CSCE 463/612
Networks and Distributed Processing
Spring 2025

Network Layer III

Dmitri Loguinov
Texas A&M University

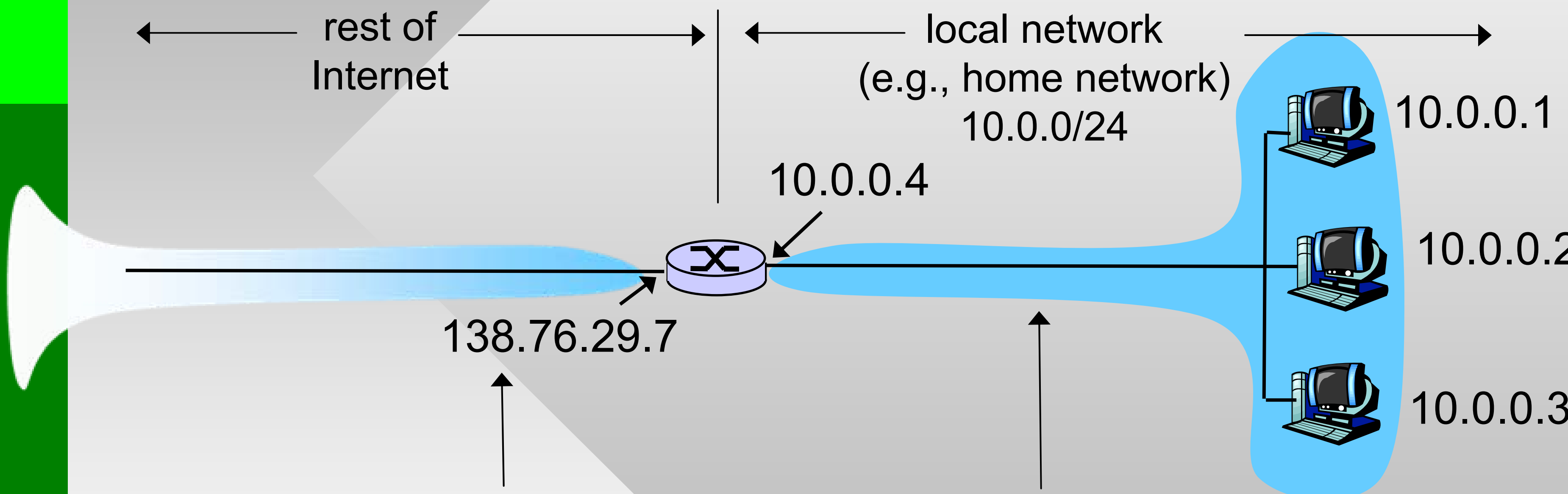
April 8, 2025

Homework #4 Grading

Curve: 80 A, 70 B, etc.

- Default mode: final grading will use 3 homeworks
  - Homework contribution = (hw1+hw2+hw3) / 3
- Extra-credit option A: use hw4 in place of any previous homework
  - Swapping out hw1, we get (hw4+hw2+hw3) / 3
- Extra-credit option B: add 20% of hw4 to other homeworks
  - (hw1 + hw2 + hw3 + 0.2*hw4) / 3
- Example: hw1 = 21, hw2 = 80, hw3 = 70, hw4 = 60
  - Default = 57, option A = 70, option B = 61
- Example: hw1 = 62, hw2 = 72, hw3 = 64, hw4 = 60
  - Default = option A = 66, option B = 70

