1. Introduction:Communication Networks and Services

Contents:

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Computer Networks & Packet Switching
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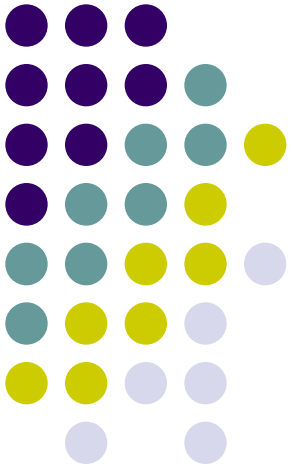
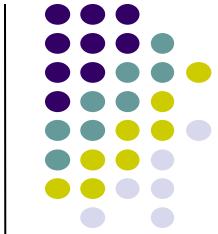
Key Factors in Network Evolution
Network Classification

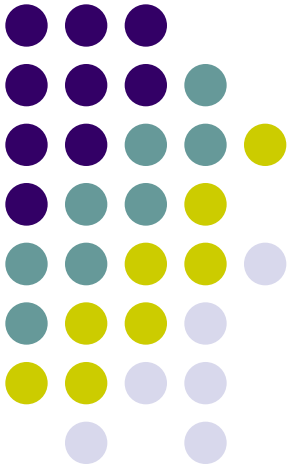


Slides are adapted from the Textbook: "Communication Networks" by Widjaja and Garcia

Introduction:Communication Networks and Services



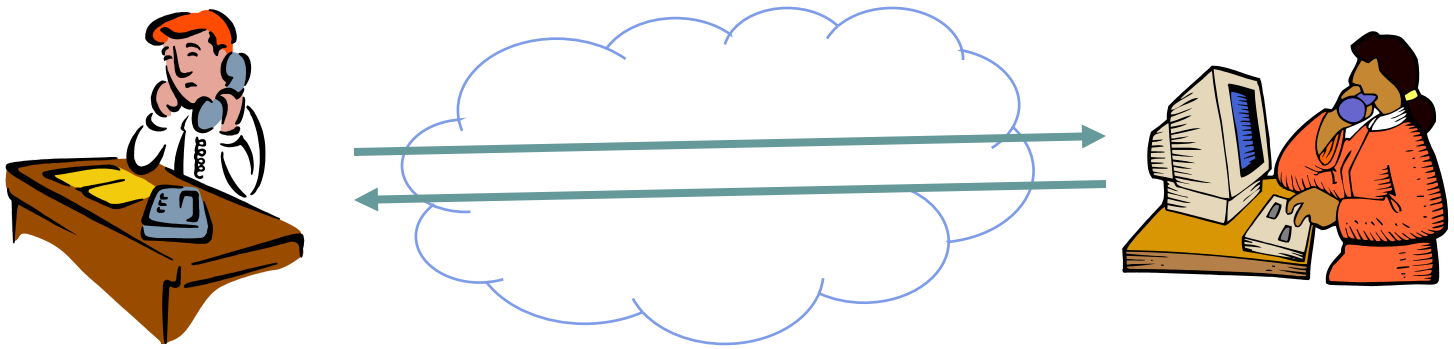
Network Architecture and Services



Communication Services & Applications

- A **communication service** enables the exchange of information between users/equipment at different locations.
- Communication services & applications are everywhere.

