ECE 1150: Computer Networks

Technology Milestones,
Circuit Switching & Packet Switching

Mai Abdelhakim, PhD

ECE Department

Swanson School of Engineering

University of Pittsburgh

Key takeaways from previous units

- Numerous applications
- Abstract model: Network is composed of devices and links
- Based on direction of communications, network can be
  - Simplex, half duplex, full duplex
- Networks can be classified based on geographical coverage
  - PAN, LAN, MAN, WAN
- Network has a topology, which defines how devices are connected
  - Star, tree, mesh, ring

Objectives of This unit

- Intro to performance metrics
- Technology milestones

Value of Communications Systems

- Depends on context / objective
  - Depends on function

- Depends on performance
  - How to measure the performance?

What are the Elements of Performance in Networks?

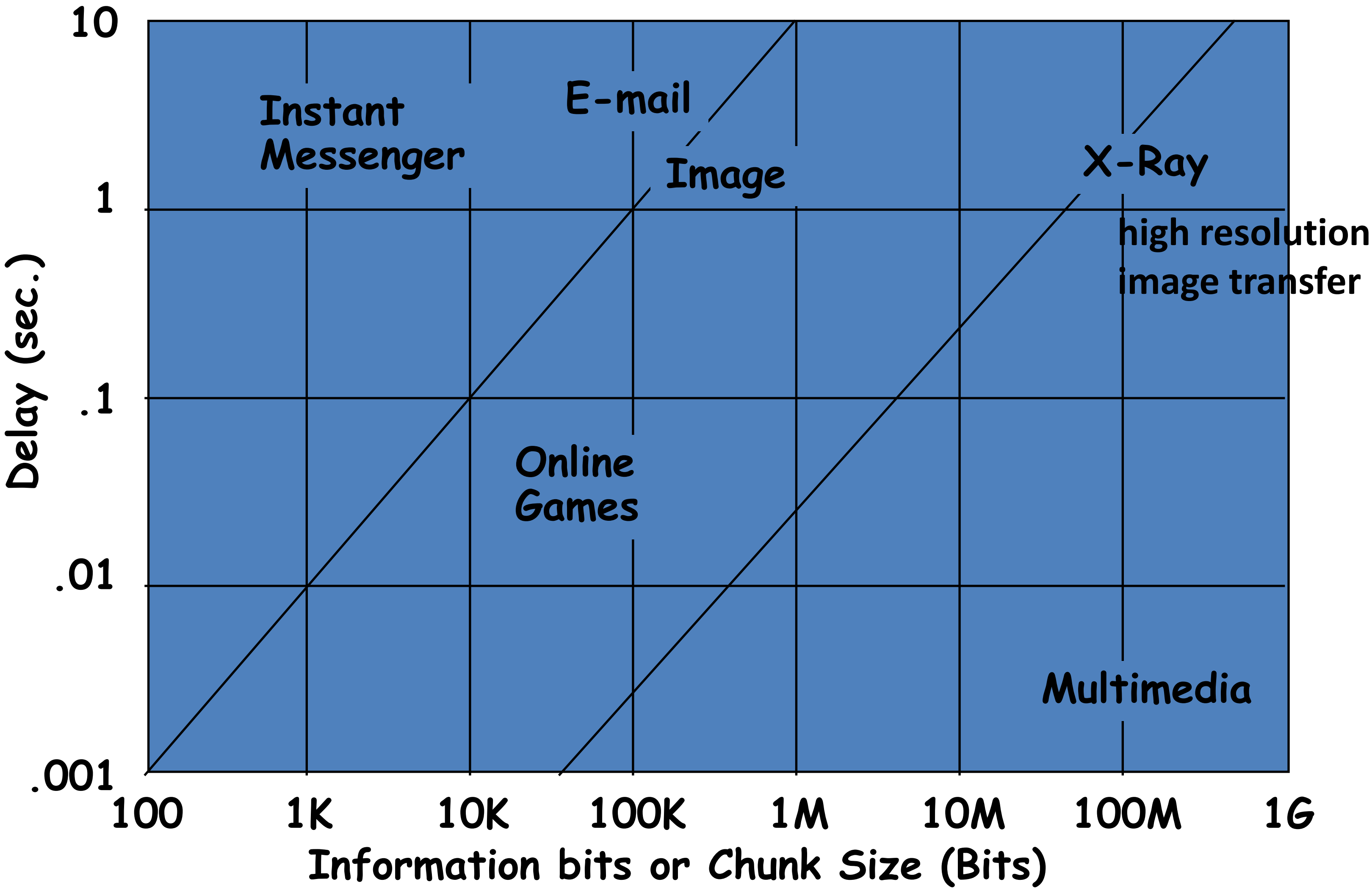
- **Delay**: response time, latency (seconds)
- **Jitter**: variations in delay
- **Speed**: Bit rate, throughput (bits per second)
- **Power consumption**
- **Accuracy**: error rate (ratio, percentage)
- **Dependability**: Reliability and security

Performance

Performance **requirements depend on application**:

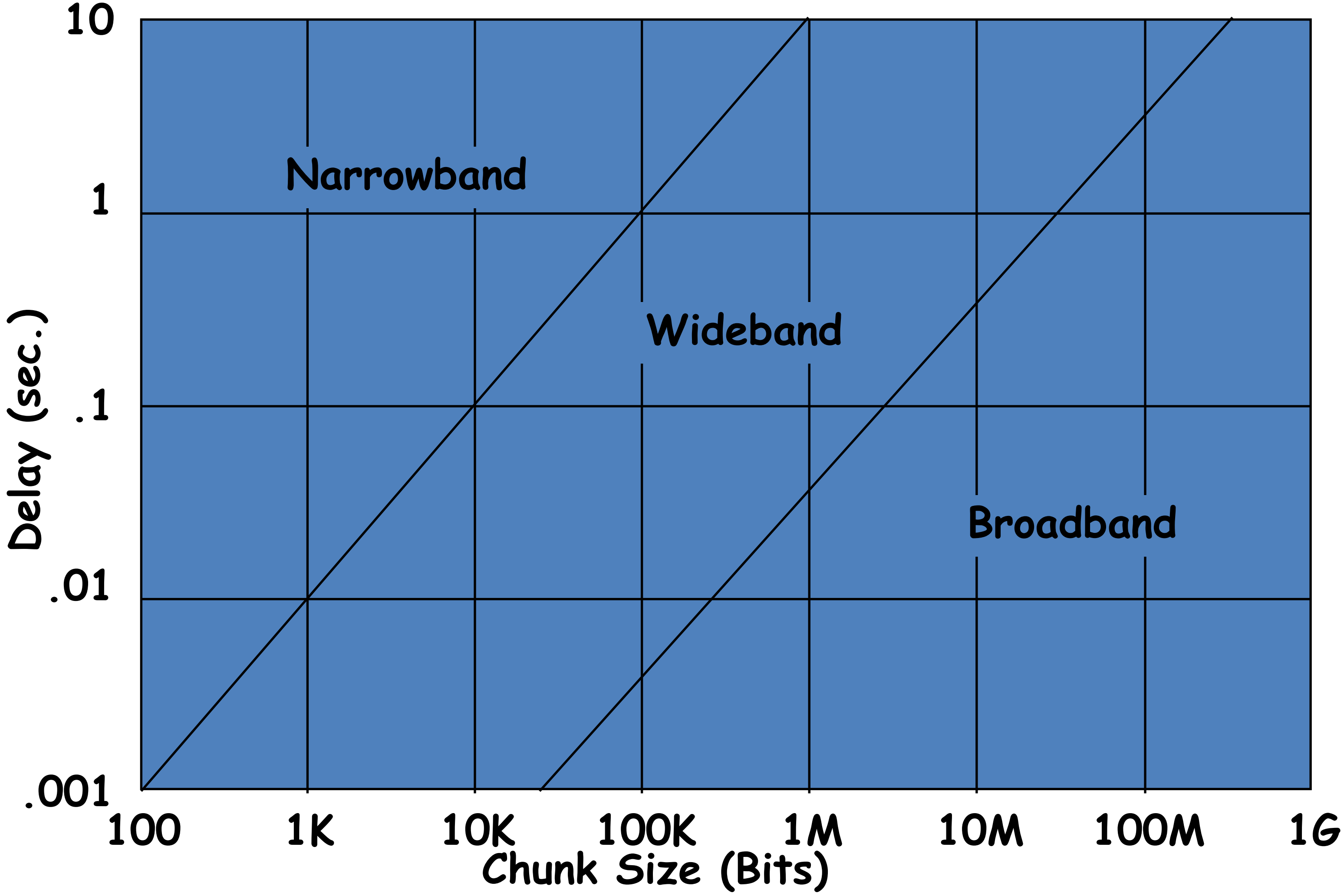
- (Tophat) **Q_Performance**
  Voice calls: low errors or less delay is more important?

Delay vs. Data Chunk Size



Delay vs. Data Chunk Size

Based on the data rate, transmissions can be classified into **narrowband, wideband, broadband**



Milestones in Networks

- Telegraph
- Circuit switching
- Packet switching

Telegraph infrastructure

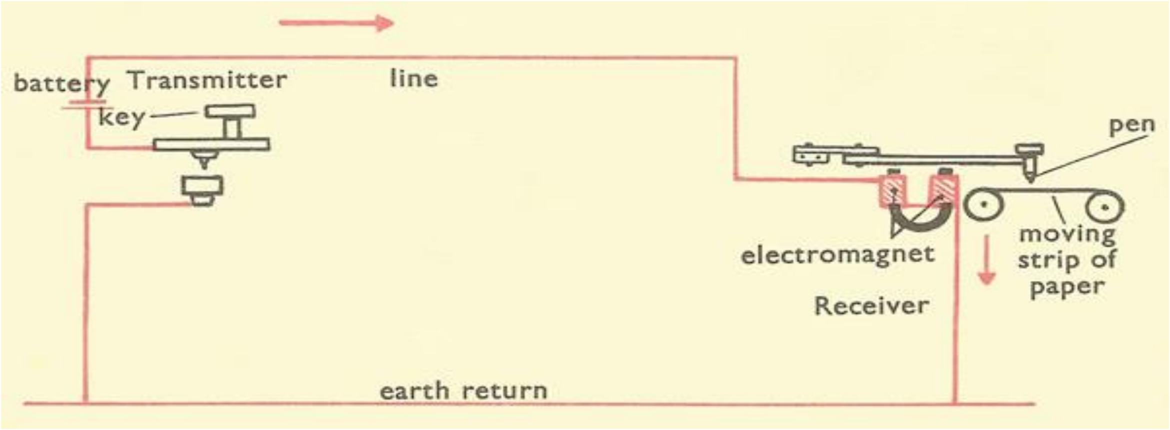
- Telegraph is one of the earliest instances of networks
  - Patented in the United States in 1840 by Samuel F. B. Morse
- Information carried as electrical signals over wires
- Early infrastructure
  - Vail's finger key

  - Morse Register

Technology Milestones – Telegraph

- Transmitter: Connect and release a switch to send data

- Receiver: electromagnet, pull a marker to draw a line on a paper

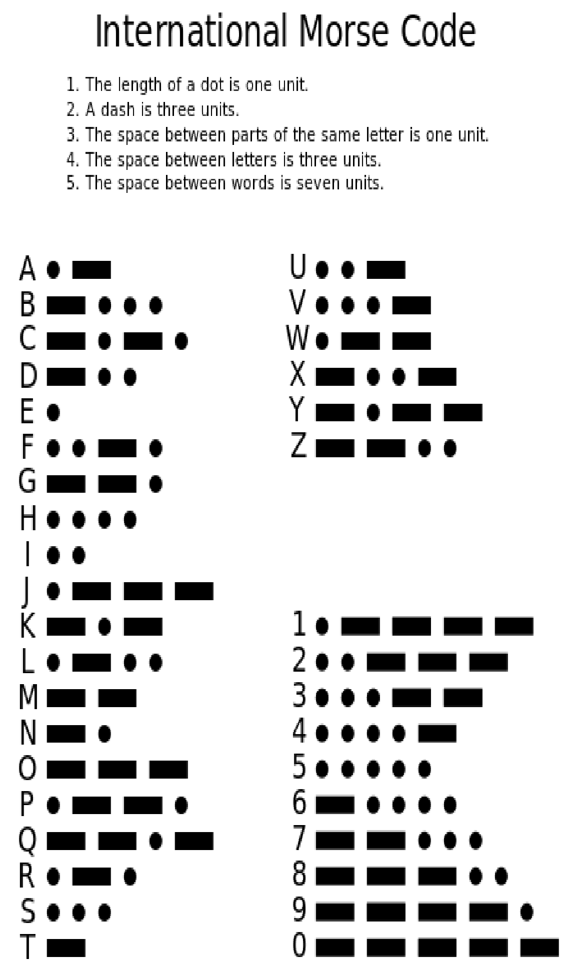


How can information be exchanged?

