CSE/EE 461: Introduction to Computer Communications Networks
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Module 5
IP/ICMP and the Network Layer

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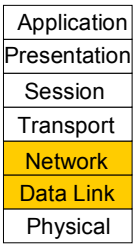
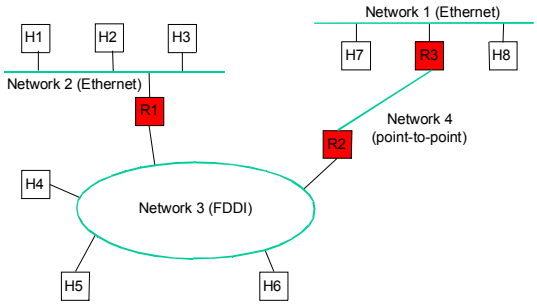
Last Time

- Focus:
  - What to do when one shared LAN isn't big enough?
- Interconnecting LANs
  - Bridges and LAN switches
  - But there are limits …



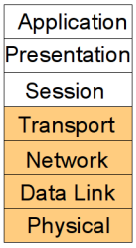
This Time: Internetworks

- Set of interconnected networks, e.g., the Internet
  - Scale and heterogeneity



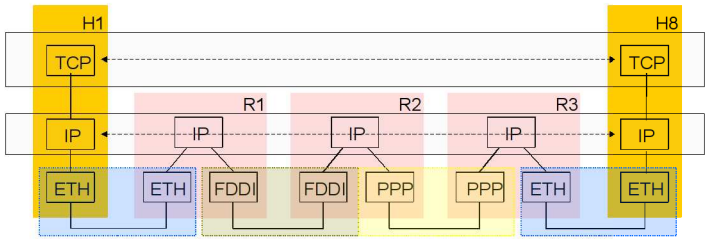
The Protocol Stack

- Thinking about roles:
  - Transport: Process to Process
    - Example: TCP
      Reliable bytestream
  - Network: Host to Global Host
    - Example: IP
      Unreliable datagram
  - Data Link/Physical: Host to Local Host
    - Example: Ethernet
      Pretty reliable frame delivery



As a picture

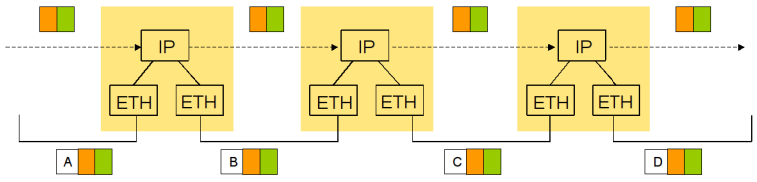
- IP is the network layer protocol used in the Internet
- Routers are network level gateways
- Packet is the term for network layer protocol data units (PDUs)



Packet formats: encapsulation

- View of a packet on the (Ethernet) wires

- Routers work with IP header, not higher
  - Higher would be a "layer violation"
- Routers strip and add link layer headers



Network Layer Goals

- Run over heterogeneous Link/Physical layers
  - Motivates minimizing promises about the service
    - End-to-end argument
- Global delivery
  - Must be scalable
  - This requires a new addressing scheme (IP addresses)
    - Want address of remote host to give clue to direction to send packet
- Low overhead switching
  - Minimal processing of IP packet
    - E.g., don't have to rewrite IP header (much…)
  - "Fast path" processing
- Network control / diagnosis
  - If I'm having trouble communicating, what's wrong?
    - Routers have IP addresses, just like everyone else
    - Ping / traceroute

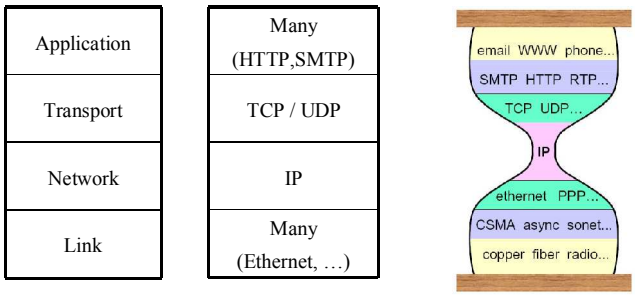
Review: Network Service Models

- Datagram delivery: postal service
  - connectionless, best-effort or unreliable service
  - Network can't guarantee delivery of the packet
  - Each packet from a host is routed independently
  - Example: IP
- Virtual circuit models: telephone
  - connection-oriented service
  - Signaling: connection establishment, data transfer, teardown
  - All packets from a host are routed the same way (router state)
  - Example: ATM, Frame Relay, X.25

