CSE 461: Computer networks

Spring 2021

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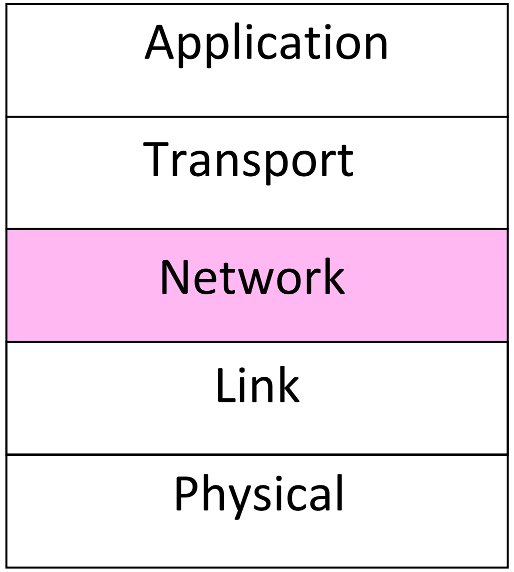
Network Layer (IP)

Recall the protocol stack

Application	– Programs that use network service
Transport	– Provides end-to-end data delivery
Network	– Send packets over multiple networks
Link	– Send frames over one or more links
Physical	– Send bits using signals

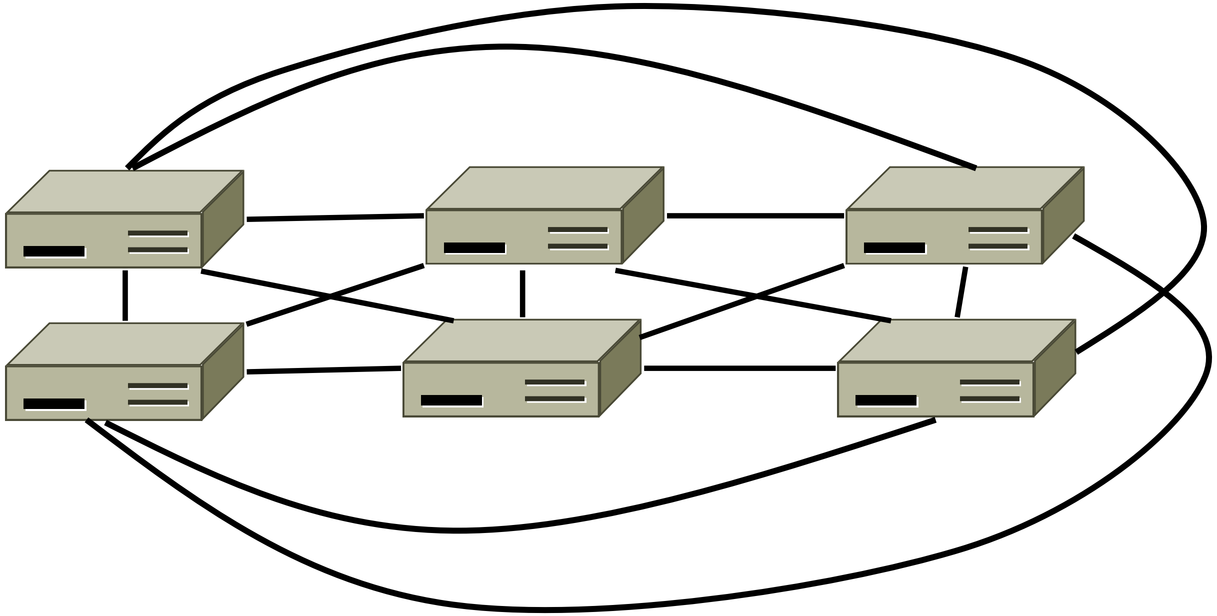
Network Layer

- How to get packets from source to destination



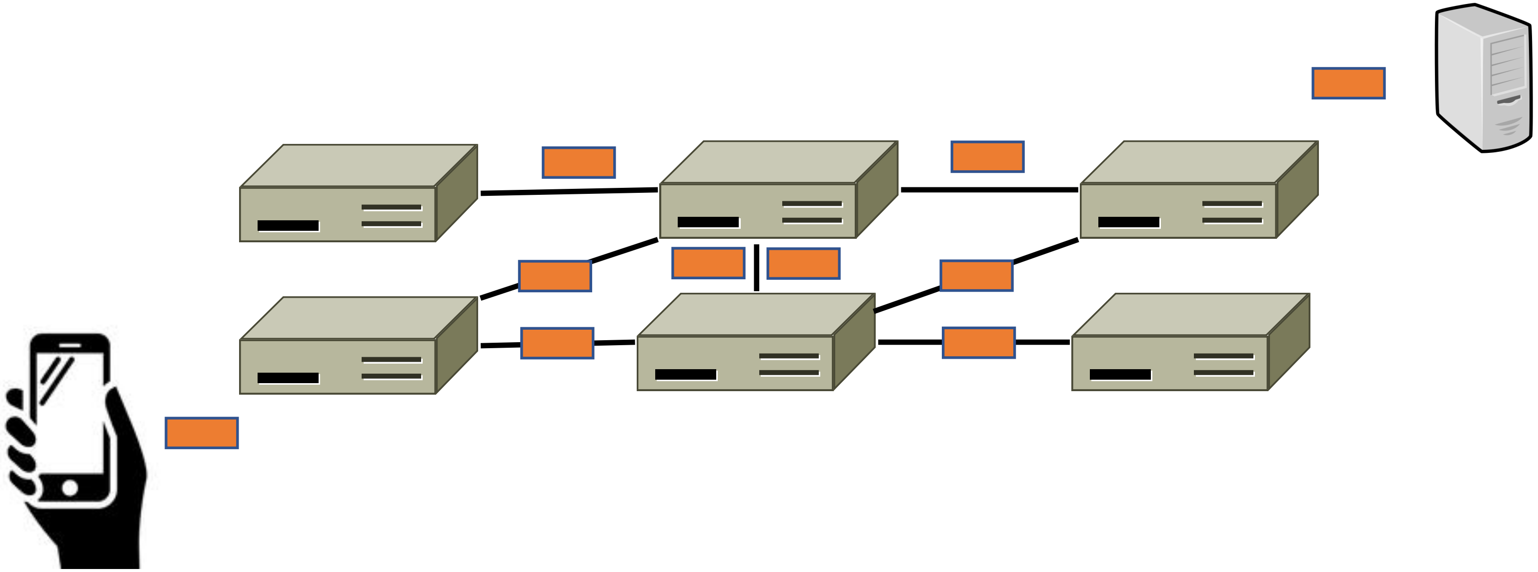
Why do we need a Network layer?

