National University of Computer & Emerging Sciences

CS 3001 - COMPUTER NETWORKS

Lecture 18

Chapter 4

27th March, 2025

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Office Hours: 11:30 am till 01:00 pm (Every Tuesday & Thursday)

Chapter 4
Network Layer: Data Plane

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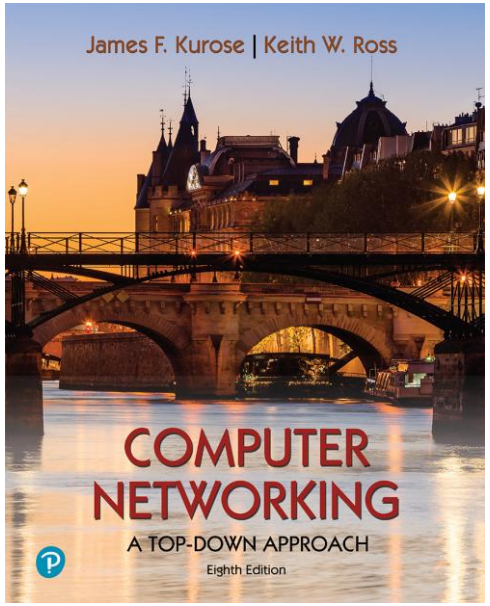
Thanks and enjoy! JFK/KWR



Computer Networking: A Top-Down Approach
8th edition
Jim Kurose, Keith Ross
Pearson, 2020

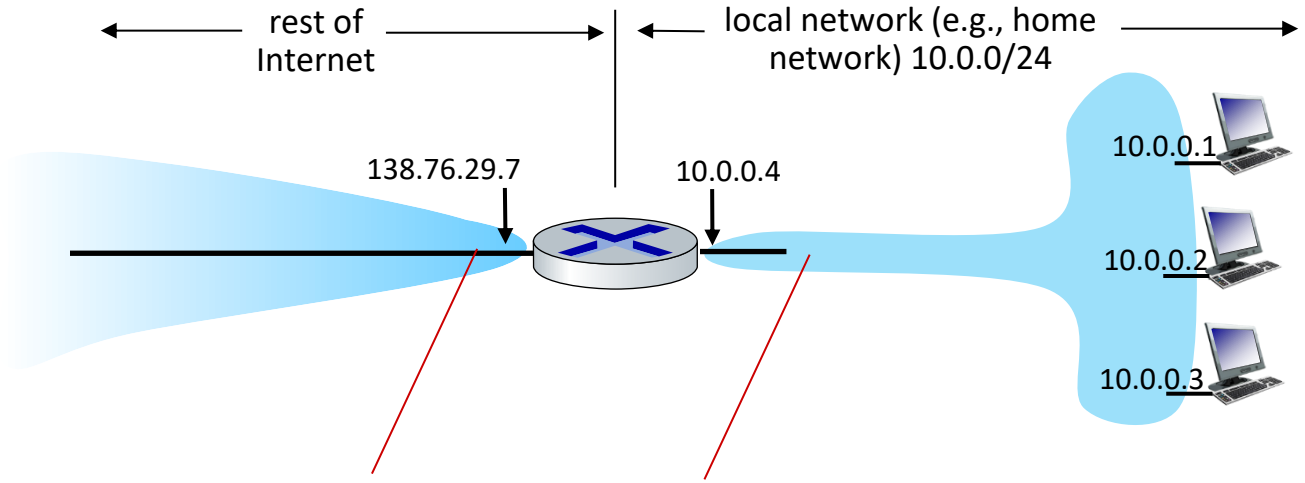
Network layer: "data plane" roadmap

- Network layer: overview
  - data plane
  - control plane
- What's inside a router
  - input ports, switching, output ports
  - buffer management, scheduling
- IP: the Internet Protocol
  - datagram format
  - addressing
  - network address translation
  - IPv6

- Generalized Forwarding, SDN
  - match+action
  - OpenFlow: match+action in action
- Middleboxes

NAT: network address translation (PAT is extension of NAT)

NAT: all devices in local network share just one (public) 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