Internet Protocol (IP)

- IP (RFC791) defines a datagram "best effort" service
  - May be loss, reordering, duplication, and errors!
  - Currently IPv4 (IP version 4), IPv6 "on the way"
- Routers forward packets using periodically updated routes
  - Routing protocols (RIP, OSPF, BGP) run between routers to maintain routes (routing table, forwarding information base)
  - Over medium term, one path from host A to host B
- Global, hierarchical addresses, not flat addresses
  - 32 bits in IPv4 (128 bits in IPv6)
  - ARP (Address Resolution Protocol) maps IP to MAC addresses for final delivery

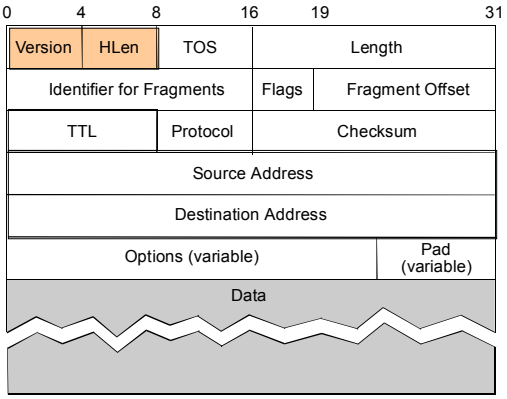
The IP Narrow Waist



Model Protocols The "narrow waist"

IPv4 Packet Format

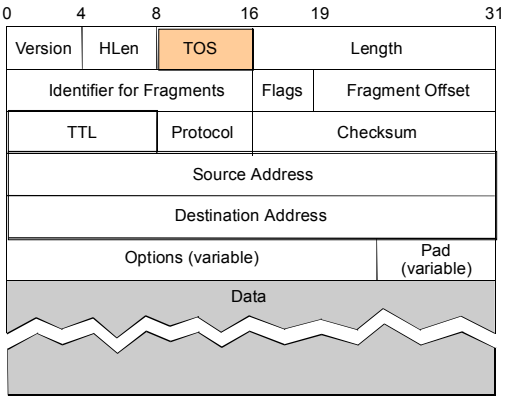
- Version is 4
- Header length is number of 32 bit words
- Limits size of options



IPv4 Header Fields …

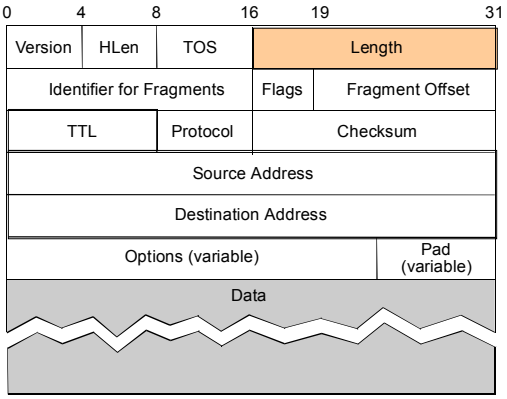
- Type of Service
- Abstract notion, never really worked out
  - Routers ignored
- But now being redefined for Diffserv

Bits 0-2: Precedence.
Bit 3: 0 = Normal Delay, 1 = Low Delay.
Bit 4: 0 = Normal Throughput, 1 = High Throughput.
Bit 5: 0 = Normal Relaibility, 1 = High Reliability.
Bit 6-7: Reserved for Future Use.



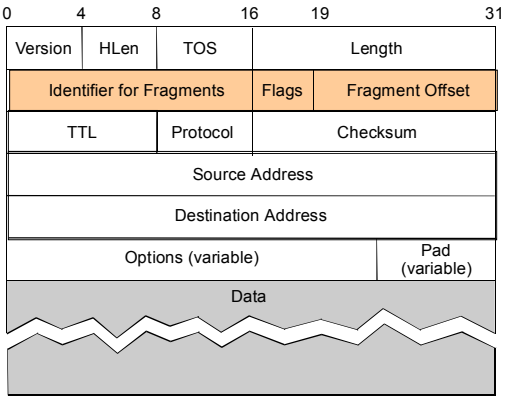
IPv4 Header Fields …

- Length of packet
- Min 20 bytes, max 65K bytes (limit to packet size)



