Lecture 1: Introduction
Internet History & Modern Networking
Computer Comms & Packet Switching

- ARPA: 1957, in response to Sputnik (the first satellite by the Soviet Union)

- Donald Davies, early 1960s
  - Coins the term “packet”


- J. Licklider & W. Clark (MIT), On-line Man Computer Communication

- L. Roberts (MIT), first ARPANET plan for time-sharing remote computers, SOSP ‘67 paper
Project Funded → ARPANET

- ARPANet
  - 1967: Connect computers at key research sites across the US using point-to-point telephone lines
  - Interface Message Processors (IMP) ARPA contract to BBN
  - Senator Ted Kennedy sent a telegram to BBN to congratulate them on winning contract to develop an "interfaith message processor".

BBN team that implemented the interface message processor
ARPANET Topology in 1969

First inter-site demo, 1969. First crash very soon after!

FIGURE 6.2  Drawing of 4 Node Network
(Courtesy of Alex McKenzie)
1967-1971: So what do we do with it?

- 1967-1972 – Vint Cerf, graduate student in Kleinrock’s lab, works on application level protocols for the ARPANET (*file transfer and Telnet protocols*)

- 1971 - Ray Tomlinson of BBN writes *email* application; derived from two existing: an intra-machine email program (SENDMSG) and an experimental file transfer program (CPYNET)
1971-1973: Network Growing

- 1970 - First 2 cross-country link, UCLA-BBN and MIT-Utah, installed by AT&T at 56kbps
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1973 – Ethernet was designed in 1973 by Bob Metcalfe at Xerox Palo Alto Research Center (PARC)

Other networks: ALOHAnet (microwave network in Hawaii), Telenet (commercial, BBN), Transpac (France)

How do we connect these networks together?
1972-1978: IP/TCP

1972-1974 – Robert Kahn and Vint Cerf develop protocols to connect networks without any knowledge of the topology or specific characteristics of the underlying nets

1977 - First three-network TCP/IP based interconnection demonstrated linking SATNET, PRNET and ARPANET

»
(NOTE: THIS MAP DOES NOT SHOW ARPA'S EXPERIMENTAL SATELLITE CONNECTIONS)
NAMES SHOWN ARE IMP NAMES, NOT (NECESSARILY) HOST NAMES

1981 – Term “Internet” coined to mean collection of interconnected networks

Early 80’s – Move to link state routing protocol to address convergence problem

1982 – Domain Name System introduced (DNS) to replace host.txt and address scale problems

1983-- ARPANET had a Flag-Day in which it transitioned to TCP/IP

1988 -- TCP congestion control in response to congestion collapse episodes in 1986

1988 - Nodes on Internet began to double every year

1988 – Internet worm affecting about 10% of the 60000 computers on the Internet (the Morris Worm)

1989 – BGP to introduce policy based routing
1990s: WWW & Commercialization

1990 – ARPANET ceases to exist
1990 – First ISP world.std.com
1990 – Tim Berners-Lee invents the Web and develops HTML and HTTP
1991 – NSFNET lifted restrictions on use of NSFNET for commercial purposes
1993 – InterNIC created by NSF to provide Internet services; Private companies transition into roles (AT&T – directory and database services; Network Solutions – registration services; CERFnet – information services)
1993 – Move to CIDR to cope with shortage of IP addresses
Today

One of the most influential inventions
- A research experiment that escaped from the lab
- ... to be the global communications infrastructure

Ever wider reach
- Today: nearly 3 billion users
- Tomorrow: more users, computers, sensors, “things”, ...
  40 to 50 billion devices by 2020

Constant innovation
- Web, P2P, social networks, virtual worlds, online markets, E-commerce, ...
The Internet Transformed Everything

The ways we do business
  – E-commerce, advertising, cloud computing, ... 

The way we have relationships
  – E-mail, IM, Facebook, Instagram, virtual worlds

How we think about law
  – Interstate commerce? National boundaries? Wikileaks?

