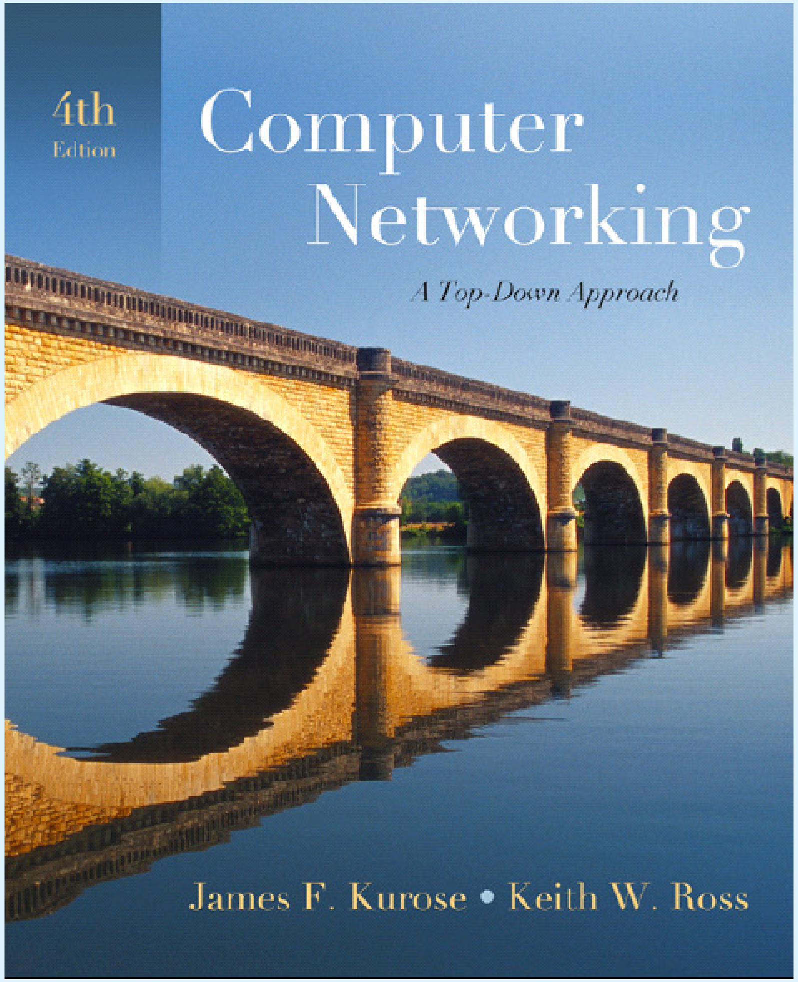
Network Layer

Bildspelet omfattar till stor del bilder som hör till följande bok:



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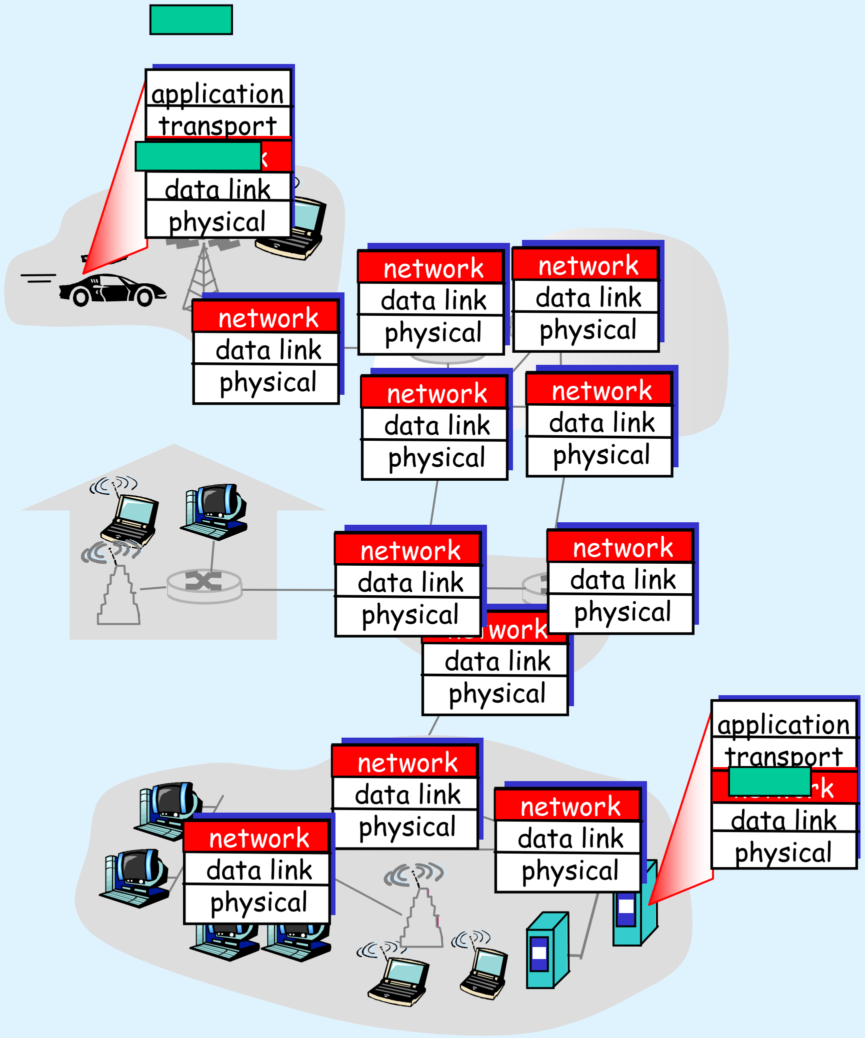
Thanks and enjoy! JFK/KWR

Computer Networking: A Top Down Approach , 4th edition.
Jim Kurose, Keith Ross, Addison-Wesley, July 2007.

