CSE160: Computer Networks

Lecture #01 – Introduction

2020-08-27

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This Lecture

1. Administrative stuff
2. Introduction to Networks
3. Statistical Multiplexing

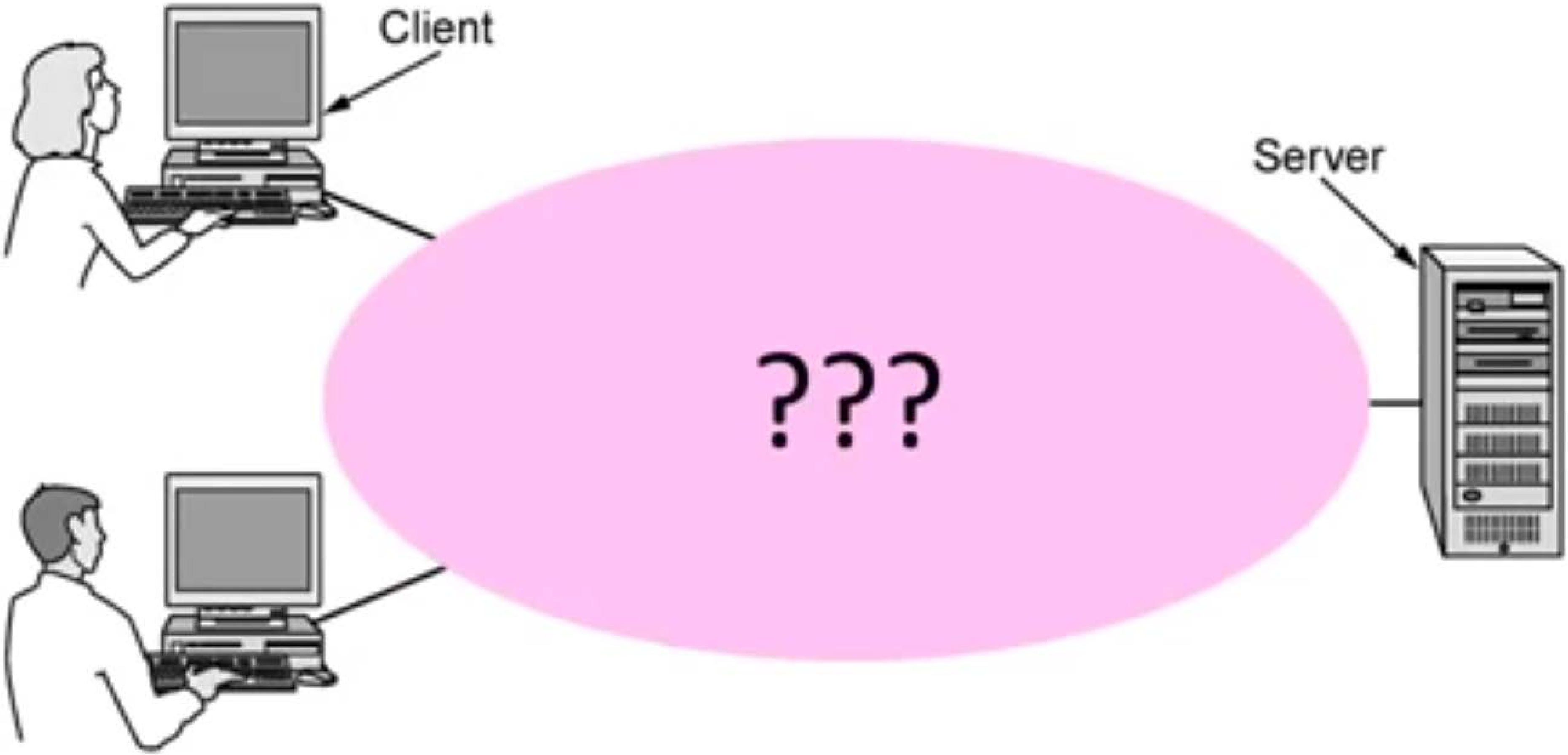
1. Administrative Stuff

- Everything you need is on the course web page
  - http://catcourses.ucmerced.edu
- Your TODO list:
  - Get Computer Networks by Peterson and Davie, Fifth Edition
  - Read chapters 1 and 2
  - Start on TOSSIM assignment Project 0 and Project 1

TAs and Student Support

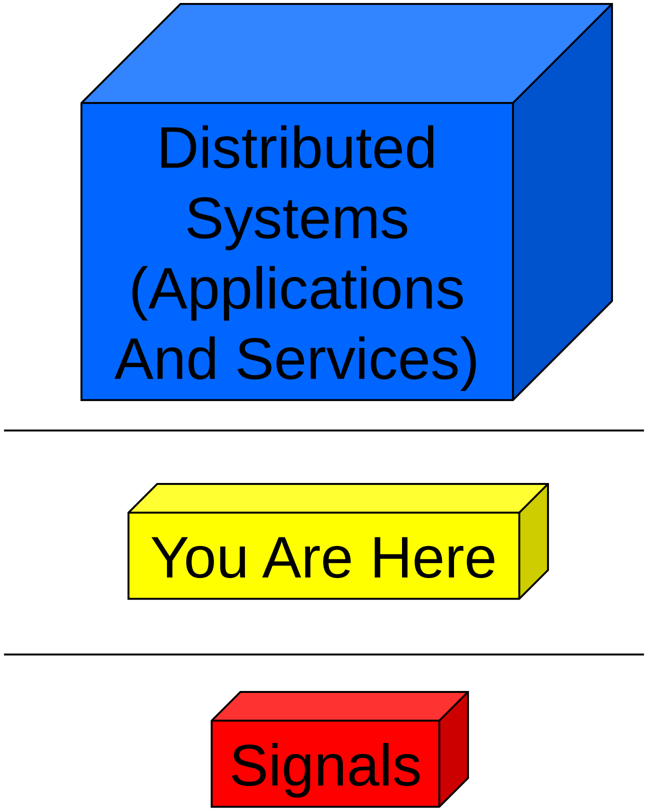
- TAs:
  - Hamid Rajabi (hrajabi2@ucmerced.edu)
- Tutoring:
  - Possible PALS Bright Center Tutor available (more on this later)

