EECS 563 Spring 2024

Communications Networks
Introduction

Victor S. Frost
Dan F. Servey Distinguished Professor
Electrical Engineering and Computer Science
University of Kansas
2335 Irving Hill Dr.
Lawrence, Kansas 66045
e-mail: vsfrost@ku.edu
http://www.ittc.ku.edu/~frost

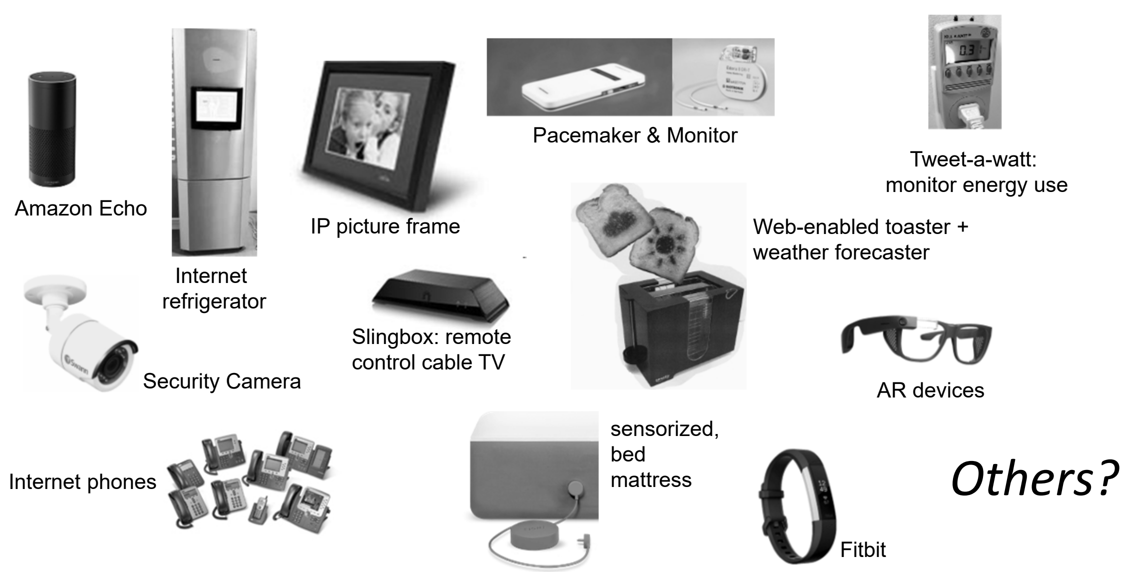
Outline

- Landscape
- Customer Expectations
- Value and Drivers of Network Technology
- Defining the Network
- Issues in Networking

Communications Landscape

- Voice
- Data: E-mail, Web, Network based applications, Images, Machine-to-Machine, IoT
- Video, Streaming, Broadcast, Video on Demand, Mobile
- Wired & wireless
- Mobility
- Separate Voice/Internet/Video networks have converged to:
  <u>An integrated packet network</u>

"Fun" Internet-connected devices



Drivers: Customer Expectations

- Sense of always connected
- Instant response, high bandwidth
- Ubiquitous connectivity
- Multimedia (video) support
- Conferencing (simultaneous communications with multiple users)

Drivers: Customer Expectations

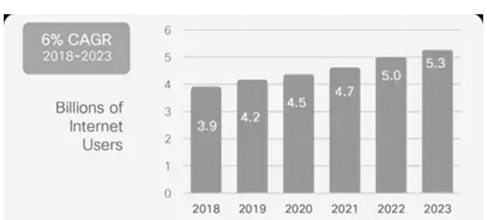
- Mobility support
- Personalized information services
- Context sensitive information services
- Absolutely secure & private
- Low-cost

The Value of the Net

- Metcalf's Law: The value of a network increases as the square of the number of connected users [some say nlog(n)]
- The value of a network increases as the square of the access bandwidth
- The value of a network increases as the square of computing power of end device
- Number of connected users, bandwidth/user and device capabilities are increasing → Value of the Net ↑