Network layer

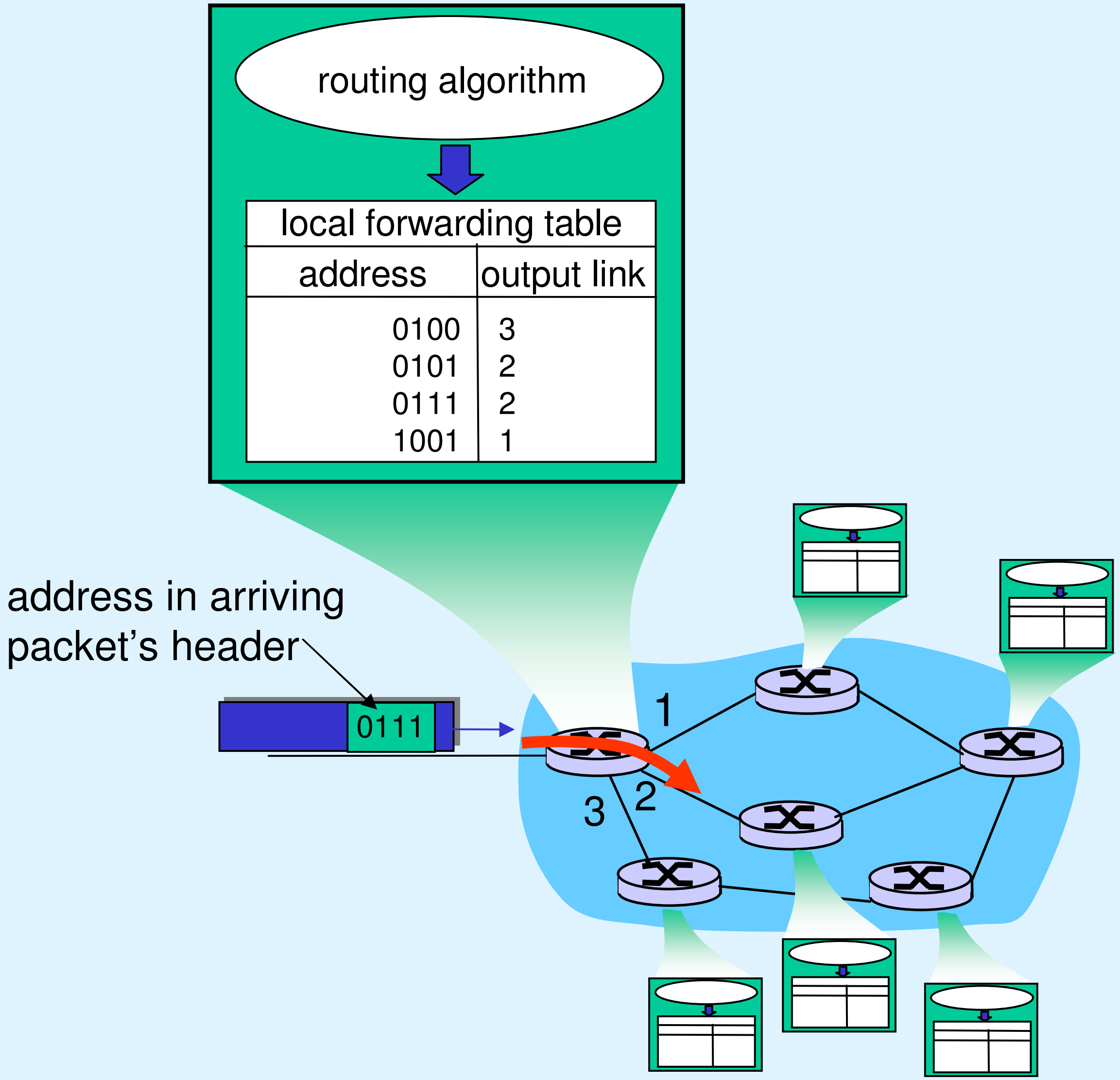
- transport segment from sending to receiving host
- on sending side encapsulates segments into datagrams
- on rcving side, delivers segments to transport layer
- network layer protocols in *every* host, router
- router examines header fields in all IP datagrams passing through it



Two Key Network-Layer Functions

- *forwarding:* move packets from router's input to appropriate router output
- *routing:* determine route taken by packets from source to dest.
  - *routing algorithms*

Interplay between routing and forwarding



Network layer connection and connection-less service

- datagram network provides network-layer connectionless service
- VC network, e.g. ATM, provides network-layer connection service
- analogous to the transport-layer services, but:
  - service: host-to-host
  - no choice: network provides one or the other
  - implementation: in network core

Forwarding table

4 billion (2^{32}) possible entries

Destination Address Range	Link Interface
11001000 00010111 00010000 00000000 through 11001000 00010111 00010111 11111111	0
11001000 00010111 00011000 00000000 through 11001000 00010111 00011000 11111111	1
11001000 00010111 00011001 00000000 through 11001000 00010111 00011111 11111111	2
otherwise	3

Longest prefix matching

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

Examples

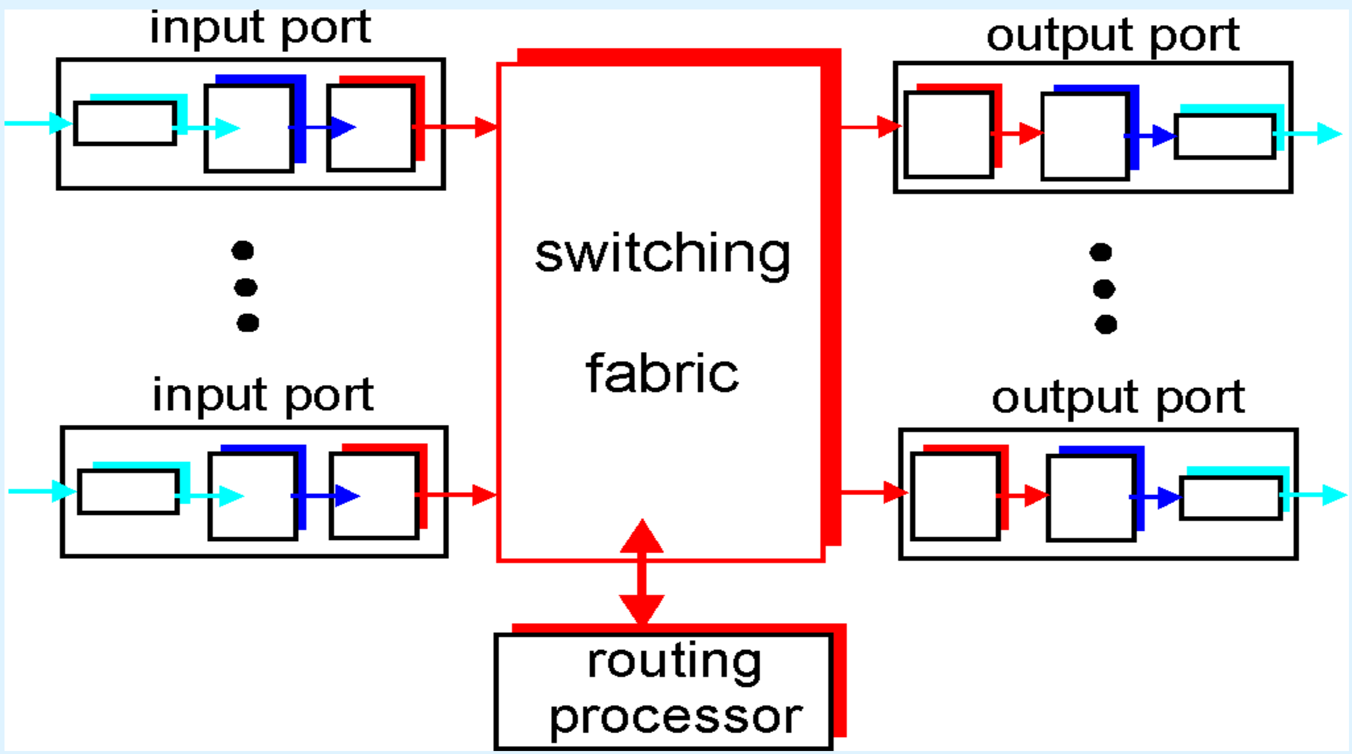
DA: 11001000 00010111 00010110 10100001 Which interface?

