15-441 15-641 Computer Networking

Lecture 1 – Introduction

Peter Steenkiste

Fall 2016

www.cs.cmu.edu/~prs/15-441-F16

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Today's Lecture

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

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Teaching Staff

- Instructors:
  - Peter Steenkiste
- Teaching assistants:
  - Priya Ranjan Jha
  - Rajul Bhatnagar
  - TBD
- staff-441@cs.cmu.edu → course staff
  - Please use this instead of emailing just one of us!
- Office hours, slides, … on the web site.

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Course Goals

- Become familiar with the principles and practice of data networking
  - Routing, transport protocols, naming, ...
  - Design of networks and services
- Learn how to write applications that use the network
  - A web server
  - Optimizing application performance
- Gain an understanding of network internals in a hands-on way
  - Content delivery and a TCP-style reliable protocol
  - How to optimize video distribution

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Course Format

- ~28 lectures
  - Cover the "principles and practice"
  - Complete readings before lecture
- 4 homework assignments
  - "Paper": Do you understand and can you apply the material?
  - "Lab": Illustrate networking concepts
  - Preparation for midterm and final
- 3 programming projects
  - How to use and build networks / networked applications
  - Application-layer programming
  - Larger, open-ended group projects. *Start early!*
- Midterm and final
  - Emphasis on understanding of course material

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Recitation Sections

- Key 441 objective: system programming - C
- Different from what you've done before!
  - Networks and services must run indefinitely
  - Must handle all errors! Must be secure
  - Interfaces specified by documented protocols
  - Concurrency involved (inter and intra-machine)
  - Must have good test methods
- Recitations address this
  - "A system hackers' view of software engineering"
  - Help develop practical skills needed in the projects (and beyond)

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Course has 3 Projects

- Web server: example of a widely used service accessed using a standard protocol
  - Implement GET, PUT, HTTPS, and cgi
- Bit torrent: exposure to network internals
  - Implement transport level functions
- Video streaming: end-to-end infrastructure for delivering high quality video
  - Uses load sensitive QoE optimization, content delivery networks, DNS redirect, ...

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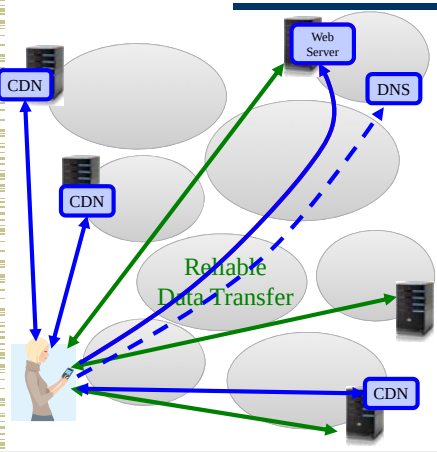
Why Three?



Somebody needs to build the apps!

- P1: HTTP server

Somebody needs to develop the network internals!

- P2: content delivery

Somebody needs to optimize user Quality of Experience!

- P3: Video distribution

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Project Logistics

- First project is solo – others are in teams of 2
- We will use piazza for communication
- You must use version control – git
  - We are flexible about where you keep the repository
- Testing is an important part of code development
  - You will have to write your own test scripts
  - We will provide some example scripts but grading will use a more extensive set of tests
  - We may use Autolab for some of the grading
- See web page and course handouts for details

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Administrative Stuff

- Watch the course web page
  - http://www.cs.cmu.edu/~prs/15-441-F16/
  - Handouts, readings, ..
  - Always check here first
- Office hours posted on web page
  - Make an appointment if you have a conflict
- Course secretary
  - Ms. Angella Malloy
  - Pick up graded assignments, …

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Grading

- Roughly equal weight in projects and testing
  - 45% for Projects I, II and III
  - 18% for Midterm exam
  - 27% for Final exam
  - 10% for Homework
- You **MUST** demonstrate competence in both projects and tests to pass the course
  - Fail either and you fail the class!