Focus of the course



Goal of this Course

- You will understand how to design and build *large, distributed computer* networks.
  - Fundamental problems in building networks
  - Design principles of proven value
  - Common implementation technologies
- This is a systems course, not queuing theory, signals, or hardware design.
- We focus on networks, with a bit of the applications and services that run on top of them (distributed systems) and a bit of low level communication signals



The Main Point

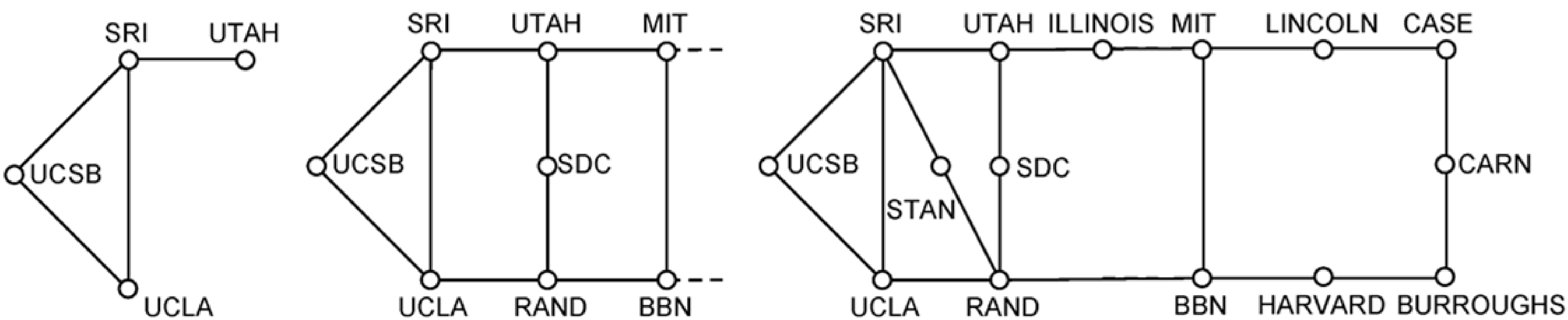
- To learn how the Internet works
  - What really happens when you “browse the web”?
  - What are TCP/IP, DNS, HTTP, NAT, VPNs, 802.11, etc. anyway?
- To learn the fundamentals of computer networks

Why learn about the Internet?

- Curiosity
- Impact on our world
- Job prospects!

