Course Overview

CS204: Advanced Computer Networks
Oct. 2, 2023
Logistics

• Lectures: MW 6:30-7:50PM, Winston Chung Hall 138
• Instructor: Zhaowei Tan
  • Email: ztan@ucr.edu
  • Office hours: Tuesdays 9-11AM; Winston Chung Hall 357

• TA: Yunshu Wang
  • Email: yunshu.wang@email.ucr.edu
  • Office hours: Fridays 11AM-1PM
    • Multidisciplinary Research Building, 3rd Floor
Why Networks?

More Users
- 97% of Americans between 18-29
- 40% of the world population scope for more users

Diverse Applications

New Challenges

Emerging Technologies

Higher Traffic
Mentioning “Networking”, you think about...

• Bunch of acronyms

- TCP
- OSPF
- IP
- BGP
- DNS
- ABR
- UMTS
- DDoS
- MCS
- MAC
- RED
- DNS
- NAT
- HTTP
- RED
- VLAN
- MCS
- MAC
- NAT
- DHCP
- SPDY
- HTTP
- TCP
Mentioning “Networking”, you think about...

• Bunch of protocols and headers

Source: https://nmap.org/book/tcpip-ref.html
Networking is...

The search for general principles to guide communication
Sample Topics in Networking

• Layering
  • What functionality to place within each layer?
  • How many layers should there be?

• Protocols
  • How to communicate within each layer, and offer nice features as intended?

• Wireless
  • How to avoid collision for one-on-one communication in an inherently broadcast environment?

• Resource allocation
  • How to share limited resources between competing users?

<table>
<thead>
<tr>
<th>Application</th>
<th>(e.g. HTTP)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transport</td>
<td>(e.g. TCP, UDP)</td>
</tr>
<tr>
<td>Network</td>
<td>(e.g. routing)</td>
</tr>
<tr>
<td>Link</td>
<td>(e.g. scheduling)</td>
</tr>
<tr>
<td>Physical</td>
<td>(e.g. modulation &amp; coding)</td>
</tr>
</tbody>
</table>
What You Will Learn in this Course

• Knowledge
  • 50%: Link layer through application layer (undergrad networking ++)
    • We expect you already have taken an undergrad level networking course
  • 50%: Emerging topics in networking (wireless, multimedia, data centers, etc.)
    • Breadth and depth!

• Skills
  • How to read papers
  • How to present a work
  • How to build networking systems
Course Structure

• Final exam (30%)
  • Week 11 Monday, 7-10PM, This classroom
  • Multiple choice + short answers
  • 1 cheat sheet allowed, US letter, both sides

• Paper Reading (30%)
  • Choose one paper from the list and present to the class (20%)
  • Write a summary report (10%)

• Course Project (40%)
  • System or networking implementation
  • Proposal (5%), Progress Report (10%), Presentation (15%), Final Report (10%)

• Rest assured; You’ll be fine if you try your best!
  • “Negative” result is a good result
Course Project

- We will offer topics related to course materials
  - Feel free to come up with your own project, as long as it’s networking related
    - Discuss with me on your project selection
    - Implementation-centric; cannot focus on paper reaching or algorithm design

<table>
<thead>
<tr>
<th>Milestone</th>
<th>Deadline^</th>
<th>Description</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Project List Released</td>
<td>Week 2 Wed</td>
<td>List of available project</td>
<td></td>
</tr>
<tr>
<td>Project Selection</td>
<td>Week 2 Sun</td>
<td>Form your team and submit your project preference</td>
<td></td>
</tr>
<tr>
<td>Project Assignment</td>
<td>Week 3 Wed</td>
<td>Finalize and notify each team on project assignment</td>
<td></td>
</tr>
<tr>
<td>Proposal*</td>
<td>Week 4 Fri</td>
<td>Describe the motivation, goal, methodology, and steps</td>
<td>5</td>
</tr>
<tr>
<td>Mid-Term Report*</td>
<td>Week 7 Fri</td>
<td>Describe the progress, obstacles, and remaining tasks</td>
<td>10</td>
</tr>
<tr>
<td>Final Presentation*</td>
<td>Week 10</td>
<td>Show us what you've done!</td>
<td>15</td>
</tr>
<tr>
<td>Final Report*</td>
<td>Week 11 Wed</td>
<td>Submit a well-formatted report on your project</td>
<td>10</td>
</tr>
</tbody>
</table>
## Paper Reading