- Cannot afford to directly connect everyone
  - Cost and link layer diversity



Why do we need a Network layer? (2)

- Cannot broadcast all packets at global scale

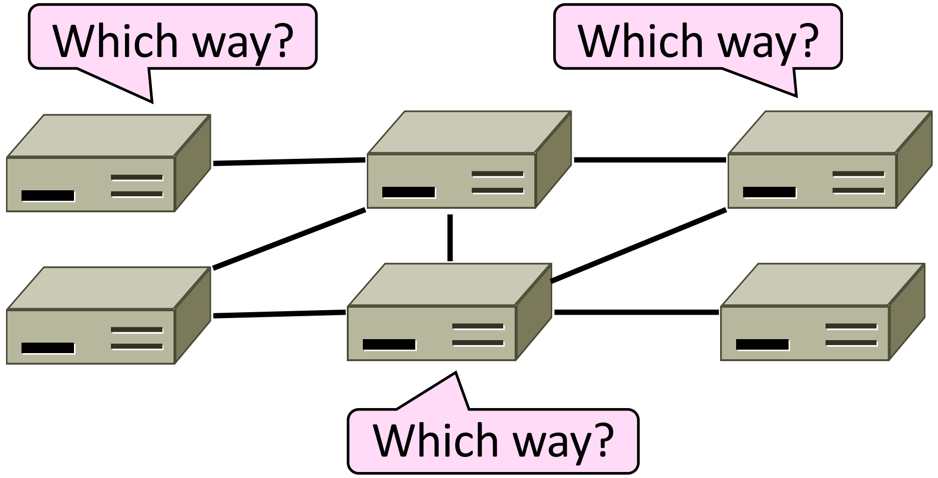


Why do we need a Network layer? (3)

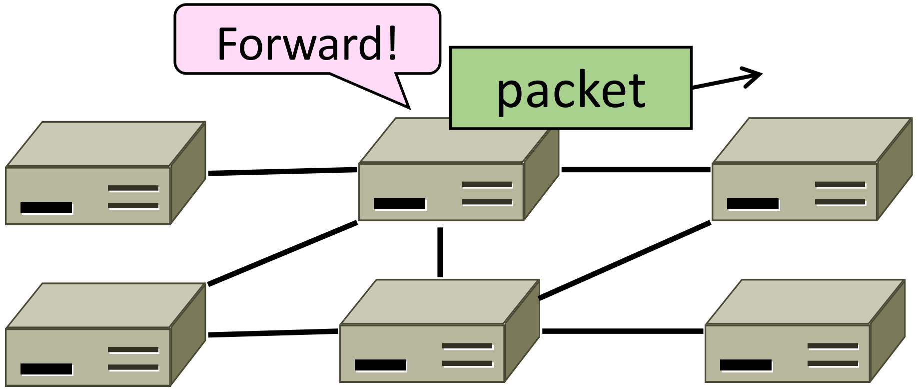
- Internetworking
  - Need to connect different link layer networks
- Addressing
  - Need a globally unique way to “address” hosts
- Routing and forwarding
  - Need to find and traverse paths between hosts

Routing versus Forwarding

- <u>Routing:</u> deciding the direction to send traffic



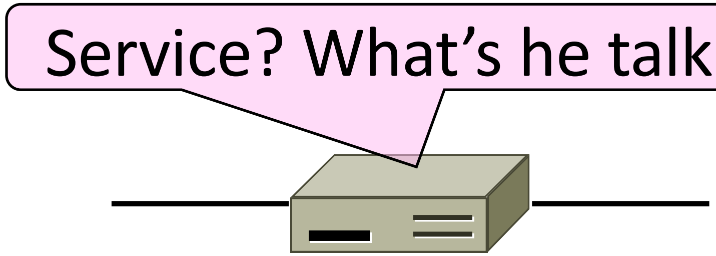
- <u>Forwarding:</u> sending a packet on its way



Network Service Models

Network service models

- What kind of service does the Network layer provide to the Transport layer?
    - How is it implemented at routers?



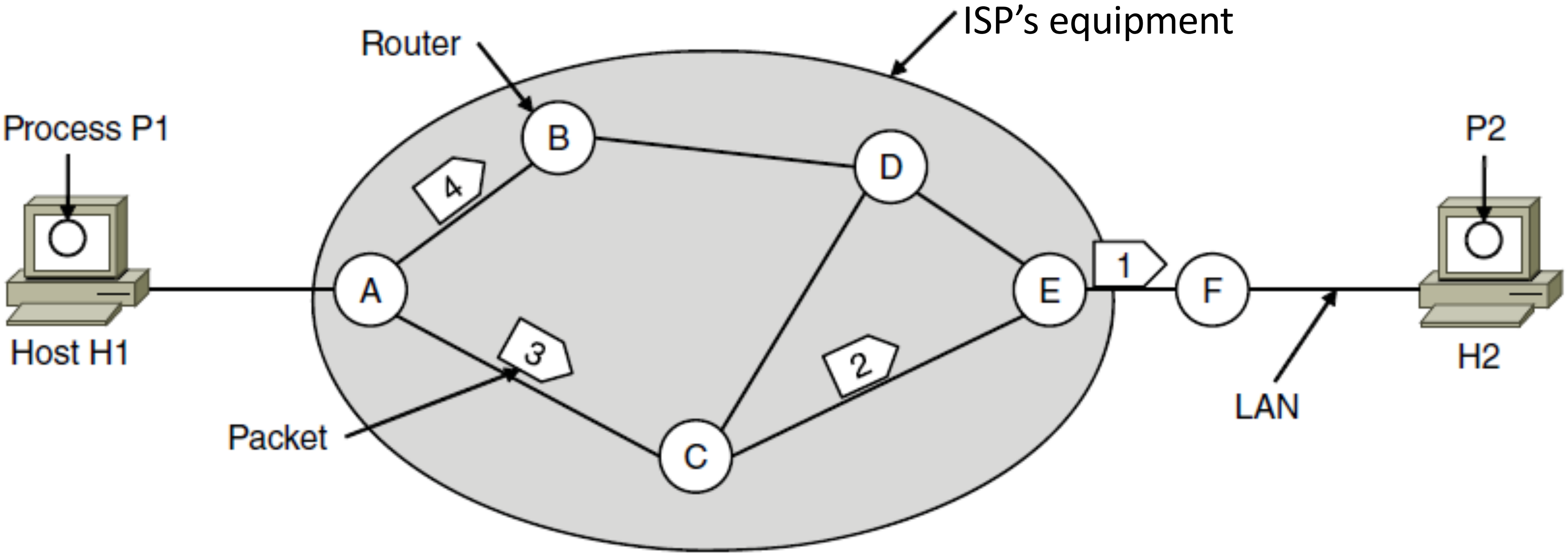
Two Network Service Models

- Datagrams, or connectionless service
  - Like postal letters
  - (IP as an example)