The way we govern
  – E-voting
  – Censorship and wiretapping

The way we fight
  – Cyber-attacks, including nation-state attacks
The Wireless and Mobile Revolution

- WiFi in everything
- Wireless Biomedical Implants
  - Deep Brain Neurostimulators
  - Gastric Stimulators
  - Insulin Pumps
  - Foot Drop Implants
  - Cochlear Implants
  - Cardiac Defibrillators/Pacemakers
- Wireless Wearables
  - Head-worn
  - Straps
  - Shirts
  - Wrist-worn
  - Clips
  - Shoe-worn/Foot pods
- Cellular Networks
- Wireless Sensors
- Drones
- Wireless Data Centers
- Connected Vehicles
Increasing Demand for Wireless Connectivity
Increasing Demand for Wireless Connectivity

The Internet of Things
An Explosion of connected possibility

Source: Mario Morales, IDC
About this class
Goals

1. To understand how wireless and wired networks work, and how to develop mobile and networked systems

2. To understand how to conduct networking research and develop innovative ideas.
General Information

• **Instructors**
  – Lecturers: Dina Katabi [dk@mit.edu](mailto:dk@mit.edu) and Fadel Adib [fadel@mit.edu](mailto:fadel@mit.edu)
  – Office hours: Thursday after class or by appointment

• **TAs**
  – Chen-Yu Hsu [cyhsu@mit.edu](mailto:cyhsu@mit.edu) Office Hours: Tue 2:30-3:30pm at 32-268
  – Mingmin Zhao [mingmin@mit.edu](mailto:mingmin@mit.edu) Office Hours: Thu 4:00-5:00pm at 32-268

• **Class Web Page**
Course Structure

• Lectures & Readings

• Problem Sets

• One Quiz

• Final Project
Lecture & Readings

Lecture

– Each class we will discuss 1-2 papers or lecture notes
– You must read the papers before class
– Most of lecture will be spent discussing/debating the papers
– Come prepared to discuss the main ideas!

Questions about readings

– A few questions will be posted on class webpage per lecture
– Submit answers online by midnight the night before lecture (see class webpage)
Syllabus Summary

• **Wireless Networks**
  – How WiFi and cellular networks work

• **Sensors and the Internet of Things**
  – Smart home sensors
  – Localizing people using the signal from their cell phones

• **Wired Networks**
  – Internet architecture and protocols
  – Data Centers

• **Miscellaneous**
  – ML in networking
  – Security
  – Apps, e.g., video
Rest of Today

A sampler of class topics
Indoor Localization with Wireless Signals
GPS has changed how we navigate outdoor space

GPS does not work indoors...
Now, we can use RF for Indoor localization

Navigation

Business Analytics

Inventory
How Do We Localize?

Measure distances between phone and access point?
Measuring Distance

Distance = speed of light \times \text{propagation delay}

We can use signal property to measure propagation delay
WiFi-Based Indoor GPS

Single Point WiFi Localization
Localization works even with RFIDs

Battery-free stickers to tag any and every object
Smart Homes

- RFID-tagged Laptop
- Laptop Charger
- RFID-tagged Laptop
- RFID-tagged Handbag
Smart Homes

Charger left behind!

RFIDs on the Door Frame
X-Ray Vision
Imagine having X-ray vision!
Device behind wall
Emotion Recognition with RF Signals
Was there a **moment** in your life when you looked at someone's **face**?
EQ-Radio: Emotion recognition using wireless signals
Data Centers

Microsoft

Google

Facebook
These things are really big

- 10-100K servers
- 100s of Petabytes of storage
- 100s of Terabits/s of Bw (more than core of Internet)
- 10-100MW of power (1-2 % of global energy consumption)
- 100s of millions of dollars

Slide by George Porter (UCSD)
Networking *Inside* Datacenters

1. User request
2. 100s of Intra DC messages
3. Picasso

Art is a lie that makes us realize the truth.

"Everything you can imagine is real."
"Bad artists copy. Good artists steal."
"It is your work in life that is the ultimate seduction."
"The chief enemy of creativity is good sense."
"Inspiration does exist, but it must find you working."
"I'd like to live as a poor man with lots of money."
"Art is a lie."

Deadline = 250ms
Deadline = 50ms
Deadline = 10ms

"Computers are useless. They can only give you answers."
Datacenter Networking Challenges

- Very high speeds (10-100Gbps links)
- Tiny round trip times (microseconds)
- Dense, multi-path topologies
- Cheap switches with small buffers
- Message latency is King

On the other hand...
- Single administrative domain
- No need to be compatible with outside world
Network Programmability
Software Defined Network (SDN)
Software Defined Network (SDN)

Replace distributed protocols with “logically centralized” software programs
Programmable Data-plane

Can we program new data-plane algorithms?

- Congestion control
- Measurement
- Load balancing
- Packet scheduling

Traditionally, these algorithms are hard-coded into router hardware
Software vs. Hardware routers

10–100X gap between hardware and software routers
Programmable router hardware

Same performance as fixed-function chips,
Some programmability