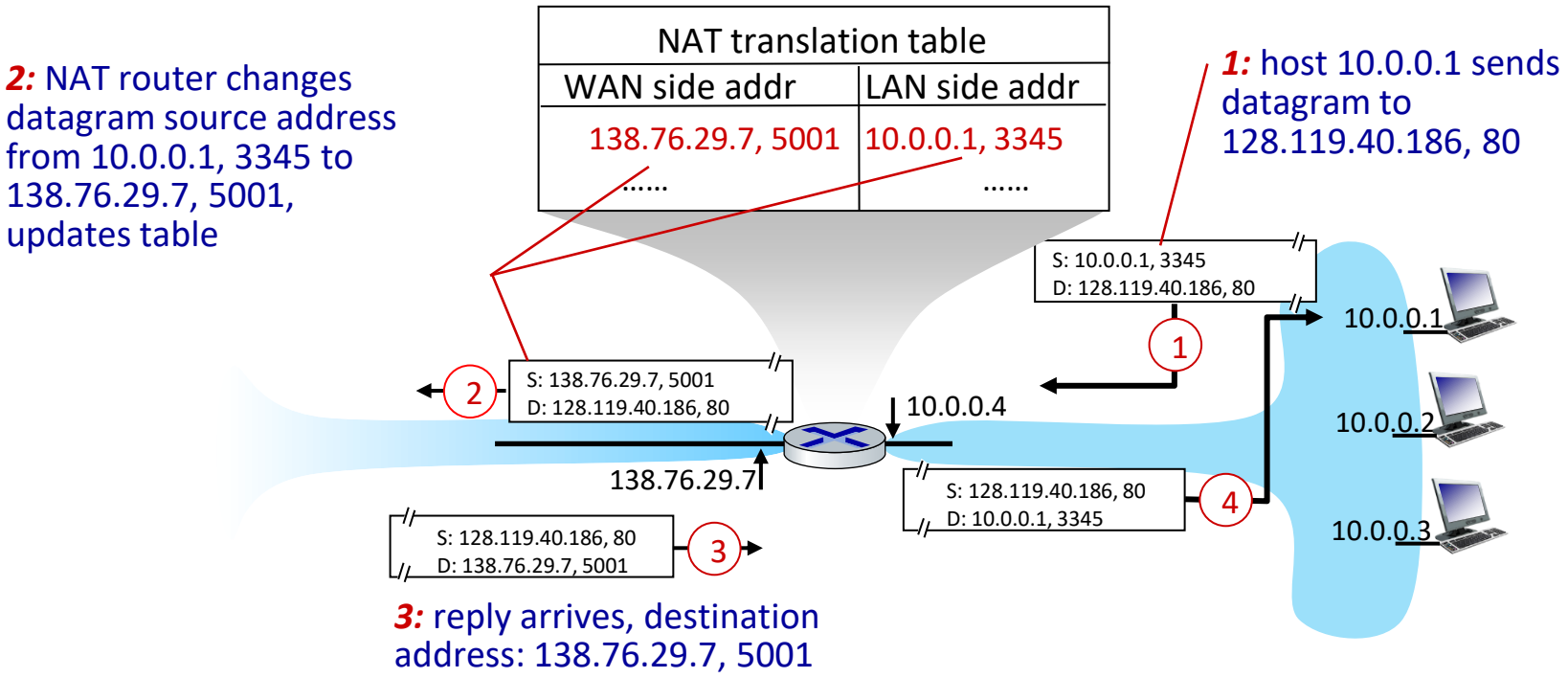
- all devices in local network have 32-bit addresses in a "private" IP address space (10/8, 172.16/12, 192.168/16 prefixes) that can only be used in local network
- advantages:
  - just one IP address needed from provider ISP for *all* devices
  - can change addresses of host in local network without 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
- Implemented in the border (access) router separating the private & the public network
- Was introduced with Windows 2000

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
  - ***Study*** NAT Traversal Problem & Solutions (including static configuration, UPnP / IGD & relaying)