- Virtual circuits, or connection-oriented service
  - Like a telephone call

Datagram Model

- Packets contain a destination address; each router uses it to forward packets, maybe on different paths



Datagram Model (2)

- Each router has a forwarding table keyed by address
  - Gives next hop for each destination address; may change

A's table (initially)

A	
B	B
C	C
D	B
E	C
F	C

Dest. Line

A's table (later)

A	
B	B
C	C
D	B
E	B
F	B

C's Table

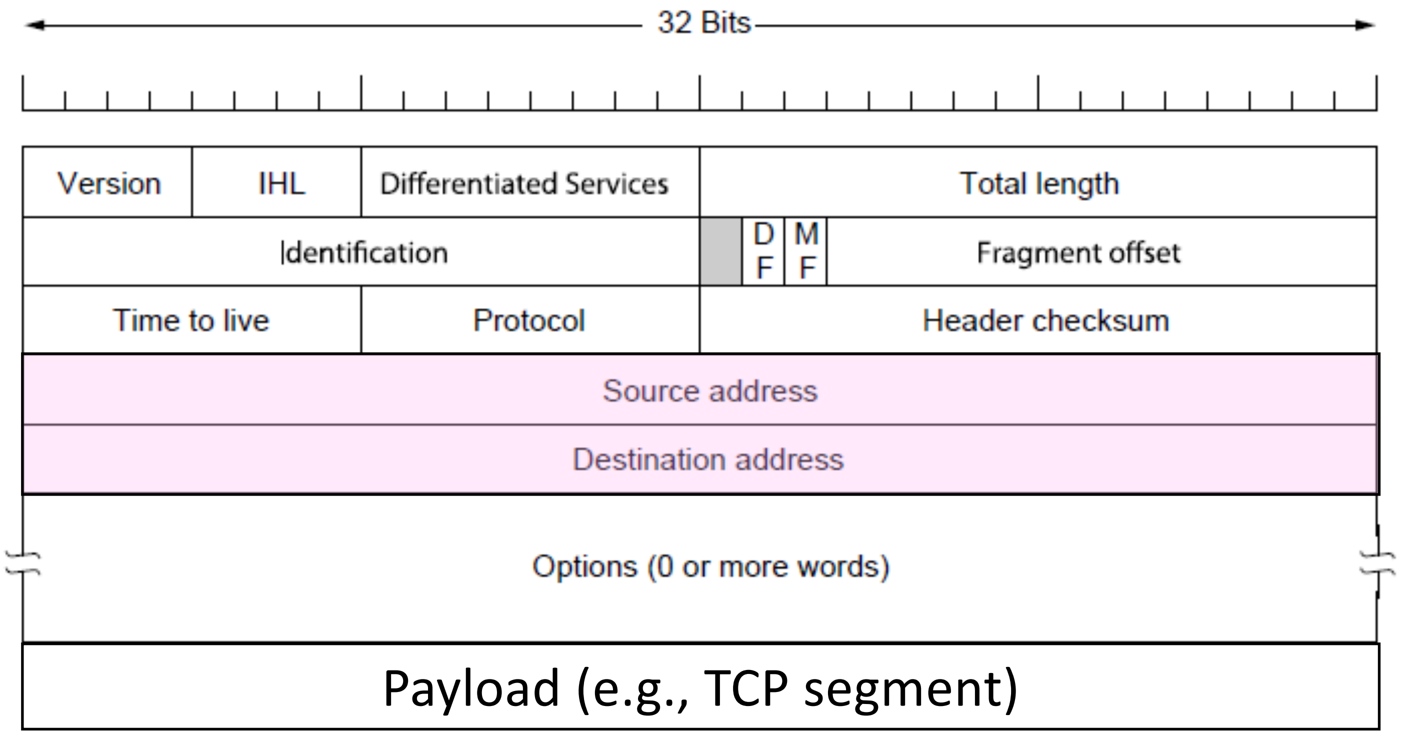
A	A
B	A
C	
D	E
E	E
F	E

E's Table

A	C
B	D
C	C
D	D
E	
F	F

IP (Internet Protocol)

- Network layer of the Internet, uses datagrams (next)
  - IPv4 carries 32 bit addresses on each packet