Drivers: Technology
Traffic Growth

- Internet still growing
- Access rates increasing
  - Cable 100's-1000 Mb/s
  - FTTH ~100's to 1 Gb/s
  - Wireless → Gb/s
- https://www.cisco.com/c/en/us/solutions/collateral/executive-perspectives/annual-internet-report/white-paper-c11-741490.html#Trends - March 2020



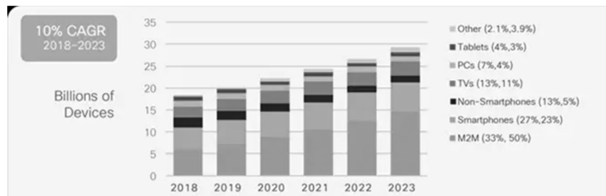
Compound Annual Growth Rate – CAGR

Table 1. Internet users as a percentage of regional population

Region	2018	2023
Global	51%	66%
Asia Pacific	52%	72%
Central and Eastern Europe	65%	78%
Latin America	60%	70%
Middle East and Africa	24%	35%
North America	90%	92%
Western Europe	82%	87%

Drivers: Technology

- Moore's Law
  - Processing power doubles every 18 months
  - Moore's Law has been true since ~1965
- Gilder's Law (The Law of Telecoms)
  - Total telecommunications system capacity (b/s) triples every three years



Global device and connection growth

Connection Speeds

Table 5. Fixed broadband speeds (in Mbps), 2018–2023

Region	2018	2019	2020	2021	2022	2023	CAGR (2018–2023)
Global	45.9	52.9	61.2	77.4	97.8	110.4	20%
Asia Pacific	62.8	74.9	91.8	117.1	137.4	157.1	20%
Latin America	15.7	19.7	34.5	41.2	51.5	59.3	30%
North America	56.6	70.1	92.7	106.8	126.0	141.8	20%
Western Europe	45.6	53.2	72.3	87.4	105.6	123.0	22%
Central and Eastern Europe	35.0	37.2	57.0	65.5	77.8	87.7	20%
Middle East and Africa	9.7	11.7	25.0	29.0	34.9	41.2	33%

Table 7. Average mobile network connection speeds (in Mbps) by region and country

Region	2018	2019	2020	2021	2022	2023	CAGR (2018–2023)
Global speed: All handsets	13.2	17.7	23.5	29.4	35.9	43.9	27%
Asia Pacific	14.3	18.0	24.7	32.4	39.0	45.7	26%
Latin America	8.0	11.2	15.7	21.1	24.8	28.8	29%
North America	21.6	27.0	34.9	42.4	50.6	58.4	22%
Western Europe	23.6	31.2	40.1	48.2	54.4	62.4	21%
Central and Eastern Europe	12.9	15.7	21.3	30.3	36.1	43.0	27%
Middle East and Africa	6.9	9.4	13.3	17.6	20.3	24.8	29%

Speed Record

- July 14, 2021 “fastest internet speed, achieving a data transmission rate of 319 Terabits (10^{12}) per second (Tb/s)”
- From https://interestingengineering.com/japan-shattered-internet-speed-record-319-terabits
- “The new record was made on a line of fibers more than 1,864 miles (3,000 km) long.”

Drivers: Others

- Economic
- Public Policy/Regulatory
- Local Laws and Culture

Sidebar: Network Neutrality

What is network neutrality?

- *technical:* how an ISP should share/allocation its resources
  - packet scheduling, buffer management are the *mechanisms*
- *social, economic* principles
  - protecting free speech
  - encouraging innovation, competition
- enforced *legal* rules and policies

Different countries have different "takes" on network neutrality

Sidebar: Network Neutrality

2015 US FCC *Order on Protecting and Promoting an Open Internet:* three "clear, bright line" rules:

- no blocking … "shall not block lawful content, applications, services, or non-harmful devices, subject to reasonable network management."
- no throttling … "shall not impair or degrade lawful Internet traffic on the basis of Internet content, application, or service, or use of a non-harmful device, subject to reasonable network management."
- no paid prioritization. … "shall not engage in paid prioritization"

ISP: telecommunications or information service?