NAT: Network Address Translation



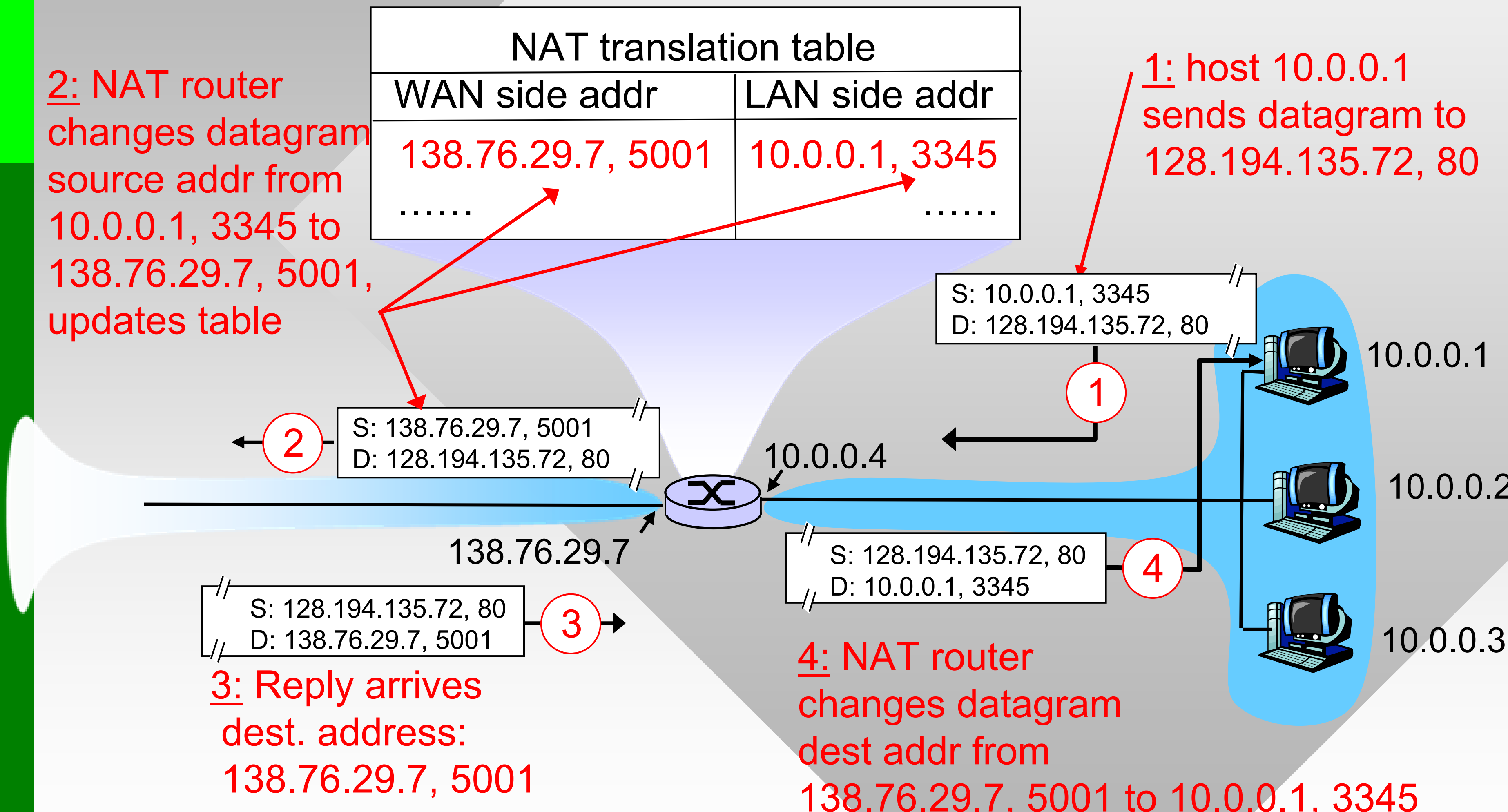
All datagrams *leaving* local network have the same single source NAT IP address: 138.76.29.7, different source port numbers

Datagrams with source or destination in this network have 10.0.0/24 address for source, destination (as usual)

NAT: Network Address Translation

- Local network uses just one IP address as far as the outside word is concerned
  - No need to be allocated a range of addresses from ISP – just one IP address is used for all devices
  - Can change addresses of devices in local network without notifying outside world
  - Can change ISP without changing addresses of devices in local network
  - Devices inside local net not explicitly addressable or visible to outside world (a security plus)
- To see your NAT IP and current NAT port, visit http://ipchicken.com/

NAT: Network Address Translation



WAN = Wide Area Network

NAT: Network Address Translation

- 16-bit port-number field
  - Up to 64K simultaneous connections with a single LAN-side address
- NAT is controversial:
  - Routers should only process up to layer 3
  - Violates the end-to-end argument
- Makes inbound connections difficult
  - Inbound connections needed in P2P and other applications
  - May be overcome by UPnP or manually configuring NAT to route incoming connections to a particular host
- Some believe that address shortage should instead be solved by IPv6