DA: 11001000 00010111 00011000 10101010 Which interface?

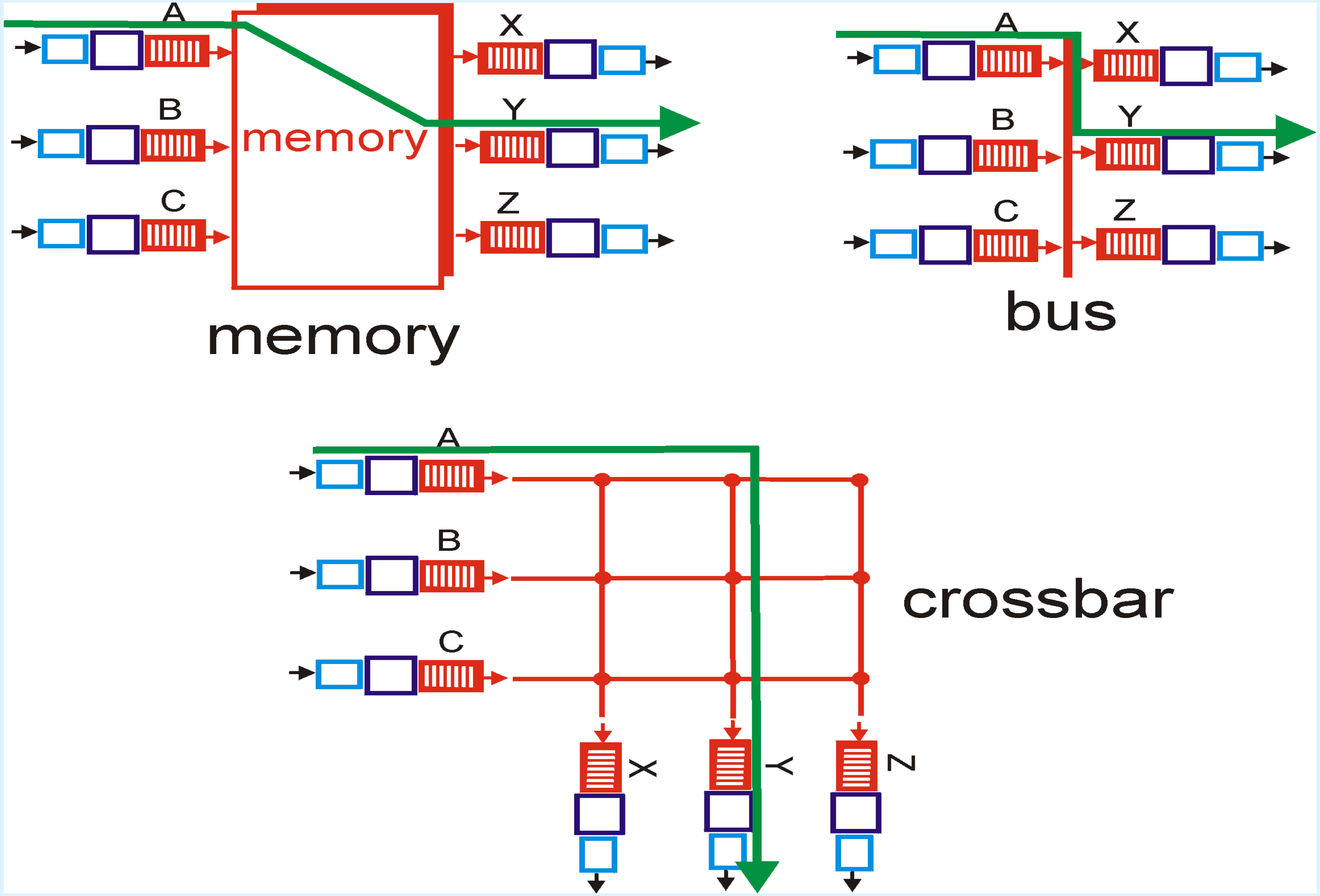
Router Architecture Overview

Two key router functions:

- run routing algorithms/protocol (RIP, OSPF, BGP)
- *forwarding* datagrams from incoming to outgoing link



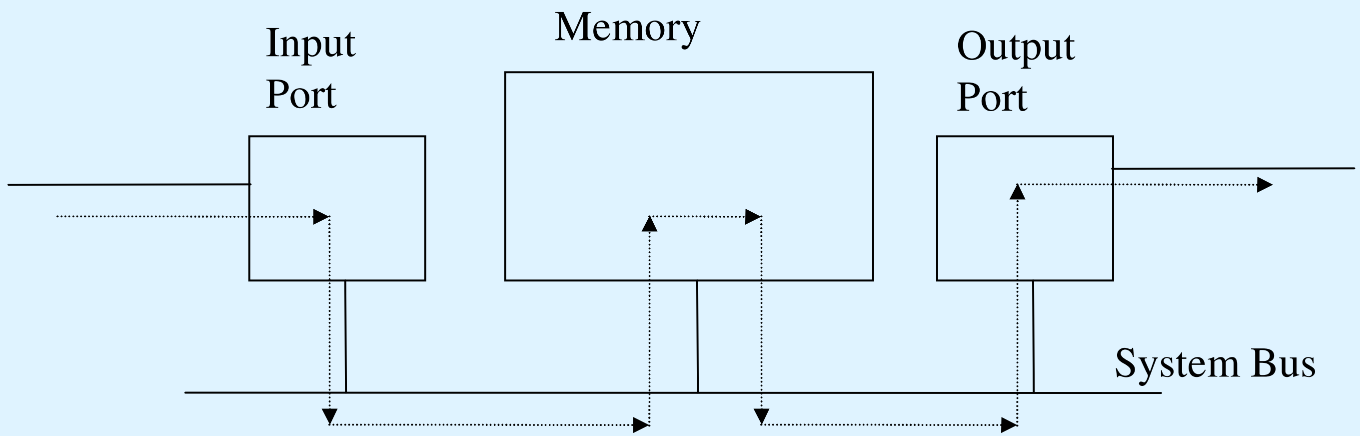
Three types of switching fabrics



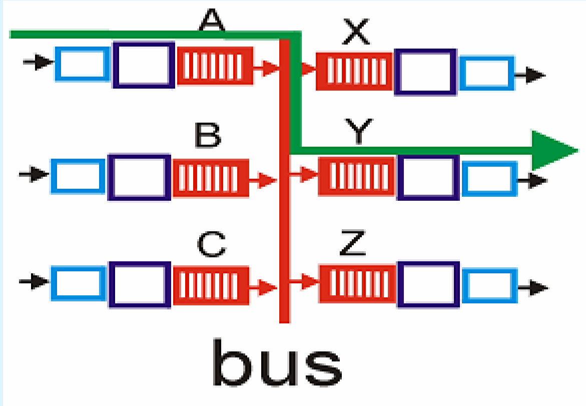
Switching Via Memory

First generation routers:

- traditional computers with switching under direct control of CPU
- packet copied to system's memory
- speed limited by memory bandwidth (2 bus crossings per datagram)



Switching Via a Bus

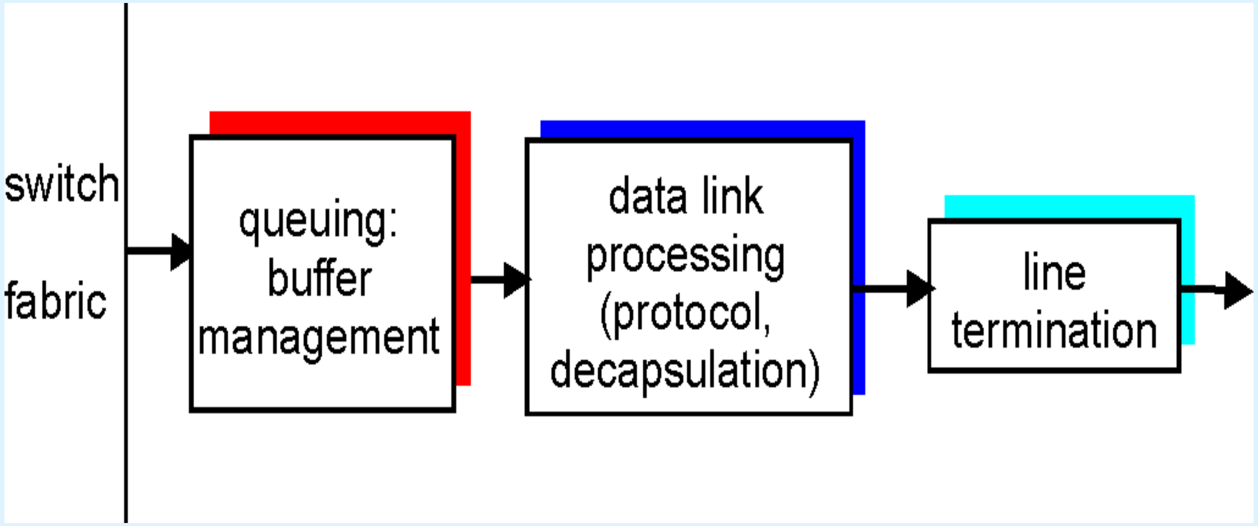


- datagram from input port memory to output port memory via a shared bus
- bus contention: switching speed limited by bus bandwidth
- 32 Gbps bus, Cisco 5600: sufficient speed for access and enterprise routers

Switching Via An Interconnection Network

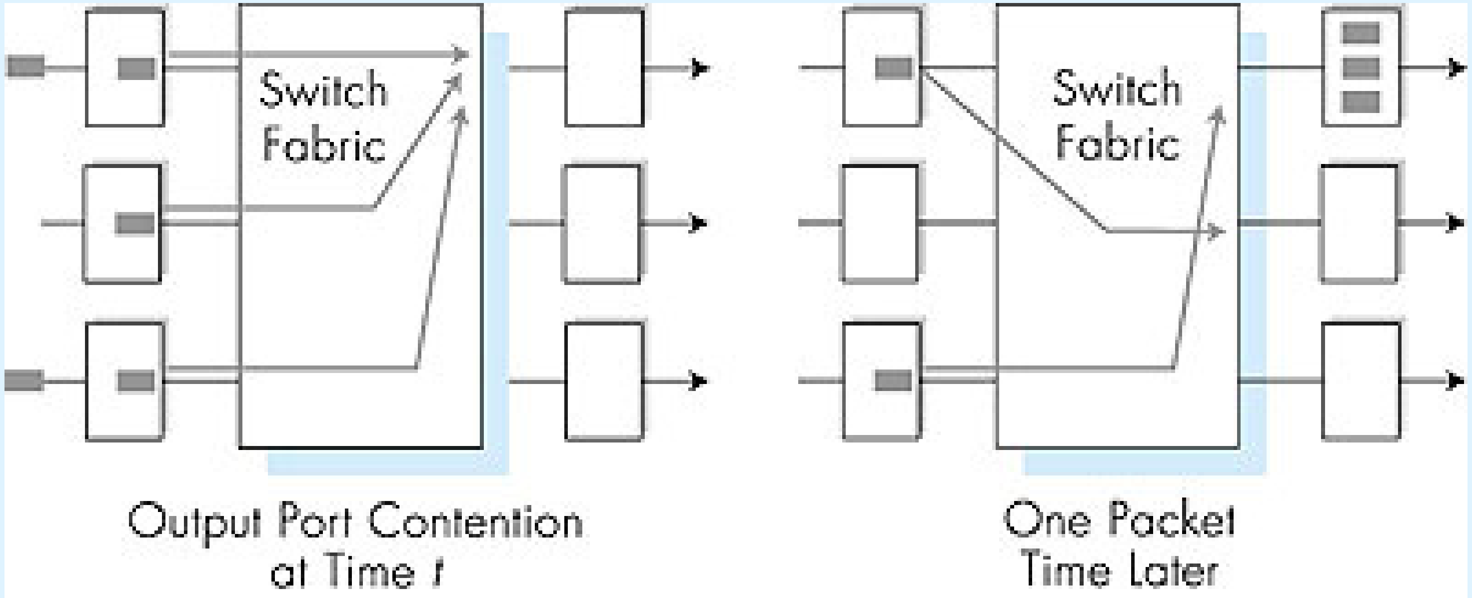
- overcome bus bandwidth limitations
- Banyan networks, other interconnection nets initially developed to connect processors in multiprocessor
- advanced design: fragmenting datagram into fixed length cells, switch cells through the fabric.
- Cisco 12000: switches 60 Gbps through the interconnection network

Output Ports



- *Buffering* required when datagrams arrive from fabric faster than the transmission rate
- *Scheduling discipline* chooses among queued datagrams for transmission

Output port queueing



- buffering when arrival rate via switch exceeds output line speed
- *queueing (delay) and loss due to output port buffer overflow!*

How much buffering?

