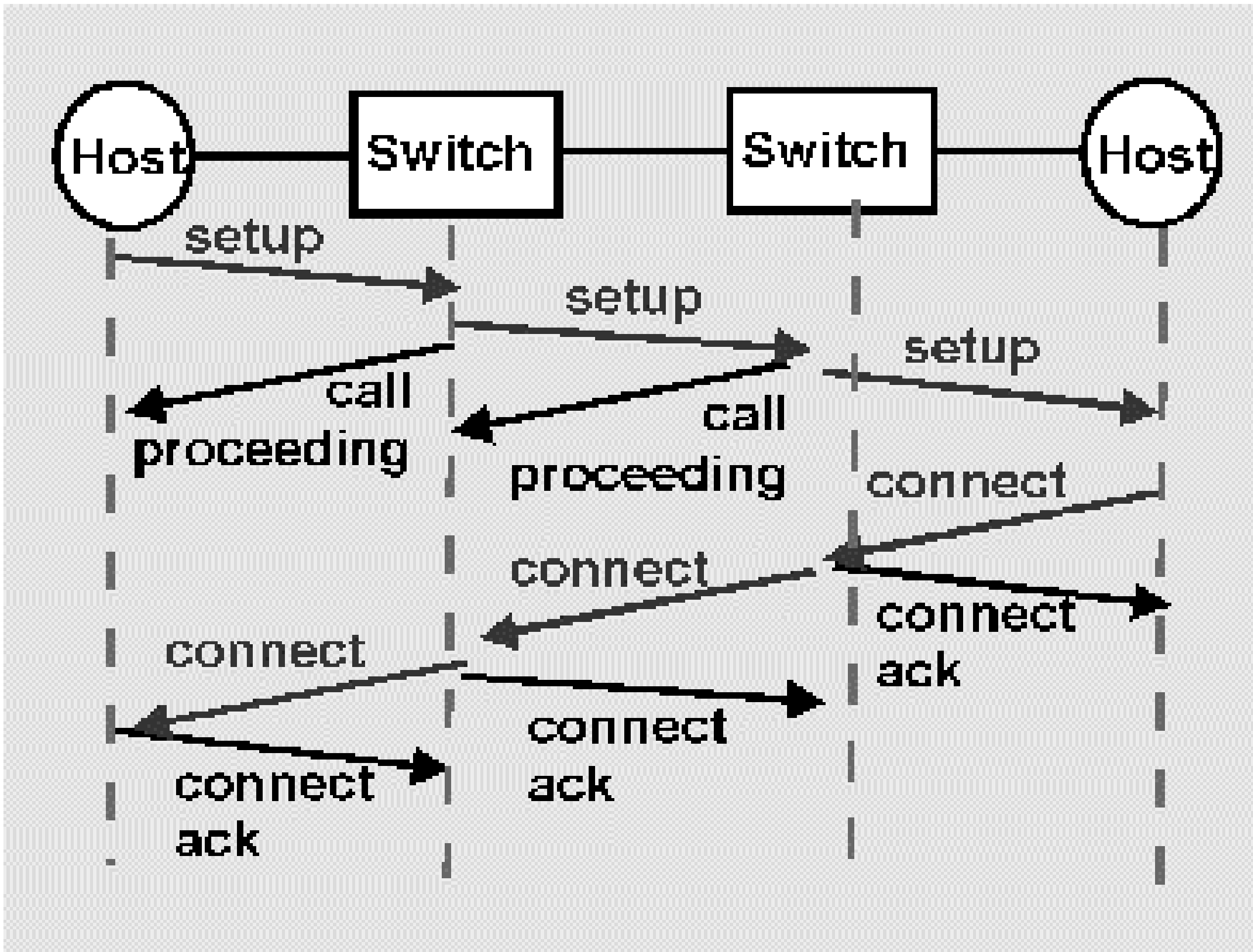
ATM networks: Virtual-circuit Oriented

- VCI/VPI together identify call
- multiple calls (VCI) bundled into same VP
  - network can switch on VP basis only
  - less state (network only sees VP's)
  - all VC's in VP follow same path