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Policy on Collaboration

- Working together is important
  - Discuss course material in general terms
  - Work together on program debugging, ..
  - Collaborating on projects P2 and P2
- Final submission must be your own work
  - Homeworks, midterm, final, projects
- Submitting or using someone else's work is an academic integrity violation (i.e., cheating)
  - We will follow the university policy on reporting violations
  - Voluntarily sharing your work is also a policy violation
- Web page has details, e.g., university policy, etc.

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Code Reuse in Projects

- The project code you submit must be your work!
  - Exception is the starter code provided by us, standard libraries, packages mentioned in the project handout
  - If in doubt, ask the course staff
- We use tools to compare submissions
  - These tools are very good
  - Don't compete with them (the odds are against you)
- Some students have put their projects on the web
  - This violates the collaboration policy
  - If you can find the code, so can we

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Late Work and Regrading

- Late work will receive a 15% penalty/day
  - No assignment can be more than 2 days late
  - Only exceptions are documented illness and family emergencies
- Requests for regrading must be submitted in writing to course secretary within 2 weeks.
  - Do not contact us by e-mail
  - Office hours are fine for discussion but not for regrading
  - Regrading of assignment will be done by original grader
- No assignments with a "short fuse"
  - Homeworks: ~1-2 weeks - Projects: ~4 weeks
  - Start on time!
  - Every year some students discover that a 4 week project cannot be completed in a week

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The Slides

- The slides are a resource that is shared by the many instructors of 15-441/15-641
  - Also some sharing with 18-345
- They include contributions from Peter Steenkiste, Srini Seshan, Dave Andersen, Hui Zhang, Eric Anderson, and others

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  - What is a network?
  - What is the Internet
  - Internet design
- A whirlwind tour of the course

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What is a Network?

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

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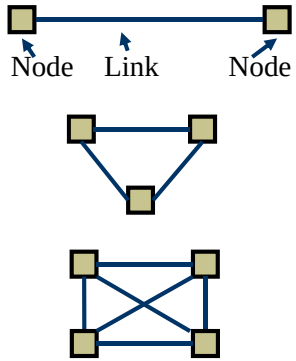
Basic Building Block: Nodes, Links

- 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?



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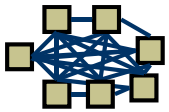
Scaling the Network

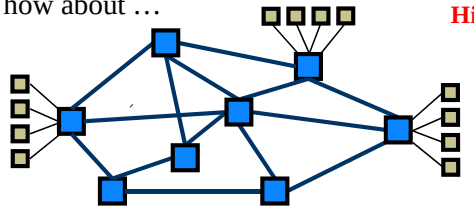


(N^2) Wires for everybody!

Or one wire

Or how about …

But First a bit of History



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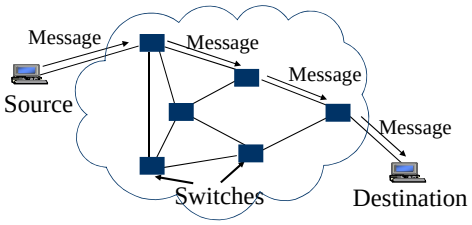
Networks Have Been Around for a Long time!

- 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

Electric Telegraph Networks

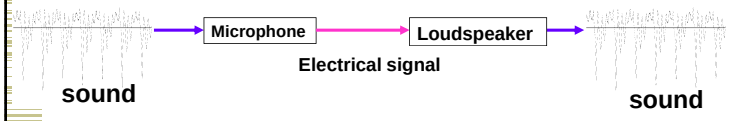
- Electric telegraph networks exploded
  - Message switching & Store-and-Forward operation
  - Key elements: Addressing, Routing, Forwarding
- Optical telegraph networks disappeared