- Rule of thumb (RFC 3439): average buffering equal to B = RTT·C
  - e.g., $RTT_{typical}$ = 250 msec, C = 10 Gbps link:

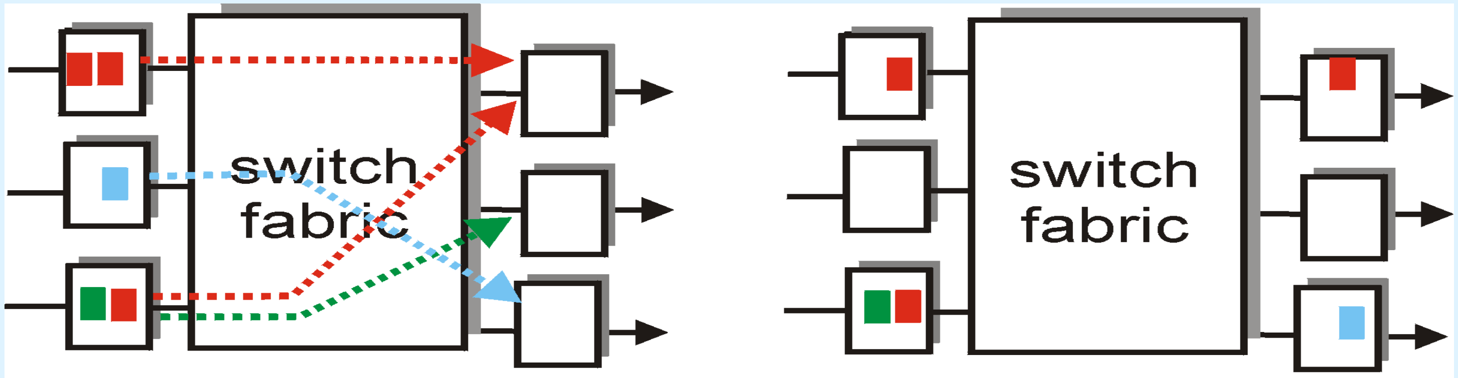
$$B = RTT \cdot C = 2.5 \text{ Gbit}$$

- Recent recommendation: with N flows, buffering equal to

$$B = \frac{RTT \cdot C}{\sqrt{N}}$$

Input Port Queuing

- Fabric slower than input ports combined -> queueing may occur at input queues
- Head-of-the-Line (HOL) blocking: queued datagram at front of queue prevents others in queue from moving forward
- *queueing delay and loss due to input buffer overflow!*

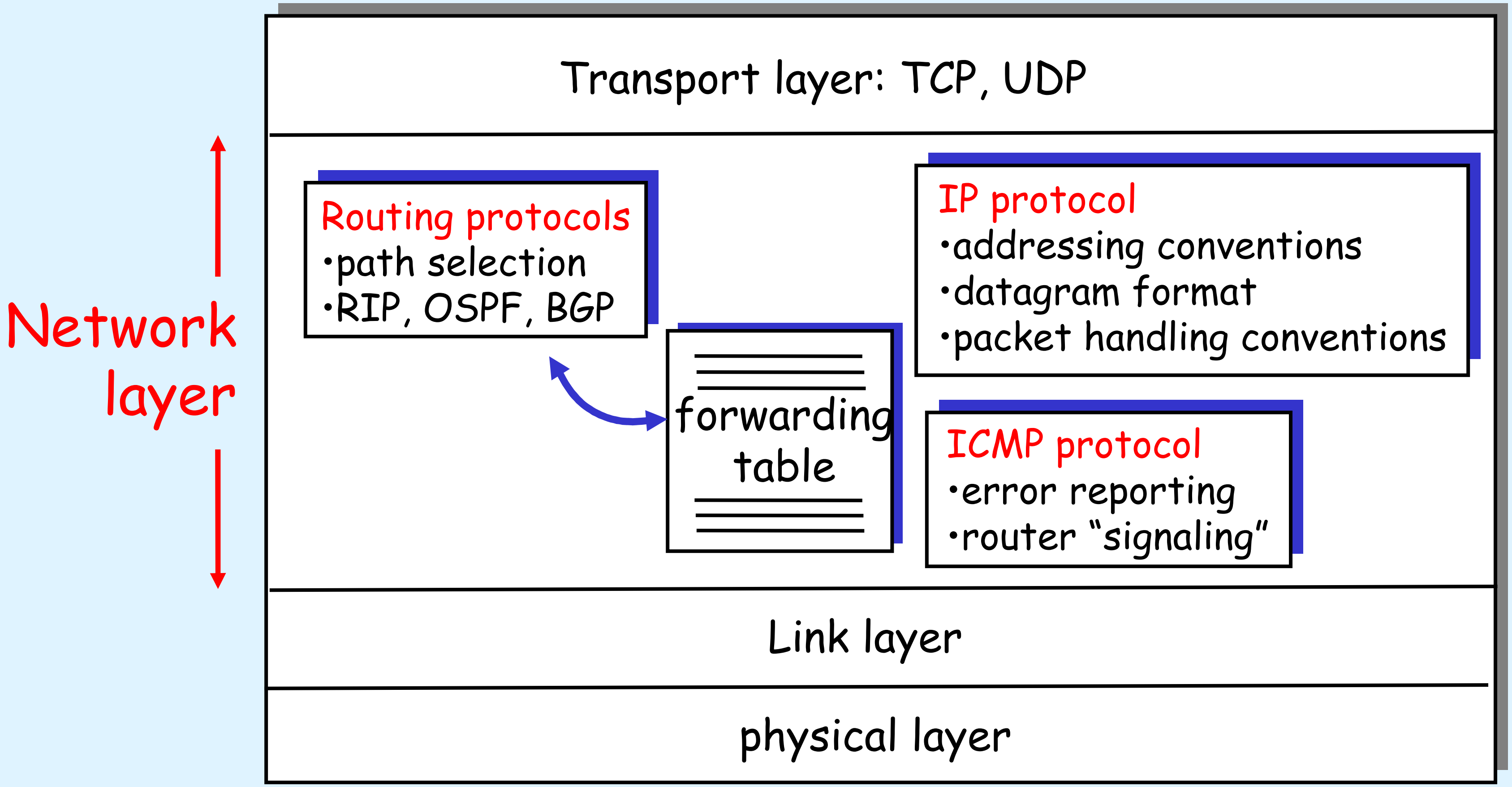


output port contention at time t - only one red packet can be transferred

green packet experiences HOL blocking

The Internet Network layer

Host, router network layer functions:



IPv4 datagram format

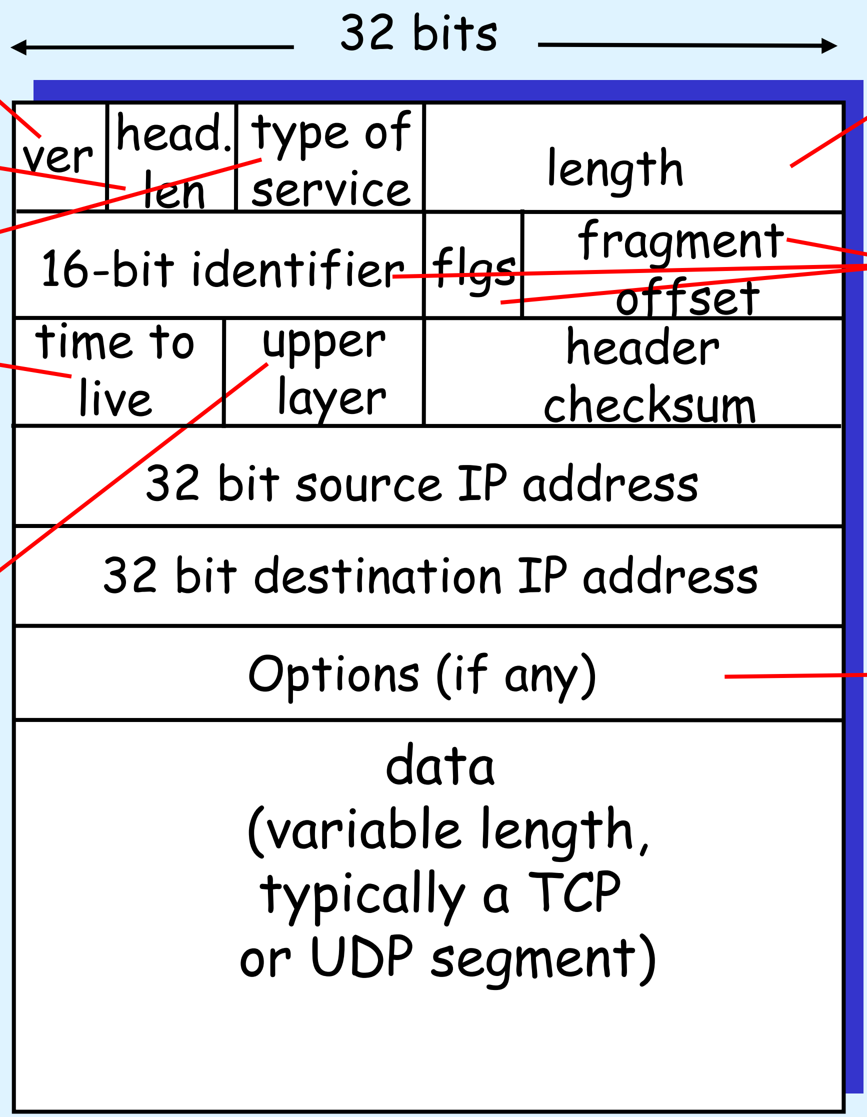
IP protocol version number

header length (bytes)

"type" of data

max number remaining hops (decremented at each router)

upper layer protocol to deliver payload to



total datagram length (bytes)

for fragmentation/ reassembly

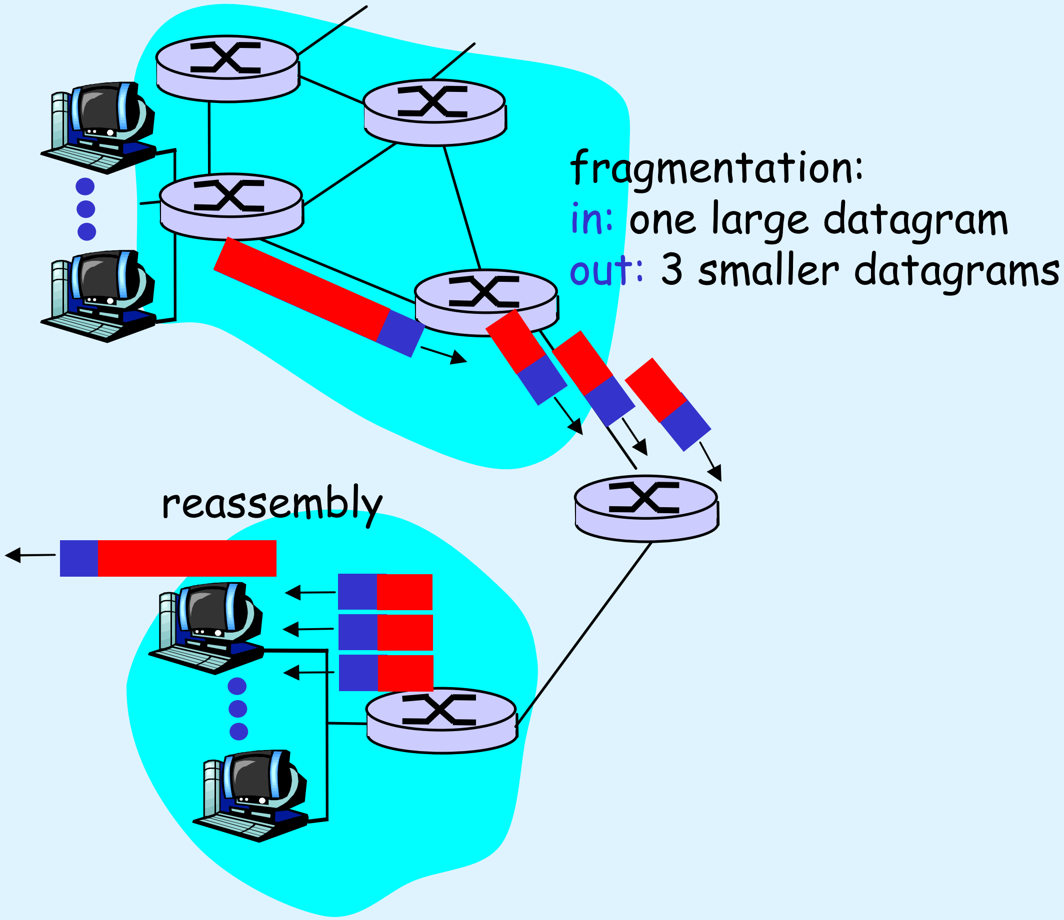
E.g. timestamp, record route taken, specify list of routers to visit.

