18-345: Introduction to Telecommunication Networks
Lectures 1: Course Overview

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Spring 2015
www.cs.cmu.edu/~prs/nets-ece

Course Overview

• Administrivia
  • Objective
  • People, course communications
  • Grading, course policies
• Why are networks important?
• A whirlwind tour of the course

Instructors

• Instructor.
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• Teaching assistant.
  • Antonio Rodriguez
• Course secretary
  • Kathy McNiff, Gates 9213

Course Goals

• Become familiar with the principles and practice of data networking
  • Routing, transport protocols, naming, ...
• Learn how to write applications that use the network
  • Use web and peer-to-peer style applications
• Get some understanding about network internals in a hands-on way
  • Implementing different types of protocol, error recovery, conformance with standards, etc.
Course Materials

- References
  - Computer Networking – A Top-Down Approach, by J. Kurose and K. Ross, Addison Wesley
  - Computer Networks, Wetherall and Tanenbaum

Course Format

- ~28 lectures
  - Cover the “principles and practice”
- 6 homework assignments
  - Practice for tests – not graded
- 4 programming projects
  - How to use and build networks / networked applications
  - Larger, open-ended group projects. *Start early!*
- 6 in class quizzes
  - Short in-class tests on the last block of lectures
- Midterm and final
  - Two 2-hour in class tests

Getting Questions Answered

- Administrative: start with web site
  - If the answer is not there, please send us e-mail
- Course material: class, office hours
  - Typically requires a discussion – piazza or e-mail often does not work well
- Projects: piazza, office hours
  - Piazza: others might have the same question
  - Office hours for more complicated issues

Projects and Recitation Sections

- Key objective: system programming
- Different from what you’ve done before!
  - Can use C or Java
  - Often designed to run indefinitely – must handle all errors!
  - Interfaces specified by documented protocols
  - Concurrency involved (inter and intra-machine)
  - Must have good test methods
- Recitations to provide project background, discuss programming tools and skills
Administrative Stuff

• Watch the course web page
  • [http://www.cs.cmu.edu/~prs/nets-ece/](http://www.cs.cmu.edu/~prs/nets-ece/)
  • All handouts, readings, project information, ..
  • If something is missing on the web site, please let us know asap
• This course does not use blackboard
• Read bboard - piazza
  • E-mail on things like grades should go to instructor (do not use piazza for this!)
• Office hours will be posted on web page
  • Changes will be posted in the “News” section of the web page

Grading

• Roughly equal weight in projects and testing
  • 35% for projects
  • 15% for quizzes
  • 50% for two exams
• You **MUST** demonstrate competence in both projects and tests to pass the course
  • Fail either and you fail the class!

Policy on Collaboration

• Working together is important
  • Discuss course material in general terms
  • Work together on program debugging, ..
  • Final submission must be your own work
• Projects are done in teams of two
  • Collaboration, group project skills
  • Both students must understand the project
• What we don’t want to have to say: we run all projects through cheat-checkers comparing with other old and new submissions …
• All cases of cheating will be reported

Policy on Late Work, Regrading, Exam & Quiz coverage

• Assignments must be handed in on time
  • Only exception is **documented** illness and family emergencies
• Regrading requests must be submitted in writing with secretary within 1 week
  • Entire exam or quiz will be regraded.
• Exam and Quiz coverage:
  • All materials right before the exam/quiz
  • Details will be on the web page
The Slides

- The slides are a resource that is shared by many instructors
  - Also some sharing with 15-441
- They include contributions from Peter Steenkiste, Hyong Kim, Srini Seshan, Dave Andersen, Hui Zhang, and others

Course Overview

- Administrivia
- Why are networks important?
  - What is a network?
  - What is the Internet
  - Internet design
- A whirlwind tour of the course

What is a Network?

- An infrastructure that allows (distributed) “users” to communicate with each other
  - People, devices, …
  - By means of voice, video, text, …
  - Focus on electrical/optical/RF/… (not trucks)
- It is assumed that the infrastructure is shared by many users
  - Point to point link is not very interesting
  - Value increases with the number of users!

Basic Building Block: Links

- Simplest example: 2 nodes
  - Sender changes voltage, frequency, …
  - Or maybe it is optical or wireless?
- But receiver must “understand” sender – protocols
  - More on this later
- Okay… what about more nodes?
- How about a million?
**Scaling the Network**

(N²) Wires for everybody!