Chapter 4: Roadmap

4.1 Introduction

4.2 Virtual circuit and datagram networks

4.3 What's inside a router

4.4 IP: Internet Protocol

- Datagram format
- IPv4 addressing
- ICMP
- IPv6

4.5 Routing algorithms

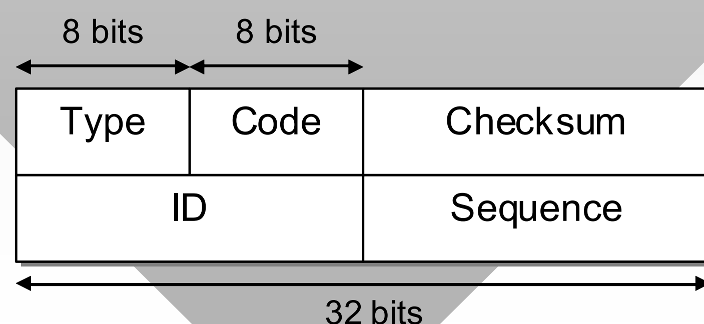
4.6 Routing in the Internet

4.7 Broadcast and multicast routing

ICMP: Internet Control Message Protocol

- Communicates network-level debug information
  - Error reporting: unreachable host, network, port, protocol
  - Echo request/reply (ping)
- Network-layer above IP
  - ICMP msgs carried in IP datagrams (“layer 3.5”)
- ICMP error message
  - Payload contains first 28 bytes of IP pkt 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
4	0	source quench (congestion control - not used)
8	0	echo request (ping)
9	0	router advertisement
10	0	router discovery
11	0	TTL expired
12	0	bad IP header



Traceroute and ICMP

- Source sends series of UDP segments to dest
  - First with TTL = 1
  - Second with TTL = 2
  - Unlikely port number
- When the n-th datagram arrives to the n-th router:
  - Router discards datagram
  - Sends to source a TTL Expired (type 11, code 0)
  - Message includes IP hdr from router & first 28 bytes of original packet
- When ICMP message arrives, source calculates RTT
  - Traceroute does this 3 times per hop

Stopping criterion

- UDP segment eventually arrives at destination host
  - Destination returns ICMP "port unreachable" packet (type 3, code 3)
  - When source gets this ICMP, it stops

Chapter 4: Roadmap

4.1 Introduction

4.2 Virtual circuit and datagram networks

4.3 What's inside a router

4.4 IP: Internet Protocol

- Datagram format
- IPv4 addressing
- ICMP
- IPv6

4.5 Routing algorithms

4.6 Routing in the Internet

4.7 Broadcast and multicast routing

IPv6

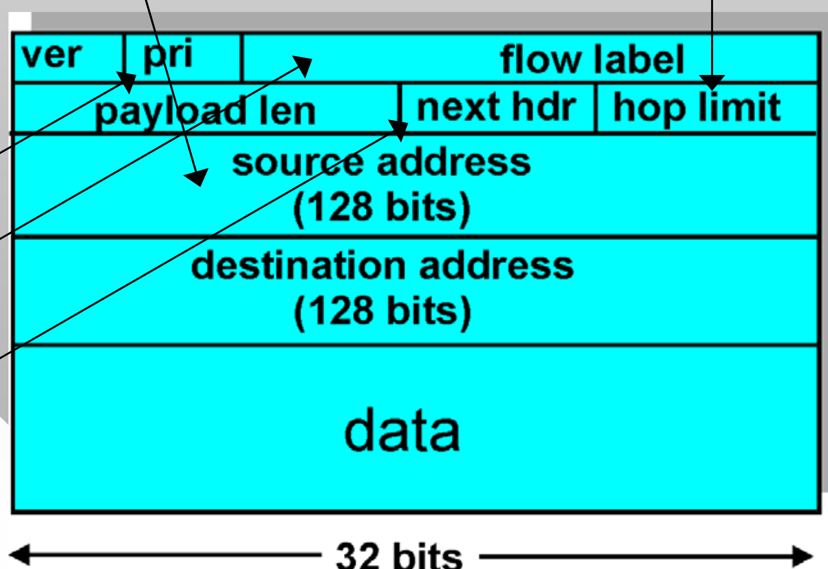
16-byte IP, e.g.,
FEBC:A574:382B:23C1:AA49:4592:4EFE:9982

