Class Calendar

Office hours for all questions, e.g., project/lab assignment related questions, like programming...

Office hours for lecture related questions, and general questions for labs and projects.
Suggestions for Labs/Projects

Labs:
- Office hour
- Email to cs3516-ta@cs.wpi.edu
- Discussion forum

Socket Programming Projects:
- Start with the simplest example in the slides
Welcome to

**CS 3516:**
Advanced Computer Networks

Prof. Yanhua Li

Time: 9:00am –9:00am M, T, R, and F
Location: Fuller 320
Fall 2016 A-term
Roadmap

Three key topics in network core

• 1. Switching, Resource allocation (chp 1.3)
• 2. Routing & Forwarding (to be discussed in Network layer chp 4)
• 3. Network Core Structure / Management / Coordination (chp 1.3)

1.3 network core

- Review on switching (resource allocation)
- Quiz 1 --- 15 mins
- network structure
The network core

- mesh of interconnected routers
- packet-switching: hosts break application-layer messages into packets
  - 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 zero propagation delay)

**one-hop numerical example:**
- $L = 7.5$ Mbits
- $R = 1.5$ Mbps
- one-hop transmission delay = 5 sec

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 router’s input to appropriate router output
**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 (*no sharing*)
- Commonly used in traditional telephone networks
Introduction

Circuit switching: FDM versus TDM

FDM

Example:
4 users

TDM

Introduction 1-10
Packet switching versus circuit switching

packet switching allows more users to use network!

example:
- 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 *

Q: how did we get value 0.0004?

* Check out the online interactive exercises for more examples
Packet switching versus circuit switching

is packet switching a “slam dunk winner?”

- great for bursty data (advantages)
  - 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 (chapter 7)

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

Like parking lots.
Quiz I

No textbook/notes.
1 page (A4 sized) cheat sheet is allowed.
Roadmap

1.3 network core

- Review on switching (resource allocation)
- Quiz 1 --- 15 mins
- network structure
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...

Tier 1 ISPs: Level 3, AT&T, Sprint, NTT
Internet structure: network of networks

But if one global ISP is viable business, there will be competitors ... which must be interconnected.
Internet structure: network of networks

... 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 its data centers to Internet, often bypassing tier-1, regional ISPs
Tier-1 ISP: e.g., Sprint
Click here for a closer look at the Sprint network on the East Coast.

Click here for a closer look at the Sprint network in Washington state.

Click here for a closer look at the Sprint network in Northern California.

Pearl City in Hawaii is a future network location.
AT&T IP BACKBONE NETWORK
2Q2000

OC1 (45 Mbps), OC2 (155 Mbps), …, OC192 (10 Gbps)
Internet Users in the World by Geographic Regions - 2012 Q2

Source: Internet World Stats - www.internetworldstats.com/stats.htm
2,405,518,376 Internet users estimated for June 30, 2012
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Questions?