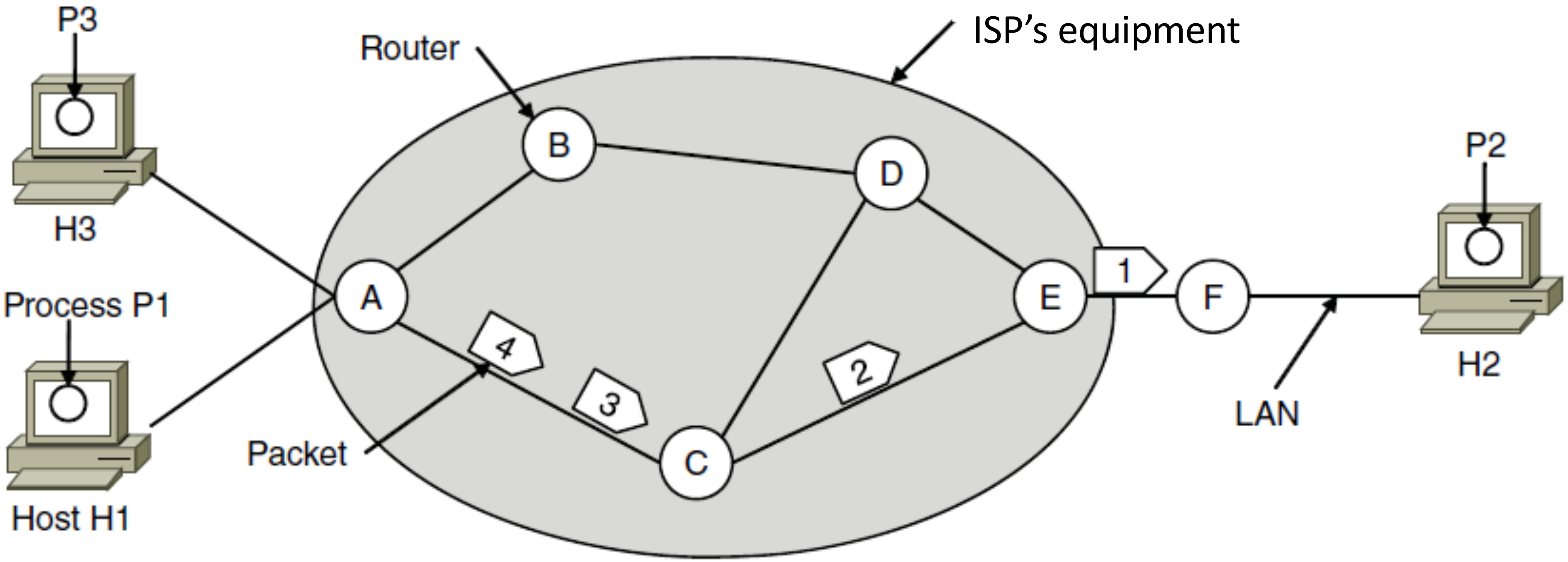
Virtual Circuit Model

- Three phases:
  1. Connection establishment, circuit is set up
     - Path is chosen, circuit information stored in routers
  2. Data transfer, circuit is used
     - Packets are forwarded along the path
  3. Connection teardown, circuit is deleted
     - Circuit information is removed from routers

- Just like a telephone circuit, but virtual in that no bandwidth need be reserved; statistical sharing of links

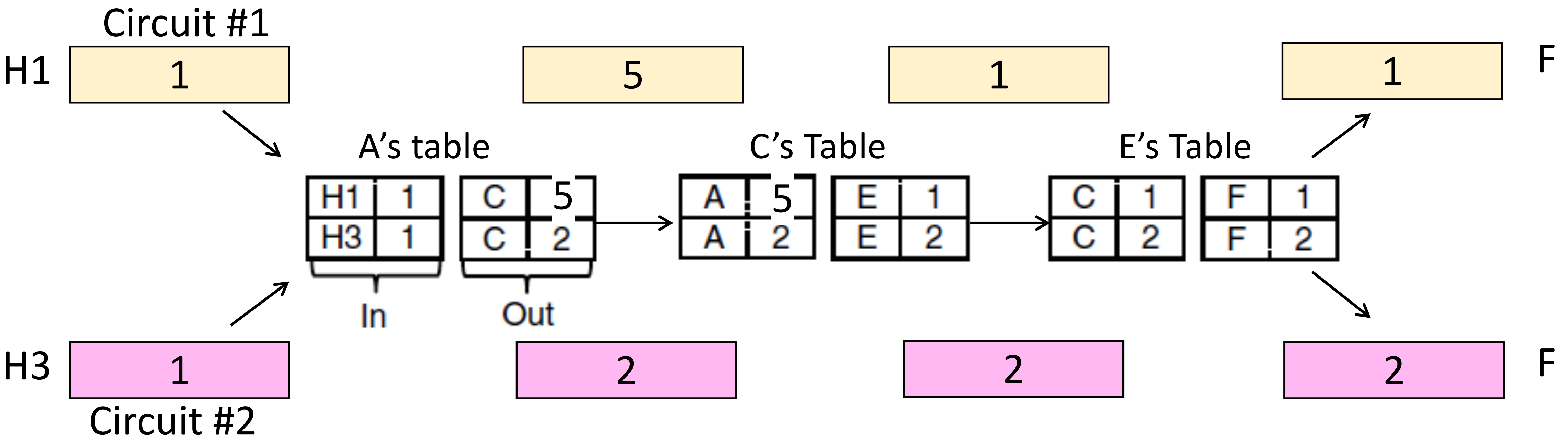
Virtual Circuits

- Packets contain a short label to identify the circuit
  - Labels don't have global meaning, only unique for a link



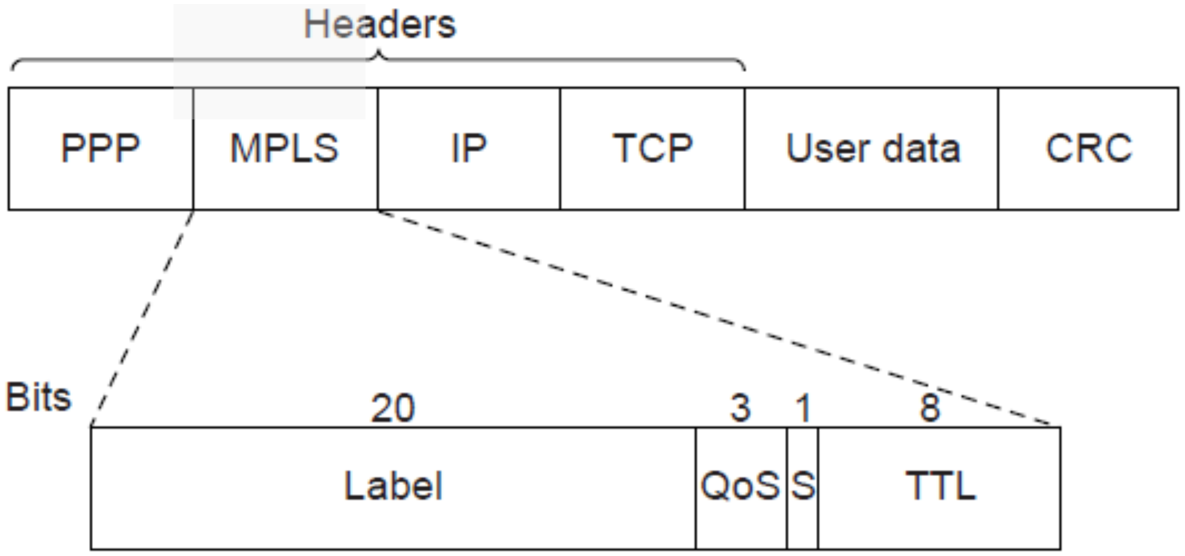
Virtual Circuits (2)

- Each router has a forwarding table keyed by circuit
  - Gives output line and next label to place on packet



MPLS (Multi-Protocol Label Switching, §5.6.5)

- A virtual-circuit like technology widely used by ISPs
  - ISP sets up circuits inside their backbone ahead of time
  - ISP adds MPLS label to IP packet at ingress, undo at egress



