Introduction

What is this course about?

- Theory vs practice
  - CSC358: Theory
  - CSC309 and CSC458: Practice
- Need to have solid math background
  - In particular, probability theory
- Overview
  - Principles of computer networks, layered architecture
  - Connectionless and connection-oriented transports
  - Reliable data transfer, congestion control
  - Routing algorithms, multi-access protocols,
  - Delay models, addressing, and some special topics

Overview: internet protocol stack

- Application: supporting network applications
  - FTP, SMTP, HTTP
- Transport: process-process data transfer
  - TCP, UDP
- Network: routing of datagrams from source to destination
  - IP, routing protocols
- Link: data transfer between neighboring network elements
  - Ethernet, 802.111 (WiFi), PPP
- Physical: bits "on the wire"

Logistics (1/3)

- Prerequisite knowledge
  - Probability theory is a must
  - Mathematical modeling
  - Data structures & algorithms

- Course components
  - Lectures: concepts
  - Tutorials: problem solving
  - Assignments: mastering your knowledge
  - Readings: preparing you for above
  - Optional assignments: things in practice, bonus

Logistics (2/3)

- Text book

- Lecture slides
  - Many slides are (adapted) from the above source
  - © All material copyright
  - All rights reserved for the authors
Logistics (3/3)

- For important information on:
  - Lecture and tutorial time/location
  - Contact information of course staff (instructor and TAs)
  - Office hour and location
  - Assignments specification and solution
  - Readings, lectures notes (slides), and tutorial materials
  - Deadlines and evaluation
  - Communication and announcements

- Follow the course web page, regularly

Let's begin with Chapter 1

1.1 what is the Internet?
1.2 network edge
  - end systems, access networks, links
1.3 network core
  - packet switching, circuit switching, network structure
1.4 delay, loss, throughput in networks
1.5 protocol layers, service models
1.6 networks under attack: security
1.7 history

Key terms

- Internet
- protocol
- packet ~ chunk of data
- network edge, access net, physical media, network core
- host ~ end system ~ (computing) device/machine/terminal ~ server (or client) ~ sender/transmitter ~ receiver
- router ~ (packet) switch ~ sender/transmitter ~ receiver
- packet/circuit switching
- (wired, wireless) link
- link capacity ~ link bandwidth ~ transmission rate
- propagation rate
- performance: loss, delay, throughput

What is the Internet?

What’s the Internet: “nuts and bolts” view

- millions of connected computing devices:
  - hosts=end systems
  - running network apps
- communication links
  - fiber; copper; radio; satellite
  - transmission rate: bandwidth
- Packet switches
  - routers and switches
  - forward packets (chunks of data)

“Fun” internet appliances

- IP picture frame
  http://www.ceiva.com/
- Web-enabled toaster + weather forecaster
- Internet refrigerator
- Internet phones

- Slingbox: watch, control cable TV remotely
- Tweet-a-watt: monitor energy use
Internet: “network of networks”
- Interconnected ISPs
- Protocols: control sending, receiving of msgs
  - e.g., TCP, IP, HTTP, Skype, 802.11
- Internet standards
  - RFC: Request for comments
  - IETF: Internet Engineering Task Force

Infrastructure that provides services to applications:
- Web, VoIP, email, games, e-commerce, social nets...
- Provides application programming interface
  - Hooks that allow sending and receiving app programs to "connect" to Internet
  - Provides service options, analogous to postal service

What’s the Internet: “nuts and bolts” view

What’s a protocol?

Human protocols:
- "What’s the time?"
- "I have a question"
- Introductions
... Specific msgs sent
... Specific actions taken when msgs received, or other events

Network protocols:
- Machines rather than humans
- All communication activity in Internet governed by protocols
  - Protocols define format, order of msgs sent and received among network entities, and actions taken on msg transmission, receipt

What’s a protocol?

A human protocol and a computer network protocol:

Q: Other human protocols?

A closer look at network structure:

Network edge:
- Hosts: clients and servers
- Servers often in data centers
- Access networks, physical media: wired, wireless communication links

Network core:
- Interconnected routers
- Network of networks

Access networks and physical media

Q: 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?
- Shared or dedicated?
**Access net: digital subscriber line (DSL)**

- Use existing telephone line to central office DSLAM
  - Data over DSL phone line goes to Internet
  - Voice over DSL phone line goes to telephone net
  - < 2.5 Mbps upstream transmission rate (typically < 1 Mbps)
  - < 24 Mbps downstream transmission rate (typically < 10 Mbps)

**Access net: cable network**

- HFC: hybrid fiber coax
  - Asymmetric: up to 30Mbps downstream transmission rate, 2 Mbps upstream transmission rate
  - Network of cable, fiber attaches homes to ISP router
  - Homes share access network to cable headend
  - Unlike DSL, which has dedicated access to central office

**Access net: home network**

- Wireless access networks
  - Shared wireless access network connects end system to router via base station aka “access point”
  - Wi-Fi: 11 Mbps
  - 802.11b/g (WiFi): 11, 54 Mbps transmission rate
  - 3G, 4G: LTE