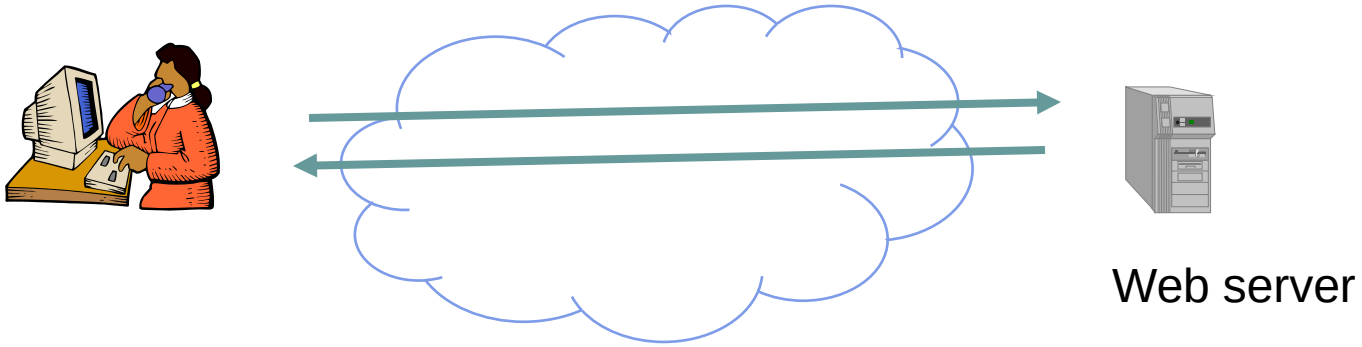
Telephone



Real-time bidirectional voice exchange

Communication Services & Applications

Web browsing / Video streaming

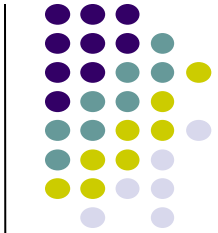


Retrieval of information from web servers

Question:

What is the main difference between these two types of applications?

Many other examples!

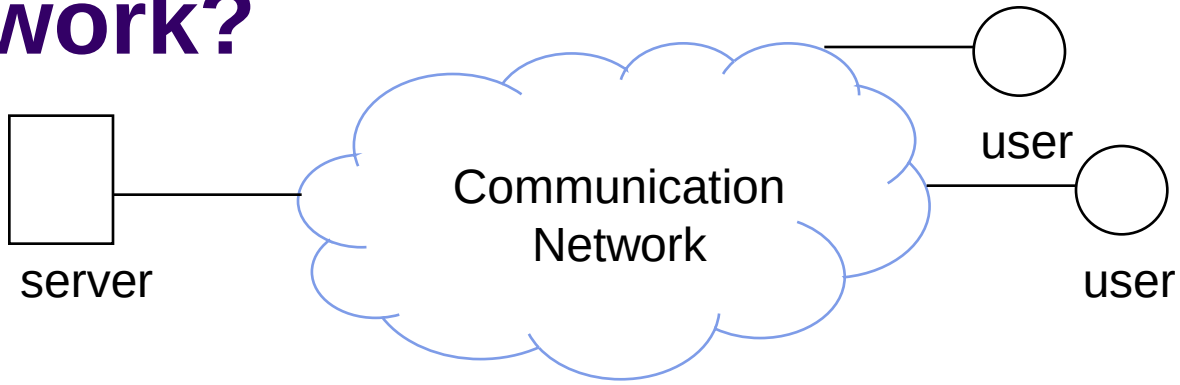


- Peer-to-peer applications
  - Bit Torrent, Napster, Gnutella, Kazaa file exchange
- Audio & video streaming
- Network games
- Text messaging in smartphones (SMS)
- Voice-over-Internet
- Social networks
  - Facebook, Twitter, …
- And many more…..

Summary: Services & Applications

- **Service**: Basic information transfer capability
  - Example: Internet reliable transfer of a stream of bytes
  - Physical layer only handles 0's and 1's.
    - Question: Where to start & stop for a stream? How do we know if error(s) occur? What if an error occurs?
- **Applications** build on communication services
  - Example: E-mail & web build on reliable stream service
  - Example: Fax and modems build on basic telephone service
- New applications may employ **combination** of services
  - Example: SMS builds on Internet reliable stream service and cellular telephone text messaging

What is a communication network?

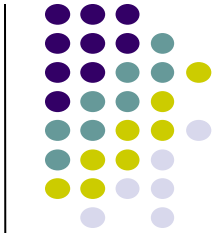


- The equipment (hardware, software) and facilities that provide the basic communication service
- Virtually invisible to the user; Usually represented by a cloud

- Equipment
  - Routers, servers, switches, multiplexers, hubs, modems, …
- Facilities
  - Copper wires, coaxial cables, optical fiber
  - Ducts, conduits, telephone poles …

How are communication networks designed and operated?