Datagrams vs Virtual Circuits

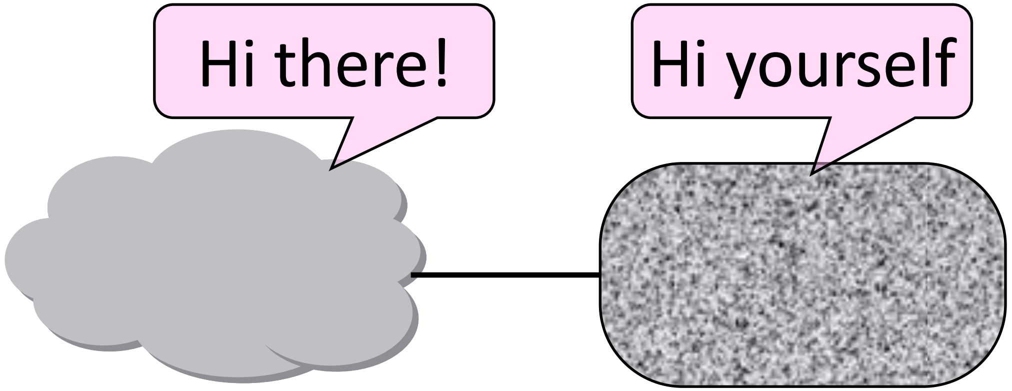
- Complementary strengths

Issue	Datagrams	Virtual Circuits
Setup phase	Not needed	Required
Router state	Per destination	Per connection
Addresses	Packet carries full address	Packet carries short label
Forwarding	Per packet	Per circuit
Failures	Easier to mask	Difficult to mask
Quality of service	Difficult to add	Easier to add

Internetworking (IP)

Topic

- How do we connect different networks together?
  - This is called internetworking
  - We'll look at how IP does it

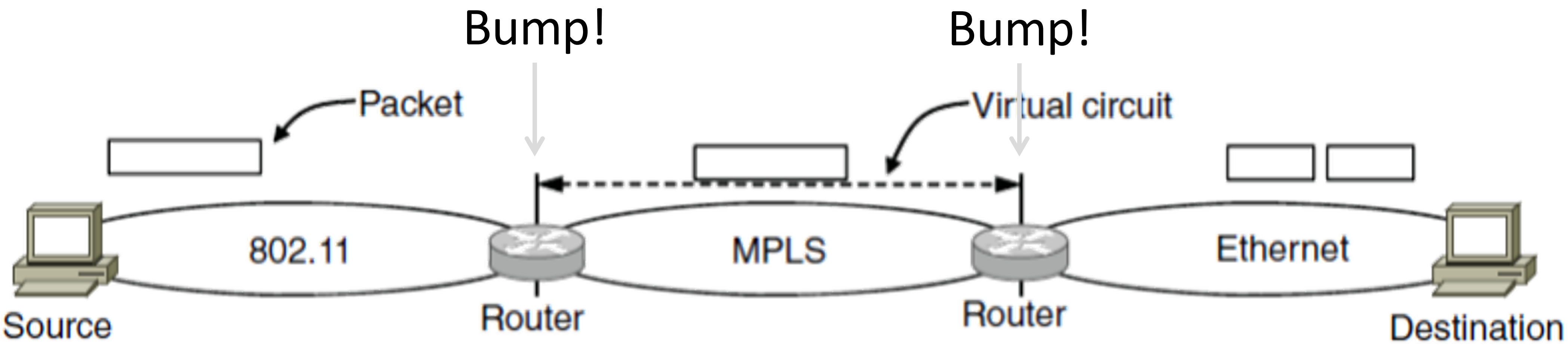


How Networks May Differ

- Lot of ways:
  - Service model (datagrams, VCs)
  - Addressing (what kind)
  - QOS (priorities, no priorities)
  - Packet sizes
  - Security (whether encrypted)
- Internetworking hides the differences with a common protocol. (Uh oh.)

Connecting Datagram and VC networks

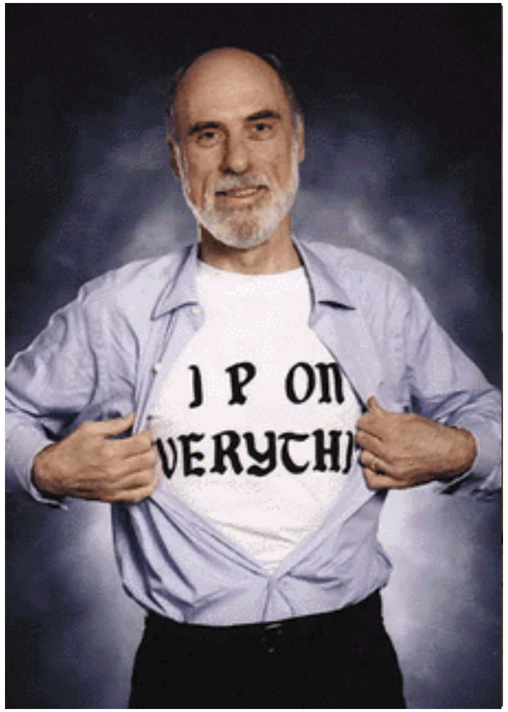
- An example to show that it's not so easy
  - Need to map destination address to a VC and vice-versa
  - A bit of a "road bump", e.g., might have to set up a VC



Internetworking – Cerf and Kahn

- Pioneers: Cerf and Kahn
  - “Fathers of the Internet”
  - In 1974, later led to TCP/IP
- Tackled the problems of interconnecting networks
  - Instead of mandating a single technology

