IP Datagrams and Datagram Forwarding

Introduction

- This unit will discuss:
- the fundamental Internet communication service
  - IP data Format of packets
  - Processing of packets by routers
  - Forwarding
  - Best-effort delivery

Connectionless Service 1

- End-to-end delivery service is *connectionless*
- Extension of LAN abstraction
  - Universal addressing
  - Data delivered in packets (frames), each with a header
- Combines collection of physical networks into single, virtual network
- Transport protocols use this connectionless service to provide connectionless data delivery (UDP) and connection-oriented data delivery (TCP)

Connectionless Service 2

- IP provides connectionless service which is an extension of packet switching in LAN
- Transport protocols use
  - UDP to provide *connectionless data delivery*
  - TCP to provide *connection-oriented data delivery*
- Universal addressing:
  - Data delivered in packets (frames), each with a header
  - Combines collection of physical networks into single, virtual network
- IP provides best effort delivery using Send & delivery

Virtual Packets 1

- Internet is a collection of heterogeneous networks
- Routers do not reformat frame headers for different format
- IP defines a *universal and virtual* packet format that is independent of the underlying hardware
  - Virtual: protocol SW creates and handles internet packet which is not recognizable by hardware
  - Universal: each comp or router contains a protocol SW that understands internet packets
- Each packet is encapsulated in hardware frames for delivery across each physical network

Virtual Packets 2

- *Packets* server same purpose in internet as frames on LAN
- Each has a header
- *Routers* (formerly *gateways*) forward between physical networks
- Packets have a uniform, hardware-independent format
  - Includes header and data
  - Can't use format from any particular hardware
- Encapsulated in hardware frames for delivery across each physical network

IP Datagram Format

- IP Datagram is a TCP/IP protocol and refers to internet packet
- Datagrams can have different sizes which include a header followed by data as in hardware frame:

  - Header area is usually fixed (*20 octets*) and can have IP options (information needed to deliver datagram to destination computer such as IP address., checksum, type, version..)
  - Data area can contain between *1 octet and 65,535* octets ($2^{16} - 1$) which is usually much larger than the header

Forwarding datagrams

- Header contains all information needed to deliver datagram to destination *computer*
  - Destination address
  - Source address
  - Identifier
  - Other delivery information
- Router examines header of each datagram and forwards datagram along path to destination

Forwarding IP Datagrams

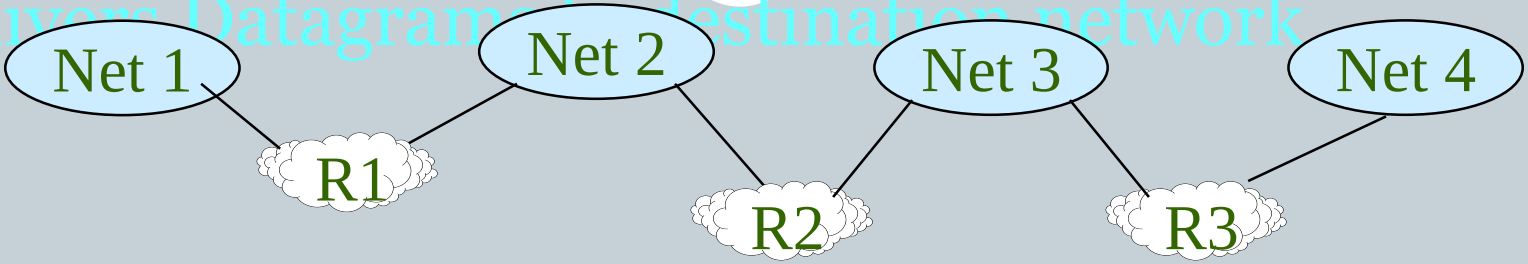
- Header contains all information needed to deliver datagram to destination computer
- Information about forwarding is stored in a *routing table* which is initialized at system startup
  - Must be updated as network topology changes
  - Contains list of destination networks and next hop for each destination

Routing table

- For efficiency, information about forwarding is stored in a *routing table*
  - Initialized at system initialization
  - Must be updated as network topology changes
- Contains list of destination networks and *next hop* for each destination

Forwarding An IP Datagram

- Delivers Datagrams to destination network



  - Routers maintain a "routing table" of "next hops"
  - Next Hop field does not appear in the datagram

Table at R2:

Destination	Next Hop
Net 1	Forward to R1
Net 2	Deliver Direct
Net 3	Deliver Direct
Net 4	Forward to R3

Routing Table

- Routing table is kept small by listing *destination networks* rather than hosts
- Can be further reduced through default route
- Entry used if destination network not explicitly listed in routing table
- E.g., UDM – unified data model- uses default routes for all off-campus networks