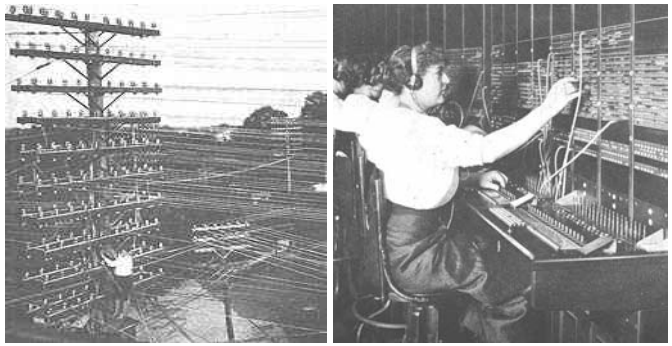
Bell's Telephone

- 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 *analog* 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



Links and Switches in Early Telephone Networks



And Some More Examples …

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

What Do All These Networks Have in Common?

- They are designed for a single application!
- How about the Internet?

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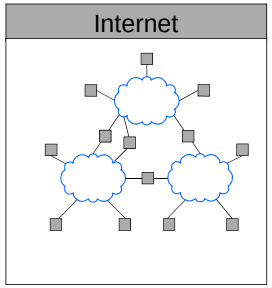
What about the Internet

- An inter-net: a network of networks.
  - Networks are connected using routers and other devices, e.g., for security, accounting, …
  - Networks can use diverse technologies
  - Typically managed by different organization
- 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



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What is the Objective of the Internet?

- Enable communication between diverse applications on diverse devices …
  - Web, peer-to-peer, video streaming, distributed processing, transactions, map-reduce, 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
- The Internet is an "engineered system"
  - Many design choices – the focus of the course!
  - Must understand the requirements – but they change over time!

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Networks Juggle Many Goals

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

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Must also Deal with “The 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

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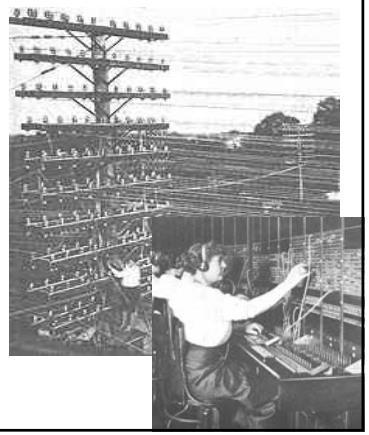
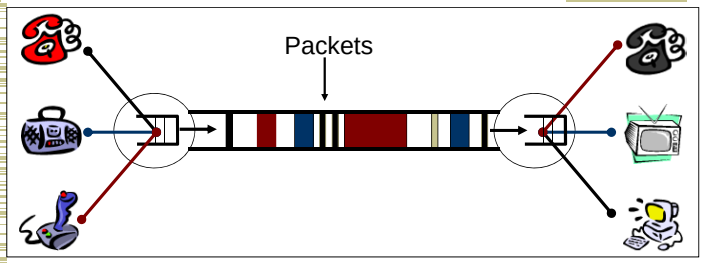
Example: Efficiency

- Is “one wire per user” an efficient solutions for the Internet?
  - No! Why?
- What is a better solutions?



Statistical Multiplexing – Packet Switching



- Users share the wires at a fine grain - packets
- Links are never idle when there is traffic - Efficient!
- But creates many challenge:
  - Congestion, packet losses, fairness, …

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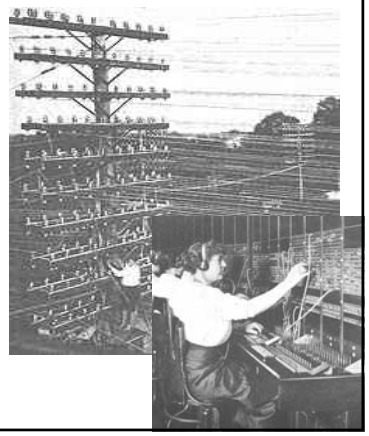
Example: Scalability

- How do you design a network to be very scalable?
- Network must be very modular …
  - More on his in lecture 2
- … and simple
  - Or at least no more complex than needed



