Internet Architecture
Internet Technologies and Regulation: Lecture 1

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The Internet: Nuts and Bolts

- Millions of connected computing devices.
  - Hosts are end systems
  - Running network applications
- Communication links
  - Fiber, copper, radio, satellite
  - Transmission rate is bandwidth
- Routers forward packets (chunks of data)
The Internet: Nuts and Bolts

- **Protocols** control sending, receiving of msgs
  - TCP, IP, HTTP, Skype, Ethernet
- **Internet**: a “network of networks”
  - Loosely hierarchical
  - Public Internet versus private intranet
- Internet standards
  - RFC: Request for comments
  - IETF: Internet Engineering Task Force
The Internet: A Service View

- **Communication infrastructure** enables distributed applications:
  - Web, VoIP, email, games, e-commerce, file sharing

- **Communication services provided to apps**:
  - Reliable data delivery from source to destination
  - “Best effort” (unreliable) data delivery
<table>
<thead>
<tr>
<th>Protocols</th>
<th>Human Protocols</th>
<th>Network Protocols</th>
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<tbody>
<tr>
<td></td>
<td>“What’s the time?”</td>
<td>Machines rather than humans</td>
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<tr>
<td></td>
<td>“I have a question”</td>
<td>All Internet communications governed by protocols</td>
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<tr>
<td></td>
<td>Introductions</td>
<td>Protocols define format, order of messages, and actions taken on messages</td>
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Specific messages sent. Specific actions taken when messages received, or other events.
Protocols

Hi

Got the time?

2:00

TCP connection request

TCP connection response

Get http://www.awl.com/kurose-ross

<file>
Network Edge

- **End systems (hosts)**
  - Run application programs, such as Web, email at “edge of network”

- **Client/server model**
  - Client host requests, receives service from always-on server
  - e.g. Web browser/server; email client/server

- **Peer-peer model**
  - Minimal (or no) use of dedicated servers
  - e.g. Skype, BitTorrent
Access networks and physical media

- How to connect end systems to edge router?
  - Residential access nets
  - Institutional access networks (school, company)
  - Mobile access networks

- Keep in mind
  - Bandwidth (bits per second) of access network?
  - Lag.
  - Shared or dedicated?
Digital Subscriber Line (DSL)

- Also uses existing telephone infrastructure
- Up to 1 Mbps upstream (today typically < 256 kbps)
- Up to 8 Mbps downstream (today typically < 1 Mbps)
- Dedicated physical line to telephone central office
Residential Access: Cable Modems

Diagram: http://www.cabledatacomnews.com/cmic/diagram.html
Ethernet Internet Access

- Typically used in companies, universities.
- 10 Mbs, 100Mbps, 1Gbps, 10Gbps Ethernet
- Today, end systems typically connect into Ethernet switch
Wireless Access Networks

- Shared wireless access network connects end system to router via base station or "access point"
- Wireless LANs
  - 802.11b/g (WiFi): 11 or 54 Mbps
- Wider-area wireless access provided by telco operator
  - 1 Mbps over cellular system (EVDO, HSDPA)
  - Next up (?): WiMAX (10's Mbps) over wide area
Home Networks

Typical home network components:

- DSL or cable modem
- Router/firewall/NAT
- Ethernet
- Wireless access point
The Network Core

- Mesh of interconnected routers.
- The fundamental question: how is data transferred through the net?
- Circuit switching
  - Dedicated circuit per call
  - Telephone net
- Packet-switching
  - Data sent through net in discrete "chunks"
Packet Switching vs. Circuit Switching

Packet switching allows more users to use network!

- 1 Mb/s link
- Each user:
  - 100 kb/s when ‘active’
  - Active 10% of time
- Circuit switching
  - 10 users
- Packet switching
  - With 35 users, probability > 10 active at same time is less than .0004
Packet Switching vs. Circuit Switching

Is packet switching entirely superior?