ARPANET ~1970

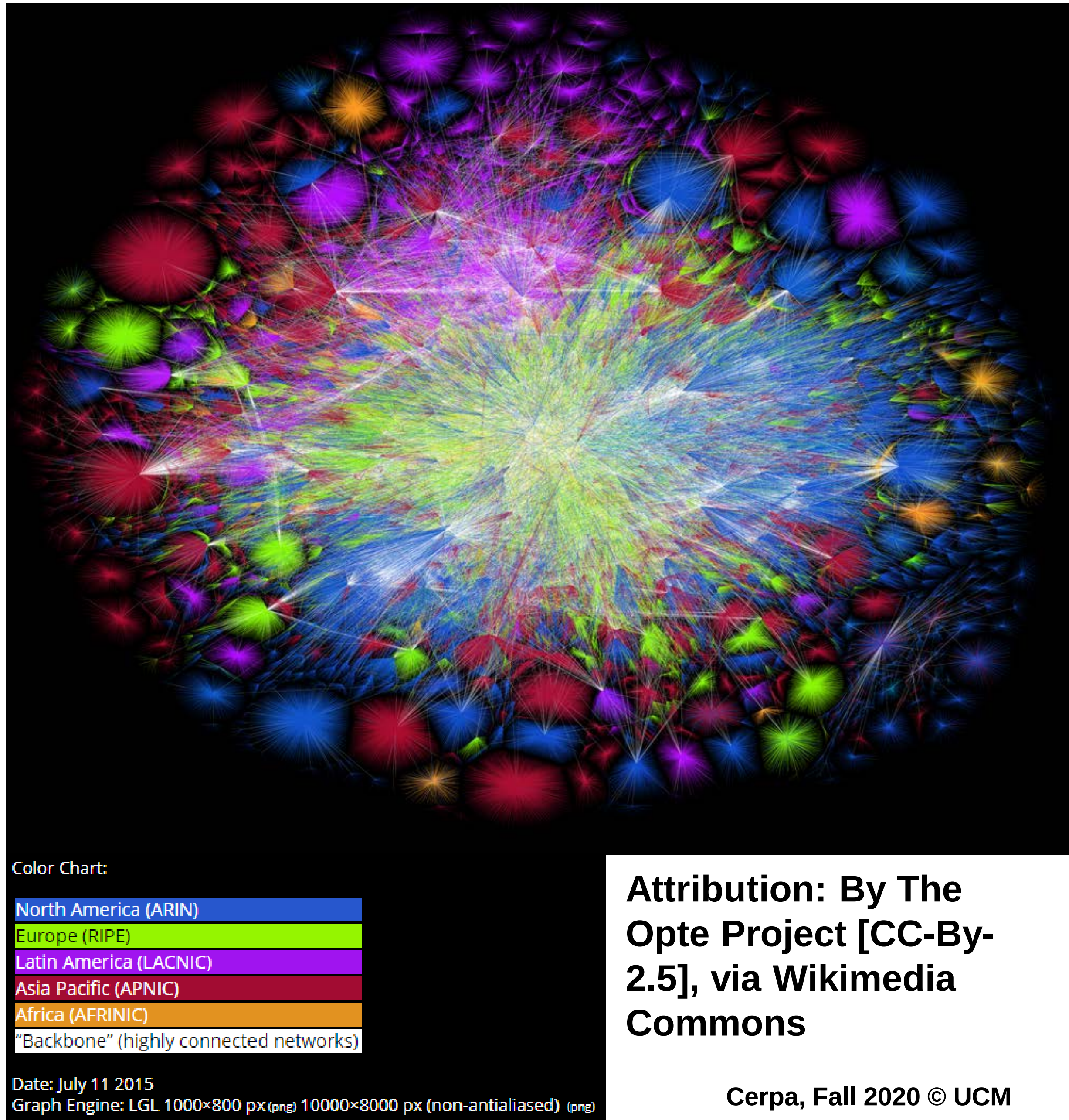
- From this experimental network …



(a) Dec. 1969. (b) July 1970. (c) March 1971.

Internet 2015

- An everyday institution used at work, home, and on-the-go
- Visualization contains millions of links



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Question

- What do you think are the issues that one has to tackle to grow from a small network to an extremely large network?

Internet – Societal Impact

- An enabler of societal change
  - Easy access to knowledge
  - Electronic commerce
  - Personal relationships
  - Discussion without censorship

Internet – Economic Impact

- An engine of economic growth
  - Advertising-sponsored search
  - “Long tail” online stores
  - Online marketplaces
  - Crowdsourcing

The Main Point (2)

- To learn how the Internet works
- To learn the fundamentals of computer networks
  - What hard problems must they solve?
  - What design strategies have proven value?

Why learn the Fundamentals?

- Apply to all computer networks
- Intellectual interest
- Change / reinvention

Fundamentals – Intellectual Interest

- Example key problem: Reliability!
  - Any part of the Internet might fail
  - Messages might be corrupted
  - So how do we provide reliability?
- Reliability solutions
  - Codes to detect/correct errors
  - Routing around failures
  - Windowing schemes between two hosts…

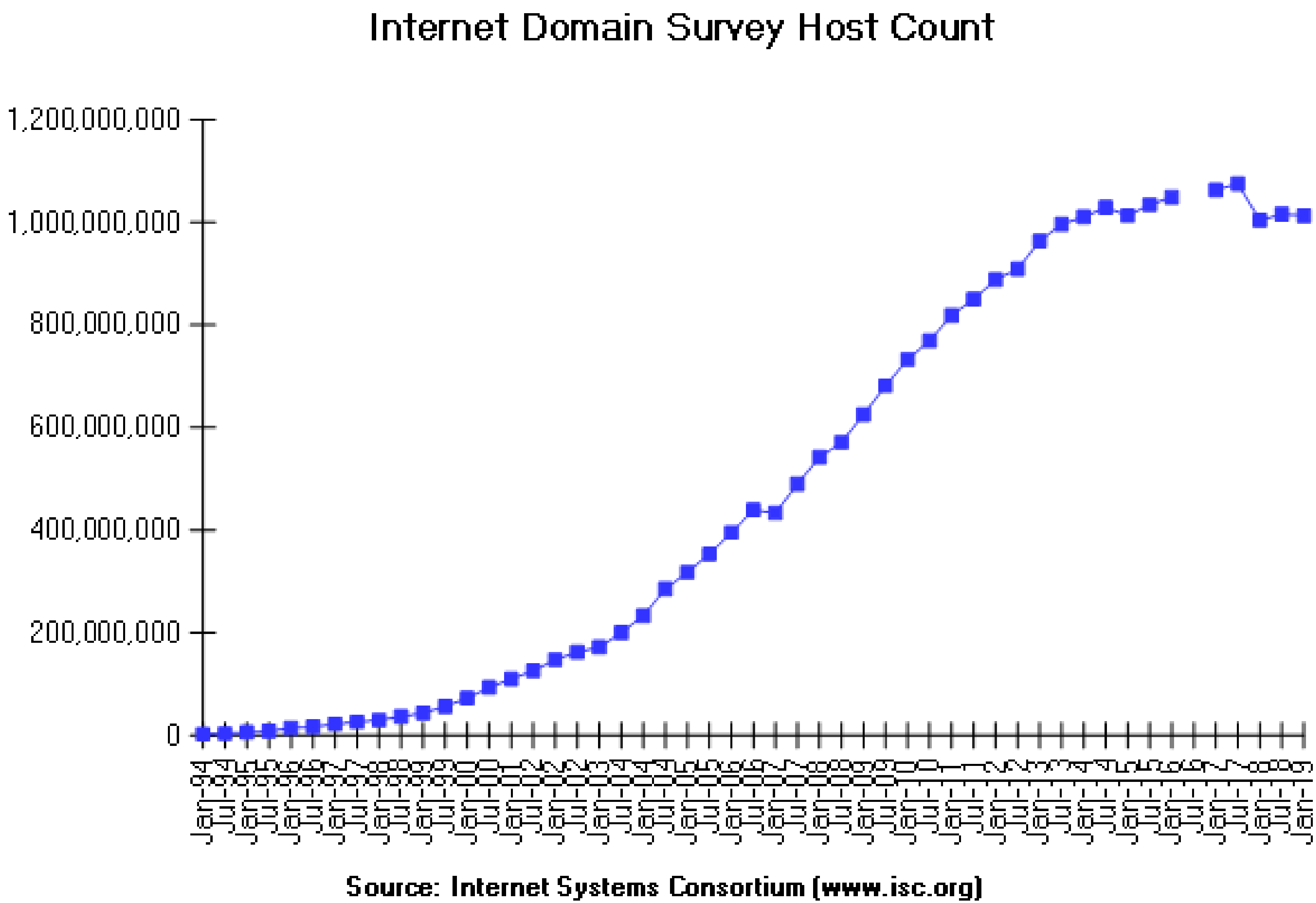
Fundamentals – Intellectual Interest (2)