<table>
<thead>
<tr>
<th>Milestone</th>
<th>Deadline</th>
<th>Description</th>
<th>Grade (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>List Released</td>
<td>Week 1 Sunday</td>
<td>[Instructor's Task] provide you with the list of available papers</td>
<td></td>
</tr>
<tr>
<td>Selection</td>
<td>Week 2 Wednesday</td>
<td>Submit your presentation preference</td>
<td></td>
</tr>
<tr>
<td>Paper Assignment</td>
<td>Week 2 Friday</td>
<td>Finalize and notify each person on final paper assignment</td>
<td></td>
</tr>
<tr>
<td>Presentation</td>
<td>Your choice</td>
<td>Present the work you studied</td>
<td>20</td>
</tr>
<tr>
<td>Summary*</td>
<td>Week 10 Friday</td>
<td>Submit the written report</td>
<td>10</td>
</tr>
</tbody>
</table>

* Template will be provided.

^ The due time is 11:55 PM on each deadline day.
<table>
<thead>
<tr>
<th>Week</th>
<th>Day</th>
<th>Date</th>
<th>Topic</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Mon</td>
<td>10/2</td>
<td>Logistics + Overview</td>
</tr>
<tr>
<td></td>
<td>Wed</td>
<td>10/4</td>
<td>Principles for Networking Design</td>
</tr>
<tr>
<td>2</td>
<td>Mon</td>
<td>10/9</td>
<td>Application Layer - HTTP</td>
</tr>
<tr>
<td></td>
<td>Wed</td>
<td>10/11</td>
<td>Application Layer - P2P</td>
</tr>
<tr>
<td>3</td>
<td>Mon</td>
<td>10/16</td>
<td>Transport Layer - MPTCP</td>
</tr>
<tr>
<td></td>
<td>Wed</td>
<td>10/18</td>
<td>Transport Layer - TCP Cubic</td>
</tr>
<tr>
<td>4</td>
<td>Mon</td>
<td>10/23</td>
<td>Paper Presentation -</td>
</tr>
<tr>
<td></td>
<td>Wed</td>
<td>10/25</td>
<td>Video Streaming, More MPTCP, etc.</td>
</tr>
<tr>
<td>5</td>
<td>Mon</td>
<td>10/30</td>
<td>Network Layer - IPv6</td>
</tr>
<tr>
<td></td>
<td>Wed</td>
<td>11/1</td>
<td>Network Layer - BGP</td>
</tr>
<tr>
<td>6</td>
<td>Mon</td>
<td>11/6</td>
<td>Link Layer - WiFi</td>
</tr>
<tr>
<td></td>
<td>Wed</td>
<td>11/8</td>
<td>Link Layer - 5G</td>
</tr>
<tr>
<td>7</td>
<td>Mon</td>
<td>11/13</td>
<td>Paper Presentation -</td>
</tr>
<tr>
<td></td>
<td>Wed</td>
<td>11/15</td>
<td>SDN, BGP, Bluetooth, etc.</td>
</tr>
<tr>
<td>8</td>
<td>Mon</td>
<td>11/20</td>
<td>Emerging Topics: Datacenter Networking</td>
</tr>
<tr>
<td></td>
<td>Wed</td>
<td>11/22</td>
<td>Emerging Topics: Edge Computing</td>
</tr>
<tr>
<td>9</td>
<td>Mon</td>
<td>11/27</td>
<td>Paper Presentation -</td>
</tr>
<tr>
<td></td>
<td>Wed</td>
<td>11/29</td>
<td>Satellite, NFV, Backscatter, etc.</td>
</tr>
<tr>
<td>10</td>
<td>Mon</td>
<td>12/4</td>
<td>Project Presentation</td>
</tr>
<tr>
<td></td>
<td>Wed</td>
<td>12/6</td>
<td>Project Presentation</td>
</tr>
<tr>
<td>11</td>
<td>Monday</td>
<td>12/11</td>
<td>7-10PM, this classroom One (1) cheatsheet (US letter, both sides) allowed</td>
</tr>
</tbody>
</table>
Academic Integrity

