Welcome to CSC358!
Introduction to Computer Networks

Course Outline
- What this course is about

Logistics
- Course organization, information sheet
- Assignments, grading scheme, etc.

Introduction to
- Principles of computer networks
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, 802.11 (WiFi), PPP

- **physical**: bits “on the wire”
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**
  - *Computer Networking*
    - *A Top-Down Approach Featuring the Internet*

- **Lecture slides**
  - Many slides are (adapted) from the above source
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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

Slingbox: watch, control cable TV remotely

Tweet-a-watt: monitor energy use

Internet refrigerator

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

- **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
What’s the Internet: a service view

- **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 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

self-reading to Page 28
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**

*frequency division multiplexing*: different channels transmitted in different frequency bands
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 devices**
  - wireless access point (54 Mbps)
  - often combined in single box

- **to/from headend or central office**
  - cable or DSL modem
  - router, firewall, NAT
  - wired Ethernet (100 Mbps)
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
Wireless access networks

- shared *wireless* access network connects end system to router
  - via base station aka “access point”

**wireless LANs:**
- within building (100 ft)
- 802.11b/g (WiFi): 11, 54 Mbps transmission rate

**wide-area wireless access**
- provided by telco (cellular) operator, 10’ s km
- between 1 and 10 Mbps
- 3G, 4G: LTE
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., 10’s-100’s Gpbs 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)
  - 11Mbps, 54 Mbps
- wide-area (e.g., cellular)
  - 3G cellular: ~ few Mbps
- satellite
  - Kbps to 45Mbps 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

\[
\text{packet transmission delay} = \frac{L \text{ (bits)}}{R \text{ (bits/sec)}}
\]
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
Packet-switching: store-and-forward

- takes $L/R$ seconds to transmit (push out) $L$-bit packet into link at $R$ bps
- **store and forward**: entire packet must arrive at router before it can be transmitted on next link
- end-end delay = $2L/R$ (assuming no other delays)

**one-hop numerical example:**
- $L = 1$ KBytes
- $R = 1.6$ Mbps
- one-hop transmission delay?

more on delay shortly …
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
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

<table>
<thead>
<tr>
<th>header value</th>
<th>output link</th>
</tr>
</thead>
<tbody>
<tr>
<td>0100</td>
<td>3</td>
</tr>
<tr>
<td>0101</td>
<td>2</td>
</tr>
<tr>
<td>0111</td>
<td>2</td>
</tr>
<tr>
<td>1001</td>
<td>1</td>
</tr>
</tbody>
</table>
Alternative core: circuit switching

end-end resources allocated to, reserved for “call” between source & dest:

- In diagram, each link has four circuits.
  - call gets 2\textsuperscript{nd} circuit in top link and 1\textsuperscript{st} circuit in right link.
- dedicated resources: no sharing
  - circuit-like (guaranteed) performance
- circuit segment idle if not used by call \textit{(no sharing)}
- Commonly used in traditional telephone networks
Circuit switching: FDM versus TDM

Example:
4 users

FDM

TDM

frequency

time

frequency

time
Packet switching versus circuit switching

packet switching allows more users to use network!

eample:

- 1 Mb/s link
- each user:
  - 100 kb/s 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?
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
- Q: 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
Question: given millions of access ISPs, how to connect them together?
Internet structure: network of networks

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.
Internet structure: network of networks

Option: connect each access ISP to a global transit ISP? Customer and provider ISPs have economic agreement.
Internet structure: network of networks

But if one global ISP is viable business, there will be competitors
But if one global ISP is viable business, there will be competitors … which must be interconnected
… and regional networks may arise to connect access nets to ISPS
Internet structure: network of networks

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

- at center: small # of well-connected large networks
  - "tier-1" commercial ISPs (e.g., Level 3, Sprint, AT&T, NTT), national & international coverage
  - content provider network (e.g, Google): private network that connects it data centers to Internet, often bypassing tier-1, regional ISPs
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