COMP 3331/9331: Computer Networks and Applications

Week 8

Network Layer: Data Plane (contd.)

Reading Guide: Chapter 4: 4.3

Network Layer, data plane: outline

4.1 Overview of Network layer
- data plane
- control plane

4.2 What's inside a router

4.3 IP: Internet Protocol
- datagram format
- fragmentation
- IPv4 addressing
- network address translation
- IPv6

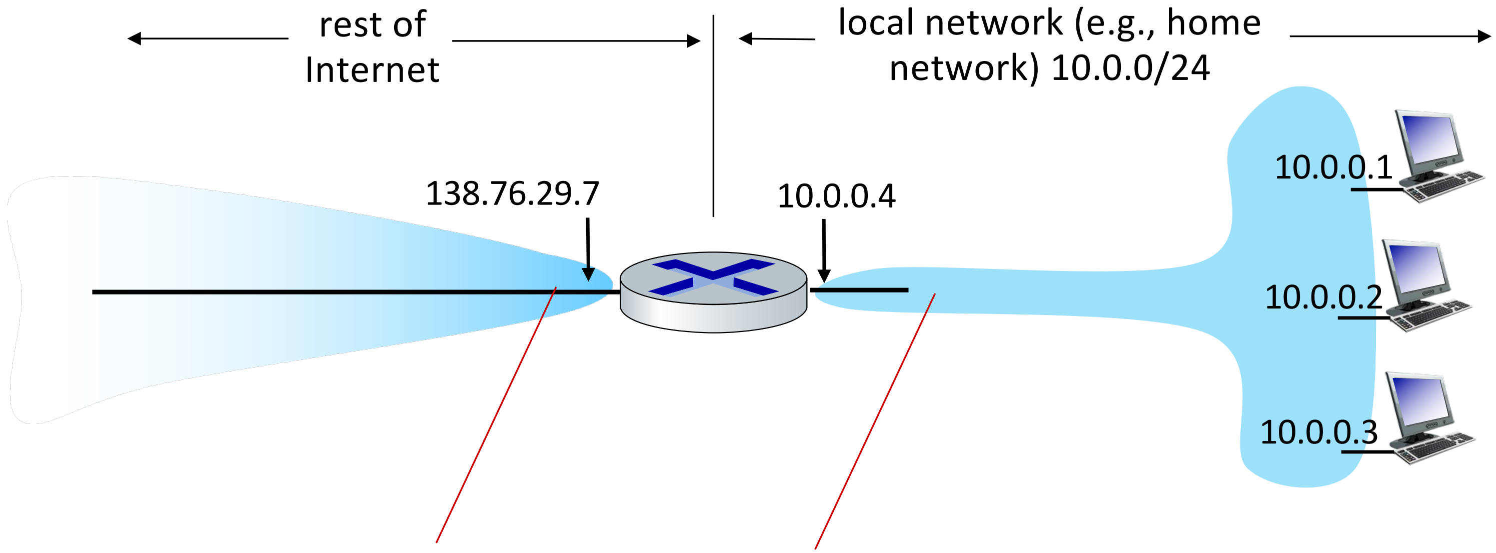
Private Addresses

- Defined in RFC 1918:
  - 10.0.0.0/8 (16,777,216 hosts)
  -172.16.0.0/12 (1,048,576 hosts)
  -192.168.0.0/16 (65536 hosts)

- These addresses cannot be routed
  - Anyone can use them in a private network
  -Typically used for NAT

NAT: network address translation

NAT: all devices in local network share just one IPv4 address as far as outside world is concerned



all datagrams *leaving* local network have *same* source NAT IP address: 138.76.29.7, but *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