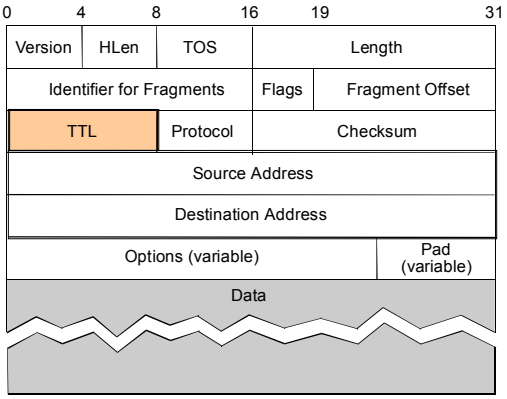
IPv4 Header Fields …

- Fragment fields
- More on this in a minute



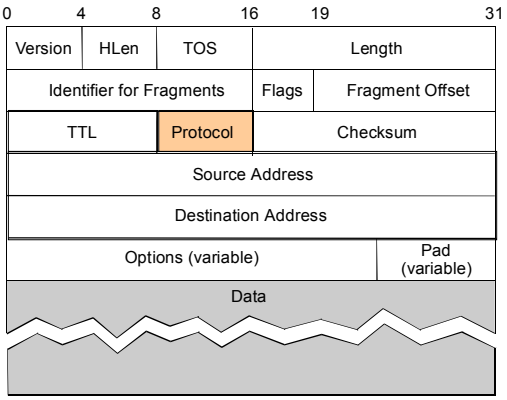
IPv4 Header Fields …

- Time To Live
- Decremented by router and packet discarded if = 0
- Prevents immortal packets
- traceroute



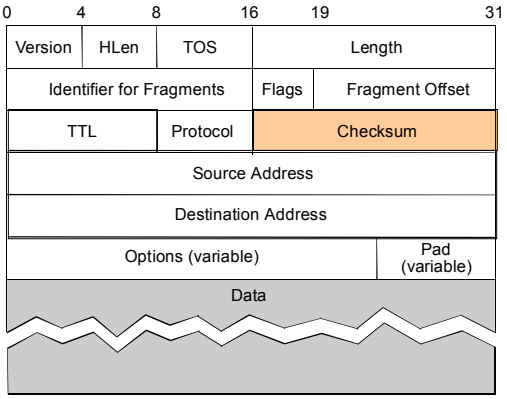
IPv4 Header Fields …

- Identifies higher layer protocol
  - E.g., TCP, UDP
- De-mux'ing key at destination host



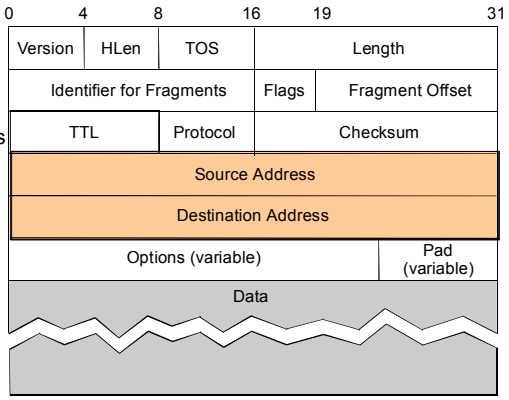
IPv4 Header Fields …

- Header checksum
  - Doesn't cover data
- Recalculated by routers (TTL drops)
- Disappears for IPv6



IPv4 Header Fields …

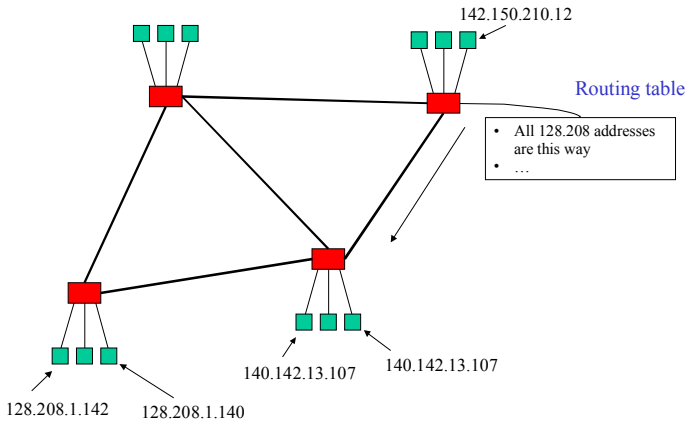
- Source/destination IP addresses
  - Not Ethernet
- Unchanged by routers
- Not authenticated by default



