COMP/ELEC 429/556
Introduction to Computer Networks

Overview
A bit about me...

- Grew up in Hong Kong
- B.S. University of Washington
- Ph.D. Carnegie Mellon University

- Research interests in networked systems
- Teach courses related to computer networks at both undergraduate and graduate levels

- CS Director of PhD Studies
My Research: The BOLD Lab

NETWORK (NETWORK)

Researchers Target Network Bottlenecks

Researchers at Rice University will use a three-year National Science Foundation grant to improve network efficiency and speed up science research.

BY COLIN WOOD (HTTP://WWW.GOVTECH.COM/AUTHORS/COLIN-WOOD.HTML) / SEPTEMBER 30, 2013
Why You Should Take This Course

• I would tell you a joke about UDP, but you probably wouldn't get it.
• I had a funny UDP joke to tell, but I lost it somewhere...
• A TCP packet walks in to a bar and says “I want a beer”, barman says “you want a beer?” and TCP packet says “yes, a beer”
• A bunch of TCP packets walk into a bar. The bartender says, “Hang on just a second, I need to close the window.”
• When I try to send SYNs to chicks, I don’t get any ACKs. Just FINs and RSTs.
• The problem with TCP jokes is that people keep retelling them slower until you get them.
Obviously Networks Make These Possible
(The Internet)
Network Crucial to Solving Hard Computational and Data Intensive Problems (Data Center Networks)

- Hadoop
- Open MPI
- TensorFlow
- Spark
- PyTorch
Networks Are Everywhere (Embedded Networks)
Long before there were computers...

- 1876: Alexander Bell invented telephone
- 1878: Public switches installed at New Haven and San Francisco, public switched telephone network is born
  – People can talk without being on the same wire!
The Advent of Computer Technology

1940s

- Different networking requirements
- Computers to computers communication
  - vs. communication between human beings
- Digital information, discrete messages
  - vs. continuous analog voice
- Circuit switching technique in telephone network hugely inefficient for computer communications
Major Internet Milestones

• 1960-1964 Basic concept of “packet switching” was independently developed by Paul Baran (RAND), Leonard Kleinrock (MIT)
  – AT&T insisted that packet switching would never work!
• 1965 First time two computers talked to each other using packets (Roberts, MIT; Marill, System Development Corp (SDC))

[Images of MIT TX-2 and SDC Q32]
Major Internet Milestones

• 1968 BBN group proposed to use Honeywell 516 mini-computers for the Interface Message Processors (i.e. packet switches)

• 1969 The first ARPANET message transmitted between UCLA (Kleinrock) and SRI (Engelbart)
  – We sent an “L”, did you get the “L”? Yep!
  – We sent an “O”, did you get the “O”? Yep!
  – We sent a “G”, did you get the “G”? Crash!
Major Internet Milestones

- 1971 First packet radio network ALOHANET (Abramson, U Hawaii)
- 1973 Ethernet invented (Metcalf, Xerox PARC)
- 1974 “A protocol for Packet Network Interconnection” published by Cerf and Kahn
  - First internetworking protocol TCP
The 2004 A. M. Turing Award Goes to...

Bob Kahn       Vint Cerf

- "For pioneering work on internetworking, including the design and implementation of the Internet's basic communications protocols, TCP/IP, and for inspired leadership in networking."

T. S. Eugene Ng  eugeneng at cs.rice.edu  Rice University
Major Internet Milestones

• 1977 First TCP operation over ARPANET, Packet Radio Net, and SATNET
• 1985 NSF commissions NSFNET backbone
• 1991 NSF opens Internet to commercial use
Network Component Examples

Links

Interfaces

Switches/routers

Ethernet

WiFi
INTERNET2 NETWORK INFRASTRUCTURE TOPOLOGY

October 2014

INTERNET2 NETWORK BY THE NUMBERS

12 L3 IPv6 (Internet Protocol version 6) sites supporting Layer 3 service
36 L3 IPv6 (Internet Protocol version 6) sites supporting Layer 2 service
62 K5 custom collaboration sites
141 Amplification racks
600 Miles/1000 miles of active network elements
1000 Miles partnered capacity with 40G communications in support of the Northern Tier Region
Course goals