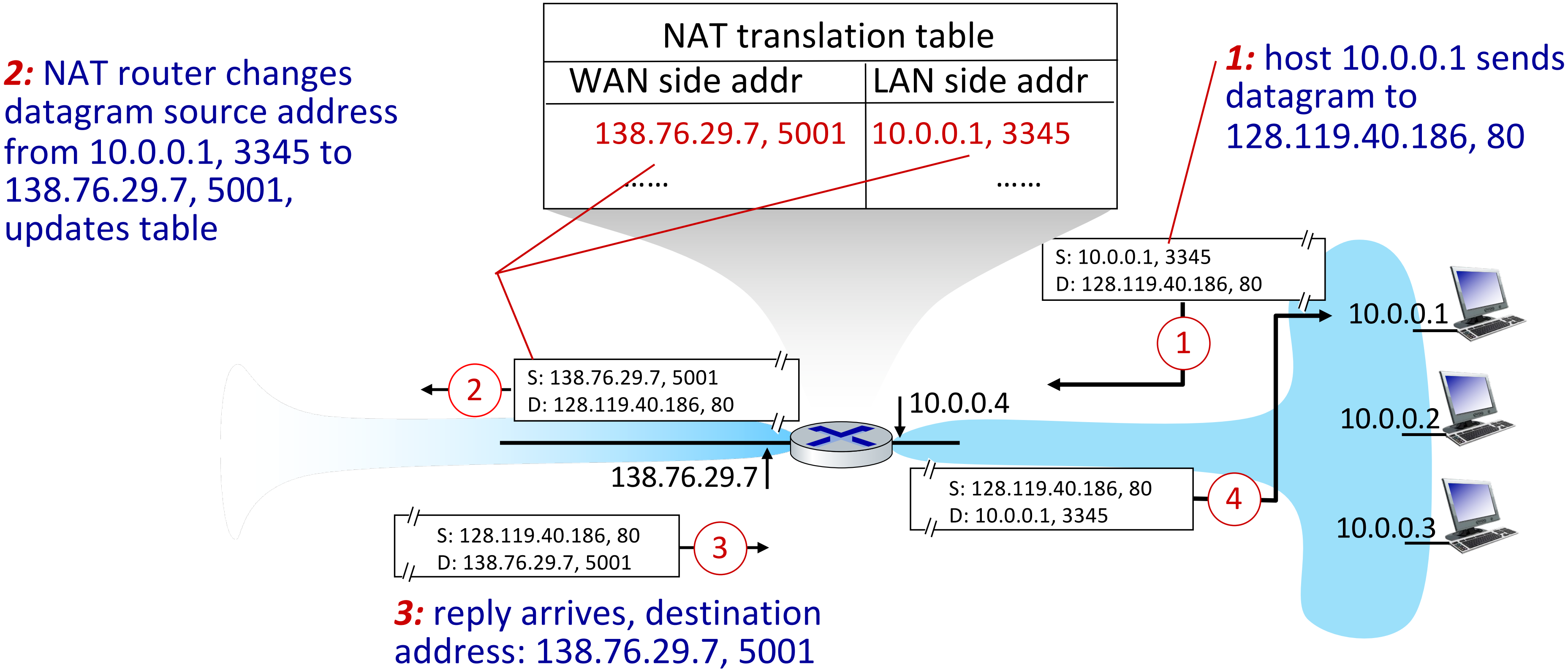
- all devices in local network have 32-bit addresses in a "private" IP address space (10/8, 172.16/12, 192.168/16 prefixes) that can only be used in local network
- advantages:
  - just one IP address needed from provider ISP for *all* devices
  - can change addresses of host in local network without notifying outside world
  - can change ISP without changing addresses of devices in local network
  - security: devices inside local net not directly addressable, visible by outside world

NAT: network address translation

implementation: NAT router must (transparently):

- outgoing datagrams: replace (source IP address, port #) of every outgoing datagram to (NAT IP address, new port #)
  - remote clients/servers will respond using (NAT IP address, new port #) as destination address
- remember (in NAT translation table) every (source IP address, port #) to (NAT IP address, new port #) translation pair
- incoming datagrams: replace (NAT IP address, new port #) in destination fields of every incoming datagram with corresponding (source IP address, port #) stored in NAT table

NAT: network address translation



NAT: network address translation

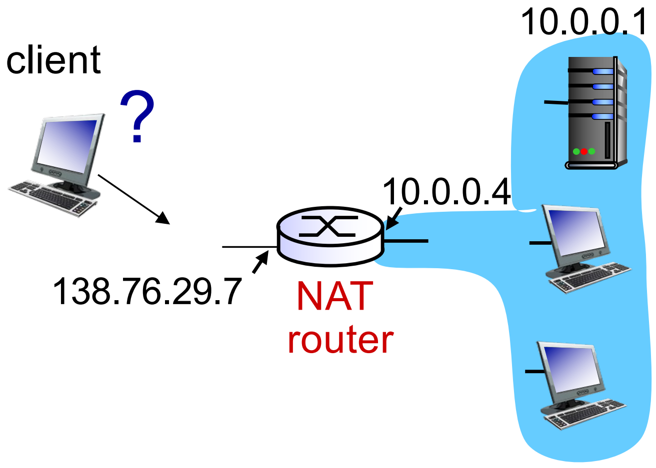
- NAT has been controversial:
  - routers "should" only process up to layer 3
  - address "shortage" should be solved by IPv6
  - violates end-to-end argument (port # manipulation by network-layer device)
  - NAT traversal: what if client wants to connect to server behind NAT?
- but NAT is here to stay:
  - extensively used in home and institutional nets, 4G/5G cellular nets

NAT: Practical Issues

- NAT modifies port # and IP address
  - *Requires recalculation of TCP and IP checksum*
- Some applications embed IP address or port numbers in their message payloads
  - DNS, FTP (PORT command), SIP, H.323
  - For legacy protocols, NAT must look into these packets and translate the embedded IP addresses/port numbers
  - Duh, What if these fields are encrypted ?? (SSL/TLS, IPSEC, etc.)
  - **Q: In some cases, why may NAT need to change TCP sequence number?? (Discussion Question on Website)**
- If applications change port numbers periodically, the NAT must be aware of this