Different technologies



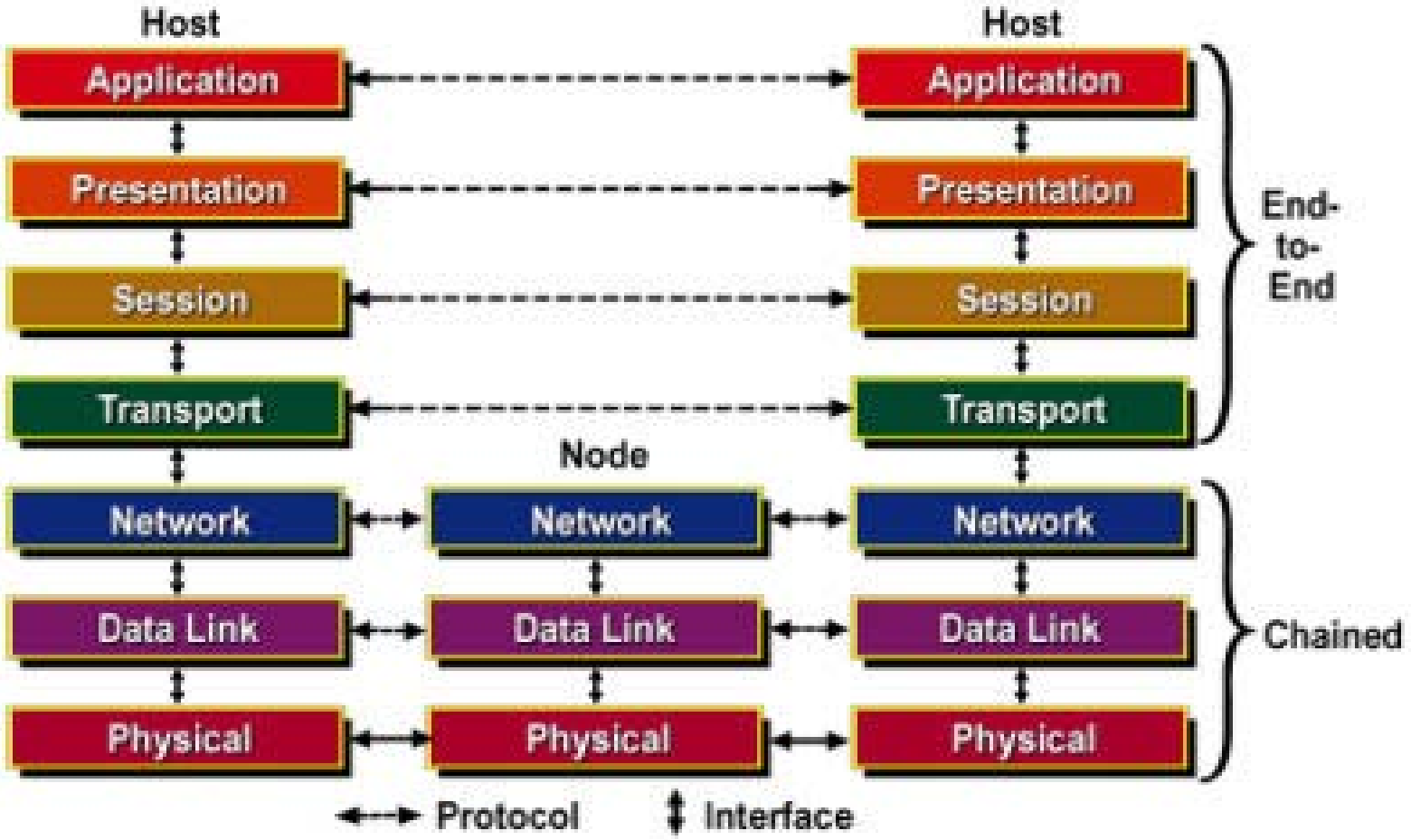
- Electrical Engineering:
  - Devices and components:
    - routers, switches, optical fiber, ….
- Communication Engineering
  - Network architecture, protocols, services
- System Engineering
  - Distributed computing: Ex, Akamai
- Software Engineering
  - Everywhere

Communication Network Architecture

- ***Network architecture:***
  - ***The plan*** that specifies how the network is built and operated
  - Architecture is driven by the network services
- Exchange of information, i.e., the communication process, is complex
  - E.g., technologies in EE, CE, SysEng, Sw Eng
- Network architecture ***partitions*** overall communication process into separate functional areas called ***layers***