IP Addresses and Datagram Forwarding

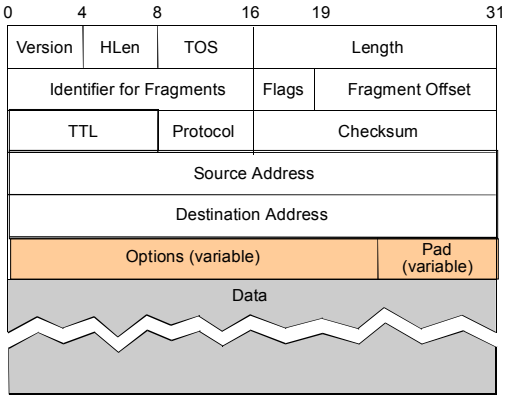
- IP addresses have hierarchy
  - MAC addresses are basically random
- How the source gets the packet to the destination:
  - if source is on same network (LAN) as destination, source sends packet directly to destination host, using MAC address
  - else source sends data to a router on the same network as the source (using router's MAC address)
  - router will forward packet to a router on the next network over (by sending out through a different one of its interfaces, and MAC address on that network for next router)
  - and so on…
  - until packet arrives at router on same network as destination; then, router sends packet directly to destination host (MAC address)
- Requirements
  - every host needs to know address of a router on its LAN
  - every router needs a routing table to tell it which neighboring network to forward a given packet on
  - Need some kind of support for mapping IP address → MAC address

IP vs. MAC addresses



IPv4 Header Fields …

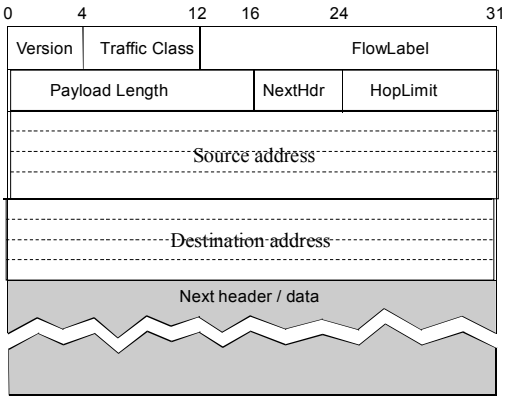
- IP options indicate special handling
  - Timestamps
  - "Source" routes
- Rarely used …



Problems / Strengths of IPv4

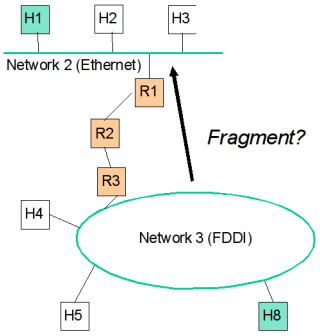
- TOS becomes traffic class / flow
- Length includes just the data
- No fragmentation info
- TTL still there
- Protocol field encoded through NextHdr
- No checksum
- Source / dest still there (but more bits)

The IPv6 header



Fragmentation: What, Why, and Why Not

- Different networks may have different frame limits (MTUs)
  - Ethernet 1.5KB, FDDI 4.5KB
- Don't know if packet will be too big for path beforehand
  - Could fragment on demand inside the network
    - IPv4
  - Could return an error to sending host
    - IPv6

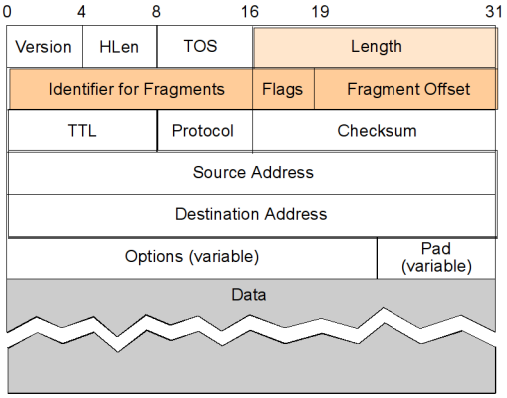


Fragmentation and Reassembly

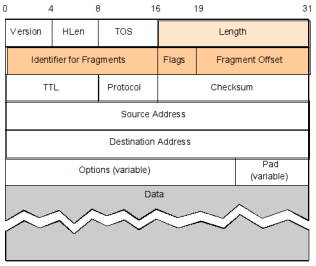
- Strategy
  - fragment only when necessary (MTU < Datagram size)
    - try to avoid fragmentation at source host
  - this implies that refragmentation must be possible
    - fragments are self-contained IP datagrams
  - delay reassembly until destination host
  - do not recover from lost fragments