NAT traversal problem

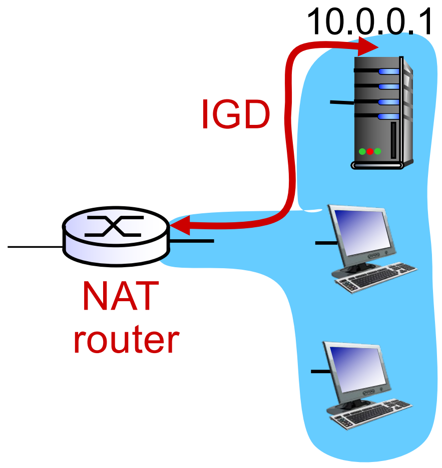
- client wants to connect to server with address 10.0.0.1
  - server address 10.0.0.1 local to LAN (client can't use it as destination addr)
  - only one externally visible NATed address: 138.76.29.7
- *Solution1:* Inbound-NAT Statically configure NAT to forward incoming connection requests at given port to server
  - e.g., (138.76.29.7, port 2500) always forwarded to 10.0.0.1 port 25000



NAT traversal problem

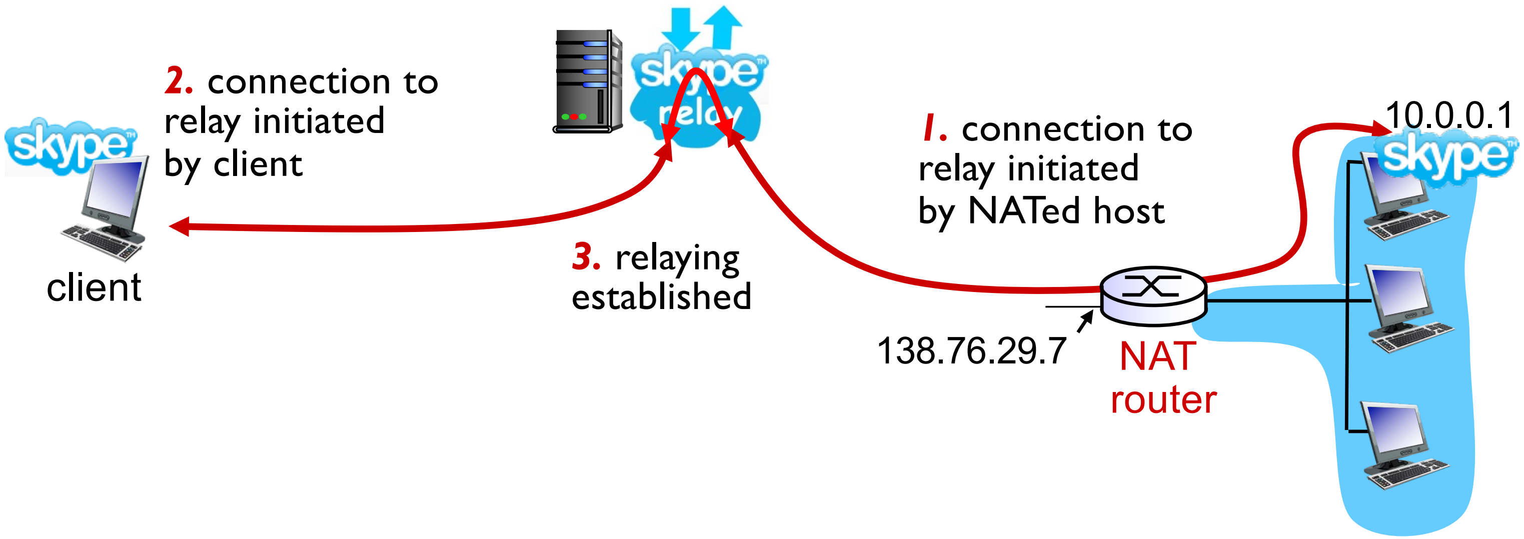
- *solution 2:* Universal Plug and Play (UPnP) Internet Gateway Device (IGD) Protocol. Allows NATed host to:
  - learn public IP address (138.76.29.7)
  - add/remove port mappings (with lease times)

  i.e., automate static NAT port map configuration



NAT traversal problem

- *solution 3:* relaying (used in Skype)
  - NATed client establishes connection to relay
  - external client connects to relay
  - relay bridges packets between to connections