Key problem	Example solutions
Reliability despite failures	Codes for error detection/correction (§2.2, 2.4) Routing around failures (§3.3)
Network growth and evolution	Addressing (§3.2) and naming (§9.3) Protocol layering (§1.3)
Allocation of resources like bandwidth	Multiple access (§2.6) Congestion control (§6.3, 6.4)
Security against various threats	Confidentiality of messages (§8.1, 8.4) Authentication of communicating parties (§8.3)

Fundamentals – Reinvention

- The Internet is constantly being re-invented
  - Growth over time and technology trends drive upheavals in Internet design and usage
- Today’s Internet is different from yesterday’s
  - And tomorrow’s will be different again
  - But the fundamentals remain the same

Fundamentals – Reinvention (2)



Fundamentals – Reinvention (3)

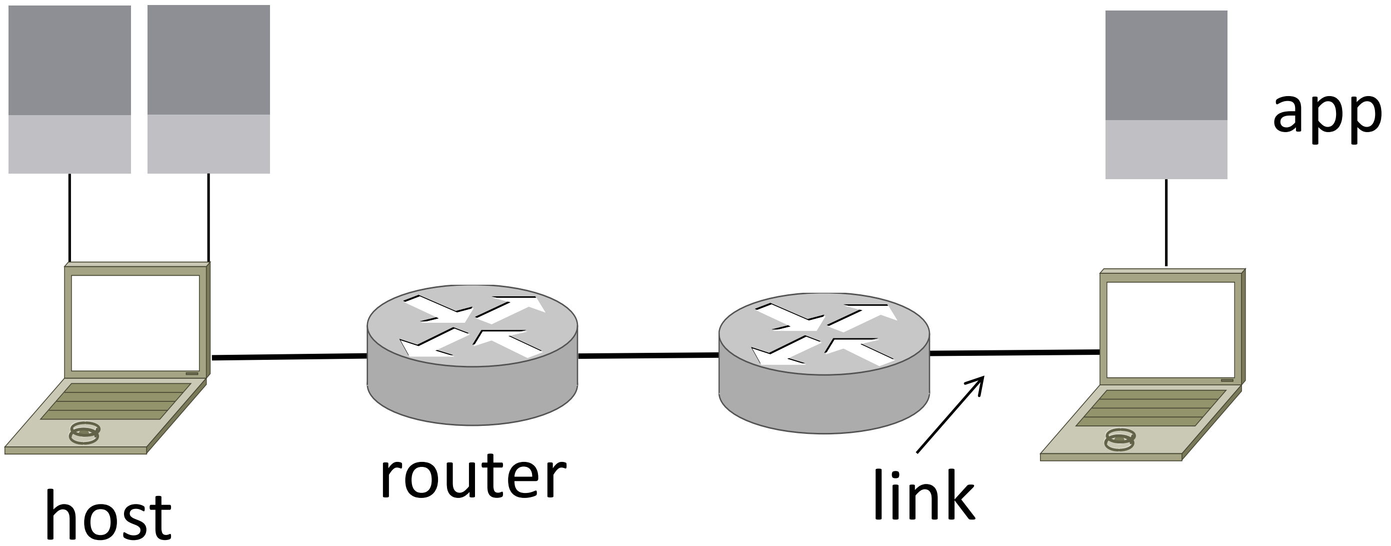
- Example of upheavals in the past 1-2 decades

Growth / Tech Driver	**Upheaval**
Emergence of the web	Content Distribution Networks
Digital songs/videos	Peer-to-peer file sharing
Falling cost/bit	Voice-over-IP calling
Many Internet hosts	IPv6
Wireless advances	Mobile devices

Not a Course Goal

- To learn IT job skills
  - How to configure equipment
    - e.g., Cisco certifications
  - But course material is relevant, and we use hands-on tools

Parts of a Network



Components Names

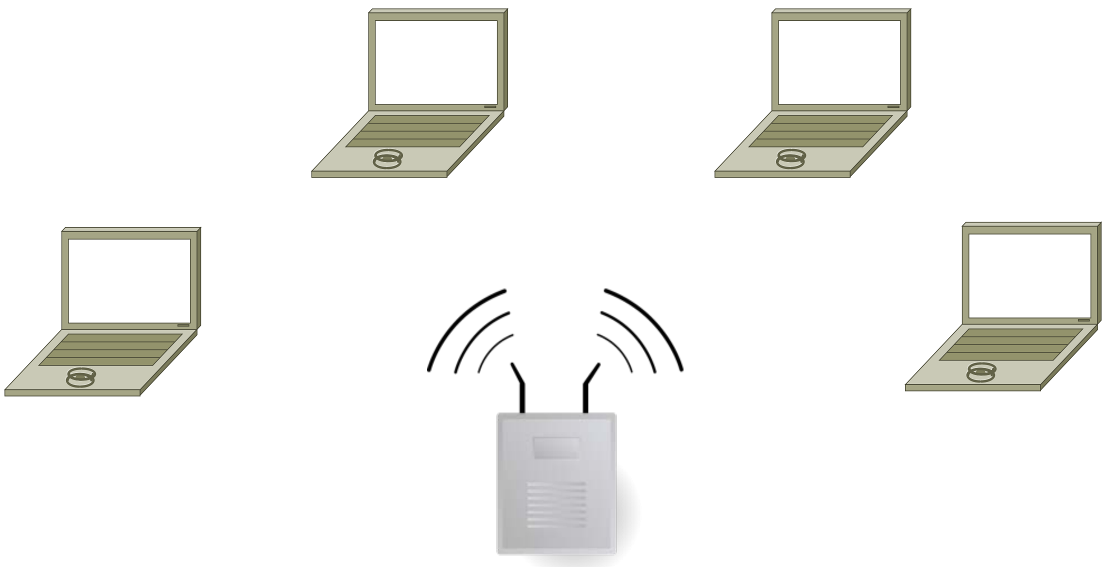
Component	Function	Example
<u>Application</u>, or app, user	Uses the network	Skype, iTunes, Amazon
<u>Host</u>, or end-system, edge device, node, source, sink	Supports apps	Laptop, mobile, desktop
<u>Router</u>, or switch, node, intermediate system, …	Relays messages between links	Access point, cable/DSL modem
<u>Link</u>, or channel	Connects nodes	Wires, wireless