- Initial motivation: 32-bit address space not large enough
- Additional motivation:
  - Simpler header format helps speed up forwarding
  - Header changes to facilitate QoS and extensions

TTL

IPv6 datagram format:

- Fixed-length 40 byte header
- No fragmentation allowed



priority of packet (QoS)

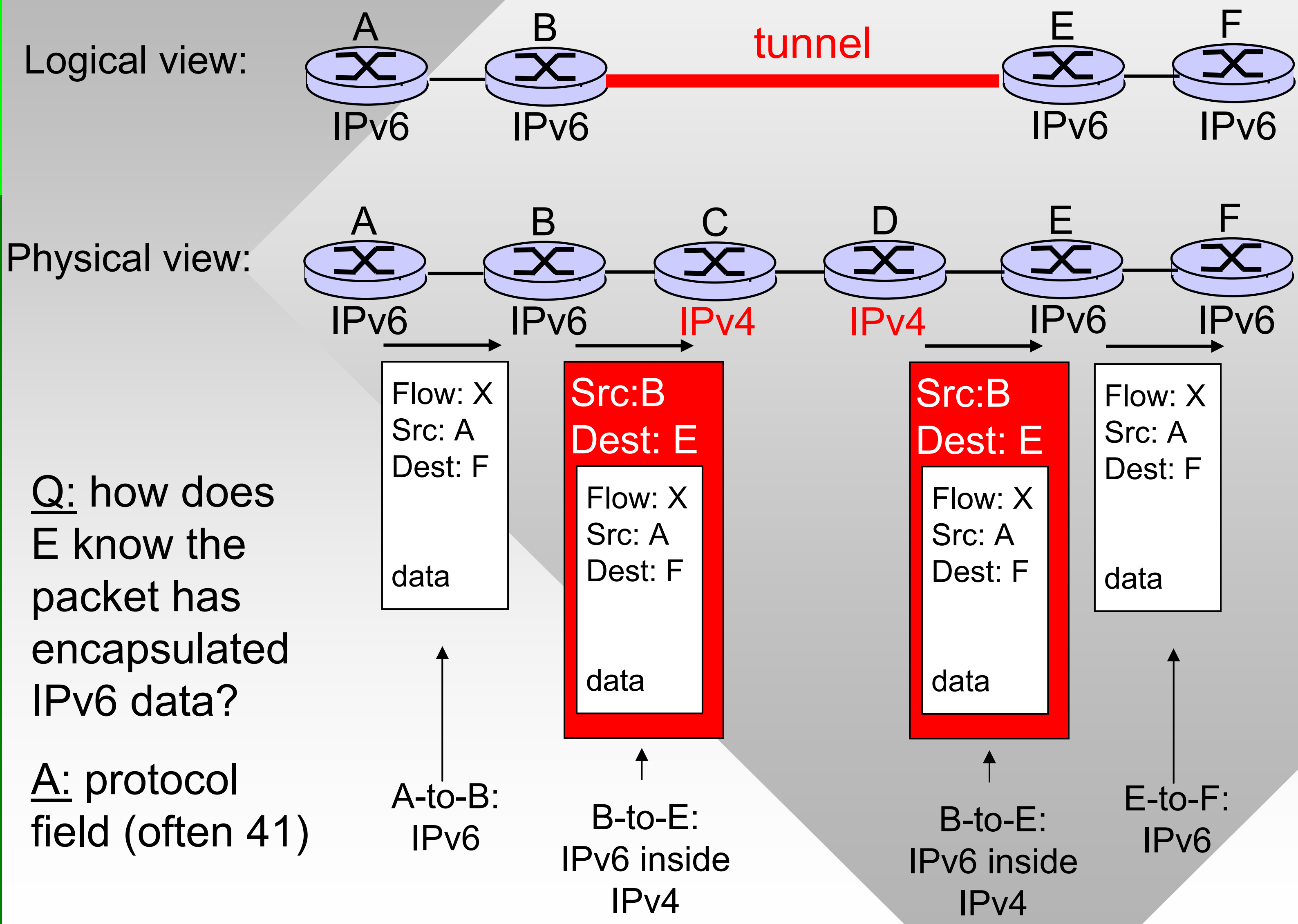
flow ID (not well defined)

upper-layer protocol (e.g., TCP, ICMP) or IPv6 extension header

IPv6 Notes

- *Checksum:* removed entirely to reduce processing time at each hop
  - Recall that IPv4 checksums the header only (TCP/UDP checksum the entire packet)
- *Options:* allowed, but outside of header, indicated by "Next Header" field
- All routers cannot be upgraded simultaneously
  - How will the network operate with mixed IPv4 / IPv6 routers?
- *Tunneling:* IPv6 carried as payload in IPv4 datagram among IPv4 routers

Tunneling



Q: how does E know the packet has encapsulated IPv6 data?