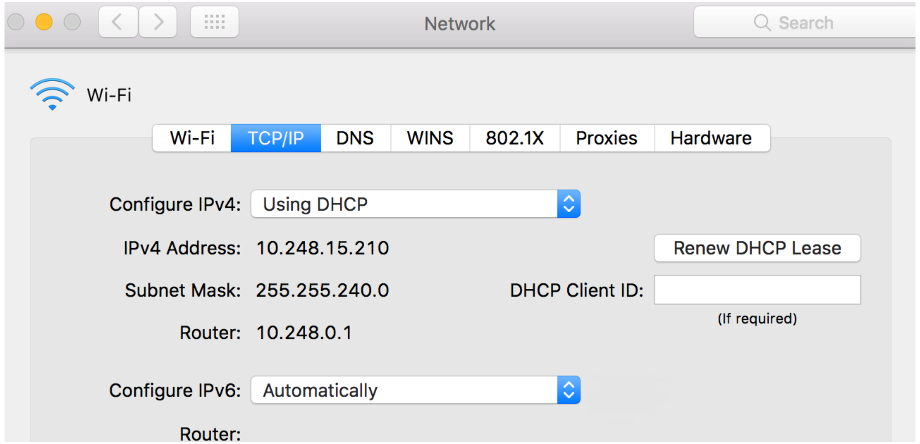


NAT: Devil in the details

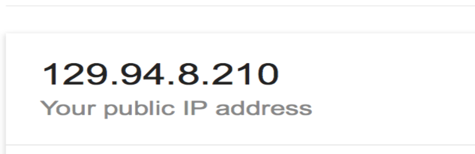
- Despite the problems, NAT has been widely deployed
- Most protocols can be successfully passed through a NAT, including VPN
- Modern hardware can easily perform NAT functions at > 100 Mbps
- IPv6 is still not widely deployed commercially, so the need for NAT is real
- After years of refusing to work on NAT, the IETF has been developing "NAT control protocols" for hosts
- Lot of practical variations
    - Full-cone NAT, Restricted Cone NAT, Port Restricted Cone NAT, Symmetric NAT, …..
        - The devil is in the detail (NOT COVERED IN THE COURSE)

Quiz

- The picture below shows you the IP address of my machine connected to the uniwide wireless network.



- However when I ask Google it says my IP address is as noted below. Can you explain the discrepancy?



Answer: My address belongs to the 10.0.0./8 address block with is a private address block which means I am behind a NAT Router. The address reported by Google is the public WAN side IP address of the NAT router.

Quiz: NAT

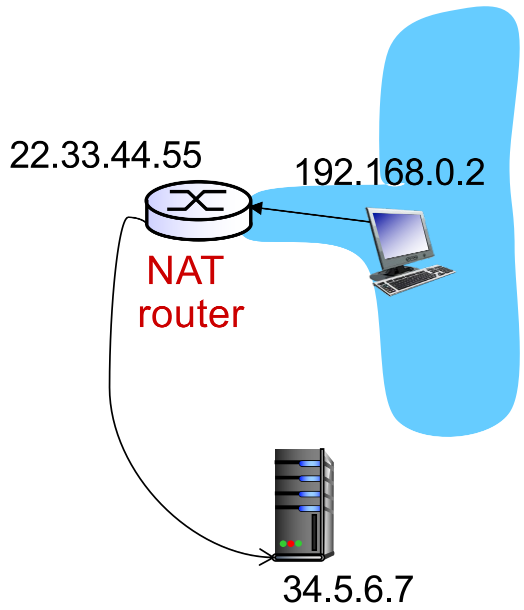
A host with a private IP address 192.168.0.2 opens a TCP socket on its local port 4567 and connects to a web server at 34.5.6.7. The NAT's public IP address is 22.33.44.55. Which of the following mapping entries *could* the NAT create as a result?

A. [22.33.44.55, 4567]→[192.168.0.2, 80]

B. [34.5.6.7, 80] → [22.33.44.55, 4567]

C. [192.168.0.2, 80]→[34.5.6.7, 4567]

D. [22.33.44.55, 3967]→[192.168.0.2, 4567]



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Answer: D

Quiz: NAT

A host with a private IP address 192.168.0.2 opens a TCP socket on its local port 4567 and connects to a web server at 34.5.6.7. The NAT's public IP address is 22.33.44.55. Suppose the NAT created the mapping [22.33.44.55, 3967]→[192.168.0.2, 4567] as a result. What are the source and destination port numbers in the SYN-ACK response from the server?