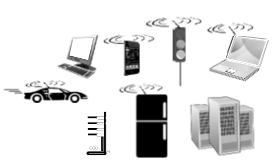
Is an ISP a "telecommunications service" or an "information service" provider?

- the answer *really* matters from a regulatory standpoint!

US Telecommunication Act of 1934 and 1996:

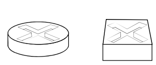
- *Title II:* imposes "common carrier duties" on *telecommunications services*: reasonable rates, non-discrimination and *requires regulation*
- *Title I:* applies to *information services:*
  - no common carrier duties (*not regulated*)
  - but grants FCC authority "… as may be necessary in the execution of its functions".

Network Elements (Definition of some terms)



Billions of connected computing *devices*:

- *hosts = end systems*
- running *network apps* at Internet's "edge"
- aka, User Equipment (UE)



Packet switches: forward packets (chunks of data)

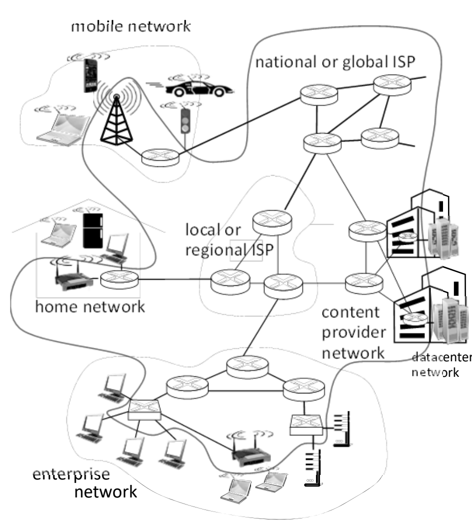
- *routers*, *switches*

Communication links

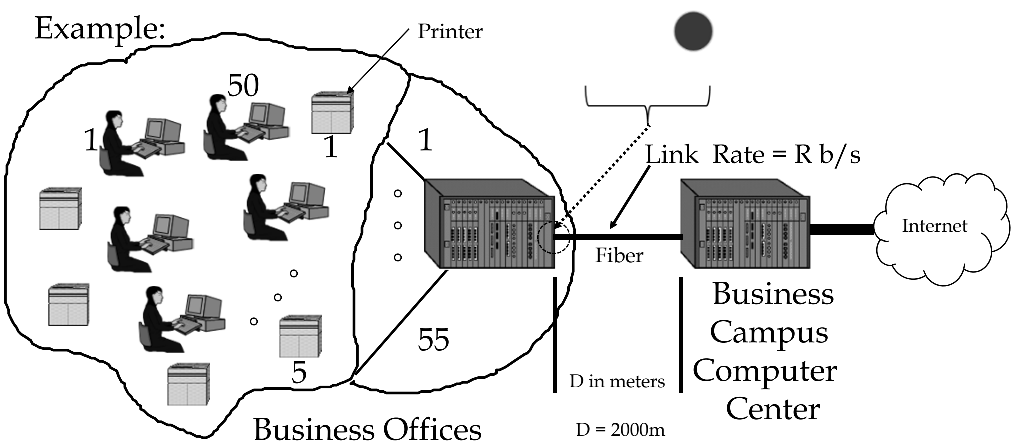
- fiber, copper, radio, satellite
- transmission rate: bits/sec bits/sec not equal to *bandwidth (Hz)*

Networks

- collection of devices, routers, links: owned and managed by an organization



Issues in Networking: Sharing

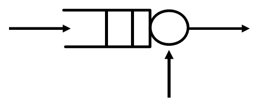


Issues in Networking: Sharing

- What is shared:
  - Link capacity
  - Buffers (memory)
  - Processing
  - Common address (name) space