- Great for bursty data
  - Resource sharing
  - Simpler, no call setup

- Excessive congestion: packet delay and loss
  - Protocols needed for reliable data transfer, congestion control

- How to provide circuit-like behavior?
  - Bandwidth guarantees needed for audio/video
  - Remains an unsolved problem
Internet Structure: Network of Networks

- Roughly hierarchical
- At center, ‘tier-1’ ISPs (e.g., Verizon, Sprint, AT&T, Cable and Wireless) provide national/international coverage
  - Treat each other as equals
Tier-1 ISP
Internet Structure: Network of Networks

- ‘Tier-2’ ISPs: smaller, often regional, ISPs
  - Connect to one or more tier-1 ISPs, possibly other tier-2 ISPs
Internet Structure: Network of Networks

- ‘Tier-3’ ISPs and local ISPs
  - Last hop (‘access’) network (closest to end systems)
Internet Protocol Stack

- Application: supporting network applications
- Transport: process-process data transfer
- Network: routing of datagrams from source to destination
- Link: data transfer between neighboring network elements
- Physical: bits ‘on the wire’
Encapsulation

source

message
segment

application
transport

network
link
physical

destination

network
link
physical

switch

router

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Internet Architecture: 22/36
IP Datagram

- IP protocol version
- Header length (bytes)
- "type" of data
- Max number remaining hops (decremented at each router)
- Upper layer protocol to deliver payload to
- Total datagram length (bytes) for fragmentation/reassembly
- 16-bit identifier
- Fragment offset
- Time to live
- Upper layer checksum
- 32-bit source IP address
- 32-bit destination IP address
- Options (if any)
- Data (variable length, typically a TCP or UDP segment)

**How much overhead with TCP?**
- 20 bytes of TCP
- 20 bytes of IP
- 40 bytes + app layer overhead

E.g. timestamp, record route taken, specify list of routers to visit.
IPv6 Header

- **Priority**: identify priority among datagrams in flow.
- **Flow Label**: identify datagrams in same ‘flow’.
  - (concept of ‘flow’ not well defined)
- **Next header**: identify upper layer protocol for data.
Internet Structure: Network of Networks

A packet passes through many networks.
Loss and Delay

- Packets queue in router buffers
  - Packet arrival rate to link exceeds output link capacity
  - Packets queue, wait for turn
Real-world Internet Delays and Routes

- What do ‘real’ Internet delay and loss look like?
- **traceroute**: provides delay measurement from source to router along end-end Internet path towards destination.
- For all $i$:
  - Sends three packets that will reach router $i$ on path towards destination
  - Router $i$ will return packets to sender.
  - Sender times interval between transmission and reply.
User Datagram Protocol (UDP)

- ‘No frills,’ ‘bare bones’ Internet transport protocol
- ‘Best effort’ service. UDP segments may be:
  - Lost
  - Delivered out of order to application
- Connectionless
  - No handshaking between UDP sender, receiver
  - Each UDP segment handled independently of others

Why is there a UDP?

- No connection establishment.
- Simple: no connection state at sender, receiver
- Small segment header
- No congestion control: UDP can send as fast as desired
Transmission Control Protocol (TCP)

- Point-to-point
  - One sender, one receiver
- Reliable, in-order byte stream
  - No ‘message boundaries’
- Pipelined
  - TCP congestion and flow control set window size
- Send and receive buffers
Transmission Control Protocol (TCP)

- Full duplex data
  - Bi-directional data flow in same connection
  - MSS: maximum segment size

- Connection-oriented
  - Handshaking (exchange of control msgs) init’s sender, receiver state before data exchange

- Flow controlled
  - Sender will not overwhelm receiver
Network Address Translation (NAT)

All datagrams leaving local network have same single source NAT IP address: 138.76.29.7, different source port numbers

Datagrams with source or destination in this network have 10.0.0/24 address for source, destination (as usual)
NAT Traversal Problem

- Relaying (used in Skype)
  - NATed client establishes connection to relay
  - External client connects to relay
  - Relay bridges packets between to connections
Multicast Routing

- Find a tree (or trees) connecting routers having local multicast group members
  - Tree: not all paths between routers used
  - Source-based: different tree from each sender to receivers
  - Shared-tree: same tree used by all group members
Diffserv Architecture

**Edge router:**
- per-flow traffic management
- marks packets as **in-profile** and **out-profile**

**Core router:**
- per class traffic management
- buffering and scheduling based on marking at edge
- preference given to **in-profile** packets
Intserv Architecture

- Architecture for providing QoS guarantees in IP networks for individual application sessions.
- Resource reservation: routers maintain state info of allocated resources, QoS requirements.
- Admit/deny new call setup requests.
Summary

- Internet overview
- Protocols
- Network edge, core, access network
  - Packet-switching versus circuit-switching
  - Internet structure
- Performance: loss, delay
- Layering, service models
- Network address translation
- QoS: differerv, intserv