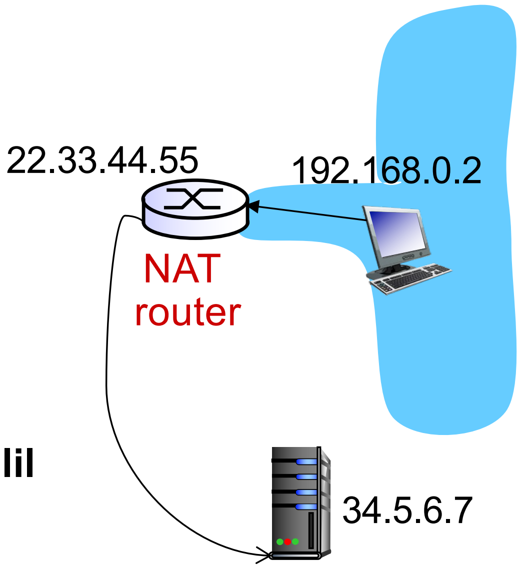
A. 80, 3967

B. 4567, 80

C. 3967, 80

D. 3967, 4567

E. 80, 4567



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Answer: A

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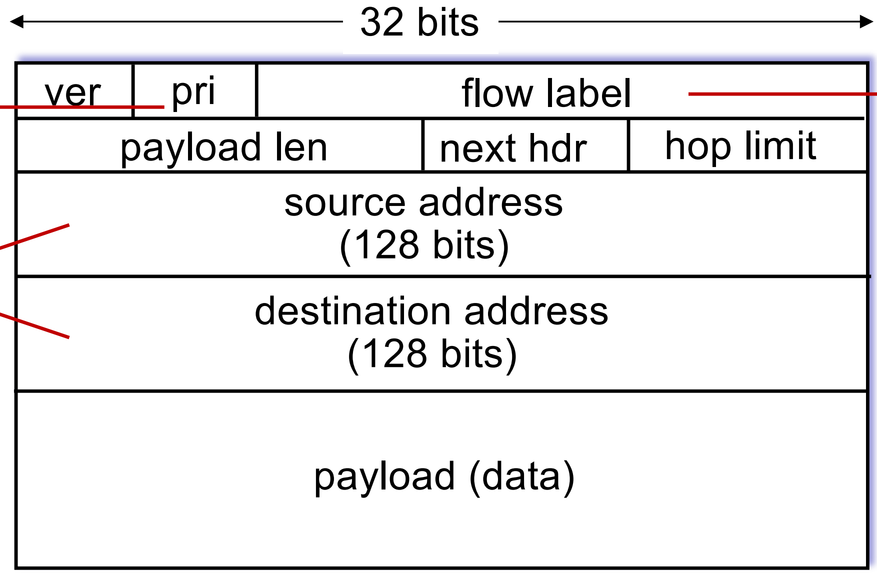
IPv6: motivation

- initial motivation: 32-bit IPv4 address space would be completely allocated
- additional motivation:
  - speed processing/forwarding: 40-byte fixed length header
  - enable different network-layer treatment of “flows”

IPv6 datagram format

priority: identify priority among datagrams in flow

128-bit IPv6 addresses



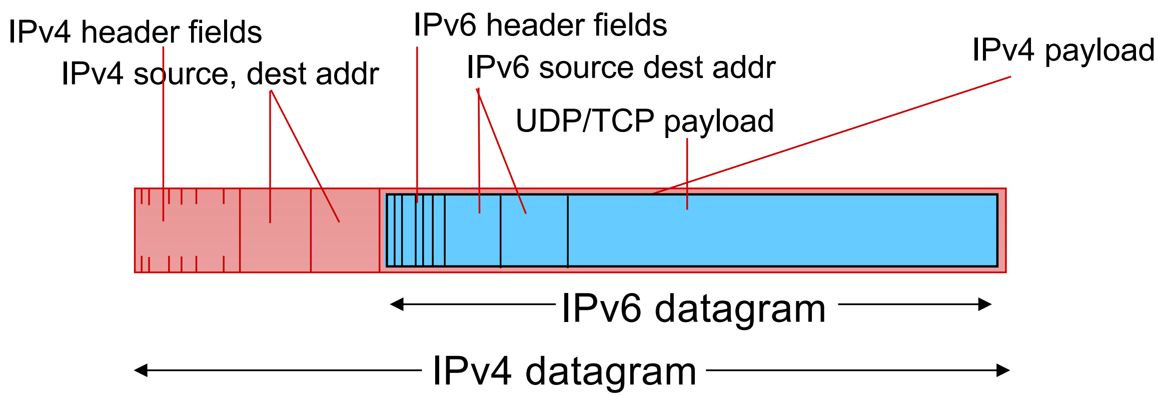
flow label: identify datagrams in same "flow." (concept of "flow" not well defined).

What's missing (compared with IPv4):

- no checksum (to speed processing at routers)
- no fragmentation/reassembly
- no options (available as upper-layer, next-header protocol at router)

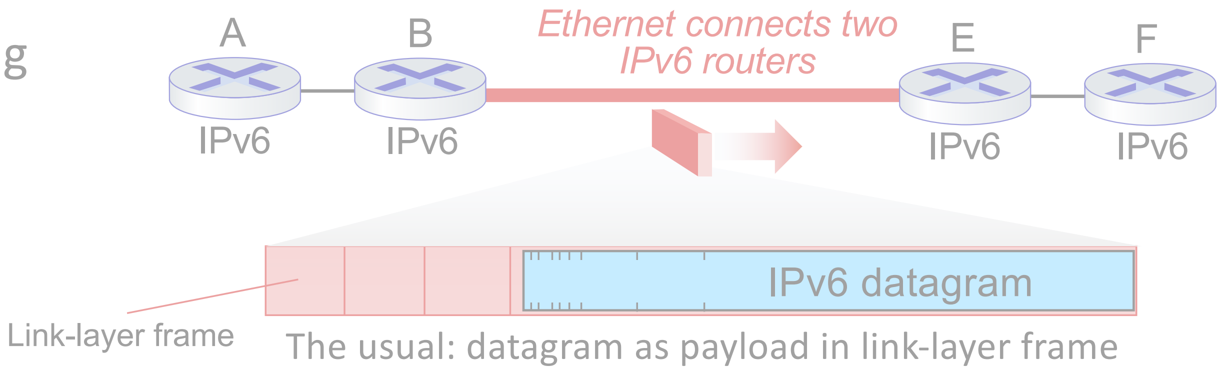
Transition from IPv4 to IPv6

- not all routers can be upgraded simultaneously
  - no "flag days"
  - how will network operate with mixed IPv4 and IPv6 routers?
- tunneling: IPv6 datagram carried as *payload* in IPv4 datagram among IPv4 routers ("packet within a packet")
  - tunneling used extensively in other contexts (4G/5G)