Issues in Networking: Sharing

- R = Peak rate (link capacity) b/s
- L=Message Length (Bytes)



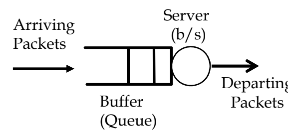
- Packet clocking (service) time (sec) = L*8 (bits)/R (bits/sec)
- One way propagation time (sec)
  = D (meters)/(Propagation speed (meters/sec)) = τ (sec)
  - Propagation speed = c = speed of light = $3x10^8$ meters/sec (in free space)
  - Propagation speed = ~$2x10^8$ meters/sec (in fiber)
- For L=9kBytes=9kB with R=100Mb/s → Packet clocking time = 0.72 ms
- For D = 2km over fiber → One way propagation time= τ = 10 us
- Round trip time (RTT) = 2τ (Not including switching, forwarding, and processing times)

Issues in Networking: Sharing

- Assume each customer and printer (55 devices) is connected using Ethernet, i.e. at 1 Gb/s
- How fast does the link between the offices and the computer center have to be to **guarantee** all the customers can use the 1 Gb/s.
- R= Rate = 55 Gb/s
- Too expensive

Issues in Networking: Sharing

- Solution: Gamble
- Assume:
  - Each host computer breaks up messages into 'smallish' units called *packets*
  - Packets from each customer are sent to a waiting line, buffer, to wait their turn to use the link
  - Packets arriving to a full buffer are discarded
  - Discarded packets are sometimes retransmitted later
- Customer information now experiences:
  - Queueing delay, waiting in line
  - Loss
- Network resources are shared, e.g.,
  - Transmission capacity
  - Addresses (more on this later)
  - Buffer (memory)

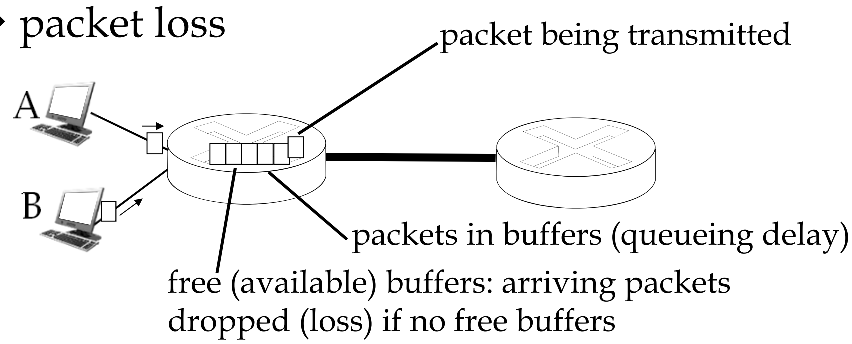


See Animation

How do packet loss and delay occur?

Packets *queue* in buffers

- packets queue, wait for turn
- arrival rate to link (temporarily) exceeds output link capacity→ packet loss



Issues in Networking: Sharing

- Customer performance requirements:
  - Delay < 100ms and Loss < 10%

  } Quality of Service Specifications
- Assume customer traffic:
  - L (bytes) =Average packet length = 9kB=9000 bytes
  - λ (packets/sec/device) =
    Packets are generated at a rate of 2 per second/device

  } Input Traffic Specification
- Using basic queueing theory
  - R = 8.6 Mb/s << 55 Gb/s
  - System size > 7 packets