**Enterprise access networks (Ethernet)**

- Typically used in companies, universities, etc
- 10 Mbps, 100Mbps, 1Gbps, 10Gbps transmission rates
- Today, end systems typically connect into Ethernet switch
**Physical media**

- **bit**: propagates between transmitter/receiver pairs
- **physical link**: what lies between transmitter & receiver
- **guided media**:
  - signals propagate in solid media: copper, fiber, coax
- **unguided media**:
  - signals propagate freely, e.g., radio

- **twisted pair (TP)**:
  - two insulated copper wires
  - Category 5: 100 Mbps, 1 Gbps Ethernet
  - Category 6: 10Gbps

**Physical media: coax, fiber**

- **coaxial cable**:
  - two concentric copper conductors
  - bidirectional
  - broadband:
    - multiple channels on cable
    - HFC

- **fiber optic cable**:
  - glass fiber carrying light pulses, each pulse a bit
  - high-speed operation:
    - high-speed point-to-point transmission (e.g., 100 Gbps transmission rate)
  - low error rate:
    - repeaters spaced far apart
    - immune to electromagnetic noise

**Physical media: radio**

- **signal carried in electromagnetic spectrum**
- **no physical "wire"**
- **bidirectional**
- **propagation environment effects**:
  - reflection
  - obstruction by objects
  - interference

- **radio link types**:
  - terrestrial microwave
    - e.g. up to 45 Mbps channels
  - LAN (e.g., WiFi)
    - 11 Mbps, 54 Mbps
  - wide-area (e.g., cellular)
    - 3G cellular: ~ few Mbps
  - satellite
    - Kbps to 45 Mbps channel (or multiple smaller channels)
    - 270 msec end-end delay
    - geosynchronous versus low altitude

**Host: sends packets of data**

- **host sending function**:
  - takes application message
  - breaks into (smaller) chunks, known as packets, of length \( L \) bits
  - transmits packet into access network at transmission rate \( R \)
    - link transmission rate, aka link capacity, aka link bandwidth

\[
\text{packet transmission delay} = \frac{L}{R} \text{ (bits/sec)}
\]

**The network core**

- **mesh of interconnected routers and links**
  - **forward** packets from one router to the next, across links on path from source to destination
  - each packet transmitted at full link capacity

- **one-hop numerical example**:
  - \( L = 1 \text{ KBytes} \)
  - \( R = 1.6 \text{ Mbps} \)
  - one-hop transmission delay?
Packet switching: queueing delay, loss

queueing and loss:
- If arrival rate (in bits) to link exceeds transmission rate of link for a period of time:
  - packets will queue, wait to be transmitted on link
  - packets can be dropped (lost) if memory (buffer) fills up

Alternative core: circuit switching

end-end resources allocated to, reserved for "call" between source & dest:
- In diagram, each link has four circuits.
  - call gets 2nd circuit in top link and 1st circuit in right link.
- dedicated resources: no sharing
  - circuit-like (guaranteed) performance
  - circuit segment idle if not used by call (no sharing)
- Commonly used in traditional telephone networks

Packet switching versus circuit switching

packet switching allows more users to use network!

example:
- 1 Mb/s link
  - each user:
    - 100 kbps when "active"
    - active 10% of time
  - circuit-switching:
    - 10 users
  - packet-switching:
    - with 11 users, what is the probability that all active at same time?
    - with 35 users, probability > 10 active at same time is less than 0.0004. Q: what if > 35 users?

Two key network-core functions

routing: determines source-destination route taken by packets
  - routing algorithms

forwarding: move packets from routers input to appropriate router output

Circuit switching: FDM versus TDM

FDM

Example: 4 users

TDM

Packet switching versus circuit switching

is packet switching a "slam dunk winner?"

- great for bursty data
- resource sharing
- simpler, no call setup
- excessive congestion possible: packet delay and loss
- protocols needed for reliable data transfer, congestion control
- How to provide circuit-like behavior?
- bandwidth guarantees needed for audio/video apps
- still an unsolved problem

Q: human analogies of reserved resources (circuit-switching) versus on-demand allocation (packet-switching)?
Internet structure: network of networks

- End systems connect to Internet via access ISPs (Internet Service Providers)
  - Residential, company, and university ISPs
- Access ISPs in turn must be interconnected
  - So that any two hosts can send packets to each other
- Resulting network of networks is very complex
  - Evolution was driven by economics and national policies
- Let’s take a stepwise approach to describe current Internet structure

Option: connect each access ISP to every other access ISP?

Connecting each access ISP to each other directly doesn’t scale: $O(N^2)$ connections.

Option: connect each access ISP to a global transit ISP? Customer and provider ISPs have economic agreement.

But if one global ISP is viable business, there will be competitors.... which must be interconnected.

Internet exchange point

Peering link
Internet structure: network of networks

… and regional networks may arise to connect access nets to ISPs

… and content provider networks (e.g., Google, Microsoft, Akamai) may run their own network, to bring services, content close to end users

Introduction

Summary

- Internet overview
- what’s a protocol?
- network edge, core, access network
  - packet-switching versus circuit-switching
  - Internet structure
- performance: loss, delay,

Next

- Assignment 1: out next week
- Delay & loss, throughput, layering & service models
- continued by more depth, detail on each layer in the following lecture