Types of Links

- Full-duplex
  - Bidirectional
- Half-duplex
  - Bidirectional
- Simplex
  - unidirectional

Wireless Links

- Message is <u>broadcast</u>
  - Received by all nodes in range
  - Not a good fit with our model



Example Networks

- WiFi (802.11)
- Enterprise / Ethernet
- ISP (Internet Service Provider)
- Cable / DSL
- Mobile phone / cellular (2G, 3G, 4G, 5G)
- Bluetooth
- Telephone
- Satellite ...

Network names by scale

Scale	Type	Example
Vicinity	PAN (Personal Area Network)	Bluetooth (e.g., headset)
Building	LAN (Local Area Network)	WiFi, Ethernet
City	MAN (Metropolitan Area Network)	Cable, DSL
Country	WAN (Wide Area Network)	Large ISP
Planet	The Internet (network of all networks)	The Internet!

Internetworks

- An <u>internetwork</u>, or <u>internet</u>, is what you get when you join networks together
  - Just another network

- The Internet (capital "I") is the internet we all use

INTERNET2 NETWORK BY THE NUMBERS

17	JUNIPER MX960 ROUTERS SUPPORTING LAYER 3 SERVICE
34	BROCADE AND JUNIPER SWITCHES SUPPORTING LAYER 2 SERVICE
62	CUSTOM COLLOCATION FACILITIES
250+	AMPLIFICATION RACKS
15,717	MILES OF NEWLY ACQUIRED DARK FIBER
8.8	TBPS OF OPTICAL CAPACITY
100	GBPS OF HYBRID LAYER 2 AND LAYER 3 CAPACITY
300+	CIENA ACTIVEFLEX 6500 NETWORK ELEMENTS
2,400	MILES PARTNERED CAPACITY WITH ZAYO COMMUNICATIONS IN SUPPORT OF THE NORTHERN TIER REGION

The networks we study

- We are interested in networks that are:
  - Large scale
  - Intrinsically Unreliable
  - Distributed
  - Heterogeneous

Intrinsic Unreliability

- Information sent from a first place to a second
  - May not arrive
  - May arrive more than once
  - May arrive in garbled fashion
  - May arrive out of order
  - May be read by others
  - May be modified by others
- Why build intrinsically unreliable networks?

Distributed

"A distributed system is a system in which I can't do my work because some computer has failed that I've never even heard of." – Leslie Lamport

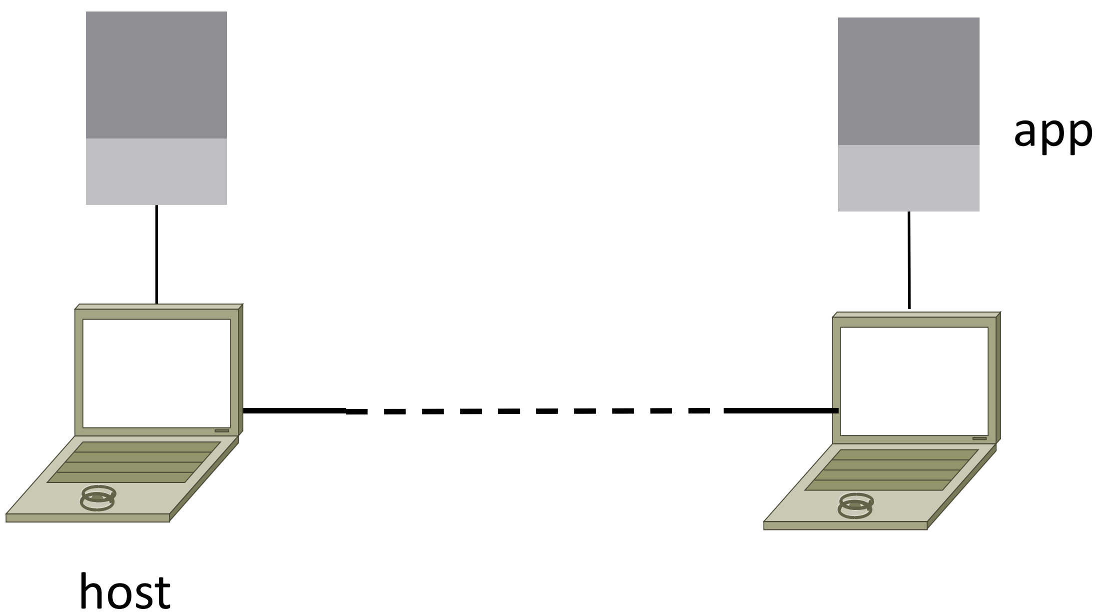
- (Hopefully) independent failure modes
- Exposed and hidden dependencies
- Independent administrative controls
- Leads to…

Heterogeneous Networks

- Heterogeneous: Made up of different kinds of stuff
- Homogeneous: Made up of the same kind of stuff
- Principles
  - Homogeneous networks are easier to deal with
  - Heterogeneous networks lead to greater innovation and scale
  - Consider telephone network vs. Internet
  - Reasons?