  } System Design

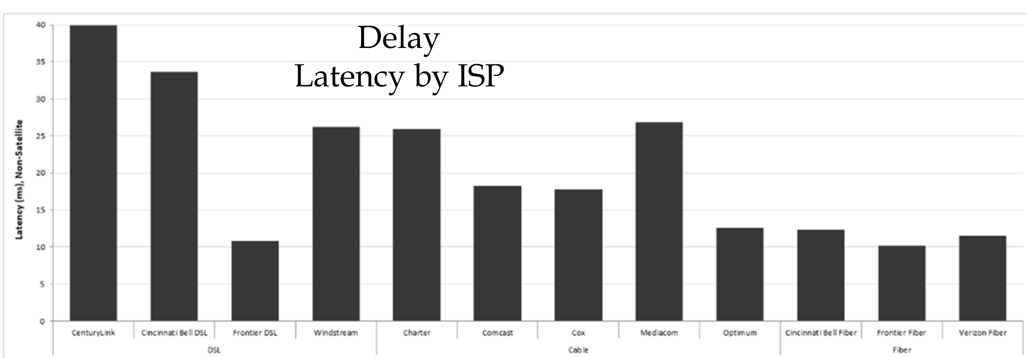
What happens when you lose your gamble:
- Packet Loss
- Delay

See the current Internet performance @ https://www.fcc.gov/reports-research/reports/measuring-broadband-america/measuring-fixed-broadband-tenth-report

Issues in Networking: Sharing

What happens when you lose your gamble:
- Packet Loss
- Delay

From: Tenth Measuring Broadband America Fixed Broadband Report
A Report on Consumer Fixed Broadband Performance in the United States, FCC, January 2021
https://www.fcc.gov/reports-research/reports/measuring-broadband-america/measuring-fixed-broadband-tenth-report#_Toc52871202

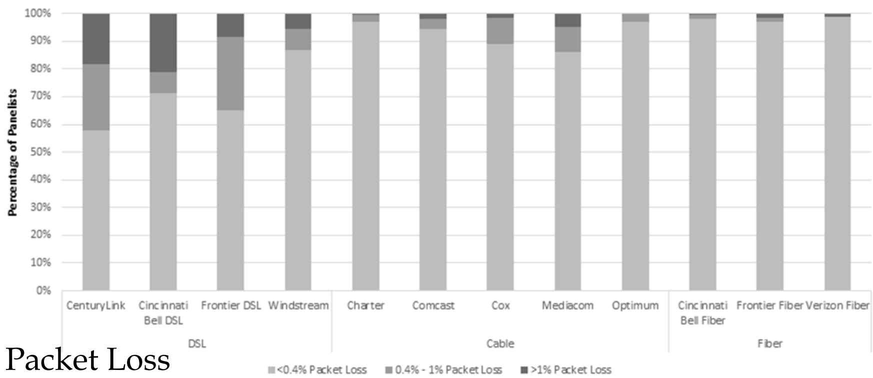


From: https://www.fcc.gov/reports-research/reports/measuring-broadband-america/measuring-fixed-broadband-eighth-report

Issues in Networking: Sharing

What happens when you lose your gamble:
- Packet Loss
- Delay

From: Tenth Measuring Broadband America Fixed Broadband Report
A Report on Consumer Fixed Broadband Performance in the United States, FCC, January 2021
https://www.fcc.gov/reports-research/reports/measuring-broadband-america/measuring-fixed-broadband-tenth-report#_Toc52871202



Packet Loss

From: https://www.fcc.gov/reports-research/reports/measuring-broadband-america/measuring-fixed-broadband-eighth-report

Issues in Networking: Protocols

Human protocols:
- "what's the time?"
- "I have a question"
- introductions

… specific messages sent

… specific actions taken when message received, or other events

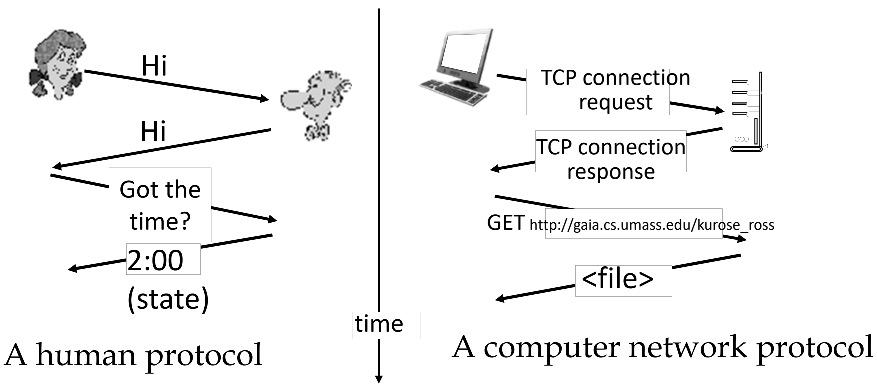
Network protocols:
- computers (devices) rather than humans
- all communication activity in Internet governed by protocols