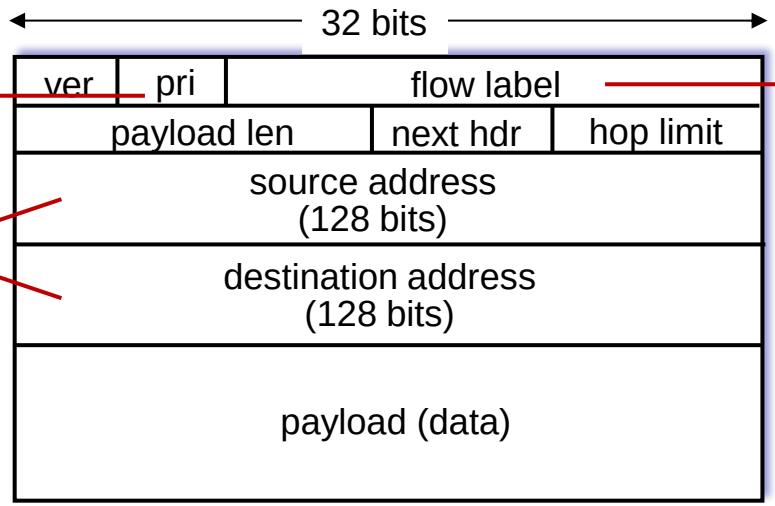
IPv6: motivation

- 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

traffic class / priority: identify priority among datagrams in flow

128-bit IPv6 addresses

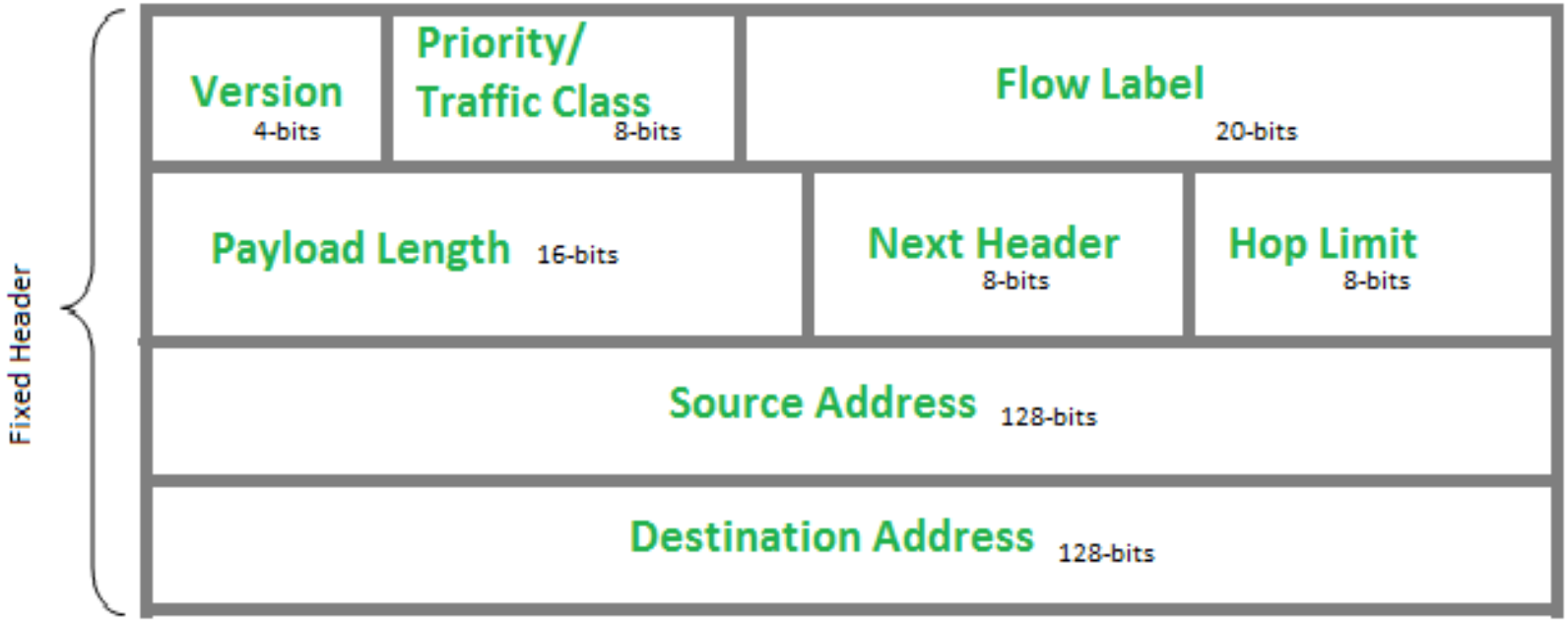


flow label: identify datagrams in same "flow." (concept of "flow" not well defined).