Fragment Fields

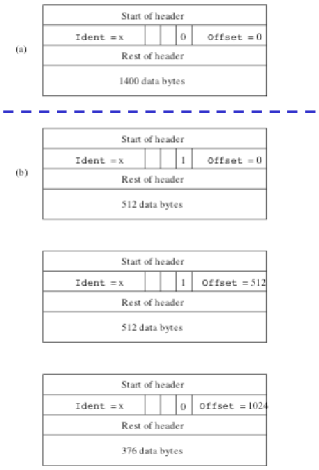
- Fragments of one packet identified by (source, dest, frag id) triple
  - Make unique
- Offset gives start, length changed
- Flags are:
  - More Fragments (MF)
  - Don't Fragment (DF)
  - Unused



Fragmenting a Packet



Packet Format



Fragment Considerations

- Making fragments be datagrams provides:
  - Tolerance of loss, reordering and duplication
  - Ability to fragment fragments
- Reassembly done at the endpoint
  - Puts pressure on the receiver, not network interior
- Consequences of fragmentation:
  - Loss of any fragments causes loss of entire packet
  - Need to time-out reassembly when any fragments lost

Avoiding Fragmentation

- Always send small datagrams
  - Might be too small
    - Why does that matter?
- "Guess" MTU of path
  - Use DF flag. May have large startup time
- Discover actual MTU of path
  - One RT delay w/help, much more w/o
    - Hosts send packets, routers return error if too large

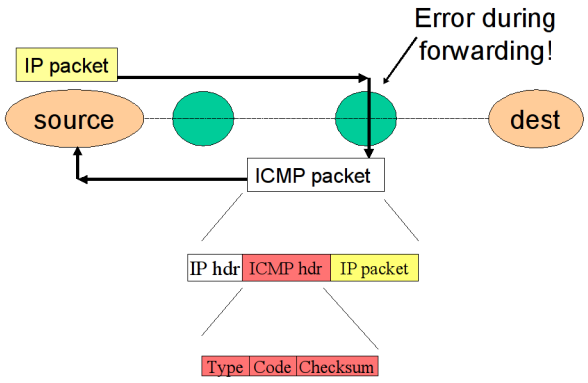
Why Not?

- Why not implement fragmentation / reassembly in the network service?
- Not often used, but
  - Header overhead in every packet
  - Processing overhead on every packet
    - "Fast path" processing requires additional checks
  - Processing overhead when fragmentation needed
    - Have to create new IP headers, so…
    - Have to compute new checksums

ICMP

- What happens when things go wrong?
  - Need a way to test/debug a large, widely distributed system
- ICMP = Internet Control Message Protocol (RFC792)
  - Companion to IP – required functionality
- Used for error and information reporting:
  - Errors that occur during IP forwarding
  - Queries about the status of the network

ICMP Generation



Common ICMP Messages

- Destination unreachable
  - "Destination" can be host, network, port or protocol
- Packet needs fragmenting but DF (don't fragment) flag is set
- Redirect
  - To shortcut circuitous routing
- TTL Expired
  - Used by the "traceroute" program
- Echo request/reply
  - Used by the "ping" program
- Cannot Fragment
- Busted Checksum

- ICMP messages include portion of IP packet that triggered the error (if applicable) in their payload

ICMP Restrictions

- The generation of error messages is limited to avoid cascades … error causes error that causes error!
- Don't generate ICMP error in response to:
  - An ICMP error
  - Broadcast/multicast messages (link or IP level)
  - IP header that is corrupt or has bogus source address
  - Fragments, except the first
- ICMP messages are often rate-limited too.

Key Concepts

- Network layer provides end-to-end data delivery across an internetwork, not just a LAN
  - Datagram and virtual circuit service models
  - IP/ICMP is the network layer protocol of the Internet
- Next: More detailed look at routing and addressing