CS 204: Advanced Computer Networks

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Lectures: MWF 12:10-1pm
Humanities and Social Sciences 1403

http://www.cs.ucr.edu/~jiasi/teaching/cs204_spring17/
Why Networks?

Supports the applications that we use today...

Social media

Video streaming

Number of Internet users

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

Why Networks?

But also a source of conflict.

Cyber security

A Look Back at the Target Breach

Network neutrality


A new plan from T-Mobile USA to allow unlimited streaming of some video services may become the first test of the federal government’s rules to prevent favoritism on the Internet.

On Tuesday, T-Mobile, the nation’s third-largest wireless carrier, said customers could stream as many videos as they want — regardless of their data plan limits — from more than two dozen video providers, including Hulu and Netflix.

http://www.huffingtonpost.com/eric-dezenhall/a-look-back-at-the-target_b_7000816.html
What is networking?

• Bunch of acronyms?
What is networking?

• Bunch of headers?

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

The search for general principles to guide communication
Some Research 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 talk to other layers?

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

• Wireless
  • How to provide a one-to-one communication in an inherently broadcast environment

<table>
<thead>
<tr>
<th>Application</th>
<th>(e.g. video streaming)</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>
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<tr>
<td>Physical</td>
<td>(e.g. OFDM)</td>
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</table>
What You Will Learn in this Course

• Knowledge
  • 1/3: Link layer through application layer
  • 2/3: current topics in networking (wireless, multimedia, data centers, etc.)

• Skills
  • How to read
  • How to present
  • How to discuss
  • How to use common networking tools
Course Structure

• Paper reading
  • 2-3 papers per week

• Classroom time
  • Lecture
  • Paper discussion

• Programming assignments
  • Multipath-TCP
  • Mininet + OpenFlow

• Project
  • Proposal, presentation, and final report
  • Can work individually in or in groups
  • Can be an extension of existing work or research (subject to approval)
## Calendar

<table>
<thead>
<tr>
<th>Week</th>
<th>Topic</th>
<th>Assignment</th>
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<tbody>
<tr>
<td>1</td>
<td>Introduction + MAC layer</td>
<td></td>
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<tr>
<td>2</td>
<td>Network layer</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Transport layer</td>
<td>MPTCP assignment</td>
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<tr>
<td>4</td>
<td>Application layer</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Content distribution</td>
<td>Project proposal</td>
</tr>
<tr>
<td>6</td>
<td>Data centers</td>
<td></td>
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<tr>
<td>7</td>
<td>Wireless</td>
<td></td>
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<tr>
<td>8</td>
<td>Security</td>
<td>SDN assignment</td>
</tr>
<tr>
<td>9</td>
<td>Future Internet (SDN, IoT)</td>
<td></td>
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<tr>
<td>10</td>
<td>Project presentations</td>
<td></td>
</tr>
<tr>
<td>Finals week</td>
<td></td>
<td>Final report due</td>
</tr>
</tbody>
</table>
Grading

• Paper summaries (20%)
  • Write a one-paragraph review for each paper

• Class participation (20%)
  • Speak up during discussion!

• Assignments (20%)
  • 2 programming assignments

• Project (40%)
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

*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:

Hi

Hi

Got the time?

2:00

TCP connection request

TCP connection response

Get http://www.awl.com/kurose-ross

<file>
Roadmap

1.1 what is the Internet?
1.2 network edge
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1.4 protocol layers, service models
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**
- **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)**

**Access net:** home network diagram showing the connection from the home network to/from the headend or central office via a cable or DSL modem, router, firewall, and NAT, with wireless devices often combined in a single box.
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
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 delay)

**one-hop numerical example:**
- $L = 7.5$ Mbits
- $R = 1.5$ Mbps
- one-hop transmission delay = 5 sec
Packet Switching: queueing delay, loss

queuing 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>
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.
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...
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

- 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
Tier-1 ISP: e.g., Sprint
Roadmap

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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”
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?
Layering of post office functionality

**layers**: each layer implements a service

- via its own internal-layer actions
- relying on services provided by layer below
Layering of post office functionality

**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
Encapsulation

source

application
transport
network
link
physical

message
segment
datagram
frame

destination

application
transport
network
link
physical

Encapsulation

link
physical

switch

network
link
physical

router
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For Next Time

• Reading
  • The Design Philosophy of the DARPA Internet Protocols
  • How to Read a Paper