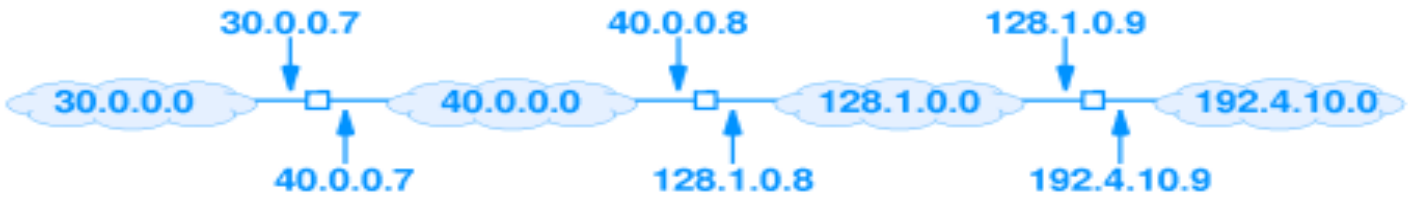
Default routes

- Routing table kept small by listing destination networks rather than hosts
- Can be further reduced through *default route*
  - Entry used if destination network not explicitly listed in routing table

Routing Tables and Address Masks

- In practice, additional information is kept in routing table
- Destination stored as network address
- Next hop stored as IP address of router
- Address mask defines how many bits of address are in prefix (net-id) used to identify network
  - Class A mask is 255.0.0.0
  - Class B mask is 255.255.0.0
  - Class C mask is 255.255.255.0
- Used for subnetting

IP Addresses and Routing Table Entries



(a)

Destination	Mask	Next Hop
30.0.0.0	255.0.0.0	40.0.0.7
40.0.0.0	255.0.0.0	deliver direct
128.1.0.0	255.255.0.0	deliver direct
192.4.10.0	255.255.255.0	128.1.0.9

(b)

Address Masks

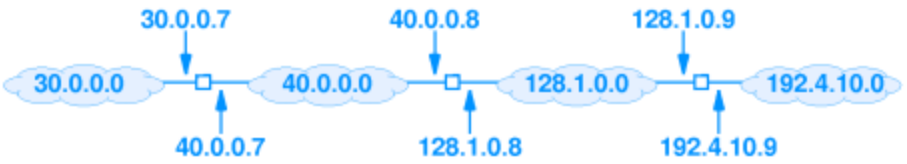
- To identify NextHop: apply address mask to destination address and compare to network address in routing table
- Can use Boolean and
- If ((Mask[i]& D) == Dest[i]) forward to NextHop[i]
- Assume a Datagram for D = 192.4.10.19, arrive at a router with a routing table as below:
- 255.0.0.0 & 192.4.10.19 = 192.0.0.0 which is not equal to row1..(1st entry fails); similarly 2nd & 3rd fail
- 255.255.255.0 & 192.4.10.19 = 192.4.10.0 which is *row4*
- Therefore use

  next hop on
  row 4 which is
  128.1.0.9

Destination	Mask	Next Hop
30.0.0.0	255.0.0.0	40.0.0.7
4.0.0.0	255.0.0.0	Deliver Direct
128.1.0.0	255.255.0.0	Deliver Direct
192.4.10.0	255.255.255.0	128.1.0.9

Example 2

- if ((Mask[i] & D) == Dest[i]) forward to NextHop[i]
- Consider 128.1.15.26:



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Destination	Mask	Next Hop
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128.1.0.0	255.255.0.0	deliver direct
192.4.10.0	255.255.255.0	128.1.0.9

(b)