Or how about …

But First a bit of History

**Communication Network Architecture**

- **Network architecture**: the plan that specifies how the network is built and operated
- Architecture is driven by the network services
- Overall communication process is complex
- Network architecture partitions overall communication process into separate functional areas called **layers** - more on this later

Next we will trace evolution of three network architectures: telegraph, telephone, and computer networks

**Network Architecture Trends**

<table>
<thead>
<tr>
<th>Year</th>
<th>Telegraph networks</th>
<th>Telephone networks</th>
<th>Internet, Optical &amp; Wireless networks</th>
<th>Next Generation Internet</th>
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</table>

**Network Architecture Evolution**

- Telegraph Networks
  - Message switching & digital transmission
- Telephone Networks
  - Circuit Switching
  - Analog transmission → digital transmission → mobile
- Internet
  - Packet switching & computer applications
  - Increasingly faster, more diverse edge & apps
- Next generation Internet ???
Telegraphs & Long-Distance Message Communications

- Courier: physical transport of the message
  - Messenger pigeons, pony express, FedEx
- Telegraph: message is transmitted across a network using signals – much faster!
  - Drums, beacons, mirrors, smoke, flags,
  - Light, electricity

Message Switching Architecture

- Network nodes were created where several optical telegraph lines met (Paris and other sites)
- **Store-and-Forward Operation**:
  - Messages arriving on each line were decoded
  - Next-hop in route determined by destination address of a message
  - Each message was carried by hand to next line, and stored until operator became available for next transmission

Electric Telegraph Networks

- Electric telegraph networks exploded
  - Message switching & Store-and-Forward operation
  - Key elements: Addressing, Routing, Forwarding
- Optical telegraph networks disappeared

Bell’s Telephone

- Alexander Graham Bell (1875) working on harmonic telegraph to multiplex telegraph signals
- Discovered voice signals can be transmitted directly
  - Microphone converts voice pressure variation (sound) into analogous electrical signal
  - Loudspeaker converts electrical signal back into sound
- Telephone patent granted in 1876
- Bell Telephone Company founded in 1877

**Signal for “ae” as in cat**

- Microphone: sound into electrical signal
- Loudspeaker: electrical signal into sound
Circuit Switching

- Source first establishes a connection (circuit) to the destination
  - Each switch along the way stores info about connection (and possibly allocates resources)
- Source sends the data over the circuit
  - No need to include the destination address with the data since the switches know the path
- The connection is explicitly torn down
- Example: telephone network (analog)

Three Phases of a Connection

1. Pick up phone
2. Dial tone
3. Dial number
4. Network selects route; Sets up connection; Called party alerted
5. Exchange voice signals
6. Connect
7. Hang up

Links and Switches in Early Telephone Networks

Circuit Switching Discussion

- Circuits have some very attractive properties.
  - Fast and simple data transfer, once the circuit has been established
  - Predictable performance since the circuit provides isolation from other users
  - E.g. guaranteed bandwidth
- But it also has some shortcomings.
  - How about bursty traffic?
    - Do you need a permanent circuit to Facebook?
    - Circuit will be idle for significant periods of time
  - How about users with different bandwidth needs?
Contrast this with Message (Packet) Switching (our emphasis)

- Source sends information as self-contained messages that have an address.
  - Source may have to break up single message in multiple packets
- Each packet travels independently to the destination host.
  - Switches use the address in the packet to determine how to forward the packets
  - Store and forward
- Analogy: a letter in surface mail.

And Some More Examples …

- Television network
  - Over the air
  - Cable TV
  - Satellite
- Radio broadcast
- Various private networks
  - E.g., for first responders, military, ...

Today’s Lecture

- Administrivia
- Why are networks important?
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What about the Internet

  - Networks are connected using routers and other devices, e.g., for security, accounting, ...
  - Networks can use diverse technologies
  - Typically managed by different organizations
- The Internet: the interconnected set of networks of the Internet Service Providers (ISPs)
  - About ~23,000 "transit" ISPs make up the Internet
  - Many more "edge" networks
What is the Objective of the Internet?

- Enable communication between diverse applications on diverse devices (“computers”)
  - Web, peer-to-peer, video streaming, distributed processing, video and audio conferencing, …
- Over very diverse infrastructures
  - The "Internet", WiFi and cellular, data center networks, corporate networks, dedicated private networks, …
- In contrast: previous networks were special purpose and fairly homogeneous in terms of technology
- Must understand application needs/demands (Thursday)
  - Traffic data rate and loss sensitivity
  - Traffic pattern (bursty or constant bit rate)
  - Traffic target (multipoint or single destination, mobile or fixed)

Packet Switching – Statistical Multiplexing

- Switches arbitrate between inputs
- Can send from any input that’s ready
  - Links are never idle when there is traffic to send
  - (Efficiency!)

Multiplexing

- Need to share network resources

How? Switched network
- Party “A” gets resources sometimes
- Party “B” gets them sometimes
- Interior nodes act as “Switches”
- Many challenges: fairness, efficiency, …

Internet Design

- In order to inter-operate, all participating networks must follow a common set of rules
- Example: requirements for packets:
  - Address format, header information, packet size limit, …
- But also: routing, error reporting, billing, …
- Also: what is the “service model”, i.e., the commitment made to applications
  - Internet: best-effort – packets can get lost, etc.
  - But some applications need reliable data delivery, a minimal bandwidth guarantee, low latency, …
Networks Juggle Many Goals

- Support rich set of applications
- Efficiency – resource use; cost
- The “ilities”:
  - Evolvability
  - Managability
  - Security (securability, if you must)
- Ease of:
  - Deployment, management
  - Creating useful applications
- Scalability