Internet Design

- In order to inter-operate, all participating networks must follow a common set of rules
  - Protocols = interfaces between modules
  - E.g., address format, header info, packet size limit, ..
- Provides a simple "service model"
  - I.e., the commitment made to applications
  - Internet: *best-effort* – packets can get lost, etc.
- But some applications need reliable data delivery, low latency, …
  - Optional, outside of core architecture

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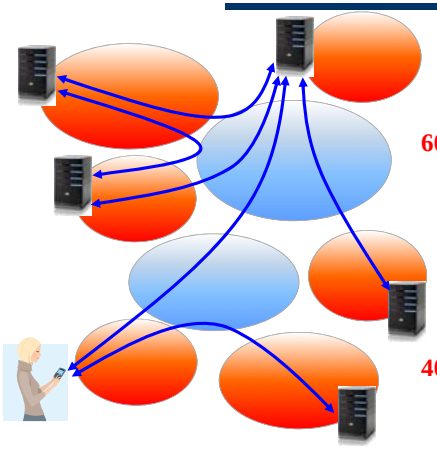
A Horizontal View: Networks



- Edge: campus, home, cloud, ..
  - End-end protocols
  - Video, skype, web browsing, CDN, …
  - Security, TLS, ..
  - Wireless, mobility

60%

- Core: Internet service providers
  - IP, BGP, ICMP, …
  - Traffic engineering, congestion, …
  - DDOS, QoS, …

40%

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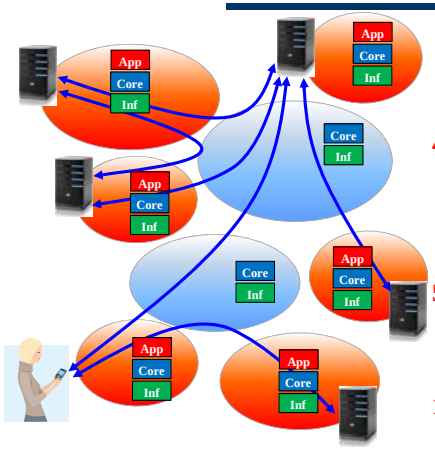
A Vertical View: Protocols



- Application:
  - HTTP, SMTP, ..
  - Content retrieval: web, video, peer-peer, CDNs, …
  - Authentication, ..
- Core protocols:
  - Packet, circuits, ..
  - TCP, IP, routing, ..
  - IPv6, mobility, …
  - QoS, traffic mgt, …
- Infrastructure:
  - Ethernet, wifi, cellular, last mile, ..

40%

50%

10%

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Whirlwind Tour of the Course

- 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, …
- Infrastructure: Ethernet, WiFi, cellular, …
- Focus is on today's Internet but also trends
  - What will the Internet look like in 10, 20, 30 years?

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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? (they did)
- What are the limits of some of the technologies?
  - Both physical and protocol limits
- Continues to evolve very quickly – wireless!

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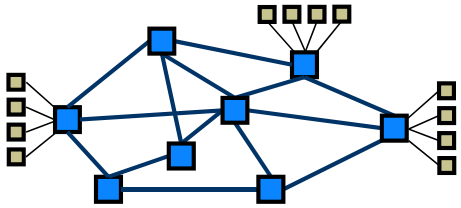
Core Networking Protocols

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
- …



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Optimizing Performance

- Intuitively: lots of bandwidth!
  - But not really: there is no free bandwidth
- But there is more to it:
  - Latency is often more critical!
  - For 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?

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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, big impact on QoE
- 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, …

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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

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Sounds Great! How Do I Get In?

- We currently still have a waiting list
  - If you are not taking the course, please drop it ASAP
- Priority will be given to students who

1. Have taken prerequisite (15/18-213 or 15-513)
   - If you have not taken this course you will have to argue that you have an equivalent background
2. Attend class (fill in form!)

- And you must have enough credits!
- Historically, all qualified students who persist by attending class get into the course

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