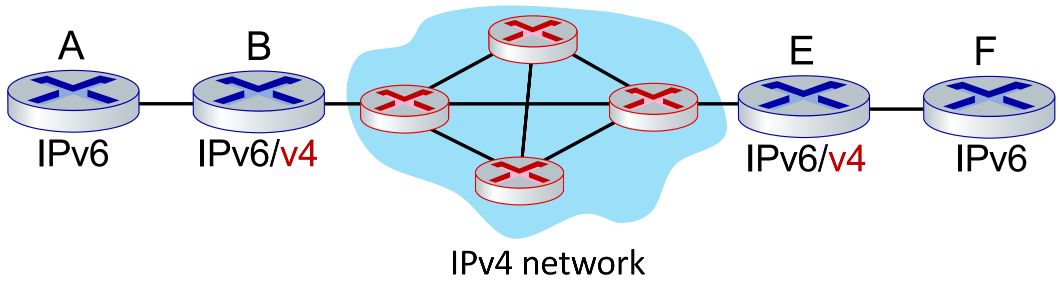


Tunneling and encapsulation

Ethernet connecting two IPv6 routers:

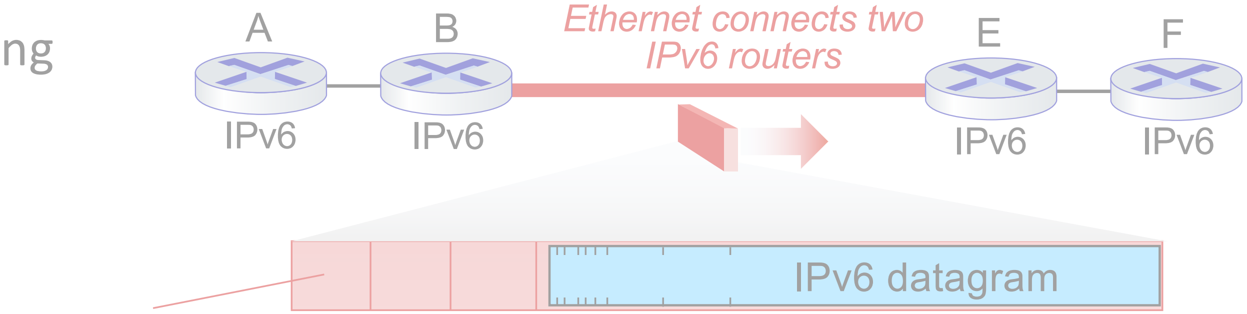


IPv4 network connecting two IPv6 routers



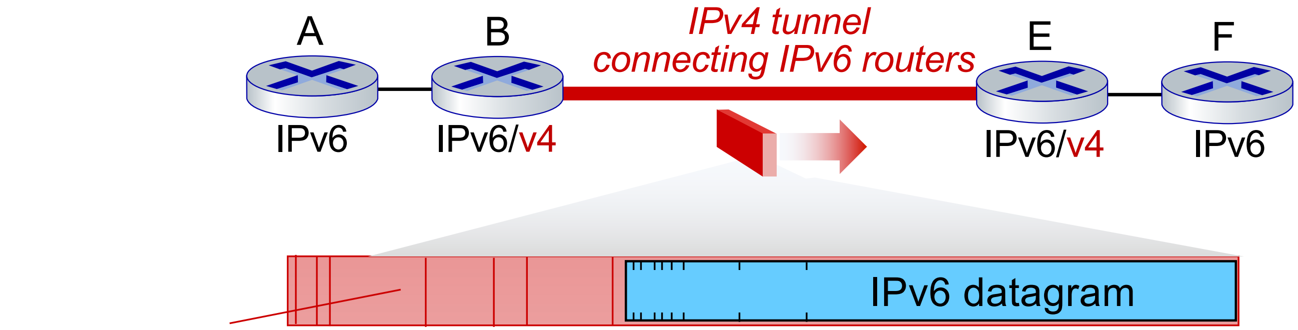
Tunneling and encapsulation

Ethernet connecting two IPv6 routers:



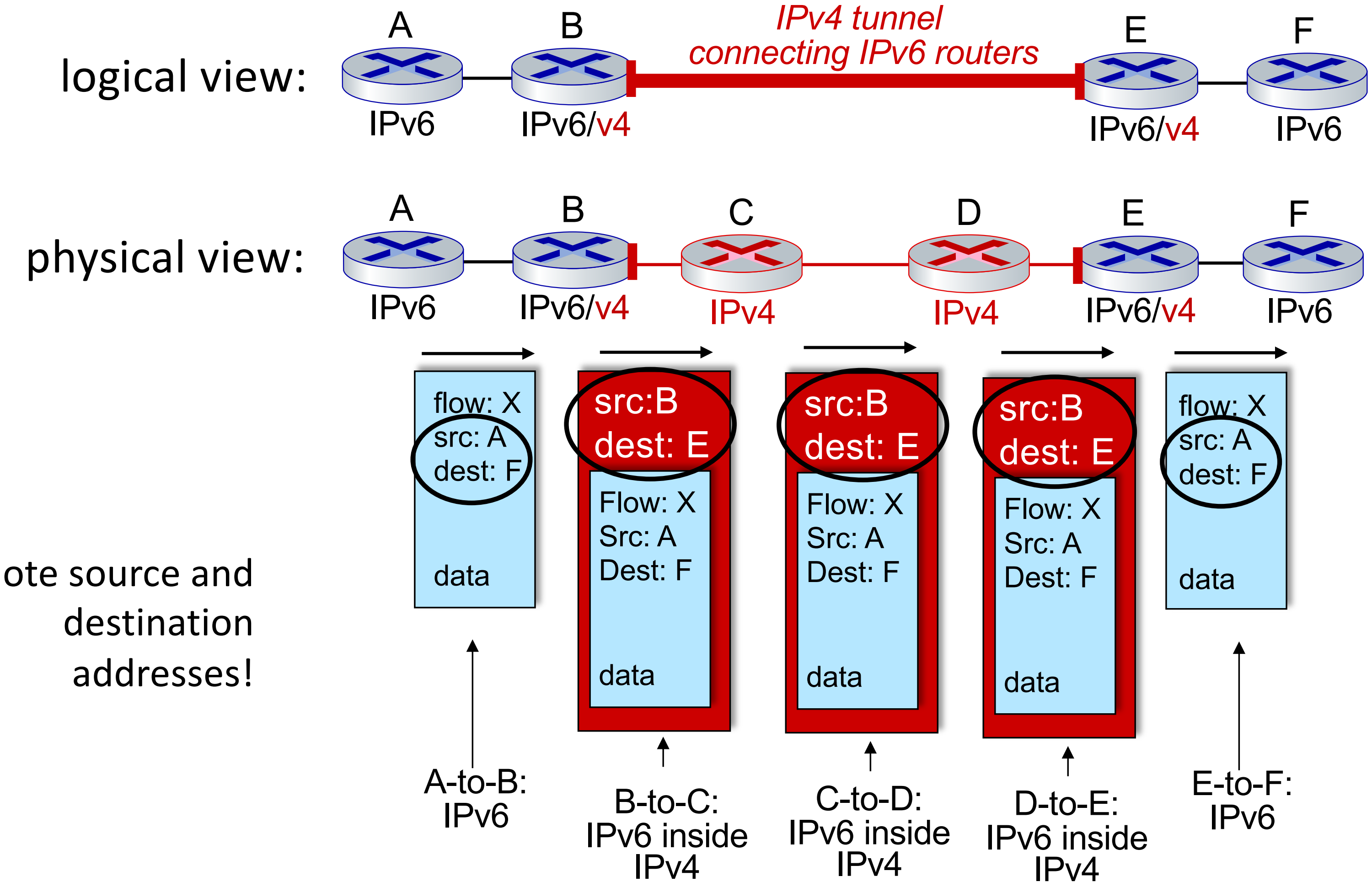
The usual: datagram as payload in link-layer frame