Next we introduce three network architectures: telegraph, telephone, and computer networks

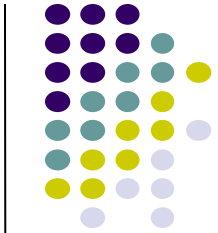
Open Systems Interconnection Reference Model (OSI RM)



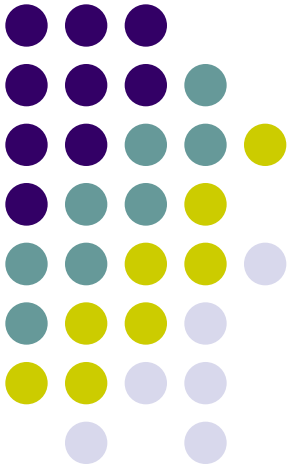
Network Architecture Evolution

- Telegraph Networks
  - Message switching & digital transmission
- Telephone Networks
  - Circuit Switching
  - Analog transmission → digital transmission
  - Mobile communications
- Internet
  - **Packet switching** & computer applications
- Next-Generation Internet (happening now)
  - Cloud networking
  - Software defined networking
  - Content-centric networking

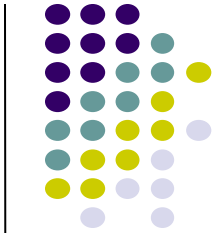
Introduction:Communication Networks and Services



Telegraph Networks & Message Switching



Telegraphs & Long-Distance Communications



Approaches to long-distance communications

- Courier: physical transport of the message
  - Messenger pigeons, pony express, FedEx
- Telegraph: message is transmitted across a network using signals
  - Drums, beacons, mirrors, smoke, flags, semaphores…
  - Electricity, light
- Telegraph delivers message much sooner

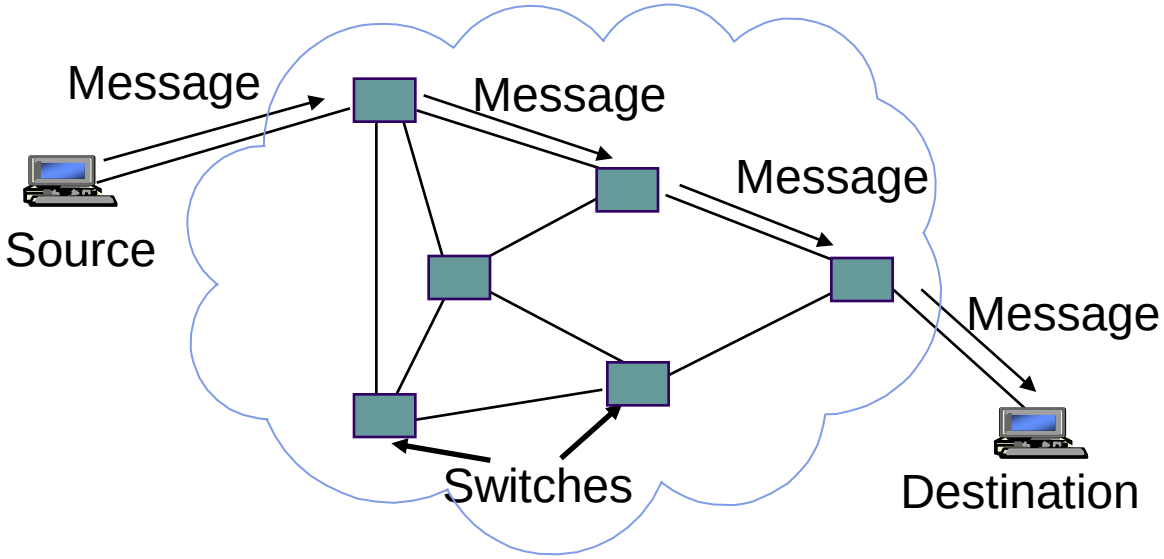
Digital Communications(1825)

- Morse code converts text message into sequence of dots and dashes (1825)
- Use transmission system designed to convey dots and dashes
- **Signal propagates at almost (2/3) the speed of light.**
  - Approximately **2×10^8** meters/second in cable