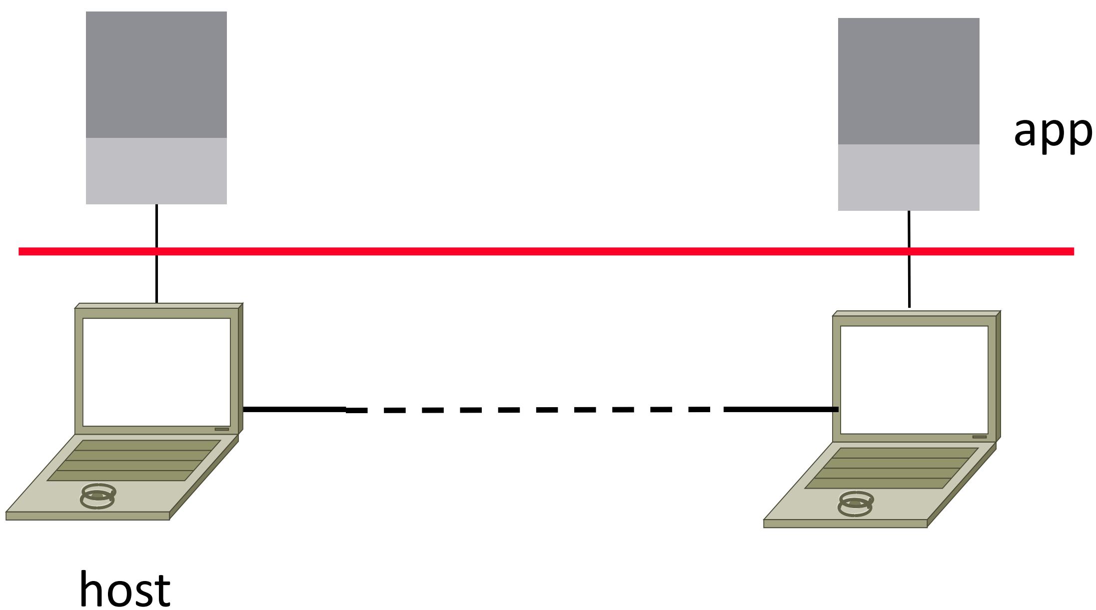
Key Interfaces

- Between (1) apps and network, and (2) network components
  - More formal treatment later on



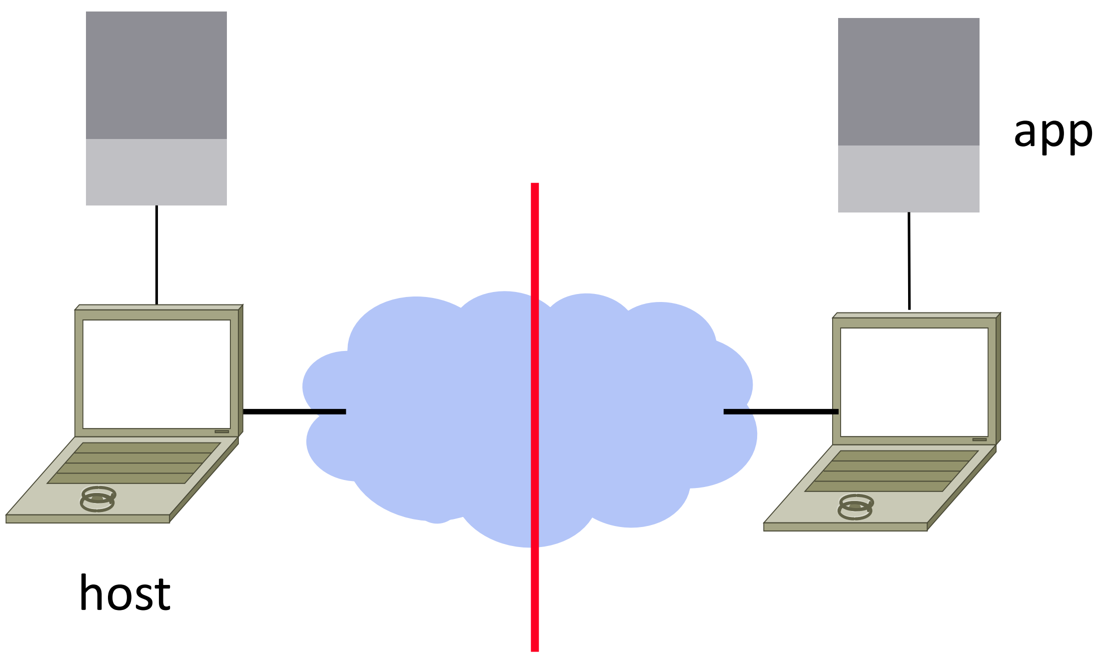
Key Interfaces (2)

1. Network-application interfaces define how apps use the network
   - Sockets are widely used in practice



Key Interfaces (3)

2. Network-network interfaces define how nodes work together
   - Traceroute can peek in the network



Example Uses of Networks

- Work:
  - Email, file sharing, printing, …
- Home:
  - Movies / songs, news, calls / video / messaging, e-commerce, …
- Mobile:
  - Calls / texts, games, videos, maps, information access …
- What do these uses tell us about why we build networks?