Protocols define the format, order of messages sent and received among network entities, and actions taken on message transmission, receipt

Modified from: 8th edition Jim Kurose, Keith Ross Pearson, 2020

What’s a protocol?

A human protocol and a computer network protocol:



Issues in Networking: Protocols

- Protocols are the rules, implemented as algorithms, that govern the interactions between network elements, e.g.,
  - Routing
  - Media Access
  - Resource Allocation
- Protocols (algorithms) implemented software or hardware
- Protocols must run in “real time”
  - Assume R = 40 Gb/s and L = 1500 Bytes
    - Router must process a packet in 0.3 μs

Issues in Networking: Protocols

- Peer protocols (geographically distributed)
  - Executed at both ends of the connection
  - Run on geographically distributed network elements
  - Use memory to save state
  - Packet events (arrival) to change state based on data in packet headers
  - Packets arrive asynchronously
- Protocols must work with inaccurate or imperfect knowledge
  - Packets are lost due to bit errors or traffic congestion
  - Instantaneous demands for network resources are unknown
  - Out-of date information due to queueing and finite propagation delay
- Protocols must be standardized

Issues in Networking: Privacy and Security

- Field of network security:
  - how bad guys can attack computer networks
  - how we can defend networks against attacks
  - how to design architectures that are immune to attacks
- Internet not originally designed with (much) security in mind
  - *original vision:* "a group of mutually trusting users attached to a transparent network" ☺
  - Internet protocol designers playing "catch-up"
  - security considerations in all layers!

Modified from: 8th edition Jim Kurose, Keith Ross Pearson, 2020

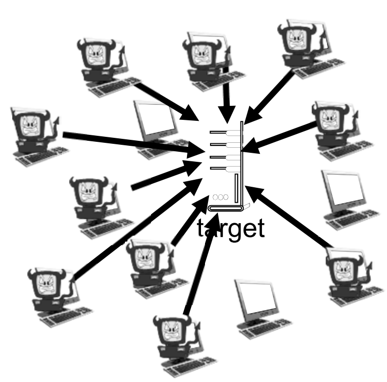
Issues in Networking: Privacy and Security

- malware can get in host from:
  - *virus:* self-replicating infection by receiving/executing object (e.g., e-mail attachment)
  - *worm:* self-replicating infection by passively receiving object that gets itself executed
- spyware malware can record keystrokes, web sites visited, upload info to collection site
- infected host can be enrolled in botnet, used for spam or distributed denial of service (DoS) attacks

Issues in Networking: Privacy and Security

Denial of Service (DoS): attackers make resources (server, bandwidth) unavailable to legitimate traffic by overwhelming resource with bogus traffic

1. select target
2. break into hosts around the network (see botnet)
3. send packets to target from compromised hosts

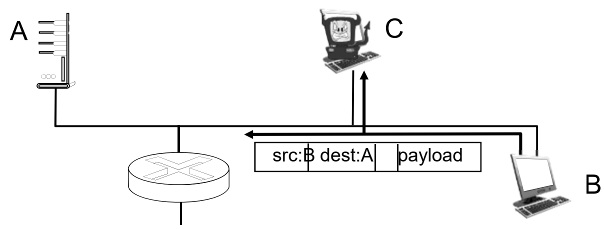


Oct. 10, 2023
"Google Cloud was hit by the largest DDoS attack in history this past August, with the digital onslaught peaking at an unprecedented 398 million requests per second (RPS)."
See: https://www.zdnet.com/article/google-cloud-aws-and-cloudflare-report-largest-ddos-attacks-ever/