IPv4 tunnel connecting two IPv6 routers



tunneling: IPv6 datagram as payload in a IPv4 datagram

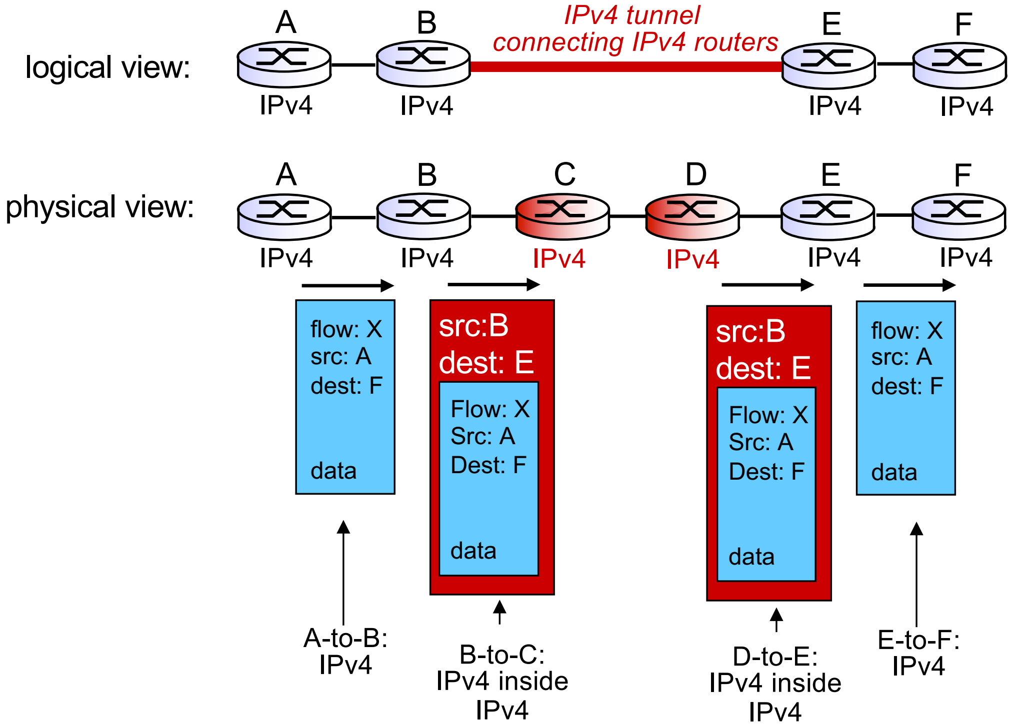
Tunneling



Note source and destination addresses!

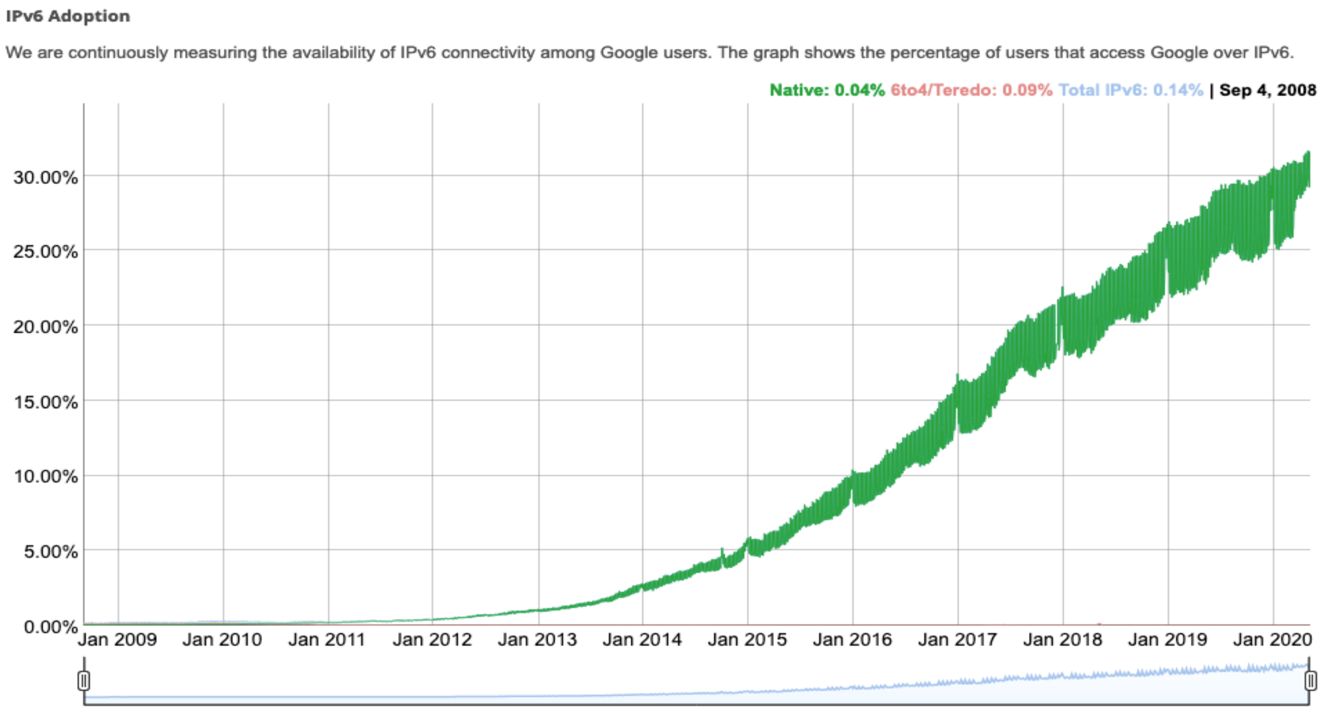
Tunneling (IPv4 over IPv4)

Used in VPNs



IPv6: adoption

- Google[1]: ~ 30% of clients access services via IPv6
- NIST: 1/3 of all US government domains are IPv6 capable



1 https://www.google.com/intl/en/ipv6/statistics.html

IPv6: adoption

- Google[1]: ~ 30% of clients access services via IPv6
- NIST: 1/3 of all US government domains are IPv6 capable
- Long (long!) time for deployment, use
  - 25 years and counting!
  - think of application-level changes in last 25 years: WWW, social media, streaming media, gaming, telepresence, …
  - *Why?*

[1] https://www.google.com/intl/en/ipv6/statistics.html