For User Communication

- From the telephone onwards:
  - VoIP (voice-over-IP)
  - Video conferencing
  - Instant messaging
  - Social networking
- What is the metric we need to be optimizing for these uses?
  - Need low latency for interactivity

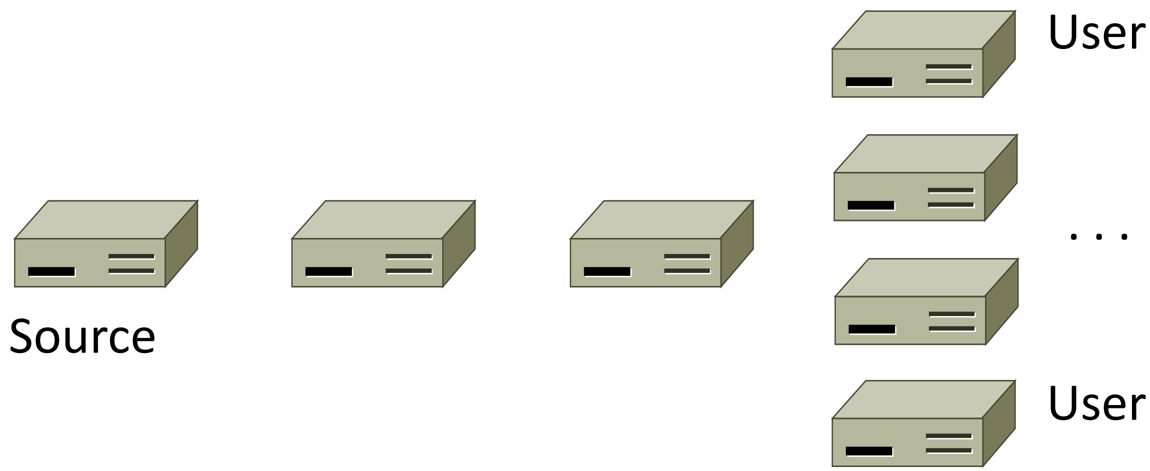
For Content Delivery

- Same content is delivered to many users
  - Videos (large), songs, apps and upgrades, web pages, …

- What is the metric that we want to optimize in such cases?

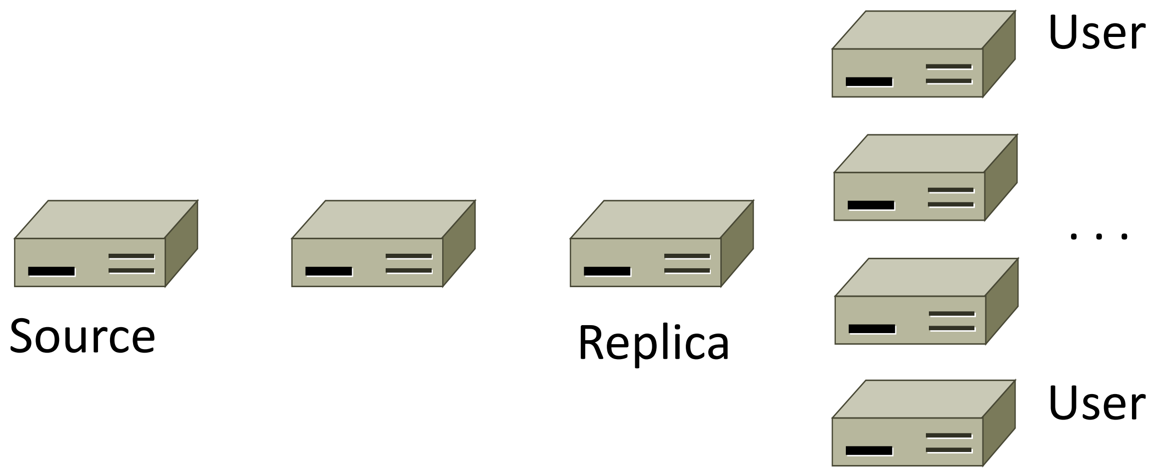
Content Delivery (2)

- Sending content from the source to 4 users takes 4 x 3 = 12 "network hops" in the example



Content Delivery (3)

- But sending content via replicas takes only 4 + 2 = 6 “network hops”



For Resource Sharing

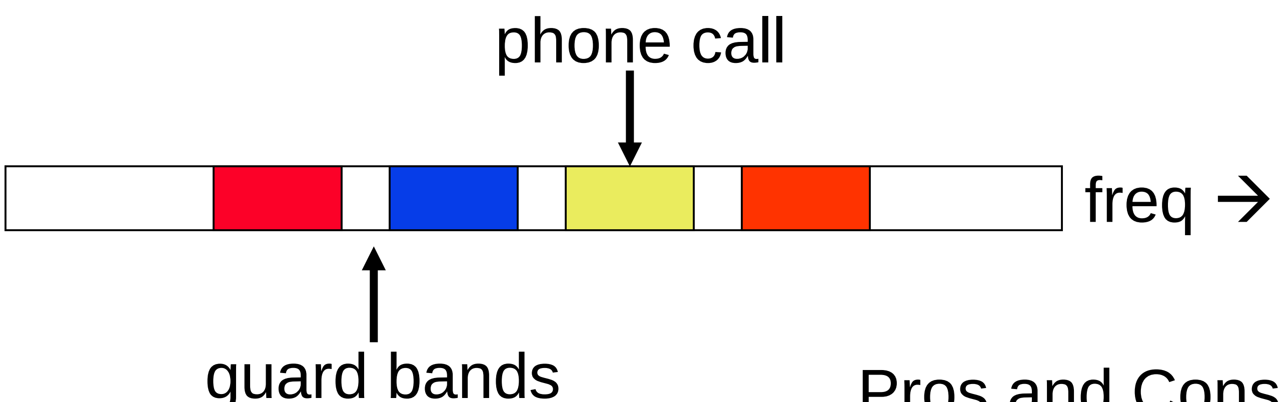
- Many users may access the same underlying resource
  - e.g. 3D printer, search index, machines in the cloud
- More cost effective than dedicated resources per user
  - Even network links are shared via statistical multiplexing

An example technical problem: multiplexing

- Networks are shared among users
  - This is an important benefit of building them
    - (why we can’t just buy everybody their own network!)
- How should you multiplex (share) a resource amongst multiple users?
  - e.g., how do you share a network link?
- First Solution: Static Partitioning
  - (Synchronous) Time Division Multiplexing (TDM, STDM)
  - Frequency Division Multiplexing (FDM)