• Cite your sources!
  • Never copy any text verbatim from any source without properly citing
  • If verbatim, then needs to be in quotes and with a citation next to the quote

• You can discuss with me or others on the project, but make sure you implement it on your own and understand what you wrote

• Plagiarism is very serious
  • If you cheat, you will receive 0 on the project/exam
    • The incidents will be reported
  • If you try your best, I will try my best to give you partial credit
    • This course might not be easy, and I understand
Useful Links

• [https://elearn.ucr.edu/](https://elearn.ucr.edu/)
  • Announcements, course materials, project submission, discussion board...

• [https://cs.ucr.edu/~ztan/courses/CS204/f23/](https://cs.ucr.edu/~ztan/courses/CS204/f23/)
  • Syllabus and quick reference without UCR login

• [https://forms.gle/F1bjhNHcwZEihHc9A](https://forms.gle/F1bjhNHcwZEihHc9A)
  • Form for any anonymous feedback
  • Alternatively, feel free to send me an email, or talk to me during office hour
  • I’ll make sure that you learn both knowledge and skills from CS204!
Review

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 protocol layers, service models

Adapted from Computer Networking: A Top-Down Approach, Kurose & Ross
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: forward packets (chunks of data)
  - routers and switches
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**
  - 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 programming interface to apps**
  • 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

protcols 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:

- Hi
- Hi
- Got the time?
- 2:00
- TCP connection request
- TCP connection response
- <file>
Roadmap

1.1 what is the Internet?
1.2 network edge
   ▪ end systems, access networks, links
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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: home network

- wireless devices
- often combined in single box
- wireless access point (54 Mbps)
- 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, 5G
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*

$$
\text{packet transmission delay} = \frac{L \text{ (bits)}}{R \text{ (bits/sec)}}
$$
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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 and queuing delay

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

<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>

dest address in arriving packet’s header
Internet structure: network of networks

**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.
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.
Internet structure: network of networks

… and regional networks may arise to connect access nets to ISPS
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
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Protocol “layers”

Networks are complex, with many “pieces”:

• hosts
• routers
• links of various media
• applications
• protocols
• hardware, software

Question:

is there any hope of organizing structure of network?

.... or at least our discussion of networks?
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”
**Layering of post office functionality**

- **Sender** writes letter
- **Sender** drops off letter at post office
- **Post office X** sends mail to city Y
- **Recipient** reads letter
- **Mailman delivers** from post office to sender’s home
- **Post office Y** receives mail from city X

**layers**: each layer implements a service
- via its own internal-layer actions
- relying on services provided by layer below

**Transport**: Delivery via UPS (signature required) or USPS (no signature required)
**Application**: the contents of the letter, e.g. photo, video, novel
Why layering?
dealing with complex systems:

• explicit structure allows identification, relationship of complex system’s pieces
  • layered reference model for discussion

• modularization eases maintenance, updating of system
  • change of implementation of layer’s service transparent to rest of system
  • e.g., change in letter language doesn’t affect rest of system

• layering considered harmful?
Next Up

• Read “The Design Philosophy of the DARPA Internet Protocols” by David Clark
  • 9 pages, relatively light read
  • Come prepared to discuss next class