The Internet is an Exciting Place
Two Billion Internet Users

Internet Users in the World by Geographic Regions - 2011

- Asia: 922.3 million
- Europe: 476.2 million
- North America: 272.1 million
- Latin America / Caribbean: 215.9 million
- Africa: 110.9 million
- Middle East: 68.6 million
- Oceania / Australia: 21.3 million

~5 Billion Devices (PCs, laptops, smartphones, etc.)

Source: Internet World Stats - www.internetworldstats.com/stats.htm
Estimated Internet users are 2,095,006,005 on March 31, 2011
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The Internet is a Tense Place
Egypt blocks Internet access amid protests

28 JANUARY 2011  Daniel Shane

Government orders telcos to block web access as protestors take to the streets

The Egyptian government has called on telecommunications providers in the country to block access to the Internet in response to widespread civil unrest.

Vodafone Egypt, one of the largest operators in the country not controlled by the state, today said it has disabled access following pressure from authorities.
Internet Traffic to and from Egypt on January 27. At 5:20 pm EST, traffic to and from Egypt across 80 Internet providers around the world drops precipitously.
Stop Online Piracy Act (SOPA)
Network Neutrality

FCC Rules Against Comcast P2P Throttling

The U.S. Federal Communications Commission has ordered Comcast to stop interfering with peer-to-peer traffic on its broadband network...
“Currently, the Internet is built using IPv4, but on February 3, 2011, the global supply of unassigned IPv4 Internet addresses was exhausted. On that date, the Internet Assigned Numbers Authority has distributed the final five blocks of approximately 16 million IPv4 addresses among the five Regional Internet Registries.”
Cyber Attacks

Send out thousands of phishing emails with link to fake website.

Victims click on link in email believing it is legitimate. They enter personal information.

PHISHING

Build fake site.

Fraudsters compile the stolen data and sell it online or use it themselves.

Fraudsters
What *is* the Internet?

3 guiding principles!
“Best-Effort Packet Delivery Service”
“Power at the Edge”

End-to-End Principle
Whenever possible, communications protocol operations should be defined to occur at the end-points of a communications system.

Keeps the network simple and scalable
Allows for easy introduction of new services at the edges
“A Network of Networks”

THE INTERNET

Client
Browser

Web server
“A Network of Networks”
How the Internet is Organizing?

Layering
Layering

• Layering is a particular form of abstraction
• The system is broken into a *vertical stack* of functions/protocols
• The service provided by one layer is based solely on the service provided by the layer below
  – This is the “up/down” interface
Layering in the Internet

- **Application**
- **Transport**
- **Network**
- **Data Link**
- **Physical**

**End-to-End Layer**
Everything else! Reliability, integrity, packet ordering, congestion control, ...

**Forwarding & routing**
Framing, coding, channel access Modulation/demodulation

- **HTTP, FTP, SMTP, BitTorrent, ...**
- **TCP, UDP**
- **IP**
- **Ethernet, WiFi, ...**
- Link and network layers are implemented everywhere.
- The end-to-end layer (i.e., transport and application) is implemented only at hosts.
An Example

Browser

GET "6.033/index.html"

Server

OK; file data

TCP

Reliable data transfer

IP

Wireless

IP

Optical

IP

T3

Ethernet

IP

SCTP

UDP

E-mail

FTP

News

File

Router

Router

Router
The Internet “Hourglass”

Applications
- Web
- FTP
- Mail
- News
- Video
- Audio
- ping
- napster

Transport protocols
- TCP
- SCTP
- UDP
- ICMP

Link technologies
- Ethernet
- 802.11
- Power lines
- ATM
- Optical
- Satellite
- Bluetooth

- Many applications, transports, and link protocols
- All use IP at the network layer: universal network layer
Network Layer

Routing (figuring out the routes) &
Forwarding (sending the packets)
How Does a Router Forwards the Packets?

- A router has input links and output links
- A router sends an input packet on the output link leading toward the packet’s destination node
- A router does not care of who generated the packet
How does the router know which output link leads to a packet destination?

- Packet **header** has the destination
- Router **looks up the destination in its table** to find output link
- Table is built using a **routing protocol**

<table>
<thead>
<tr>
<th>Destination</th>
<th>Out-link</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>out-link 1</td>
</tr>
<tr>
<td>B</td>
<td>out-link 2</td>
</tr>
<tr>
<td>C</td>
<td>out-link 3</td>
</tr>
<tr>
<td>D</td>
<td>out-link 3</td>
</tr>
</tbody>
</table>
Basic Requirements of a Routing Protocol

• Finds a path from source to destination
• Optimizes some metric (delay, cost, etc.)
• Has no (permanent) loops
Distance Vector Routing

- **Initialize**
  - Distance to self is zero and next hop is self
  - Distance to anyone else is infinity

- **Announce:** Every T seconds
  - Tell neighbors distances to all destinations

- **Update route to dst. upon message from j**
  - Distance via j = j’s distance + weight of link to j
  - If distance via j is shorter than current distance, update routing table to go via j
Example

**Objective:** Determine the route from \((R_1, \ldots, R_7)\) to \(R_8\) that minimizes the distance
Solution is simple by inspection... (in this case)

The shortest paths from all sources to a destination (e.g., $R_8$) is the **spanning tree** routed at that destination.
**Initial State:** All routers except R8 set their route length to $\infty$. R8 sets its route length to 0.
Distance Vector Routing

Example

- Every $T$ seconds, Router $i$ tells its neighbors about its current lowest-cost path to $R_8$
- Each router updates its distance as $\min(\text{current distance}, \text{received distance} + \text{link weight})$

Note, routing tables have both the next-hop and the distance
Distance Vector Routing

Example

Repeat until no distance change
Distance Vector Routing

Example

Final Iteration

| R₁  | 6, R₃ |
| R₂  | 4, R₅ |
| R₃  | 4, R₈ |
| R₄  | 6, R₇ |
| R₅  | 2, R₈ |
| R₆  | 2, R₈ |
| R₇  | 3, R₈ |

| R₁  | 5, R₂ |
| R₂  | 4, R₅ |
| R₃  | 4, R₈ |
| R₄  | 5, R₂ |
| R₅  | 2, R₈ |
| R₆  | 2, R₈ |
| R₇  | 3, R₈ |
Summary

• Internet architecture is based on layering
  E2E Layer
  Network Layer
  Link Layer
• Job of Network Layer is Routing & Forwarding
  – Routers build routing tables using routing protocol
  – Routers forward packets based on the packet’s header and the routing table