Issues in Networking: Privacy and Security

Packet "sniffing": Interception

- broadcast media (shared Ethernet, wireless)
- promiscuous network interface reads/records all packets (e.g., including passwords!) passing by

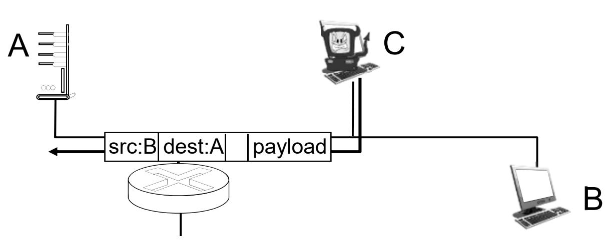


Wireshark software used for our two projects

Issues in Networking: Privacy and Security

Impersonation:

Example IP spoofing: send packet with false source address



Network Security will be covered later:

- Encryption
- Authentication
- Message integrity
- Key distribution & Certificates
- Secure Socket Layer (SSL)
- IPsec

Issues in Networking: Survivability/Resilience

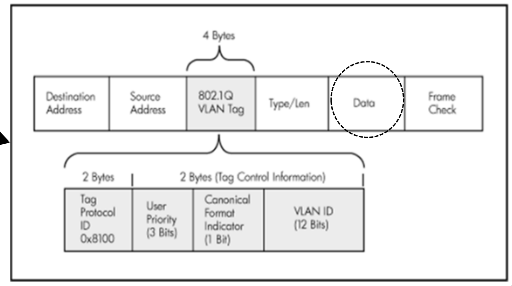
- FIBER CUT
  - Jan., 4, 1991 - New York metro area
    - 6 million homes without long-distance service
    - New York Mercantile Exchange and New York Commodity Exchange shut down
    - Fiber cuts are common
- Survivability - SS7 FAILURE
  - June, 10, 1991 - California 2 million homes without phone service
  - June, 26, 1991 – Baltimore-10 million homes in 4 states without service & U.S. government phones affected
- Survivability-SWITCH and POWER FAILURE
  - September, 17, 1991 - New York metro area
    - 2 million homes without long-distance service
    - 3 major New York airports close for 6 hours
- Facebook Outage
  - October 5, 2021
  - Six hours outage of Facebook, WhatsApp and Instagram
  - DNS issue
- More……

Issues in Networking:

- Routing → finding path from source to destination
- Addressing (naming & identifiers)
- Resource Allocation
  - Call admission control (CAC)
  - Congestion control
  - Flow control
- Time scales: Control of network resources at time scales ranging from ~10^{-10} sec to months
- Management, e.g.,
  - ISP need to add/delete users
  - Carriers/ISPs need to add/delete and administer their equipment
- Need for cooperation among competing companies

Issues in Networks

- Specific Protocols and Acronyms
  - E.g., TDM, FDM, IP, TCP, ARP, DNS, DHCP, ICMP, IPv6…..
- Boxes (Network Elements-NEs)
  - E.g., Router, switch, repeater, firewalls, "middleboxes", headend, base station, user equipment (UE)
- Header Formats….
- Tools,
  - E.g., Ping, traceroute, wireshark,….



Modified from Jennifer Rexford, "The Networking Philosopher's Problem", http://www.cs.princeton.edu/~jrex/talks/conext-student10.ppt

Networks

- Real time distributed systems
- Owned by different companies, governments, agencies, enterprises…..
- Must meet constraints, e.g.,
  - Quality of Experience (QoE)
  - Security
  - Privacy
- Large scale, e.g.,
  - Geographic
  - Number of devices (Internet of Things)
  - Range of data rates
- Must cope with a wide variety of impairments
- Must cope with imperfect knowledge