Technology Milestones – Telegraph Morse Code

- Morse code is combination of dots & dashes that represent the alphabet

  example: a = • –

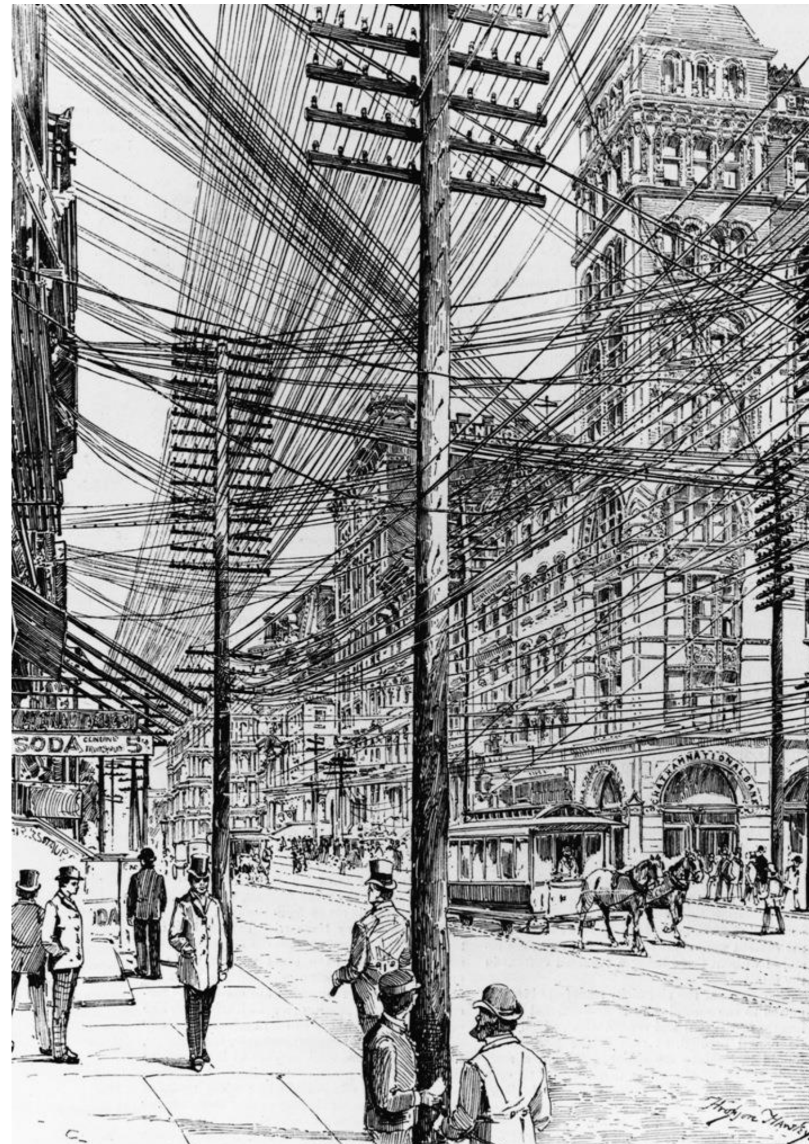


Technology Milestones – Telegraph (3)

- Relevance to modern networks:
  - **Information** is carried as **energy on a medium** between Tx and Rx
  - There is an **agreed upon pattern** between the transmitter and receiver
    - Today, instead of dots & dashes we use ‘0’ & ‘1’.

Slide modified from Agrawal

NYC around 1900,
Each cable enable one telephone connection

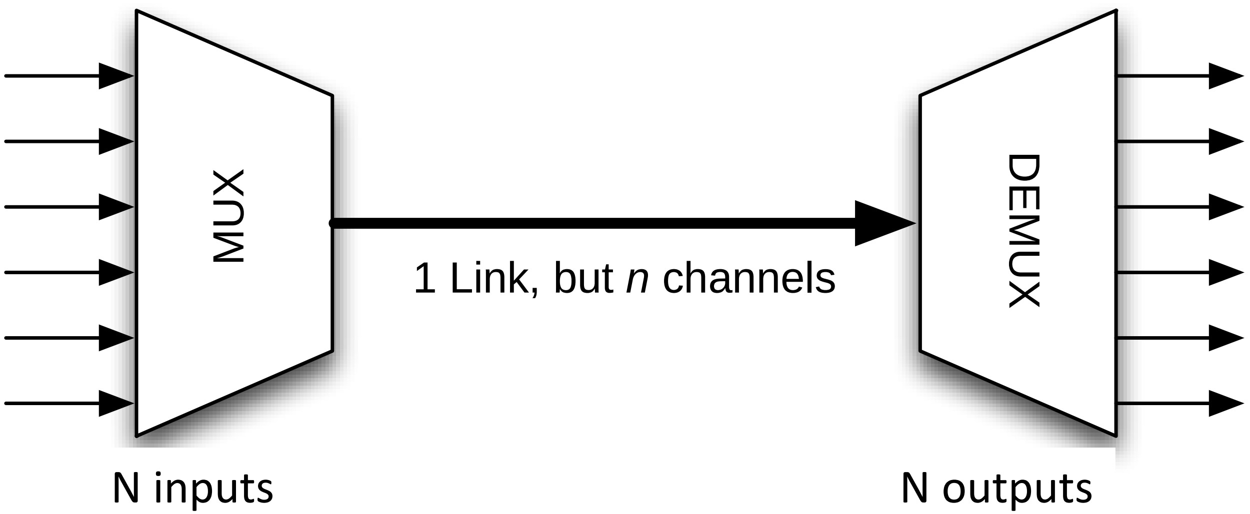


- Telegraph enabled long distance communications over a wire,
  - but it **can send only one message** at a time