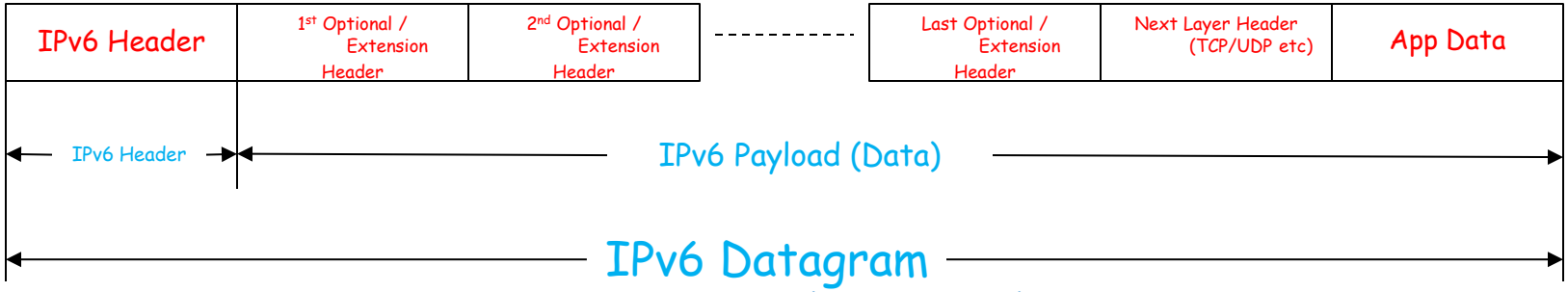
What's missing (compared with IPv4): (Changes from IPv4)

- no checksum (to speed processing at routers)
- no fragmentation/reassembly
- no options (not part of the standard IP header but can be outside of header, indicated by "Next Header" field.)
- 40 byte fixed header length

IPv6 Header


Fixed Header
Version
4-bits
Priority/
Traffic Class
8-bits
Flow Label
20-bits
Payload Length
16-bits
Next Header
8-bits
Hop Limit
8-bits
Source Address
128-bits
Destination Address
128-bits

IPv6 Next Header Field



- *An IPv6 packet header always present and of fixed size (i.e. 40 bytes)*

- *Zero or more optional / extension header(s) can be present (all can be of varying lengths)*

- *The Next Header Field is present in all the headers, including the IPv6 fixed header and any optional / extension header(s)*

- *The Next Header Field in the last optional / extension header (or in the IPv6 Fixed header in case there is no optional / extension header) indicates the upper layer protocol (such as TCP, UDP, or ICMPv6 etc.)*

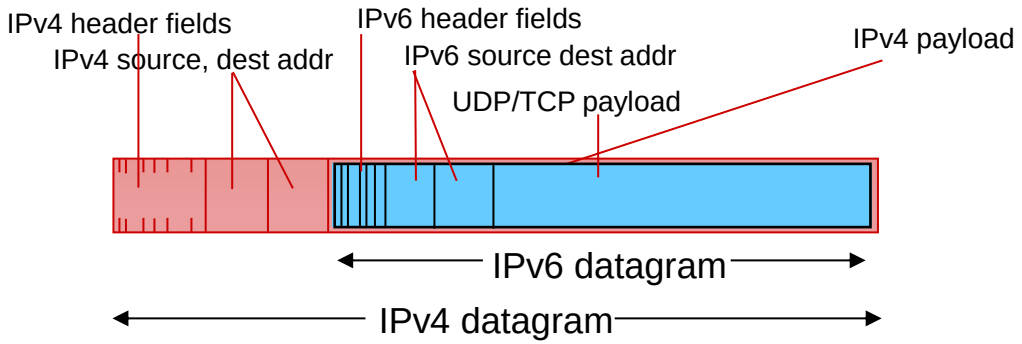
- *Unlike options in the IPv4 header, IPv6 optional / extension headers have no maximum size and can expand to accommodate all the extension data needed for IPv6 communication.*

- *While 256 next header values are possible, some typical Next Header values are given below:*

Value in Decimal	Header
6	TCP
17	UDP
58	ICMPv6
59	No Next Header
0	Hop-by-Hop Options Extension Header
43	Routing Extension Header