<u>how much overhead with TCP?</u>

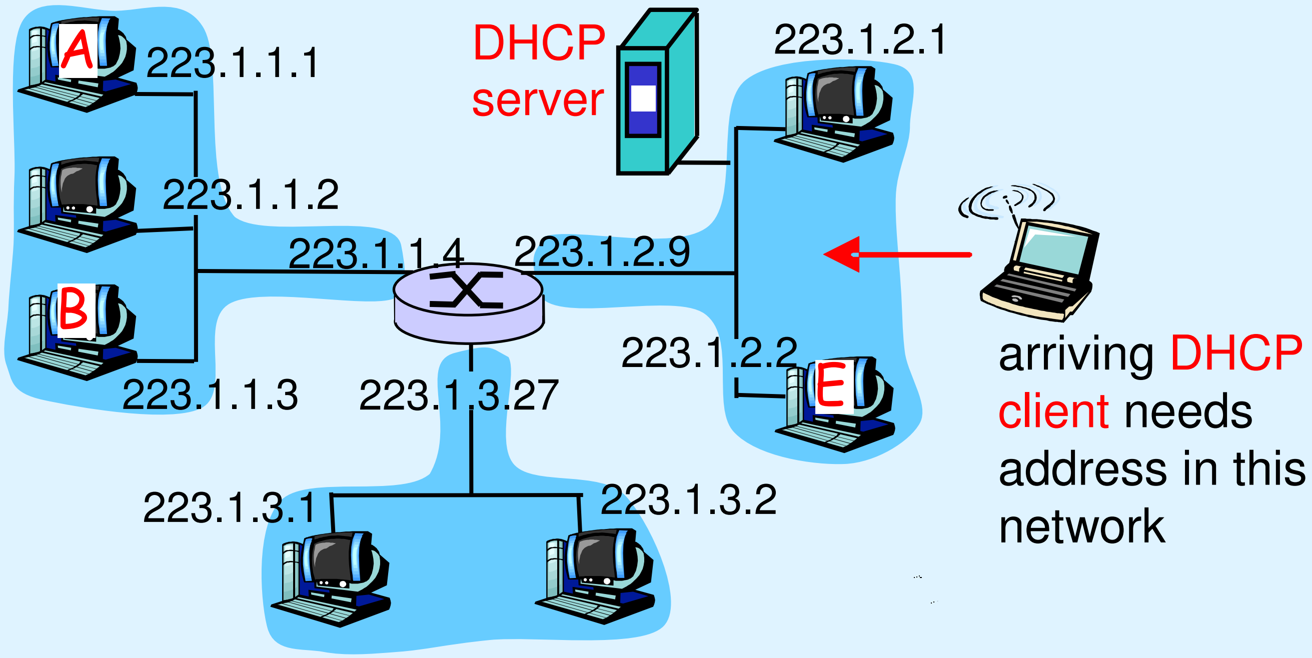
- 20 bytes of TCP
- 20 bytes of IP
- = 40 bytes + app layer overhead

IP Fragmentation & Reassembly

- network links have MTU (max.transfer size) - largest possible link-level frame.
  - different link types, different MTUs
- large IP datagram divided ("fragmented") within net
  - one datagram becomes several datagrams
  - "reassembled" only at final destination
  - IP header bits used to identify, order related fragments