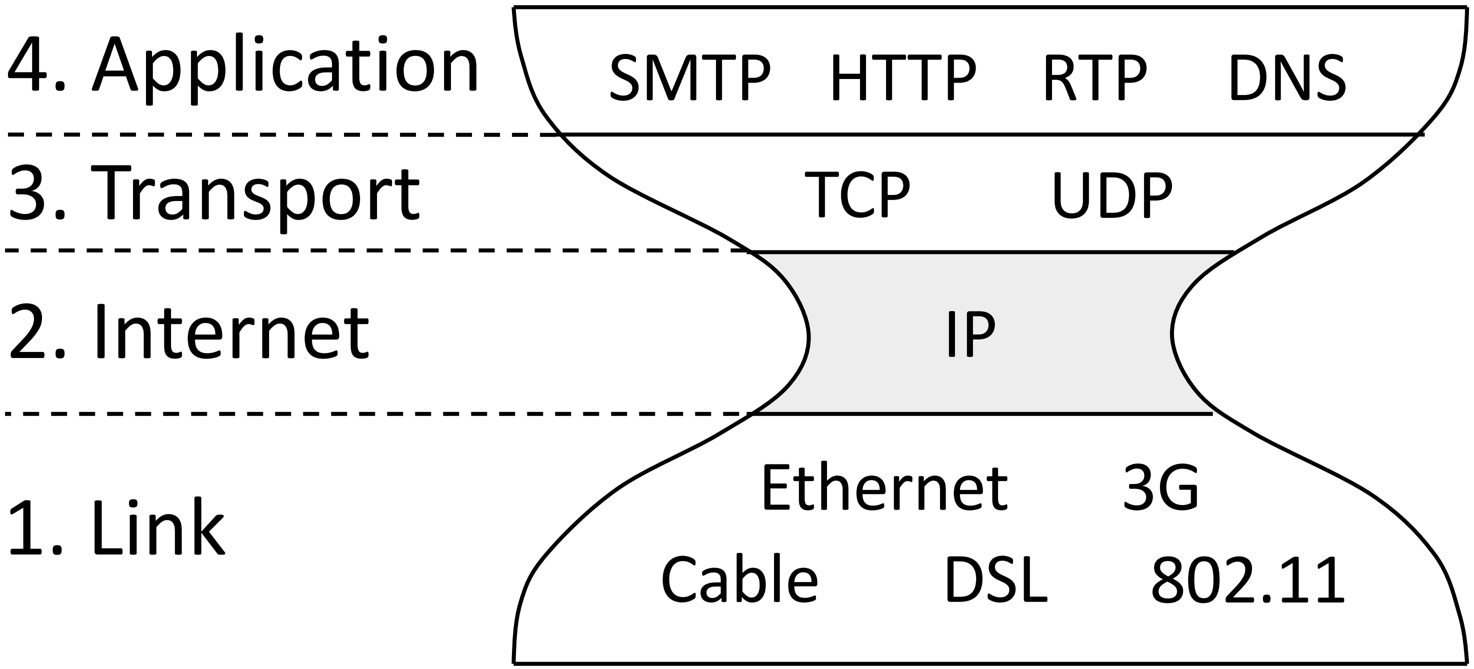
Vint Cerf



Bob Kahn

Internet Reference Model

- Internet Protocol (IP) is the "narrow waist"
  - Supports many different links below and apps above

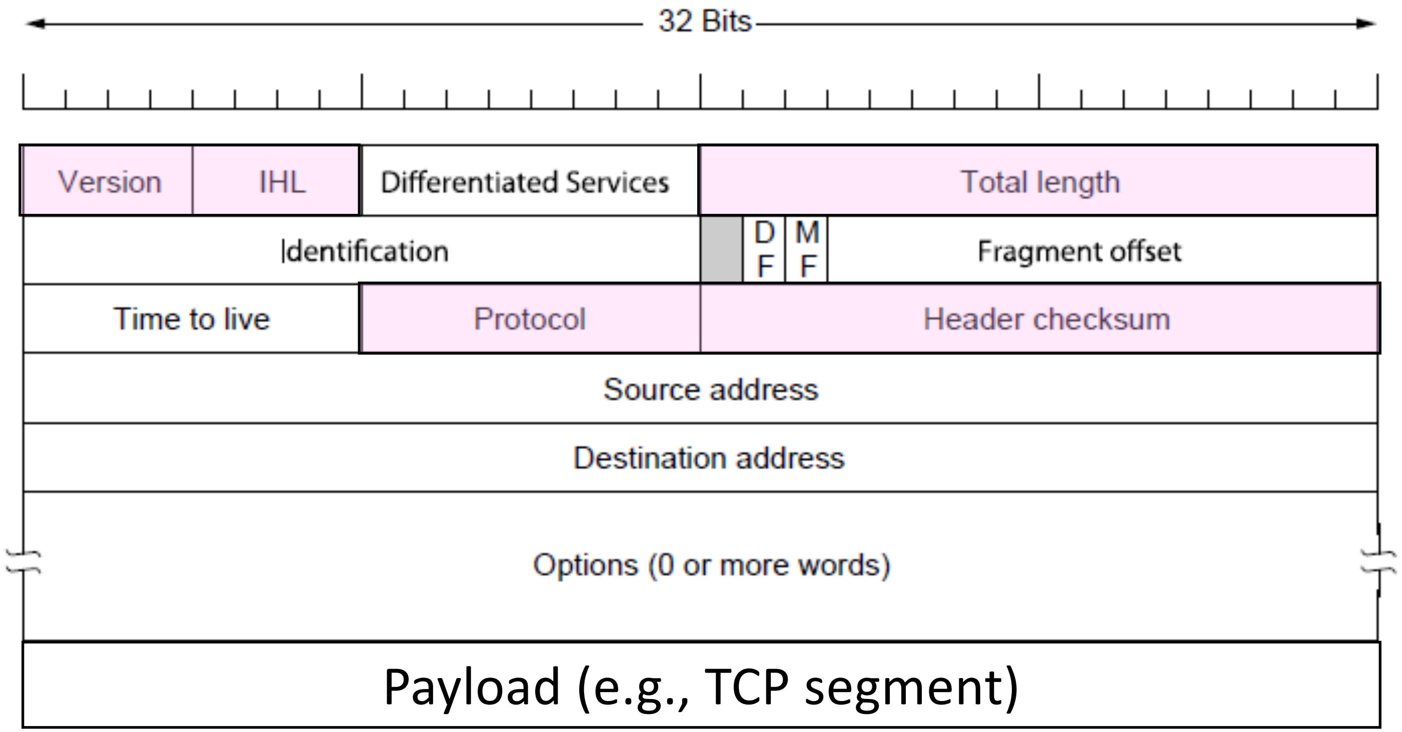


IP as a Lowest Common Denominator

- Suppose only some networks support QOS or security etc.
  - Difficult for internetwork to support
- Pushes IP to be a “lowest common denominator”
  - Asks little of lower-layer networks
  - Gives little as a higher layer service