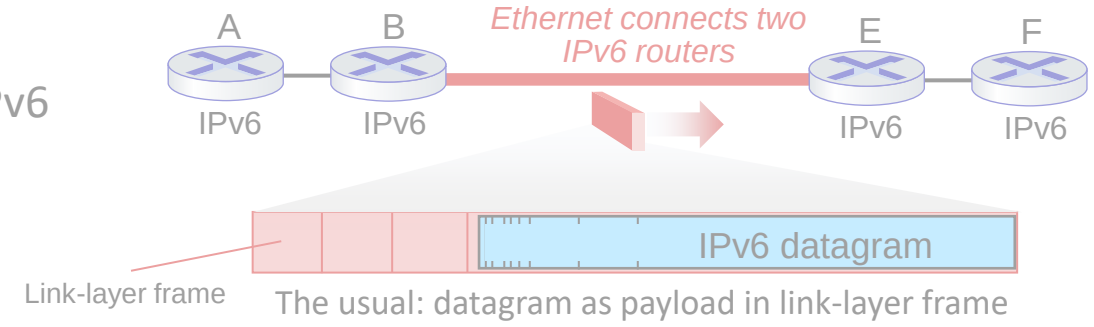
Transition from IPv4 to IPv6

- 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)
  - Also study dual stack approach (& it’s issue) for transitioning from IPv4 to IPv6

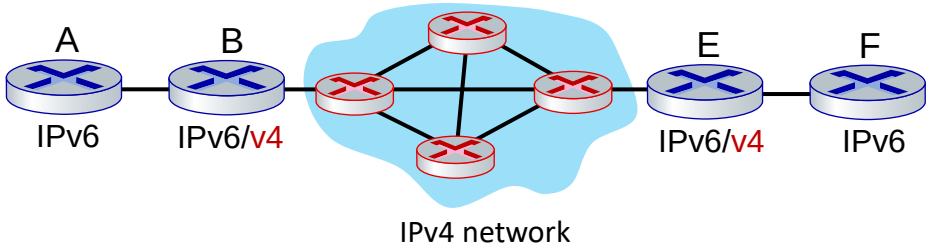


Tunneling and encapsulation

Ethernet connecting two IPv6 routers:



IPv4 network connecting two IPv6 routers



Tunneling and encapsulation

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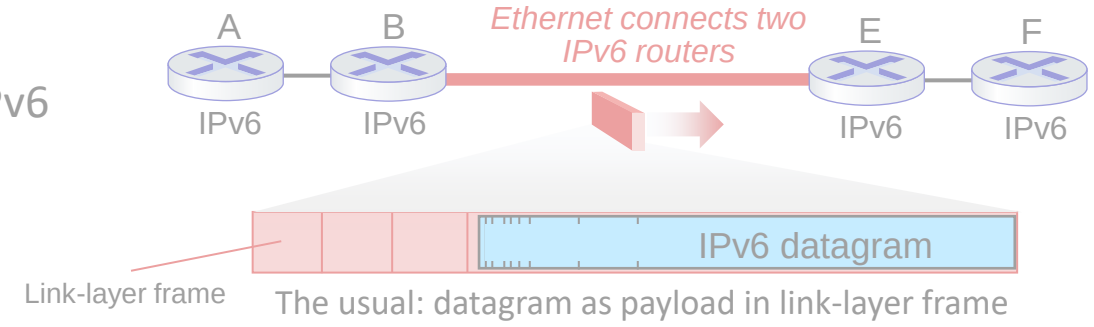
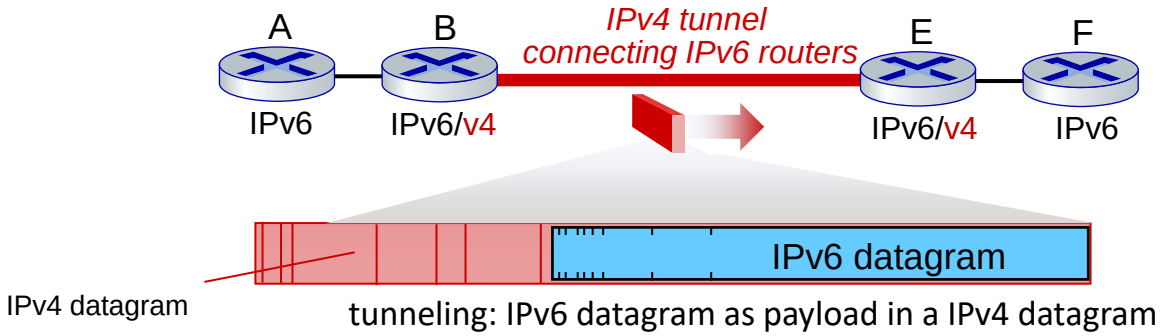
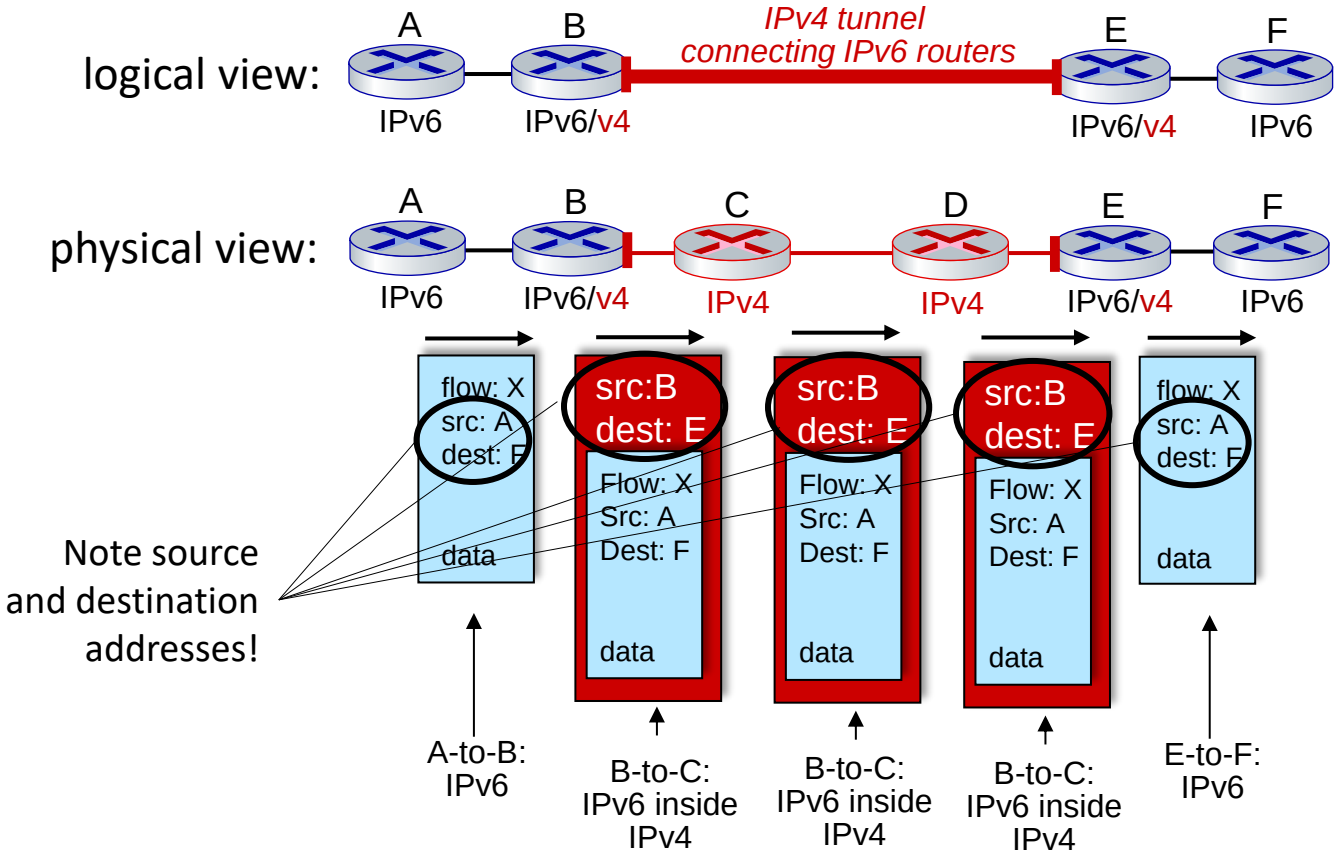