A: protocol field (often 41)

Chapter 4: Roadmap

4.1 Introduction

4.2 Virtual circuit and datagram networks

4.3 What's inside a router

4.4 IP: Internet Protocol

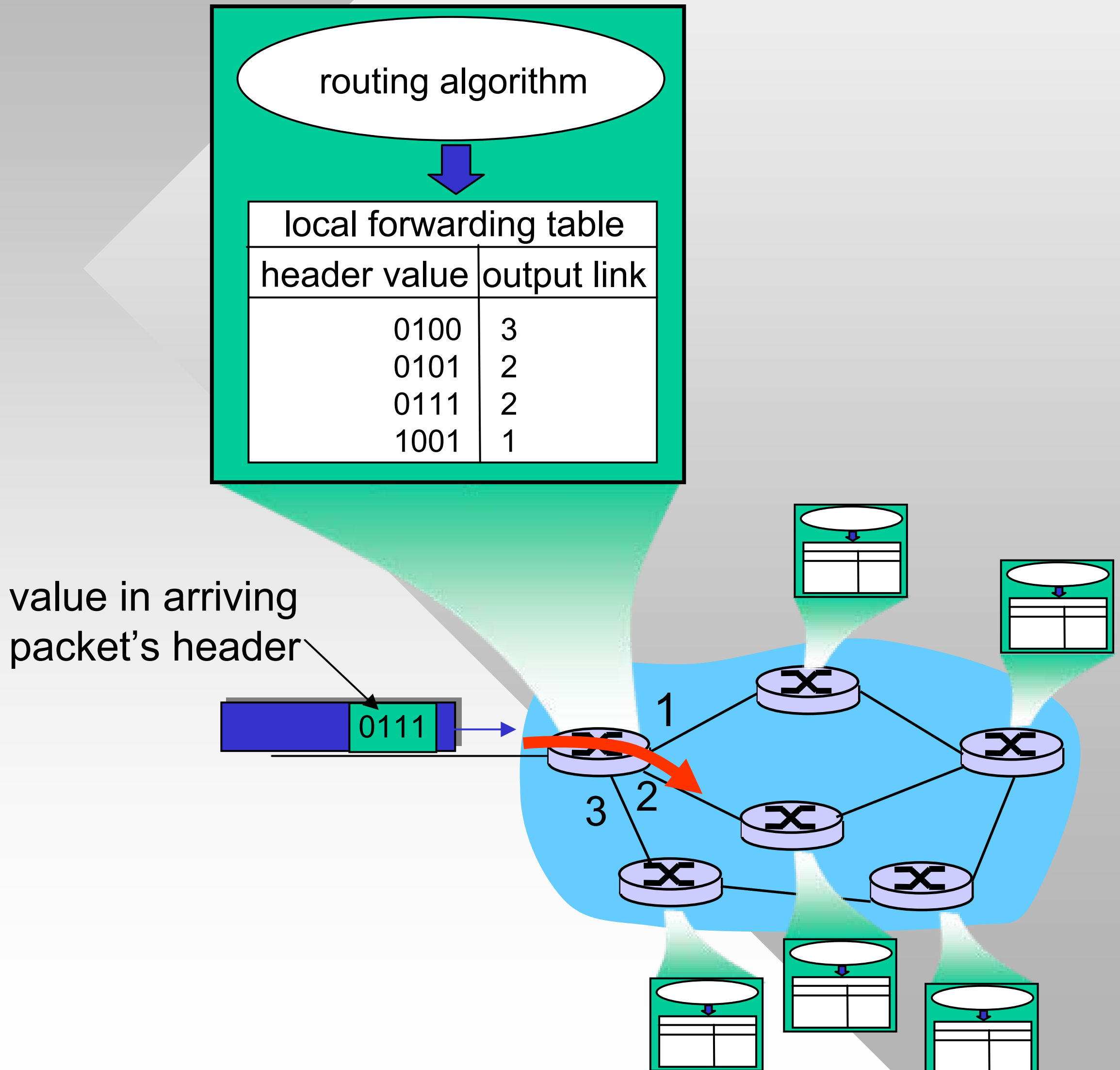
4.5 Routing algorithms

- Link state
- Distance Vector
- Hierarchical routing

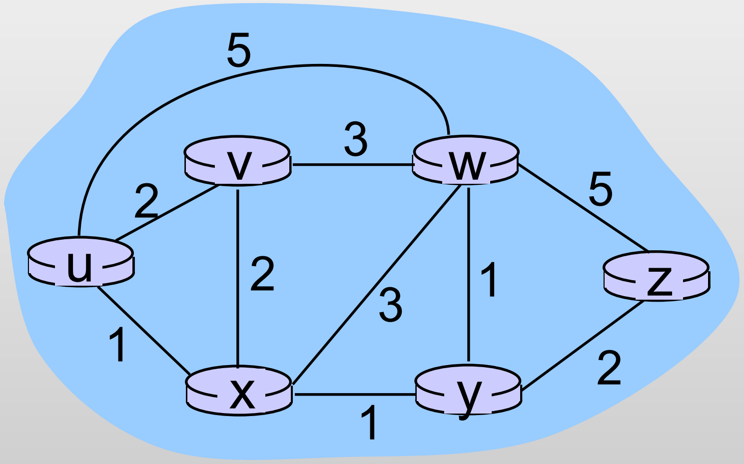
4.6 Routing in the Internet

4.7 Broadcast and multicast routing

Interplay Between Routing and Forwarding



Graph Abstraction

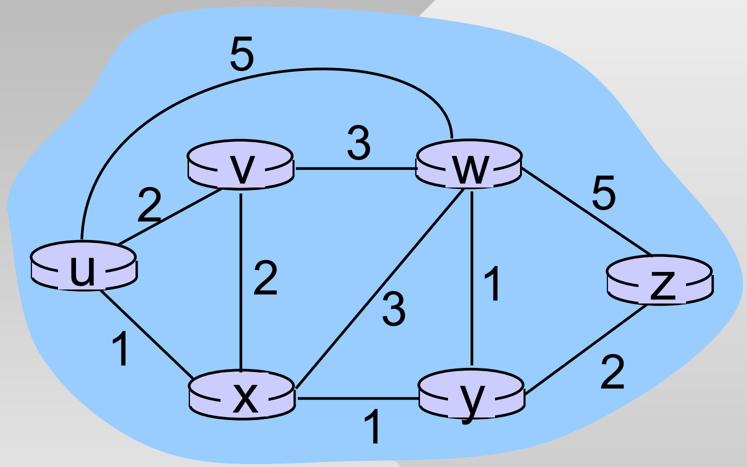


Graph: $G = (V, E)$

V = set of routers = $\{u, v, w, x, y, z\}$

E = set of links = $\{ (u,v), (u,x), (u,w), (v,x), (v,w), (x,w), (x,y), (w,y), (w,z), (y,z)\}$

Graph Abstraction: Costs



- $c(x,y)$ = cost of link (x,y)
  - E.g., $c(w,z) = 5$
- Cost options:
  - Could always be 1
  - Could be inversely related to bandwidth or be proportional to congestion
  - Physical distance

Cost of path $(x_1, x_2, x_3, \ldots, x_p) = c(x_1,x_2) + c(x_2,x_3) + \ldots + c(x_{p\text{-}1},x_p)$

Question: What's the least-cost path between u and z?

Routing algorithms find least-cost paths

Routing Algorithm Classification

Global or local information?

- Global:
  - Routers have complete topology, link cost info
  - “Link state” algorithms
- Local (decentralized):
  - Router knows physically-connected neighbors, link costs to neighbors
  - Iterative process of computation, exchange of info with neighbors
  - “Distance vector” algorithms

Static or dynamic?

