Introduction to Networking

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August 26, 2024

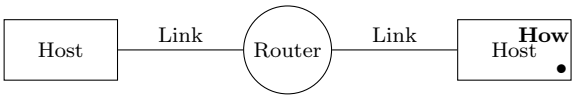
Acknowledgements

All materials for this course adapted from courses developed by Morley Mao, Mosharaf Chowdhury, Aditya Akella, Sugih Jamin, Philip Levis, Sylvia Ratnasamy, Peter Steenkiste, and many other colleagues.
Many figures and slides borrowed from Jim Kurose and Keith Ross's textbook and slides.
Recommended Textbook

A Data Network

Consists of:

- **Links** that interconnect
- **Hosts** and **Routers** in order to
  - Move data between hosts via routers
  - Hosts also called **End Systems**
  - Routers sometimes called **Switches**



The Internet

- A large, global, data network
- Focus of this class

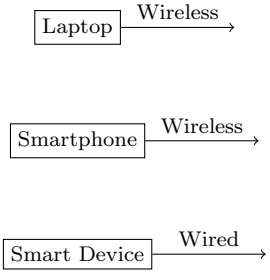
A Macroscopic View

How hosts connect to the network:
Hosts

- Laptops
- Smartphones
- Other smart devices

Links

- Wired
- Wireless



Networks and Routers

Routers

- Wireless access points
- Cell towers
- Wired switches

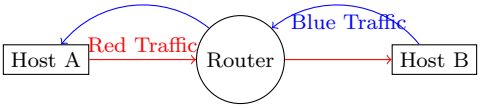
Networks

- Local ISPs
- Campus networks
- National ISPs

A Shared Network

Sharing!

- Apps and hosts share routers and links
- Red and blue traffic go over the same link



Two Ways to Share Switched Networks

- **Circuit Switching**
- **Packet Switching**

Circuit Switching

What is it?

- Circuit: a connection between sender and receiver with dedicated resources
- Analogy: multiple lanes between each pair of routers; circuit uses one of these lanes at each hop

How is it implemented?

- **Frequency-Division Multiplexing (FDM)**
  - Optical cables have different frequencies
  - Each circuit sent on a different frequency
- **Time-Division Multiplexing (TDM)**
  - Data from different connections sent in different time slots

Packet Switching

What is a packet?

- A unit of data transmitted on network
- Have a maximum size (L bits)
- Large transfers divided into multiple packets

What do routers do with packets?

- **Store and Forward**
  - Router waits to receive full packet
  - Stores it locally
  - Forwards it towards destination

Queueing at routers

- **Queue**: a sequence of packets stored in a router waiting to be transmitted
- Queues form when packets arrive faster than can be sent out
- If queue is large, router may drop packets

Which Is Better? Pros and Cons

Circuit Switching

- **Pros**
  - Predictable performance
  - Simple/fast switching (once circuit established)
- **Cons**
  - Complexity and delay of circuit setup/teardown
  - If switch fails, its circuit(s) fail

Packet Switching

- **Pros**
  - No circuit setup, faster transfers
  - Easier failure handling, re-route on different path
- **Cons**
  - Packets can be dropped, impacting performance
  - Queueing can add delays

Statistical Multiplexing

Why the Internet uses packet switching

- Computer communication is bursty
- Applications/services have on/off behavior
- Packet-switched networks can more efficiently support bursty traffic due to statistical multiplexing

An Example

- Circuit switching can only support 10 users; must build network for worst case
- Packet switching can support 35 users because probability that all users are active at the same time is low

Measures of Network Performance

1. End-to-end delay
2. Packet loss rate
3. Throughput

End-to-end Delay

Let:

- t_{sent} be time sent
- t_{recv} be time received

End-to-end delay:

$$d_{\text{end-to-end}} = t_{\text{recv}} - t_{\text{sent}}$$

Components of End-to-end Delay

- **Transmission Delay** (d_{trans})
- **Propagation Delay** (d_{prop})
- **Queueing Delay** (d_{queue})
- **Processing Delay** (d_{proc})