IPv4 tunnel connecting two IPv6 routers

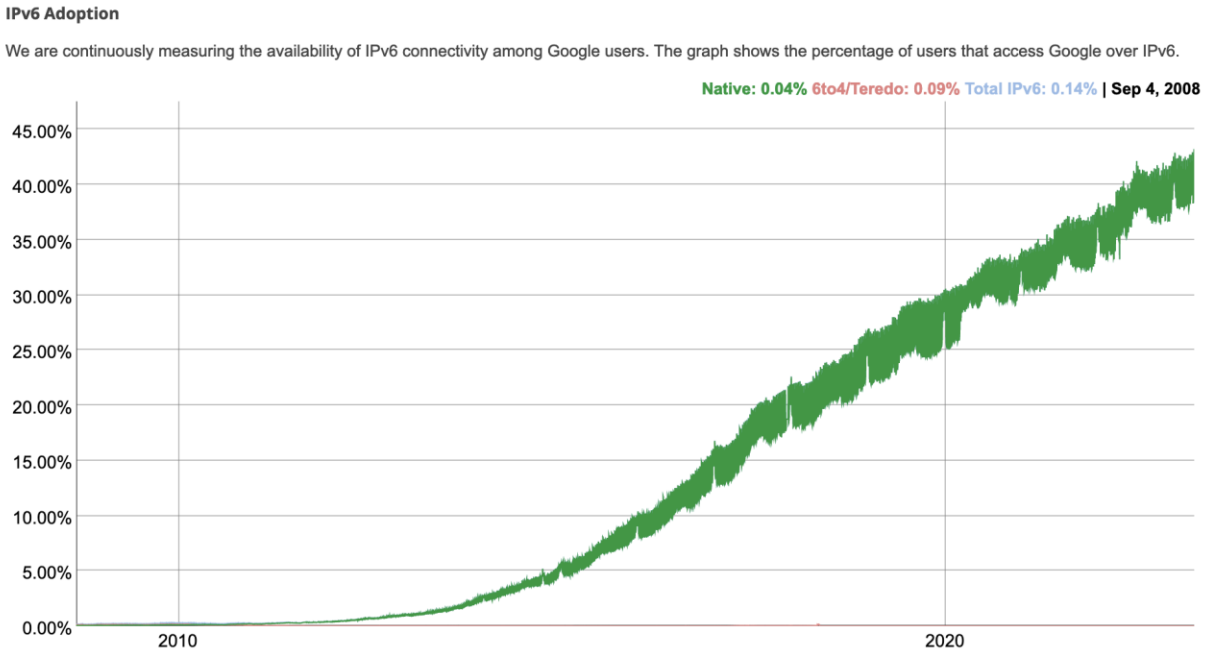


Tunneling


logical view:
A
B
IPv4 tunnel
connecting IPv6 routers
E
F
IPv6
IPv6/v4
IPv6/v4
IPv6
physical view:
A
B
C
D
E
F
IPv6
IPv6/v4
IPv4
IPv4
IPv6/v4
IPv6
Note source
and destination
addresses!
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
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
B-to-C:
IPv6 inside
IPv4
E-to-F:
IPv6

IPv6: adoption

- Google[1]: ~ 40% of clients access services via IPv6 (2023)
- NIST: 1/3 of all US government domains are IPv6 capable



IPv6: adoption

- Google[1]: ~ 40% of clients access services via IPv6 (2023)
- 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? (Expensive, Solutions like NAT take some of the pressure off.)*
  - *(Think of network layer changes akin to changing the foundation of a house while application layer changes are rapid, akin to applying a new layer of paint to a house)*

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

Assignment # 4 (Chapter – 4) (Already Announced)

- *4th Assignment will be uploaded on Google Classroom on Thursday, 27th March, 2025, in the Stream - Announcement Section*

- *Due Date: Tuesday, 8th May, 2025 (Handwritten solutions to be submitted during the lecture)*

- *Please read all the instructions carefully in the uploaded Assignment document, follow & submit accordingly*

Quiz # 4 (Chapter – 4) (Already Announced)

- *On: Tuesday, 8th May, 2025(During the lecture)*

- *Quiz to be taken during own section class only*

Eid Mubarak!