- Static:
  - Useful when routes change slowly over time
  - Manual or DHCP-based route creation
- Dynamic:
  - Routes change more quickly
  - Periodic update in response to link cost changes

Chapter 4: Roadmap

Simple Link-State Routing Algorithm

Dijkstra's algorithm

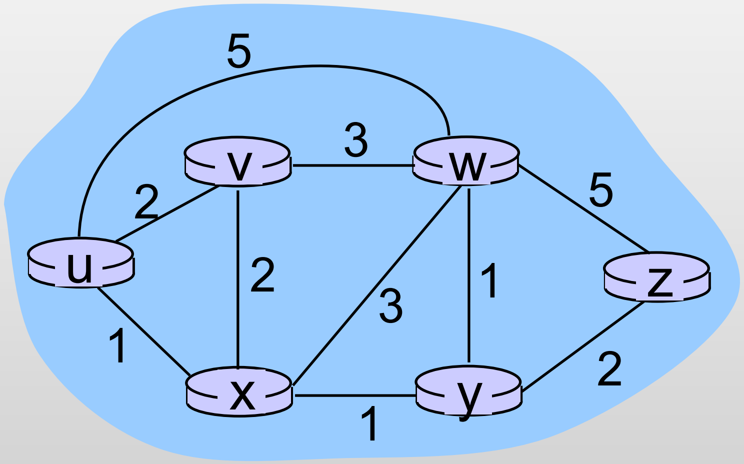
- Entire network topology and link costs known
  - Accomplished via "link state broadcast"
  - Eventually, all nodes have same info
- Computes least cost paths from one node ("source") to all other nodes
  - Gives forwarding table for that node

- *Iterative*: after k iterations, know least-cost path to k closest destinations

Notation:

- $c(x,y)$: link cost from x to y
  - Cost is ∞ if not direct neighbors
- $D(v)$: current estimate of the cost from source to destination v
- $p(v)$: predecessor of v along the least-cost path back to source
- F : set of closest nodes whose least-cost path has been finalized (i.e., known for a fact)

Dijsktra's Algorithm



Initialization:

$F = \{u\}$, $D(u) = 0$

for all nodes $v \neq u$

if v is adjacent to u

$D(v) = c(u,v)$

else

$D(v) = \infty$

do {

find node i not in F such that $D(i)$ is minimum

add i to F

for all j adjacent to i and not in F:

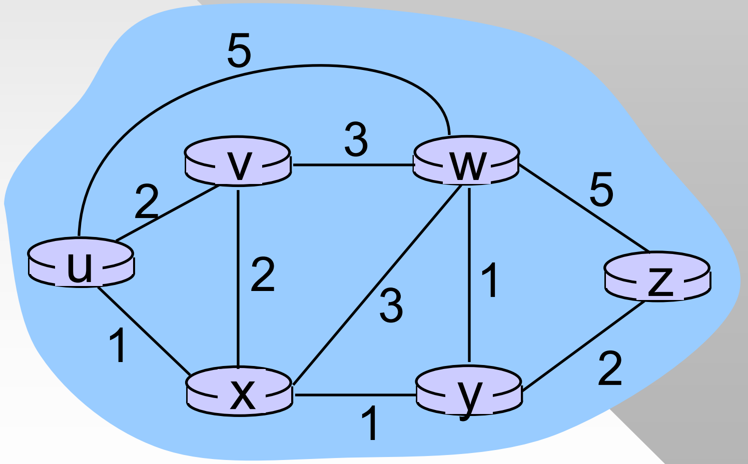
$D(j) = \min(D(j),\ D(i) + c(i,j))$

/* new cost to j is either old cost to j or known shortest path cost to i plus cost from i to j */

} while (not all nodes in F)

Dijkstra's Algorithm: Example

Step	F	$D(v),p(v)$	$D(w),p(w)$	$D(x),p(x)$	$D(y),p(y)$	$D(z),p(z)$
0	u	2,u	5,u	1,u	∞	∞
1	ux	2,u	4,x		2,x	∞
2	uxy	2,u	3,y			4,y
3	$uxyv$		3,y			4,y
4	$uxyvw$					4,y
5	$uxyvwz$					



Dijkstra’s Algorithm Discussion

Algorithm complexity: n nodes

- Iteration k: need to find min of $(n–k)$ costs, visit d_i neighbors
- Naïve implementation: $O(|E|+|V|^2)$ complexity
- Heap-based implementation: $O(|E|+|V|\cdot\log|V|)$

Oscillations possible, but only for traffic-dependent cost:

- e.g., Link cost $=$ amount of carried traffic