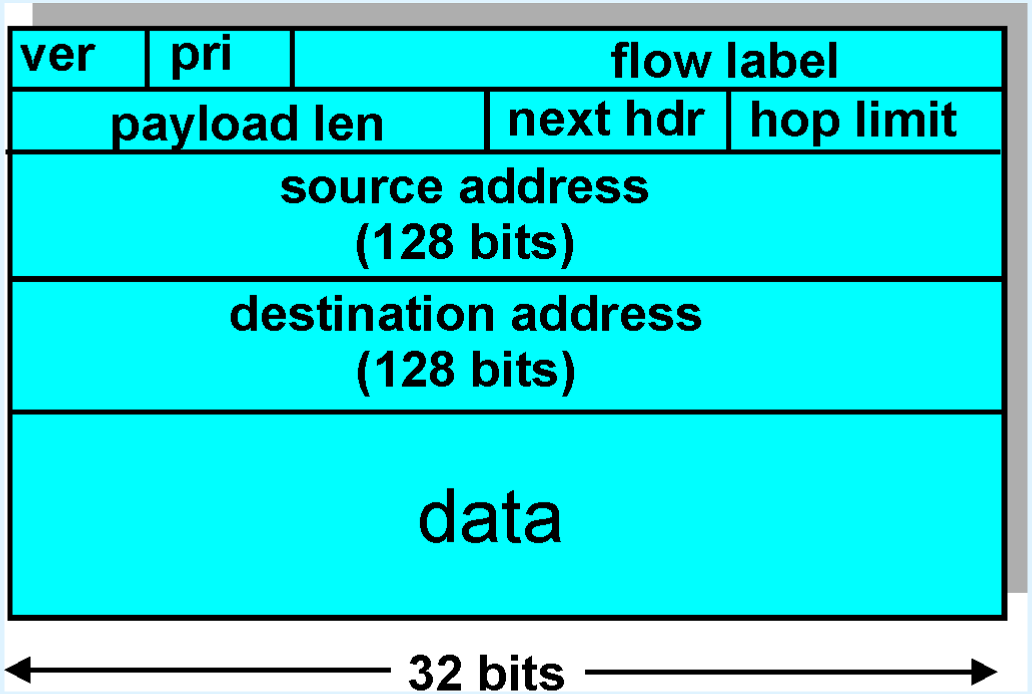


DHCP client-server scenario

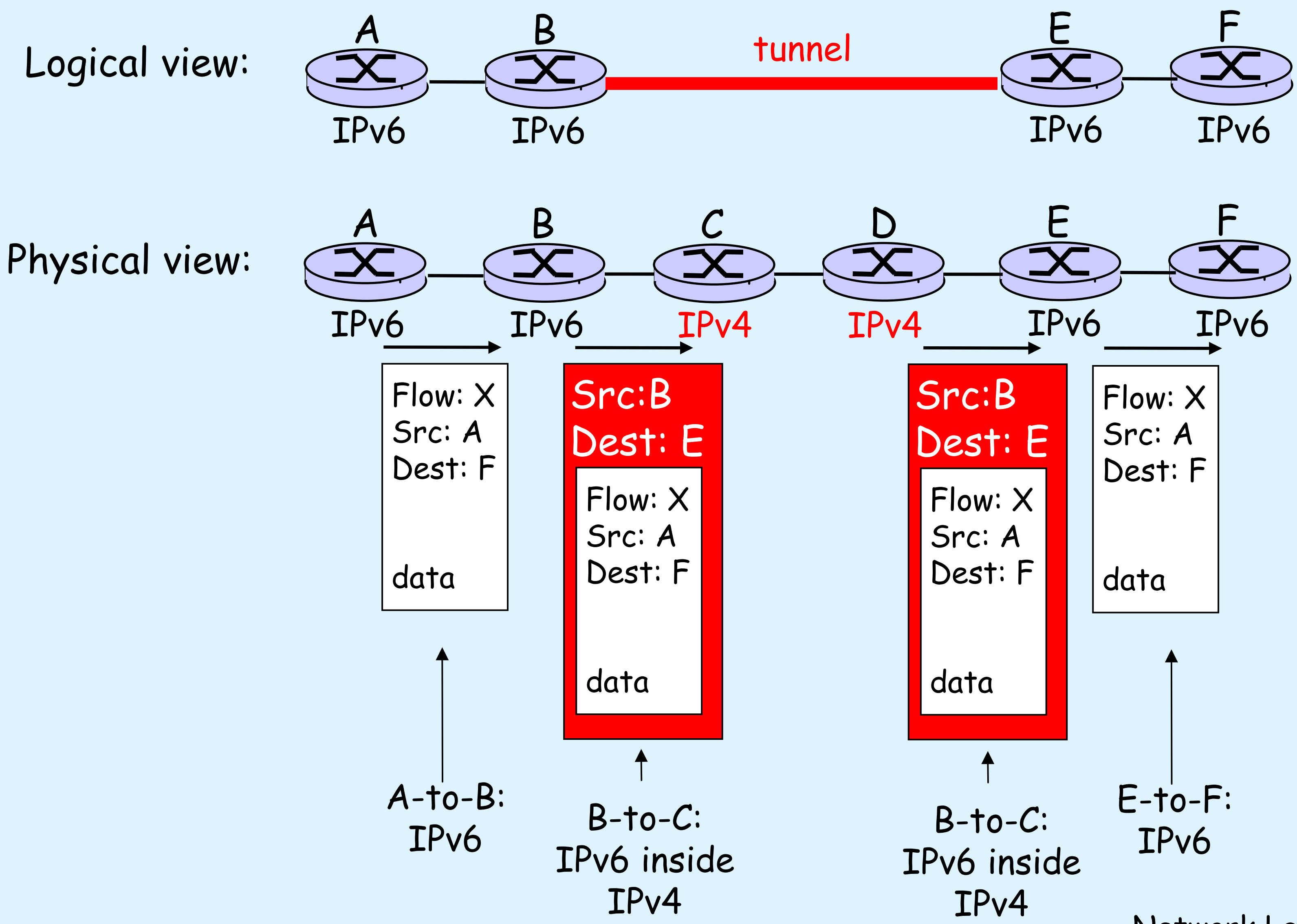


IPv6 Header

Traffic class: 8-bit traffic class ("pri" in image).
Flow label: identify datagrams in same "flow"
(concept of"flow" not well defined).
Next header: identify upper layer protocol for data.



Tunneling



Logical view:
A
B
tunnel
E
F
IPv6
IPv6
IPv6
IPv6
Physical view:
A
B
C
D
E
F
IPv6
IPv6
IPv4
IPv4
IPv6
IPv6
Flow: X
Src: A
Dest: F
data
Src:B
Dest: E
Flow: X
Src: A
Dest: F
data
Src:B
Dest: E
Flow: X
Src: A
Dest: F
data
Flow: X
Src: A
Dest: F
data
A-to-B: IPv6
B-to-C: IPv6 inside IPv4
B-to-C: IPv6 inside IPv4
E-to-F: IPv6

Link-State Routing Algorithm (LS)

Dijkstras algoritm

- Global

  OBS! Algoritmen körs lokalt i varje router och är på så sätt även **decentraliserad** till skillnad mot central routing i en speciell maskin.

- Iterativ
  - "Billigaste väg" väljs ut till varje router.
  - Nätet spänns upp router för router (steg för steg).
  - Nästa router som läggs till det logiska nätet måste kunna nås från det nuvarande logiska nätet.
  - Routrar som inte kan nås från det nuvarande "logiska nätet" sägs ha oändlig kostnad.
  - Då alla rourar ingår i det logiska nätet är algoritmen klar.

- Algoritmen beskrivs med...
  - matematisk notation
  - tabell
  - grafer

- Används av protokollet OSPF

Distance Vector Algorithm (DV)

Bellman-Fords ekvation (dynamisk prog.)

- Decentraliserad
- Iterativ
- Asynkron

  Uppdateringen görs nödvändigtvis inte i takt med andra routrar.

- Distribuerad
  - decentraliserad
  - annonsering
- Algoritmen beskrivs med…
  - matematisk notation
  - nodtabeller
  - grafer
- Används av protokollet RIP

Bellman-Ford Equation (dynamic programming)

Define

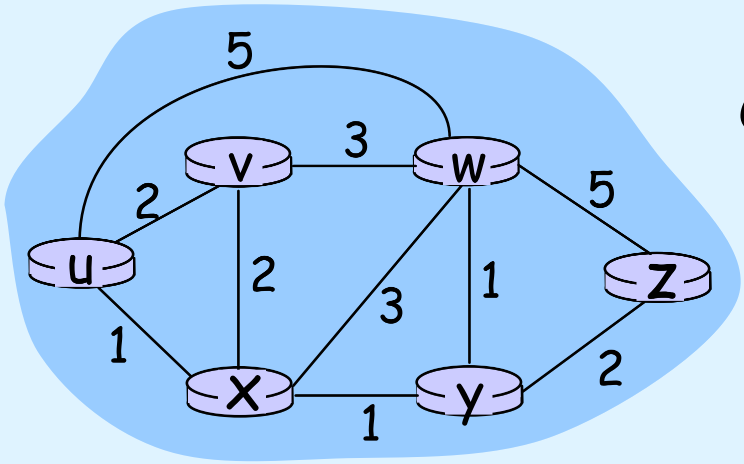
$d_x(y)$:= cost of least-cost path from x to y

Then

$$\boxed{d_x(y) = \min_v \{c(x,v) + d_v(y)\}}$$

where min is taken over all neighbors v of x

Bellman-Ford example



Clearly, $d_v(z) = 5$, $d_x(z) = 3$, $d_w(z) = 3$

B-F equation says:

$$d_u(z) = \min \{ c(u,v) + d_v(z), \; c(u,x) + d_x(z), \; c(u,w) + d_w(z) \}$$

$$= \min \{2 + 5, \; 1 + 3, \; 5 + 3\} = 4$$

Node that achieves minimum is next hop in shortest path ➜ forwarding table

DV (1)

Basic idea:

- Each node periodically sends its own distance vector estimate to neighbors
- When a node x receives new DV estimate from neighbor, it updates its own DV using B-F equation:

$$D_x(y) \leftarrow \min_v\{c(x,v) + D_v(y)\} \quad \text{for each node } y \in N$$

- Under minor, natural conditions, the estimate $D_x(y)$ *converge to the actual least cost* $d_x(y)$

DV (2)

Iterative, asynchronous:
each local iteration caused by:

- local link cost change
- DV update message from neighbor

Distributed:

- each node notifies neighbors *only* when its DV changes
  - neighbors then notify their neighbors if necessary

Each node:

wait for (change in local link cost or msg from neighbor)

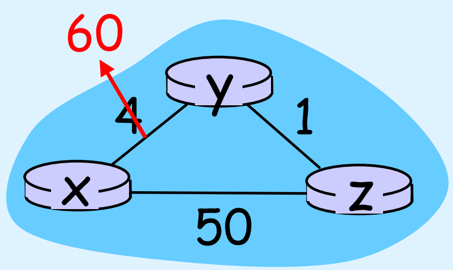
recompute estimates

if DV to any dest has changed, *notify* neighbors

DV: link cost changes

Link cost changes:

- good news travels fast
- bad news travels slow - "count to infinity" problem!
  (In figure: 44 iterations before algorithm stabilizes: see text)



Poisoned reverse:

- If Z routes through Y to get to X :
  - Z tells Y its (Z's) distance to X is infinite (so Y won't route to X via Z)
- will this completely solve count to infinity problem?

Hierarchical Routing (1)

Our routing study thus far - idealization

- all routers identical
- network "flat"

... *not* true in practice

scale: with 200 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 (2)

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

Gateway router

- Direct link to router in another AS