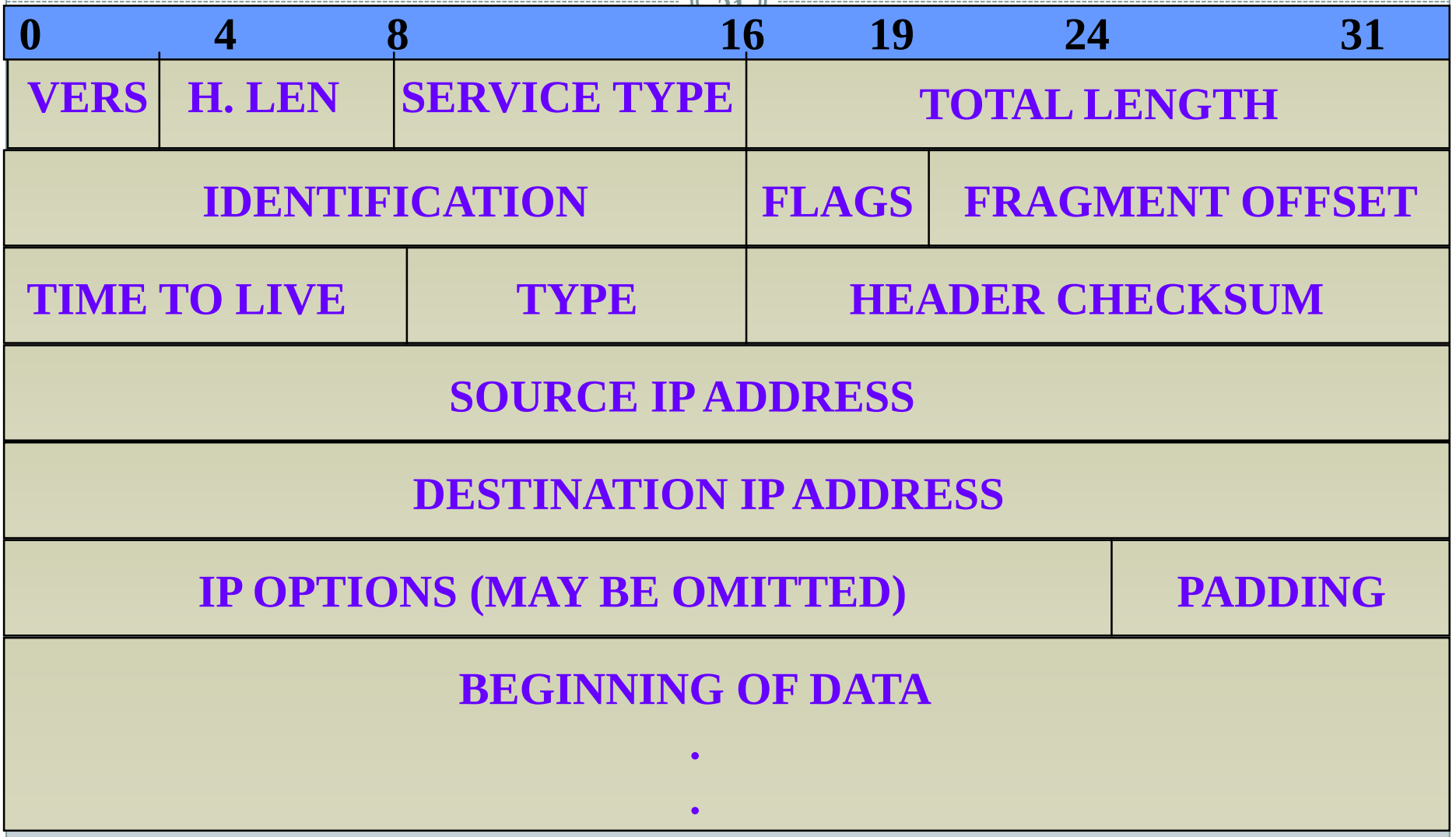
Destination and Next-Hop Addresses

- Destination address in IP datagram is always the ultimate destination
- Router looks up next-hop address and forwards datagram
- Network interface layer takes two parameters:
  - IP datagram
  - Next-hop address
- Next-hop address never appears in IP datagram

Best-Effort Delivery

- Network layer (IP) focuses on datagram delivery
- It Does not guarantee to prevent:
  - Duplicate datagrams
  - Delayed or out-of-order delivery
  - Corruption of data
  - Datagram loss
- IP can detect and report errors without fixing them
- Transport layer provide reliable delivery (TCP)
- Error and control messages are generated by *Internet Control Message Protocol (ICMP)*

IP Datagram Header Format



IP Datagram Header Fields

- *VERS* (4 bits): identify IP version (currently IPV4)
- *H. LEN* (4 bits): header length in 32-bit words (5)
- *SERVICE TYPE* (8 bits): sender's preference for latency, reliability & thruput (rarely used)
- *TOTAL LENGTH* (16 bits): total (H+D) octets in datagram which must be less than 64 KB
- *IDENT* (16 bits): identify datagram for S/D addr.
- *FLAGS* (3 bits): used for fragmentation (F, NF, ..)
- *FRAGMENT OFFSET* (13bits): fragmentation

IP Datagram Header Fields (cont'd)

- *Time to live* (8 bits): decrement in each hop; datagram discarded when equal to 0 to prevent endless
- *TYPE* (8 bits): type of protocol used in datagram (TCP, UDP..)
- *HEADER CHECKSUM* (16 bits): 1s complement sum of all 16-bit words in the header
- *SOURCE/DEST ADDRESS* (32/32 bits): IP addresses of original source and ultimate destination (does not change along the path)
- Padding (variable): makes header length a multiple of 4

IP Datagram Options

- Several options can be added between DESTINATION IP ADDRESS and data in multiples of 32 bits to IP header:
  - Record route
  - Source route
  - Time stamp
- Header with no options has H. LEN field value 5; and data begins immediately after *DESTINATION IP ADDRESS*
- Header with 96 bits of options has H. LEN field value 8

Summary

- Basic unit of data delivery in TCP/IP is IP datagram
- Routers use destination address in IP datagram header to determine the next-hop
- Forwarding information is stored in a routing table
- IP datagram header has 40 octets of fixed field information and may be options
- IP datagram can be up to 2^{16}-1=65,535 bytes
- IP can detect and report errors without fixing them
- Transport layer provide reliable delivery (TCP)