- Knowledge and skills
  - How stuff work; skills from doing hands-on projects

- Scalability
- Performance
- Coordination
- Robustness
How applications use network to communicate
How to route effectively

<table>
<thead>
<tr>
<th>Step</th>
<th>start S</th>
<th>D(B),p(B)</th>
<th>D(C),p(C)</th>
<th>D(D),p(D)</th>
<th>D(E),p(E)</th>
<th>D(F),p(F)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>A</td>
<td>2,A</td>
<td>5,A</td>
<td>1,A</td>
<td>∞</td>
<td>∞</td>
</tr>
<tr>
<td>1</td>
<td>AD</td>
<td></td>
<td>4,D</td>
<td>2,D</td>
<td>∞</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>ADE</td>
<td></td>
<td>3,E</td>
<td></td>
<td>4,E</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>ADEB</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Loop

9 find w not in S s.t. D(w) is a minimum;
10 add w to S;
1 update D(v) for all v adjacent to w and not in S:
12 \[ D(v) = \min( D(v), D(w) + c(w,v) ) \];
13 until all nodes in S;

T. S. Eugene Ng
eugeneng at cs.rice.edu
Rice University
How to scale network globally

E-BGP

you can reach net B via addr2 and the path is “AS3 AS2”

I-BGP

you can reach net B via addr1 and the path is “AS3”

E-BGP

you can reach net B via addr1 and the path is “AS3”

AS1

AS2

AS3

addr2

addr1
How to make communication reliable

- Three-Way Handshake
  - Each side notifies other of starting sequence number it will use for sending
  - Each side acknowledges other’s sequence number
    - SYN-ACK: Acknowledge sequence number + 1
    - Can combine second SYN with first ACK
How to share the network effectively

- No congestion $\rightarrow$ rate increases by one packet/RTT every RTT
- Congestion $\rightarrow$ decrease rate by factor 2

Rates equalize $\rightarrow$ fair share
How to achieve predictable performance

• Decides how the output link capacity is shared by flows
• A chance to be smart: Transmission of packets held in queues can be *scheduled*
  – Which stored packet goes out next? Which is more “important”?
  – Impacts quality of service

![Diagram of classifier and scheduler with flows](image)
Understand Internet’s limitations

So whatever happened internally at Verizon caused aggregation for these prefixes to fail which resulted in the introduction of thousands of new /24 routes into the global routing table.
Understand Internet’s insecurity

HACKER REDIRECTS TRAFFIC FROM 19 INTERNET PROVIDERS TO STEAL BITCOINS

How Pakistan knocked YouTube offline (and how to make sure it never happens again)

YouTube becoming unreachable isn’t the first time that Internet addresses were hijacked. This sparks interest in better security, it may be the last.
Prepare for new innovations in massive cloud data center environments
And in new software defined networking technologies
Learning from each other

• I try not to spoon feed you the answers
  – Help you discover part of the solution
  – Let you feel smug

• Peer to peer discussions
  – Help to draw out the questions
  – Some like it, some don’t
  – IMHO, it helps most students

• Refrain from non-course related activity in class
Assignments

• 2 Homeworks (done individually)
• 2 Exams (done individually)
• 3 Projects (done in groups of up to 4 people)
  – Networked Application, Reliable Data Transport, Distributed Routing
  – 4 Flexible Slip Days for each student
Walk through Canvas and Q&A
This semester will present many challenges

• We can overcome these challenges together
• Lessons from Spring 2021
• Online learning is *harder*
  – Come to live lectures, discuss the ideas interactively (can still review videos later)
  – Do not rely on offline videos alone; you will fall behind
• Online group project work is *harder*
  – Look for teammates early
  – Try to work together in-person when safe to do so
• The class is bigger than ever before
  – 120 students with tens on waiting list
  – Previous max was 84
Who’s still here and want to continue?

• If you are staying in the course, please answer Google form with your name and NetID
  – e.g. abc42
  – Not your vanity ID
• If you are going to drop, no need to submit
• https://forms.gle/4LhdFUfyYUWy6WcEA