	Morse Code		Morse Code		Morse Code		Morse Code
A	· —	J	· — — —	S	· · ·	2	· · — — —
B	— · · ·	K	— · —	T	—	3	· · · — —
C	— · — ·	L	· — · ·	U	· · —	4	· · · · —
D	— · ·	M	— —	V	· · · —	5	· · · · ·
E	·	N	— ·	W	· — —	6	— · · · ·
F	· · — ·	O	— — —	X	— · · —	7	— — · · ·
G	— — ·	P	· — — ·	Y	— · — —	8	— — — · ·
H	· · · ·	Q	— — · —	Z	— — · ·	9	— — — — ·
I	· ·	R	· — ·	1	· — — — —	0	— — — — —

Electric Telegraph Networks

- Electric telegraph networks exploded
  - Message switching & Store-and-Forward operation
  - Key elements?
    - Addressing
    - Routing
    - Forwarding

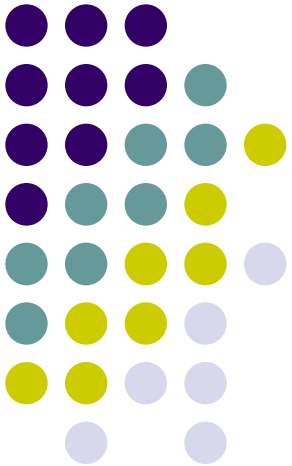


Elements of Telegraph Network Architecture

- Digital transmission
  - Text messages converted into symbols (dots/dashes, zeros/ones)
  - Transmission system designed to convey symbols
- Multiplexing
  - *Framing* is needed
- Message Switching
  - Messages contain source & destination *addresses*
  - *Store-and-Forward:* Messages forwarded hop-by-hop across network
  - *Routing* according to destination address

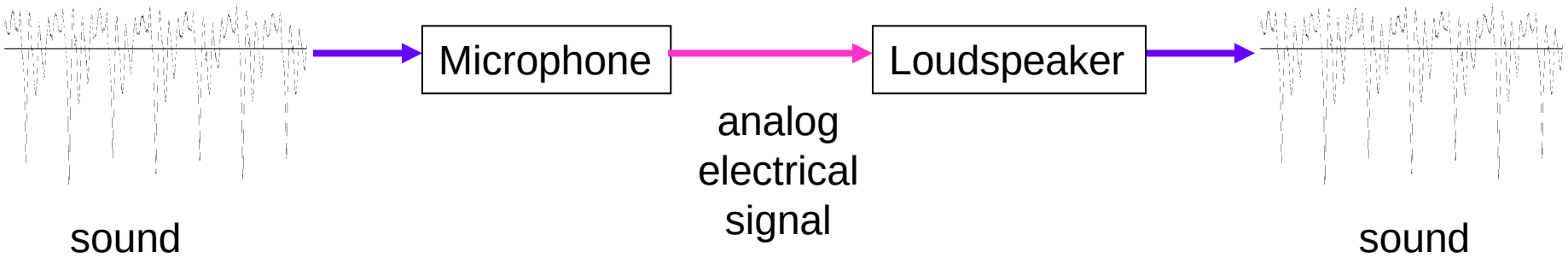
Introduction: Communication Networks and Services

Telephone Networks and Circuit Switching



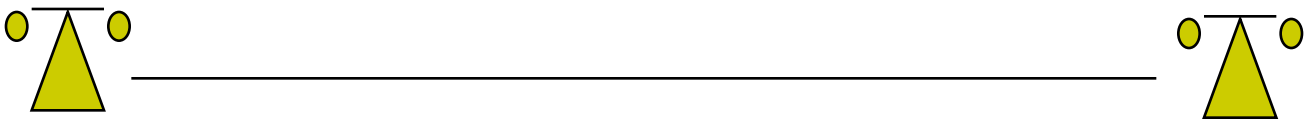
Bell's Telephone

- Alexander Graham Bell (1875) discovered voice signals can be transmitted directly
  - Bell moved to **Canada** in 1870 at age 23.
  - Microphone converts voice pressure variation (sound) into *analogous* electrical signal
  - Loudspeaker converts electrical signal back into sound
- Telephone patent granted in 1876
- Bell Telephone Company founded in 1877