Total delay at a router:

$$d_{\text{router}} = d_{\text{queue}} + d_{\text{proc}} + d_{\text{trans}} + d_{\text{prop}}$$

Packet Loss Rate

Let:

- N be number of packets sent
- l be number of packets lost
- p be packet loss rate

Packet loss rate:

$$p = \frac{l}{N}$$

Recovering from packet loss

- Hosts/applications detect when a packet is lost
- Retransmit lost packets to recover from loss

Throughput

Definitions

- If B bits are transferred from sender to receiver in time t, then:

$$\text{Throughput} = \frac{B}{t}$$

- **Instantaneous Throughput**: when t is small
- **Average Throughput**: over the duration of a connection

Pipe Model of a Link

What is a model?

- A mathematical or mental construct that helps understand a physical process

Pipe Model

- A link is modeled as a pipe (though it doesn't carry water!)
- Helps us understand link behavior

Will use this model later in the course.

Queueing

Why do queues form at routers?

- If packets arrive faster than the router can process, they are placed into a queue
- **Queueing delay**:
  - $t_{p,e}$: time when packet p enters queue
  - $t_{p,l}$: time when it leaves queue
  - $d_{\text{queue}} = t_{p,l} - t_{p,e}$
- Transient overload when packets are queued

When do queues never form?

- If router can process and send packets faster than they arrive, no queues form

When can a router drop packets?

- If router runs out of memory (buffer), it may drop a packet

Queueing Delay

Per-packet queueing delay:

$$d_{\text{queue}} = t_{p,l} - t_{p,e}$$

Characterized by statistical measures:

- Average queueing delay
- Variance of queueing delay
- Probability delay exceeds a threshold value

Queueing Theory

- Complex mathematical discipline studying queue behavior under different conditions
- **Little's Law**:

$$L = \lambda \times W$$

  - L: Average length of queue
  - λ: Average arrival rate
  - W: Average wait time
- Independent of arrival pattern and service times

Processing Delay

- Router processing involves reading and possibly modifying the packet
- d_{proc} is usually negligible

End-to-End Delay

Delay at router:

$$d_{\text{router}} = d_{\text{queue}} + d_{\text{proc}} + d_{\text{trans}} + d_{\text{prop}}$$

End-to-end delay:

$$d_{\text{end-to-end}} = \sum_{\text{routers}} d_{\text{router}}$$

Why do delays add up?

- Store-and-forward routers wait to receive the full packet before processing

Summary

- **Elements of Network**: Links, hosts, routers
- **Internet**: Network of networks
- **Sharing**: Circuit vs. packet switching
- **Packet Switching**: Multiplexing, packet loss, queueing
- **Measures**: Loss rate, delay, throughput

Additional Reading

- Sections 1.1, 1.3, 1.4 from the recommended textbook

Layering and Protocols

Ramesh Govindan
September 3, 2024

The Web

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September 4, 2024

Widely-used Networked Applications

- **Communication**: E-mail, Text messaging, Social networking
- **Entertainment**: Gaming, Video streaming (e.g., YouTube)
- **Information**: Web, Internet Search
- **Telepresence**: Voice over IP, Video conferencing (e.g., Zoom)

Will learn later how many of these work.

What is the Web?

The Logical View

- Database of hypertext documents
- Origins in the 90s by Tim Berners-Lee at CERN to facilitate scientific collaboration

Hypertext and Hyperlinks

- **Hypertext**: Text containing hyperlinks
- **Hyperlink**: Reference to another document or object

Hypertext Markup Language (HTML)

- Language for marking up text
- Markups for formatting and hyperlinks

How it Works

User types URL into browser.
Browser

- Sends request to server over the Internet

Server

- Responds with page contents