Connection Setup in ATM

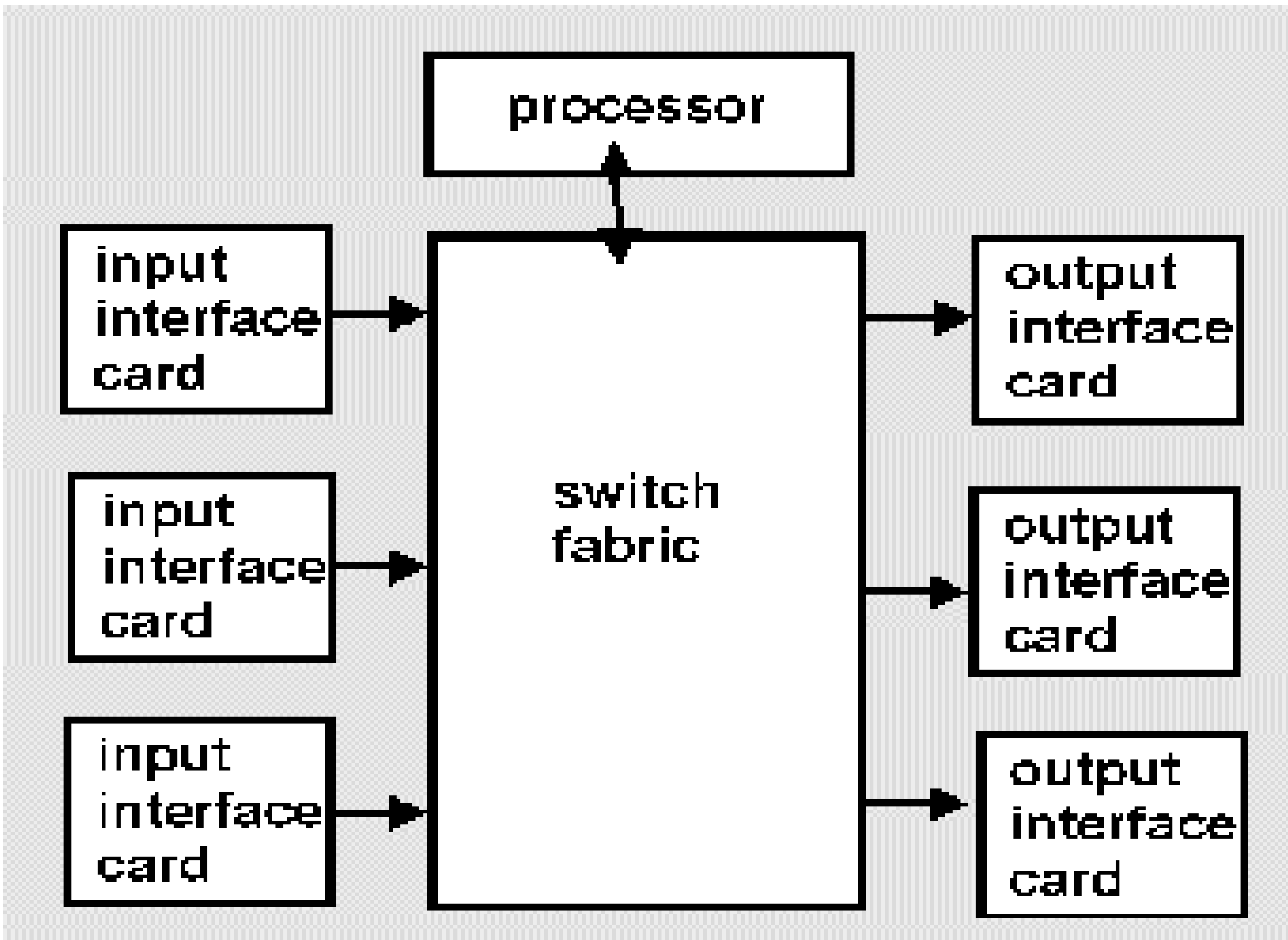
- messages ("signaling") used to setup up call through network
- state info (VP switching info - which output line to switch incoming VC) set up in switches
- meaning of call setup messages:


Host
Switch
Switch
Host
setup
setup
setup
call
proceeding
call
proceeding
connect
connect
connect
connect
ack
connect
ack
connect
ack

ATM Call Setup (cont)

Observations:

- unlike Internet, switches involved in call setup
  - state creation
  - ACKing between switches
- wait one RTT before sending data
  - unlike UDP
  - same as TCP
- what if connection breaks?
  - other switches must remove state
- ATM standard does not specify a routing protocol


processor
input
interface
card
input
interface
card
input
interface
card
switch
fabric
output
interface
card
output
interface
card
output
interface
card

Switches and Routers: What's Inside

Input interface cards:

- physical layer processing
- memory buffers to hold incoming packet

Switch fabric:

to move packets from input to output

Output interface cards:

- memory buffers to hold outgoing packets
- physical layer processing

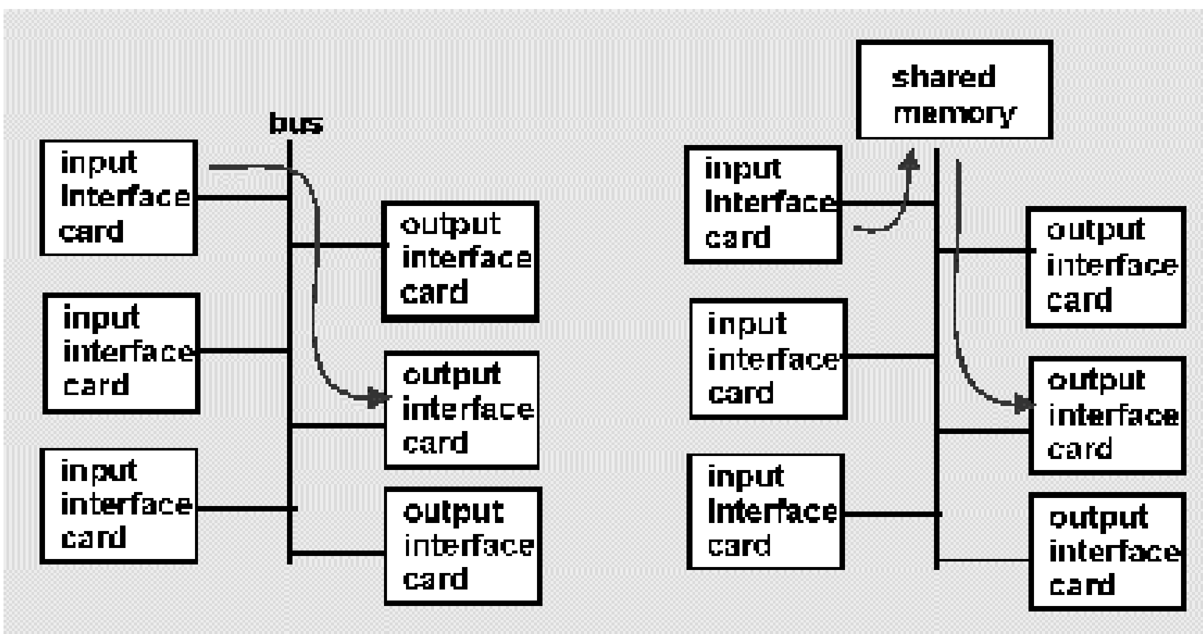
Control processor: routing table updates, supervisory (management) functions

- will typically not touch the packets being switched

Switching Fabrics

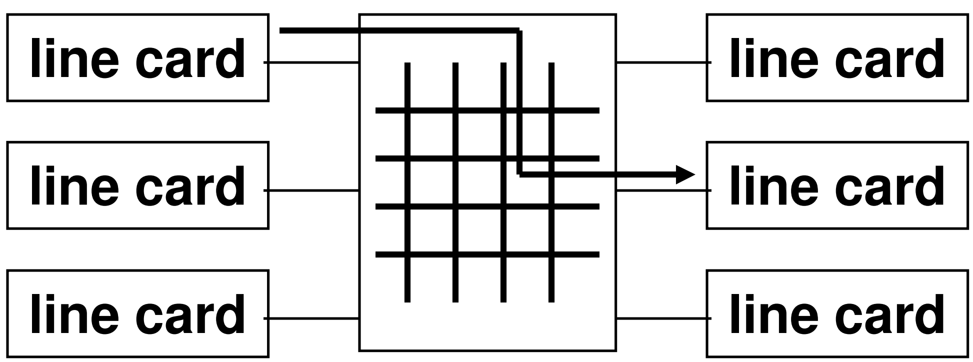
Three ways to switch:

- **switching via memory:** input line ports write to memory, output ports read from memory
- **switching via a bus:** bus (backplane) connects input and output ports
  - e.g.: Baynetworks Backbone Node has one GBps bus



Switching Fabrics

- **switching via a crossbar:** crossbar switch connects input and output ports
  - e.g.: Cisco 12000 series provide 5-60Gbs



IP Routing Table Lookup

Longest prefix matching:

- entries in routing table are prefices of IP address

Q: how to do lookup

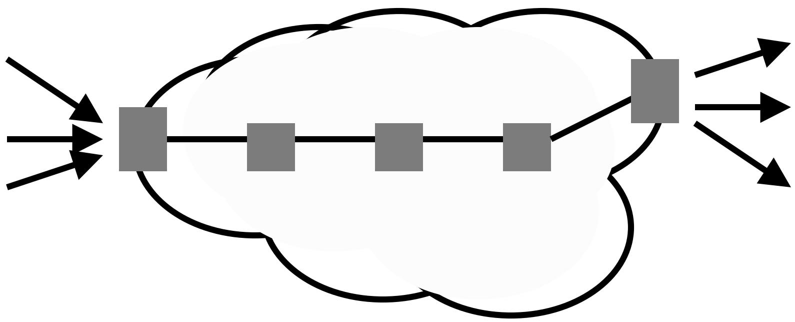
- efficiently
- low storage requirements

Current approaches:

radix tries, Patricia tries, content addressable memories

Multiprotocol Label Switching (MPLS)

- best of ATM and IP over single network



- add header with fixed length“label” to IP packet
- switch (route) based on label
- merge flows with common ingress/egress routers
- switching (routing) very fast

Network Layer: Summary

Network service: datagram versus VC

Theory of routing protocols

- link state and distance vector
- multicast
- broadcasting

Case studies:

- Internet
  - IPv4, IPv6
  - protocols for exchanging routing information: RIP, OSPF, BGP
- ATM