Signaling

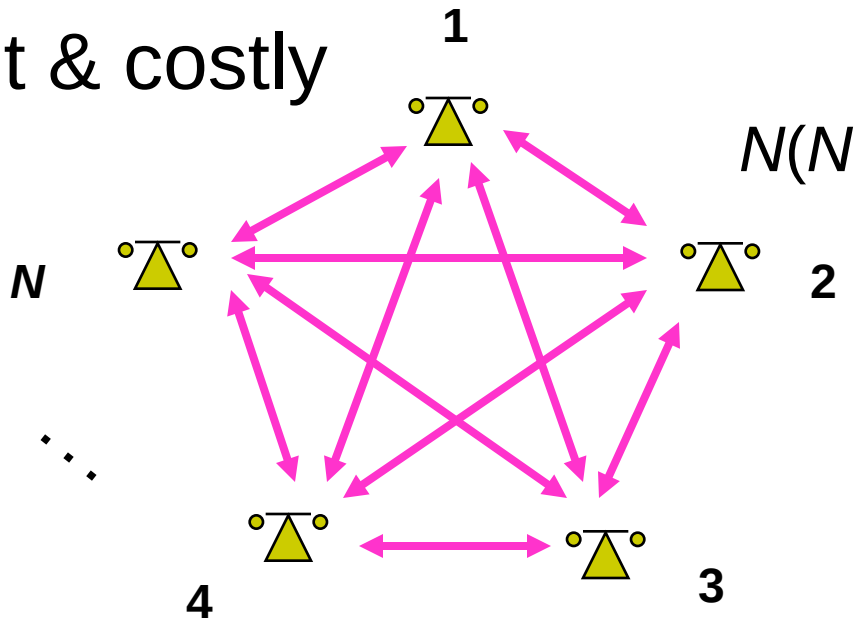
- ***Signaling*** required to establish a call
  - Flashing light and ringing devices to alert the called party of incoming call
  - Called party information to operator to establish calls



Signaling + voice signal transfer

The N^2 Problem

- For N users to be fully connected *directly*
- Requires $N(N-1)/2$ connections
- Requires too much space for cables
- Inefficient & costly