Technology Milestones – Multiplexing

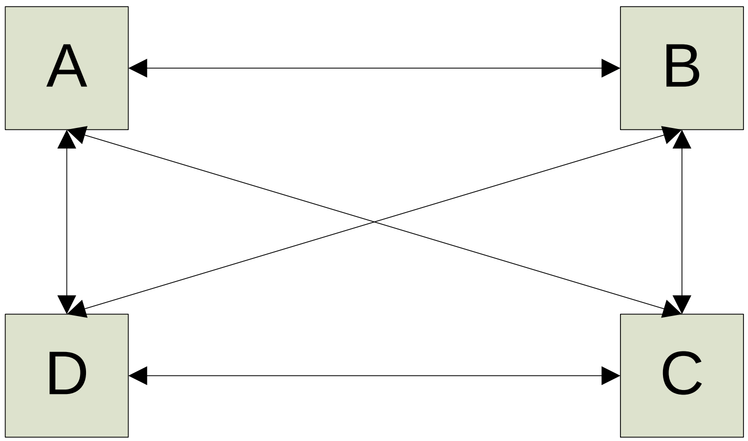
- **Enables sending more** **than one message over the same link** (wire)
  - Patented in 1874, by Thomas Edison (**Quadruplex telegraph** , 4 messages)
- **Without multiplexing:**
  - You would be able to **listen to only one radio station** at a time in your location (cannot change it)
  - Need **a cable for each TV channel**
    - Imagine laying 200 cables to support 200 TV channels
- **With multiplexing:**
  - Single cable for all TV channels

Multiplexing



Technology Milestones – Circuit Switching

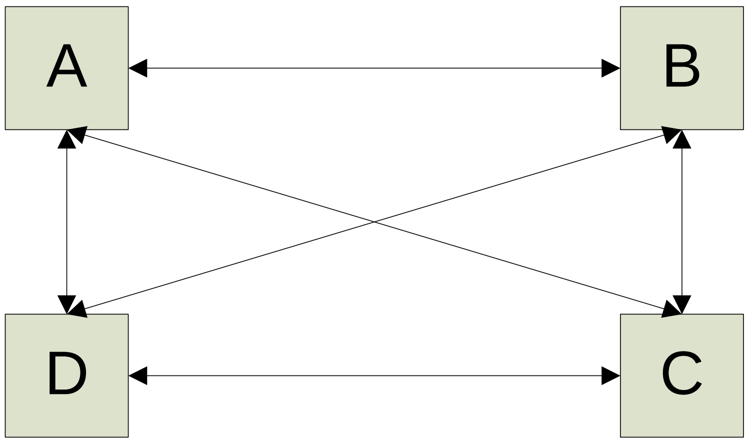
- **One wire** can connect **to multiple destinations** (patented in 1891, Strowger)
- Switch: connect different locations on as-needed basis



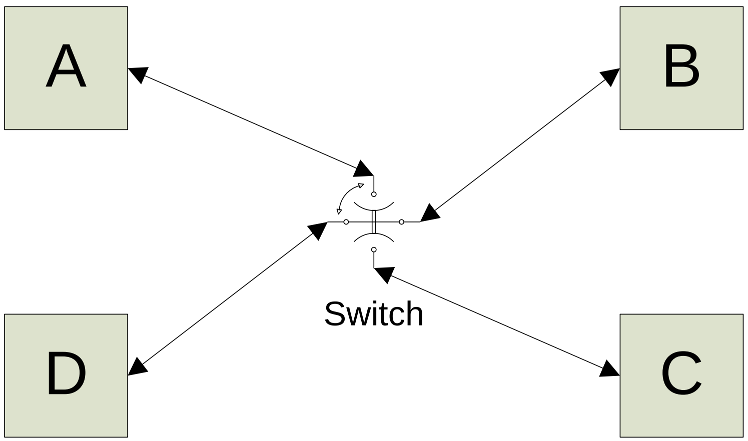
6 wires needed without a switch

Technology Milestones – Circuit Switching

- **One wire** can connect **to multiple destinations** (patented in 1891, Strowger)
- Switch: connect different locations on as-needed basis
- Reduce cabling

