Announcements

- Fishnet 2 due Wednesday
- Demo in section on Thursday

Last time...

- Heterogeneity: How can we support a range of media & applications?
  - IP as a layer of indirection
  - Layering revisited
  - The Internet hourglass

Internet vs. OSI Protocol Models
Hourglass Analogies

- Key idea: A central abstraction that makes it easier to cope with heterogeneity at the top & bottom.

```
Dishes; meals          Ingredients
  Cooking             Investors
                      Machine Code
```

“IP over everything, everything over IP”

- A Standard for the Transmission of IP Datagrams on Avian Carriers

- Pigeon-powered Internet takes flight

- The Bongo Project
  - http://eagle.auc.ca/~dreid/

This time...

- More on IP and the network layer

- Topics:
  - IP in the protocol stack
  - IP header format
  - Error reporting (ICMP)
  - Path MTU problem

The Network Layer

- Job is to provide end-to-end data delivery between hosts on an internetwork
  - Forwarding
  - Routing
In terms of protocol stacks

In terms of packet formats

In terms of protocol stacks

Internet Protocol (IP)

- IP (RFC791) defines a “best effort” service
  - May be loss, reordering, duplication, and errors!
  - Currently IPv4 (IP version 4)
  - IPv6 on the way

- Global, hierarchical address scheme
  - Distinct from link layer addresses
  - 32 bits in IPv4 address; 128 bits in IPv6 address
  - More on this later!

IPv4 Packet Format
IPv4 Header Fields ...

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ICMP

- ICMP =

- Companion to IP – required functionality

- Used for error and information reporting:
  - 
  - 

ICMP Generation

Error during forwarding!
Common ICMP Messages

- Destination unreachable
  - “Destination” can be network, host, protocol, or port
- Redirect
  - To shortcut circuitous routing
- TTL Expired
  - Used by the traceroute program
- Echo request/reply
  - Used by the ping program

ICMP Restrictions

- Want to avoid overloading the network with ICMP packets
- Don’t generate ICMP error in response to:
  - 
  - 
  - 
- ICMP messages are often rate-limited too.

MTU problem

- Different networks may have different maximum frame sizes (MTUs)
  - e.g.,
    Ethernet 1.5K,
    FDDI 4.5K
- Don’t know beforehand if packet will be too big for path

MTU strategies

- What can we do to make sure packets “fit” on each network?
Fragment Fields

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Fragmentation consequences

- Loss of any fragments causes
- Reassemble at destination
  - Need time out in case fragments are lost
- Fragmentation is a burden for routers

Path MTU Discovery

- Path MTU is the smallest MTU along path
  - Packets less than this size don’t get fragmented
- Avoid fragmentation by having hosts learn path MTUs
- Hosts send packets, routers return error if too large
  - Hosts discover limits, can fragment at source
  - Reassembly at destination as before
- Learned lesson from IPv4, streamlined in IPv6

Key Concepts

- The IP protocol provides end-to-end data delivery on the Internet.
- ICMP provides error reporting.
- The Path MTU problem is an important issue resulting from heterogeneity.
- Next time: Sockets & applications