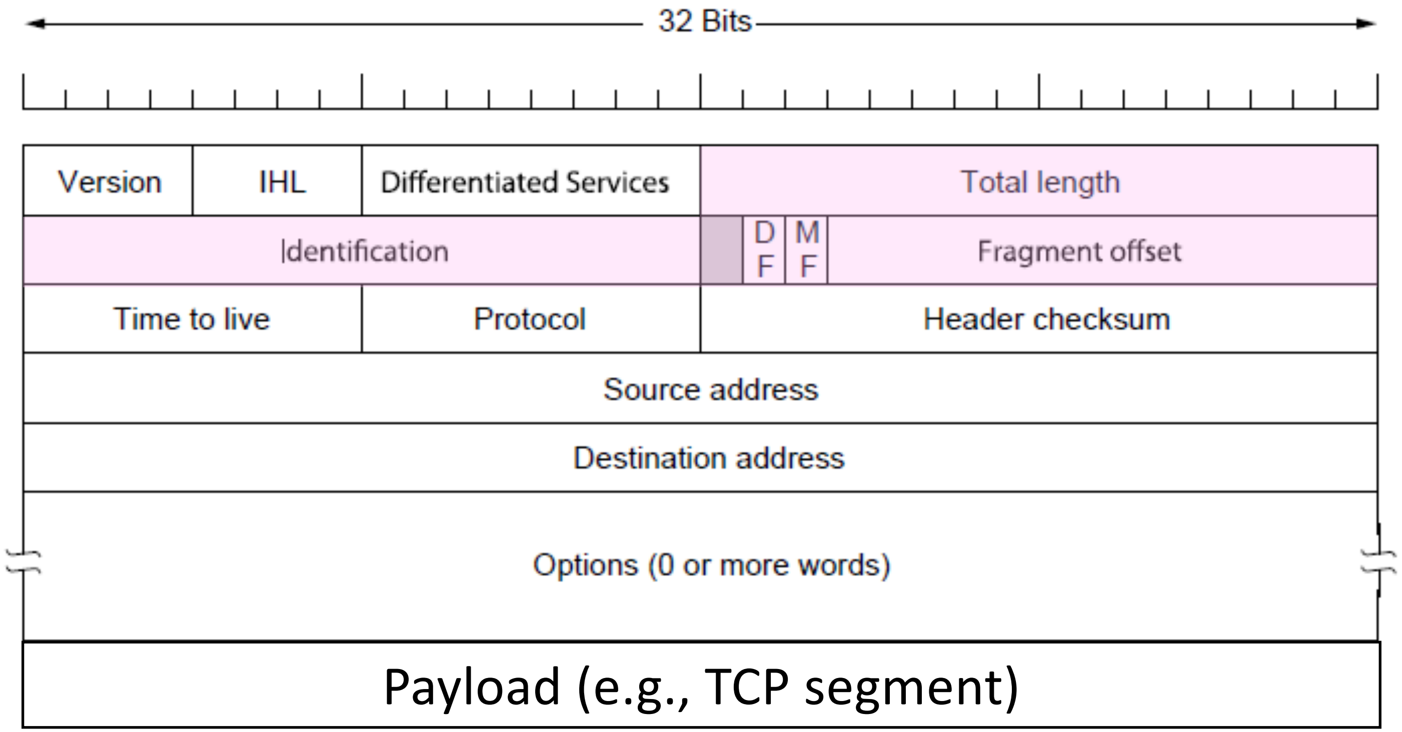
IPv4 (Internet Protocol)

- Various fields to meet straightforward needs
  - Version, Header (IHL), Total length, Protocol, and Header Checksum



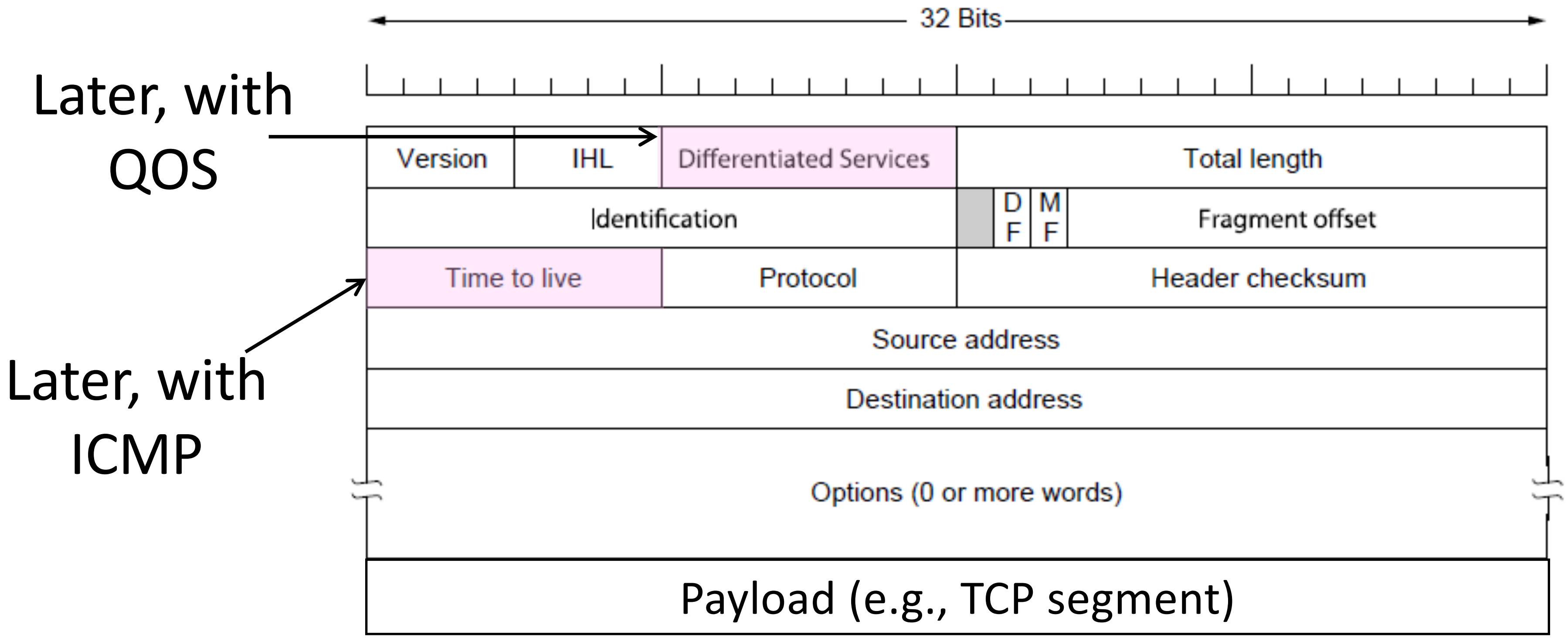
IPv4 (2)

- Some fields to handle packet size differences (later)
  - Identification, Fragment offset, Fragment control bits