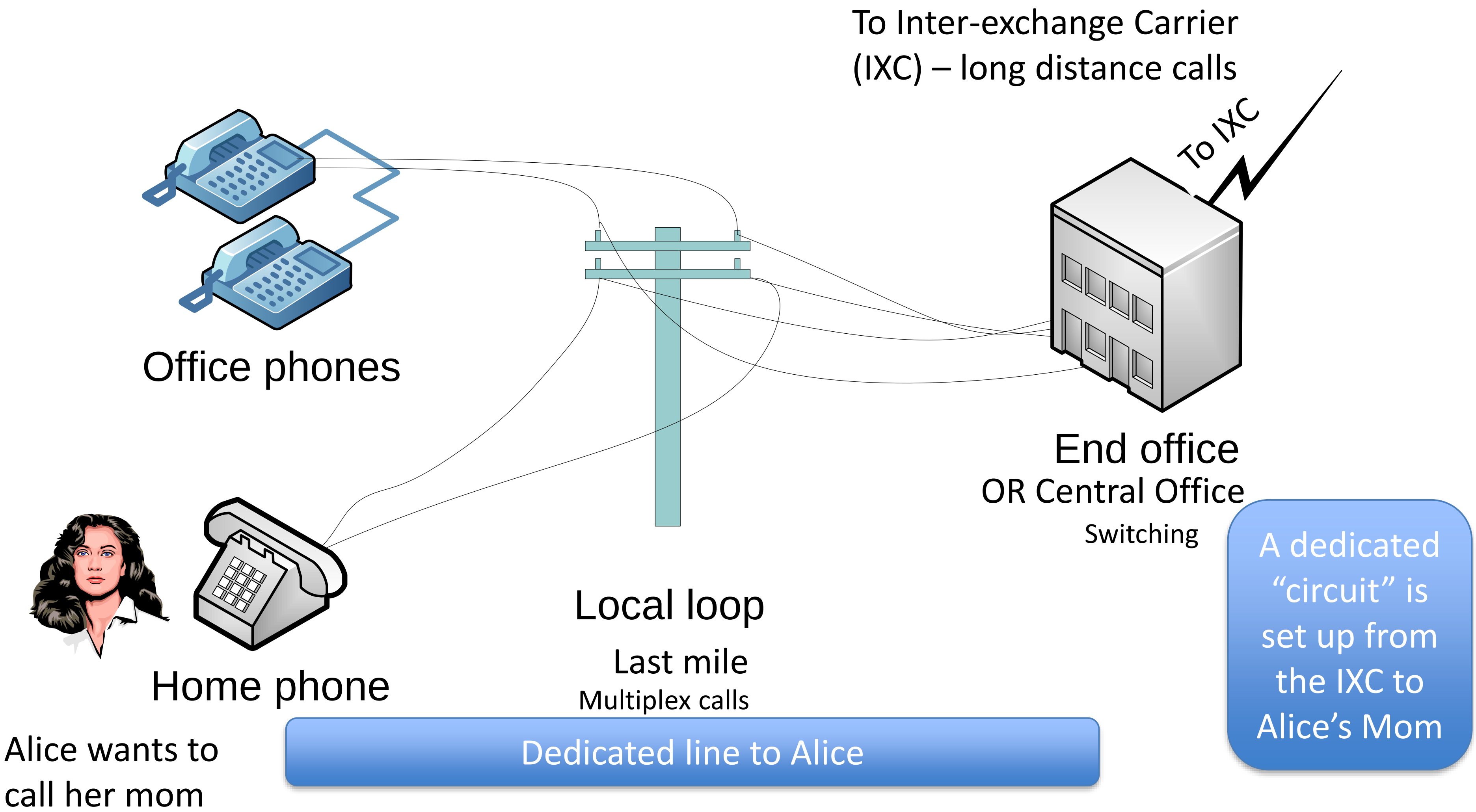


6 wires needed without a switch



4 wires needed with a switch

Telegraph, multiplexing and circuit switching led to the development of phone networks



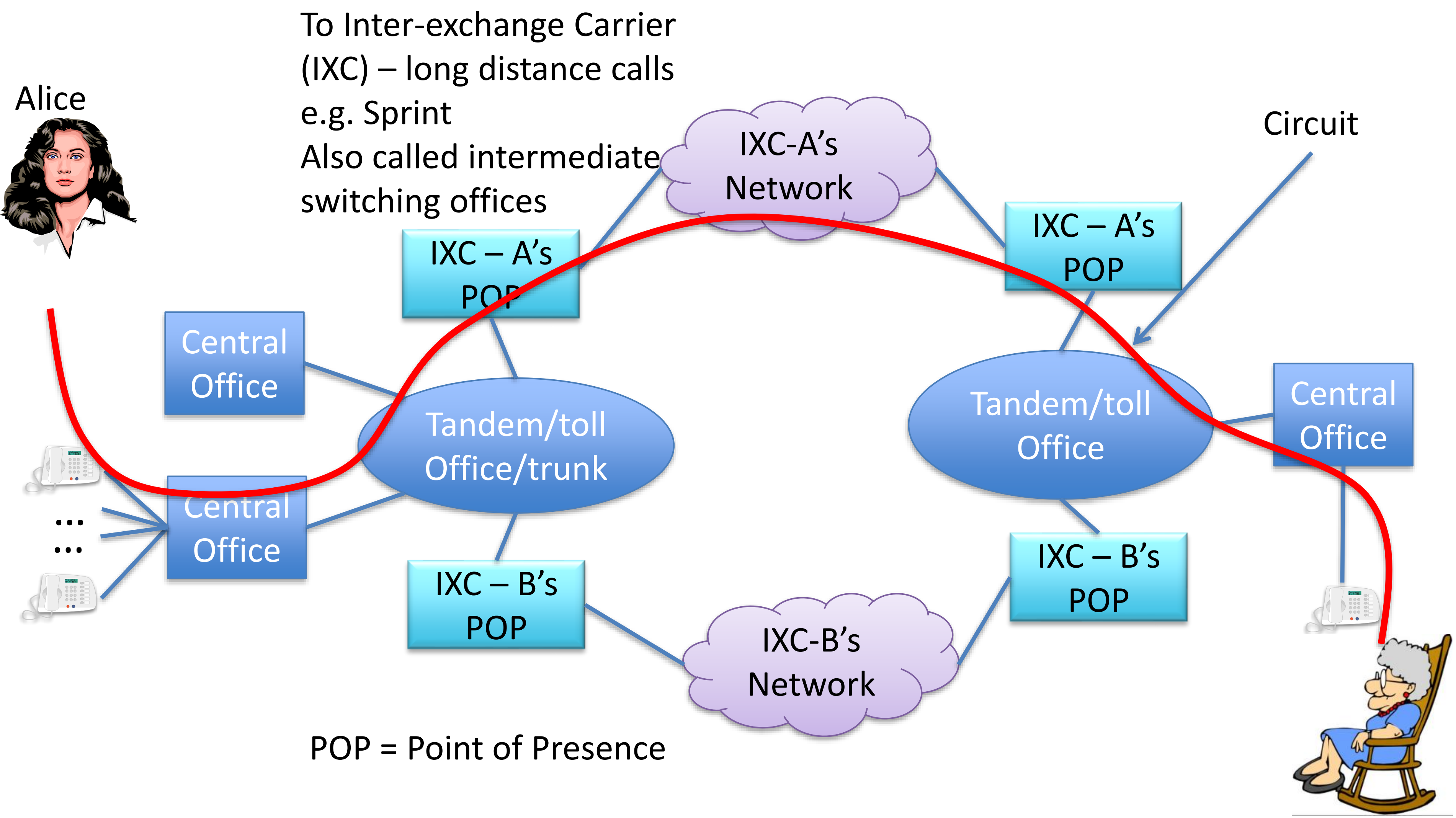
Circuit Switching

- **Circuit Establishment:** Prior to communications, the "network" establishes the circuit

- The circuit **reserves** **resources**
  - Bandwidth (time slots, frequency chunks) (details later)