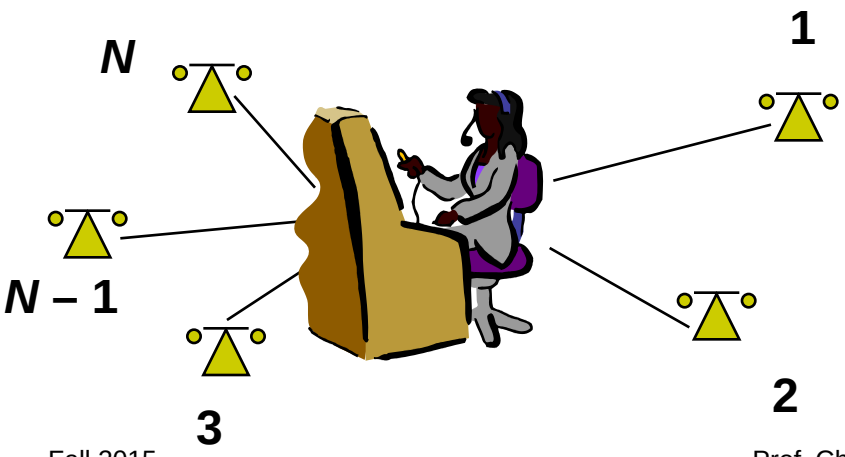


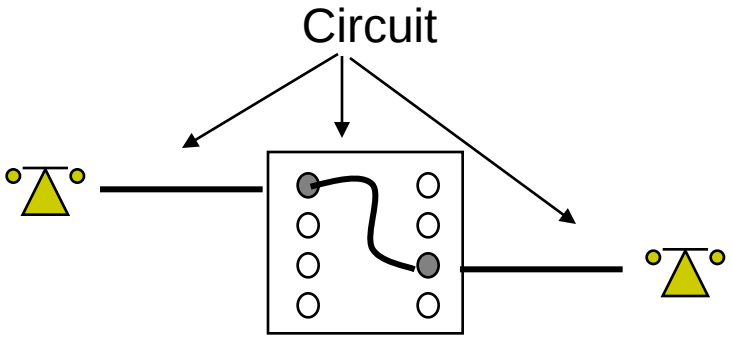
$N = 1000$

$N(N-1)/2 = 499500$

Circuit Switching

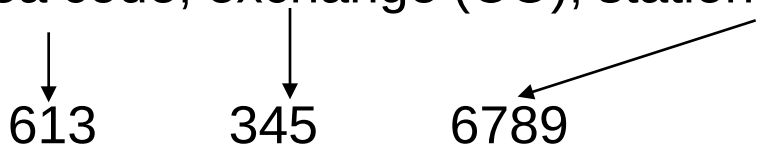
- Patchcord panel switch invented in 1877
- Operators connect users on demand
  - Establish ***circuit*** to allow electrical current to flow from inlet to outlet
- Only *N* connections required to central office





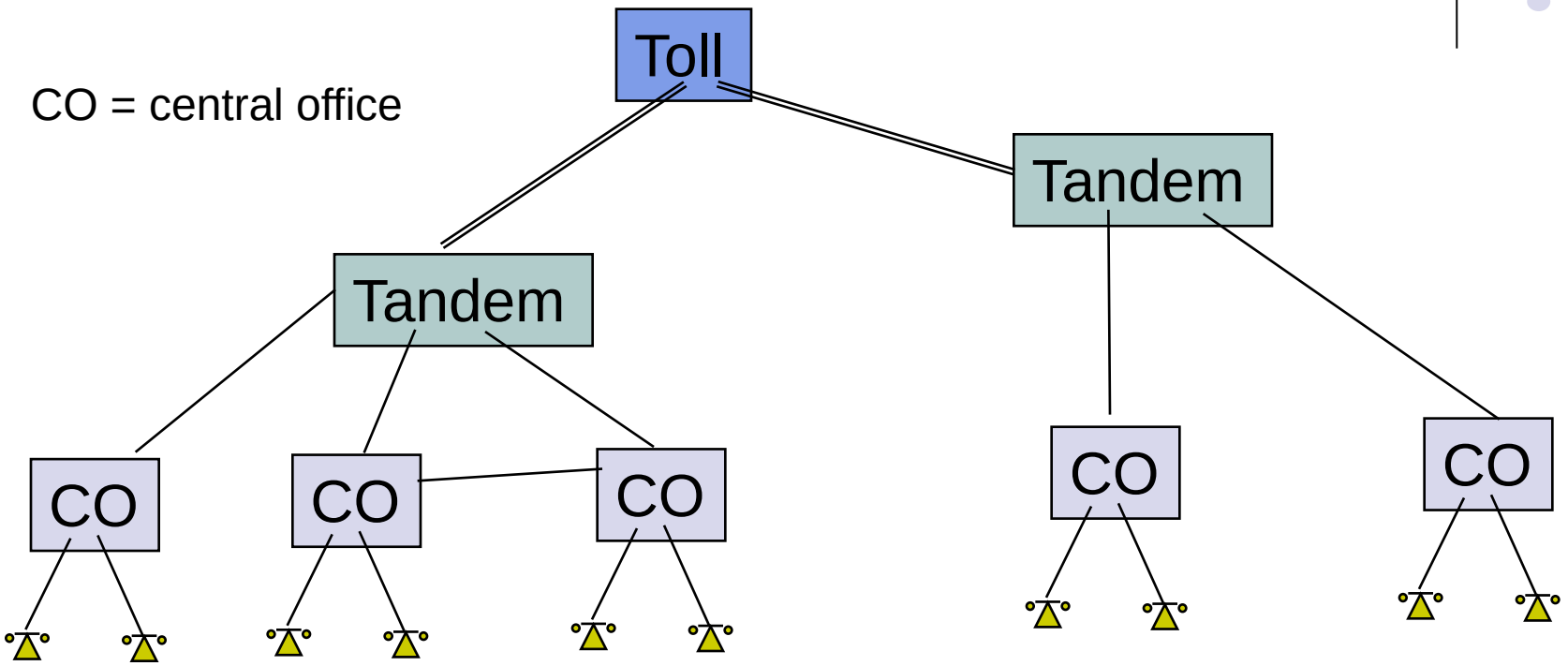
Telephone Switch

- Human operators intelligent & flexible
  - But expensive and not always discreet
- Strowger invented automated switch in 1888
- Decimal telephone numbering system
- Hierarchical network structure simplifies routing
  - Area code, exchange (CO), station number