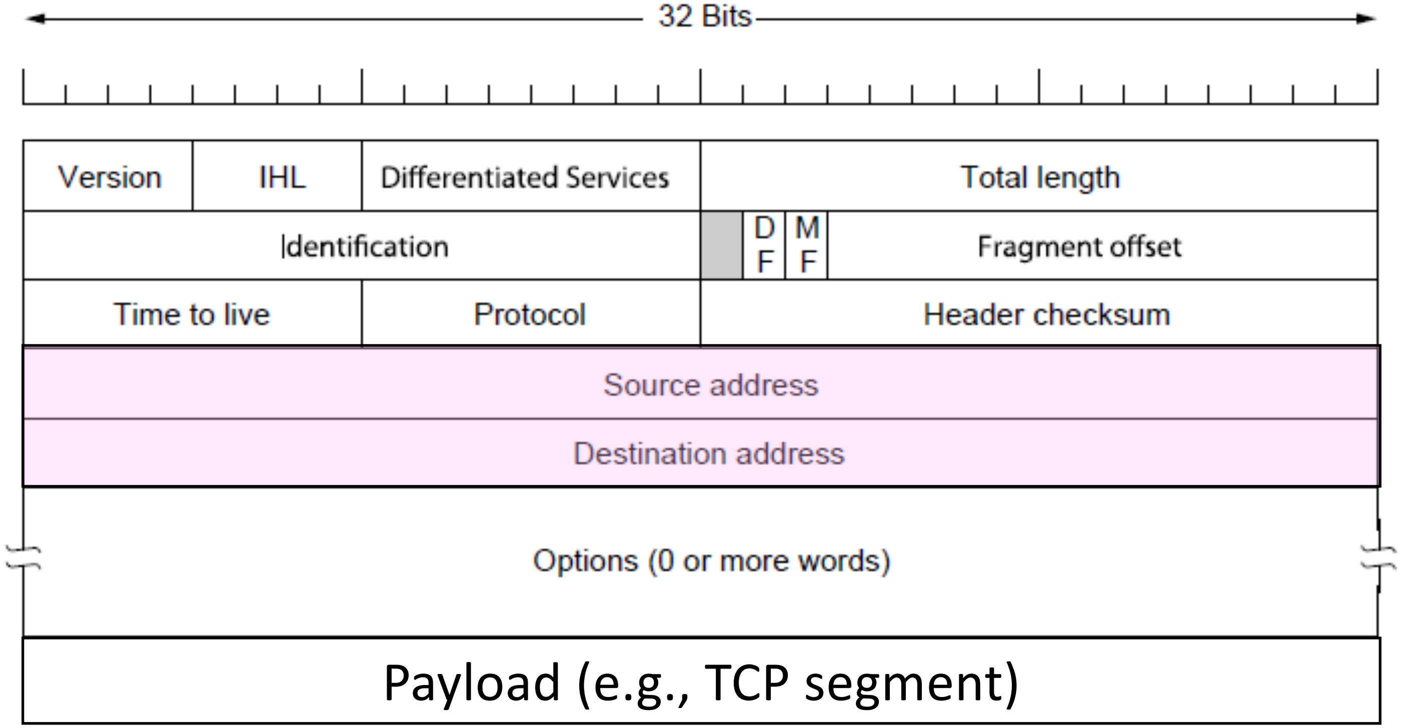
IPv4 (3)

- Other fields to meet other needs (later, later)
  - Differentiated Services, Time to live (TTL)



IPv4 (4)

- Network layer of the Internet, uses datagrams
  - Provides a layer of addressing above link addresses (next)



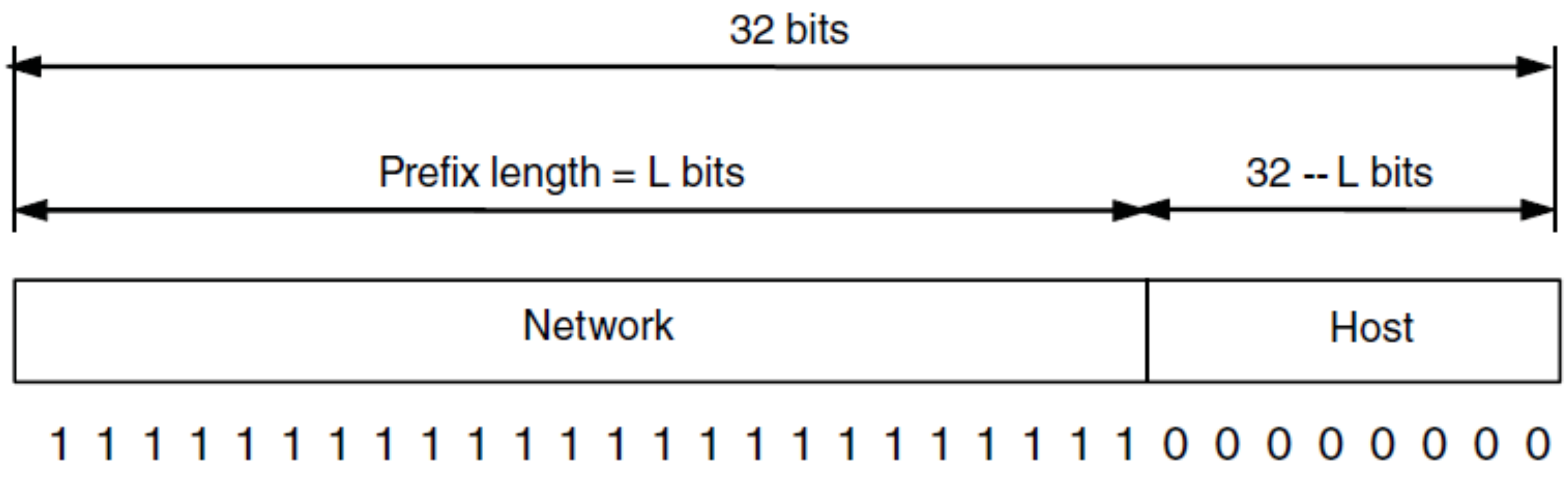
IP Addresses

- IPv4 uses 32-bit addresses
  - Later we'll see IPv6, which uses 128-bit addresses
- Written in "dotted quad" notation
  - Four 8-bit numbers separated by dots

8 bits	8 bits	8 bits	8 bits		
aaaaaaaa	**bbbbbbbb**	**cccccccc**	**dddddddd**	↔	**A.B.C.D**
00010010	00011111	00000000	00000001	↔	??

IP Prefixes

- Addresses are allocated in blocks called prefixes
  - Addresses in an L-bit prefix have the same top L bits
  - There are 2^{32-L} addresses aligned on 2^{32-L} boundary



IP Prefixes (2)

- Written in “IP address/length” notation
  - Address is lowest address in the prefix, length is prefix bits
  - E.g., 128.13.0.0/16 is 128.13.0.0 to 128.13.255.255
  - So a /24 (“slash 24”) is 256 addresses and /32 is 1 address