Must also Deal with “Real World”

- Economics and public policy play a big role in the design of the Internet
  - ISPs are competing for customers but they must also work together
  - They must make money – no ISPs, no Internet
- Public policy looks after user interests and tries to promote competition and innovation
- Users will only use the network if they get value out of it
  - Concerns such as privacy can stifle use

Success Factors for New Services

- Technology not only factor in success of a new service
  - Three factors considered in new telecom services

Transmission Technology

- Relentless improvement in transmission
  - High-speed transmission in copper pairs
    - DSL Internet Access
  - Higher call capacity in cellular networks
    - Lower cost cellular phone service
  - Enormous capacity and reach in optical fiber
    - Plummeting cost for long distance telephone
  - Allows innovation in applications, services
    - E-mail → chat → audio → video
    - Peer to peer, cloud computing
Processing Technology

- Relentless improvement in processing & storage
- Moore’s Law: doubling of transistors per integrated circuit every two years
- RAM: larger tables, larger systems
- Digital signal processing: transmission, multiplexing, framing, error control, encryption
- Network processors: hardware for routing, switching, forwarding, and traffic management
- Microprocessors: higher layer protocols and applications
- Higher speeds and higher throughputs in network protocols and applications

Moore’s Law

![Moore's Law Chart]

Market

- The network effect: usefulness of a service increases with size of community
  - Metcalfe's Law: usefulness is proportional to the square of the number of users
  - Phone, fax, email, ICQ, …
- Economies of scale: per-user cost drops with increased volume
  - Cell phones, PDAs, PCs
  - Efficiencies from multiplexing
- S-curve: growth of new service has S-shaped curve, challenge is to reach the critical mass

The S Curve

![S Curve Chart]
Regulation & Competition

- Telegraph & Telephone originally monopolies
  - Extremely high cost of infrastructure
  - Profitable, predictable, slow to innovate
- Competition feasible with technology advances
  - Long distance cost plummeted with optical tech
  - Alternative local access through cable, wireless
  - Radio spectrum: auctioned vs. unlicensed
- Internet supports multiple applications
  - Innovation leads to new apps and usage models
  - Regulation needed to ensure competition and universal access

Standards

- New technologies very costly and risky
- Standards allow players to share risk and benefits of a new market
  - Reduced cost of entry
  - Interoperability and network effect
  - Compete on innovation
  - Completing the value chain
  - Chips, systems, equipment vendors, service providers
- Example:
  - 802.11 LAN, IP, HTTP/SMTP/…

Standards Bodies

- Internet Engineering Task Force
  - Internet standards development
  - Request for Comments (RFCs): www.ietf.org
- International Telecommunications Union
  - International telecom standards
- IEEE 802 Committee
  - Local area and metropolitan area network standards
- Industry Organizations
  - MPLS Forum, WiFi Alliance, World Wide Web Consortium

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Whirlwind Tour of the Course

- Infrastructure: hardware (or close to it)
- Core networking protocols: IP, dealing with errors and congestion, routing, …
- Optimizing performance: QoS techniques, caching, CDNs, peer-peer, …
- Making it work well: security, management, …
- IP everywhere: the Internet, last mile, wireless, mobility, data center, video, IP-TV, skype, …
- Focus is on today’s Internet but also trends
  - What will the Internet look like in 10, 20, 30 years?

Infrastructure

- Why do we have different types of “wires”?
  - And why do I care?
- Ethernet is very old, so why is it so fast?
  - Can’t they find something better?
- What are the limits of some of the technologies?
  - Both physical and protocol limits

Core Networking Protocols

Think: traffic on the roads

- How do I found a path to my destination
- How do I specify addresses
- What if my car breaks down?
- How do I deal with traffic jams
- …

Optimizing Performance

- Intuitively: lots of bandwidth!
- But there is more to it:
  - Latency is often more critical!
  - How voice and video – can I offer guarantees?
  - Can I beat the speed of light?
    - Hint: this can make you rich
  - Why did we use peer to peer networks?
  - And why did they (mostly) go away?
### Making the Network Work Well

- Good technology is only a small part of the puzzle – deployment and management issues are equally (or more) critical
  - Involves many people, high cost
- How do I secure my network?
  - Lots of bad guys: DOS, compromised hosts, privacy leaks, botnets, …
- How I manage resources, reduce operator errors, deal with failures, …
  - And how does it differ in LAN, WAN, wireless, …

### IP Everywhere

- Using IP technology has become attractive
  - Cheap commodity hardware, lots of tools, people trained in the technology, end-to-end support, …
- The (public) Internet: our focus
  - How do you optimize “the web”: CDNs, caching, …
- Data centers: very special requirements
  - Map-reduce, 3-tier business apps, load balancing, …
- IP TV, voice/video conferencing:
  - Very high QoE expectations
- Wireless and mobile apps
  - For many users, primary way of accessing Internet
- Residential networking