- **"Resources" are** **dedicated** until connection is **terminated**

Circuit Switched Voice Call (simplified)



As if there is an **exclusive "wire" between phones**

Voice Call on Landline

- The “trunk” **“multiplexes” many voice calls**
  - Trunk between central office and other switching offices. Analogy: many pieces of mail and packages to the same state being flown over a plane

- You **terminate the connection to release resource** and it can go to someone else

- Circuit switched networks typically **bill by the minute**

Circuit Switching Performance

- Performance (e.g. delay) predictability?
- Tophat: **Q_CircuitSwitching**

Circuit switching

In circuit switching, after a circuit is established, the performance is

A	Predictable
B	Highly unpredictable

Circuit Switching Performance

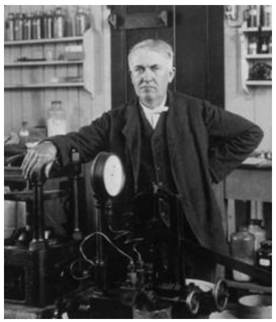
- One performance metric reflecting reliability is **“call blocking”**
  - Happens when there is no sufficient resources to establish circuits
    - Analogy: bus is full

Slide modified from Agrawal

Technologies Milestones

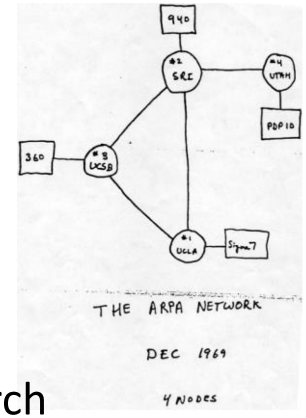
By 1972, the ARPANET comprised 37 computers

1840
Samuel Morse patents Telegraph in the U.S.



1874
Thomas Edison Invents quadruplex switch

3/10/1891
Strowger switch patented



Started by ARPA (Advanced Research Projects Agency, now DARPA) ..

Stanford Research Institute (SRI)

10/29/1969
First Internet transmission Between UCLA and SRI

ARPANET

Packet switching

Over 100 years of Circuit Switched Networks

3/7/1876
Alexandar Graham Bell
Makes first telephone call

7/20/1969
Neil Armstrong and “Buzz” Aldrin land on the moon

First packet switching transmission in 1969

- ARPA project:
  - First packet transmission occurred on Oct 29, 1969, in California Between SRI and UCLA

Milestones – Packet Switching

- **Limitation of circuit switching**
  - Typically cannot communicate with more than **one receiver** at the same time
  - **Resources wasted ..**
    - Since they are reserved for connection (even if it is not used) until connection is terminated -- **Not scalable**
- **Packet switching** is used in computer networks

Browsing Amazon.com

Boots her computer and

Opens browser

Browser is called the “**client**” **software**

Alice

Types

http://www.amazon.com

“www.amazon.com” is the identity of “**server**”(s)

Browser “loads” page

Always on!

Questions

- How does the browser know **what** and **where** amazon.com is?
- How does request reach amazon server?
- What if Alice is also **browsing pitt.edu at the "same" time she is browsing amazon**?
- How does the browser know if it has received the elements of the html **page correctly**?

Questions

- How does the browser know **what** and **where** amazon.com is?
  - **Addressing**
- How does request reach amazon server?
  - **Routing & protocols**
- What if Alice is also **browsing pitt.edu at the “same” time she is browsing amazon**?
  - **Multiplexing of applications**
- How does the browser know if it has received the elements of the html **page correctly**?
  - **Error control**

Analogy to Sending a Greeting Card (1)

Alice wishes to send a greeting card to grandma

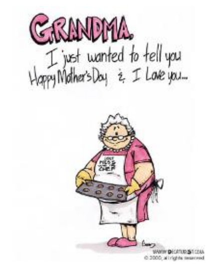
Analogy to computer network:

Alice

Goes to store, gets card

Computer

Writes card for Grandma



Prepare information

Calls Mom for address!

DNS

Fixes stamp, Drives

Mails card

Send to OS

Sending a Greeting Card (2)

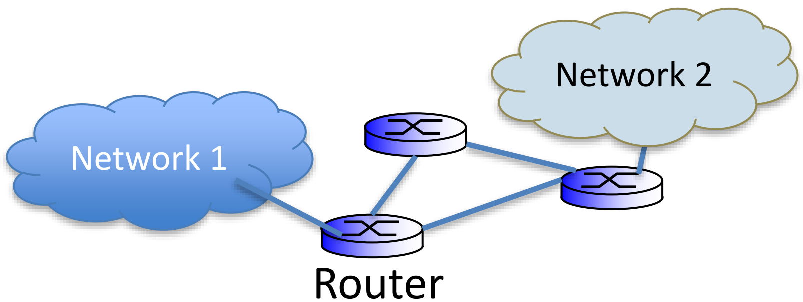
- Truck **picks up** the mail from mail box & mail goes to "**sorting facility**"
  - Mail to the same zip code go together (**multiplexed)**
- Mail is sorted by **route** and delivered
- In computer system: **addressing & routing**

Things to note

- Performance metric is
  - Delay
    - Analogy: Delayed Christmas deliveries
- **Bottleneck** due to **limited capacity** or other reasons
  - Analogy: Weather, trucks, flights, people
- What if you need to send many items? Some are bulky?