Frequency Division Multiplexing

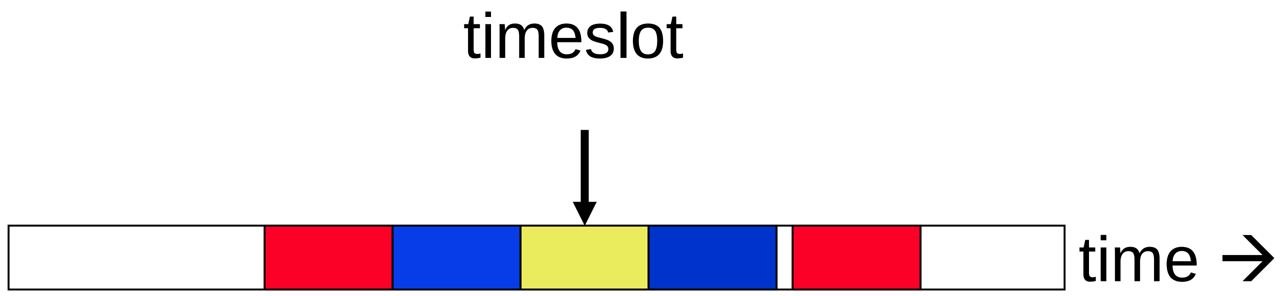
- Simultaneous transmission in different frequency bands
- “Speaking at different pitches”
  - e.g., take one 3MHz signal and break it into 1000 3KHz signals
    - Analog: Radio, TV, AMPS cell phones (800MHz)
  - also called Wavelength DMA (WDMA) for fiber



Pros and Cons?

Time Division Multiplexing

- “Slice up” the given frequency band between users
- Speaking at different times
  - Digital: used extensively inside the telephone network
  - T1 (1.5Mbps) is 24 x 8 bits/125us; also E1 (2Mbps, 32 slots)



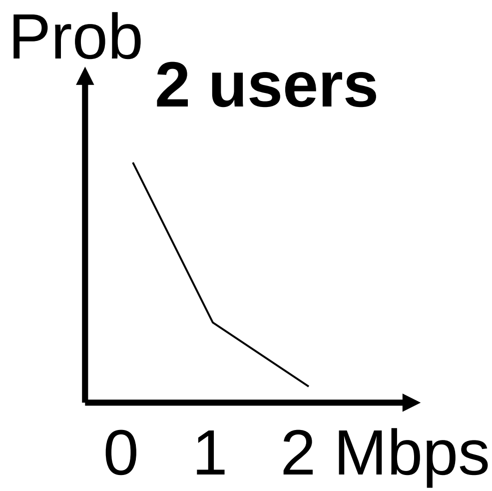
Pros and Cons?

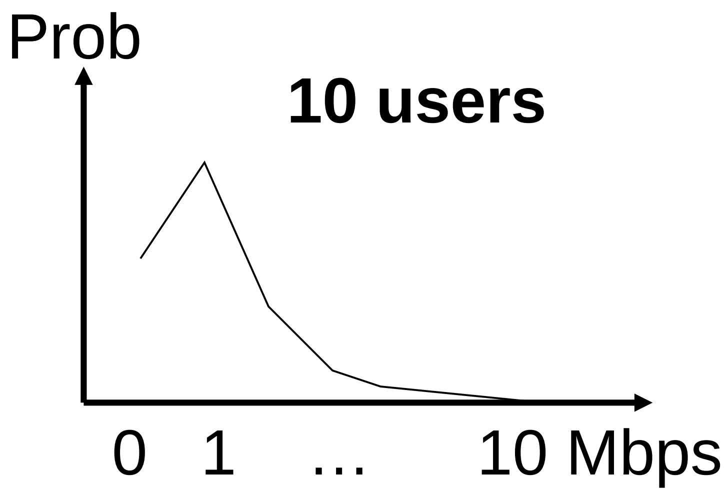
Statistical Multiplexing

- Static partitioning schemes are not well-suited to data networks. Why?
  - Because peak rate >> average rate.
    - it's rare for many clients to want to transmit at the same time.
    - so, statically assigning fractions of the link wastes capacity, since users tend to underuse their fraction
  - (Q: When would S.P. schemes be well suited to communications?)
- If we share on demand we can support more users
  - Based on the statistics of their transmissions
    - If you need more, you get more. If you need less, you get less.
    - It's all supposed to "balance out" in the end
  - Occasionally we might be oversubscribed
  - This is called statistical multiplexing -- used heavily in data networks

Why We Like Statistical Multiplexing

- One user sends at 1 Mbps and is idle 90% of the time.
  - 10 Mbps channel; 10 users if statically allocated
- Two scenarios: 2 users in the population, or 10 users in population
  - what is the probability of a certain bandwidth consumption at any given moment in time?





Example continued

- For 10 users, Prob(need 10 Mbps) = Prob (10 users) = $(0.10)^{10} = 10^{-10}$ = 0.00000001%
- Not likely! So keep adding users …
- For 35 users, Prob(>10 users) = Prob (11 users) + … + Prob (35 users) = $10^{-11} + \ldots + 10^{-35}$ = 0.17% which is acceptably low
- With statistical multiplexing, we can support three times as many users than static allocation!
- What's the rub?

Key Concepts

- Networks are comprised of links, switches and hosts
- Networks are used to share distributed resources
  – Key problems revolve around effective resource sharing
- Multiplexing lets multiple users share a resource
- Static multiplexing is simple
  – but not efficient unless the workloads are static
- Statistical multiplexing is more complicated
  – not guaranteed to work
  – but well-suited to data communications (bursty traffic)