Packet Switching

- **Information are in “addressed” packets**
- **Routing data** based on address in packets
- **Packet switches** are called **routers**
  - Routers are devices used to interconnect two or more networks



Slide modified from Agrawal

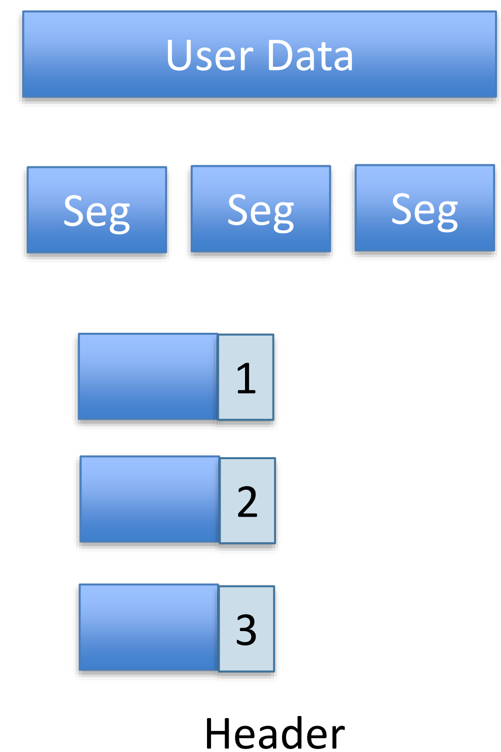
Packetization --Analogy in retail

- Large items are broken down into smaller kits to easily ship/transport them

Slide modified from Agrawal

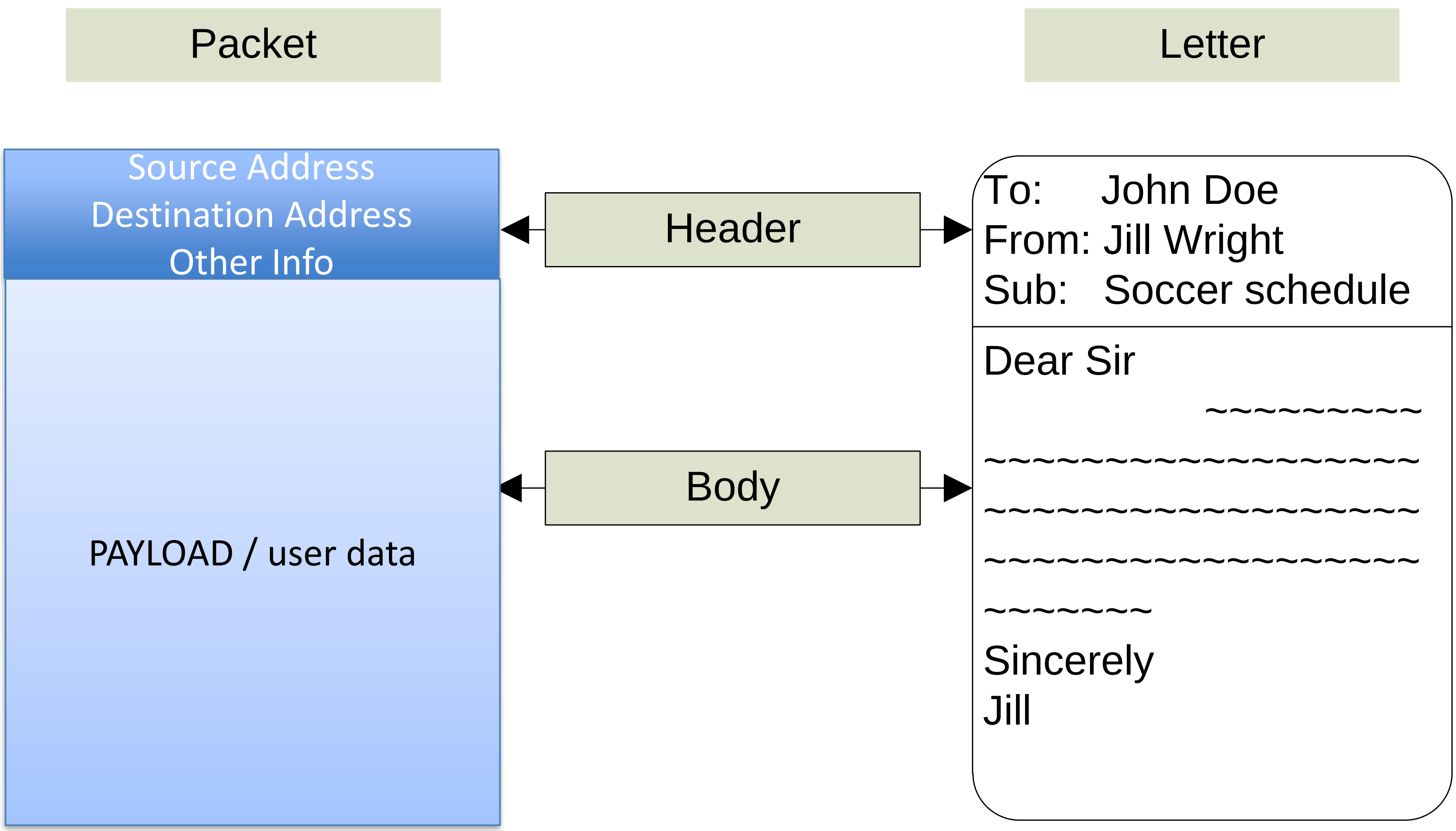
Packetization overview

- **Packetization** is
  - Breaking down user data into **small segments**
- Each packet has **two parts**
  - **Data** to be delivered
  - “**Overhead**” required for successful **delivery** and **integration** with other packets



Slide modified from Agrawal

Packets Analogy



Advantages of Packet Switching

- Allow you to **connect with multiple devices**:
  - E.g. At the same time access information from server A, download music from server C, while chatting

Advantages of Packet Switching

- Network **resources** are allocated **as needed**
  - In packet switching “Channel” is **occupied only during the transmission of the packet**

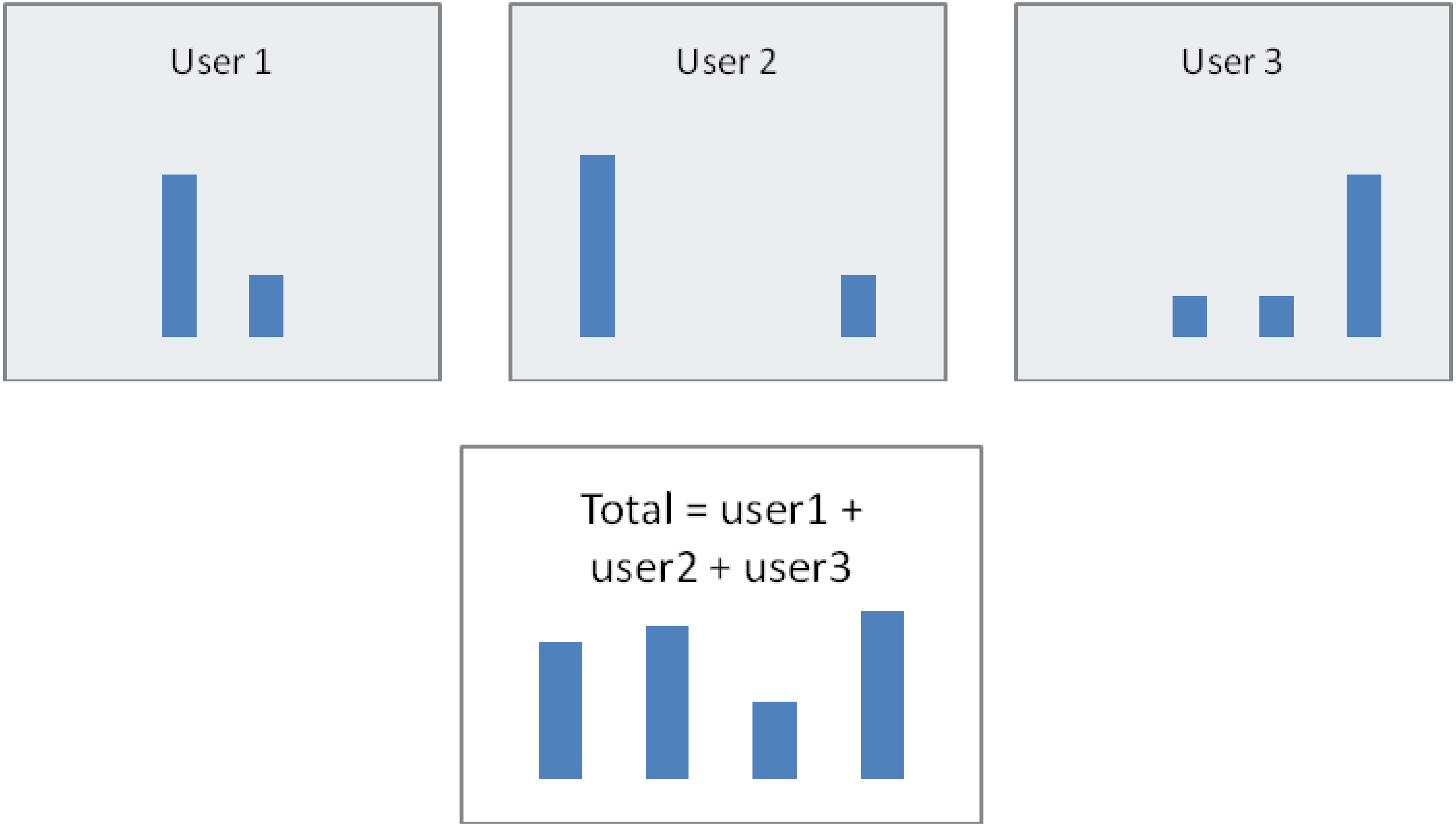
- Packet switching improves **link utilization**
  - No resource waste like in circuit switching
  - Packet switching is 3-100 times more efficient than circuit switching

Why Packet Switching Is better Suited for Internet?

- **Bursty traffic**
  - short periods of **large volume** of data downloaded or uploaded, **followed by idle** periods of minimal activity
    - Browsing behavior: download a page (burst of data) then idle time to read it (no data sent or received)

- **Traffic aggregation**
  - Packet switching aggregates network data traffic

Traffic Aggregation



Why Packet Switching is Reliable?

- Packet switches are called **routers**
  - Routers connect two or more networks
  - Routers locate other routers close to destination

- **Mesh** topology in backbone improves **reliability**
  - If one router failed, another router serves
  - Note in circuit switching, if a link or switch failed, the call is dropped.

Packet Switching vs. Circuit Switching

- **No connection set-up and tear-down** in packet switching

- Packet switched networks typically **bill by MB** (Mega Byte)
  - Instead of by minutes as in circuit switching

Q_switching

Dial a number and wait for an answer, this is

A	Circuit switching
B	Packet switching

Q_switching_2

Send a text message or an email

A	This is circuit switching
B	This is packet switching

The Network Core

- Mesh of interconnected routers or switches
- The fundamental question: how is data transferred through net?

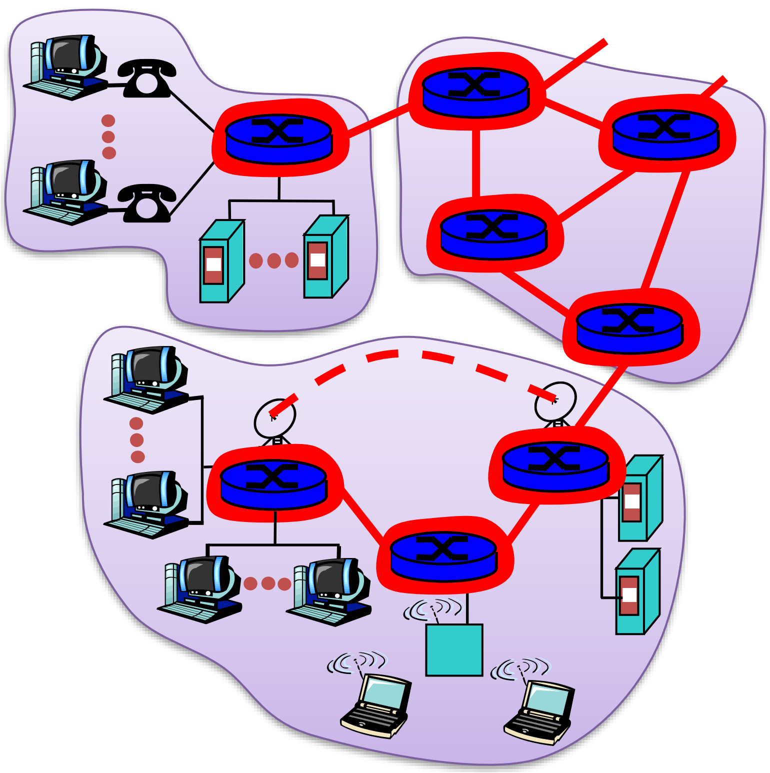


Figure from Kurose & Ross

Slide modified from Agrawal

Anatomy of a web request