CO: Central office (see next slide)

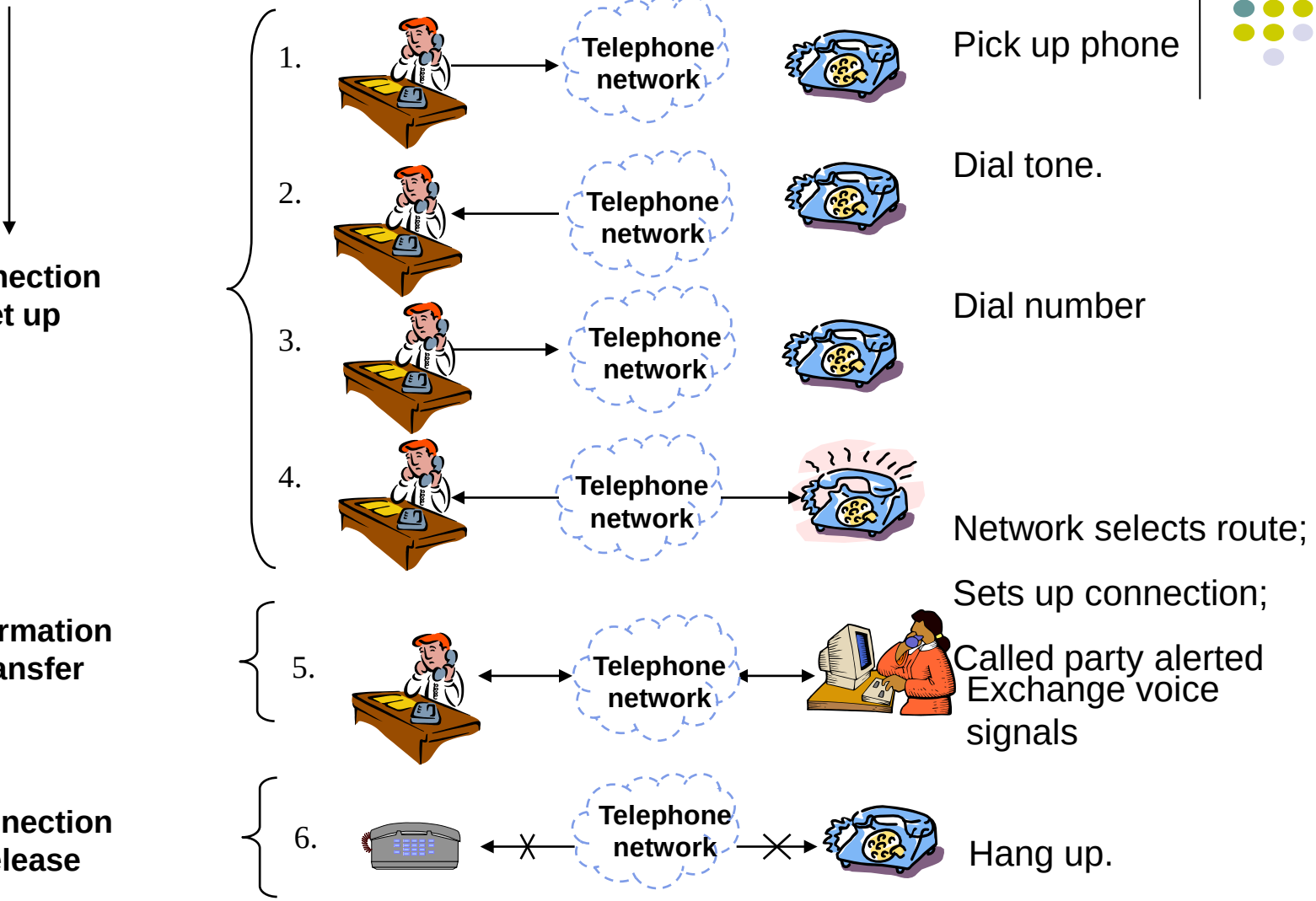
Hierarchical Network Structure



Telephone subscribers connected to local CO (central office)

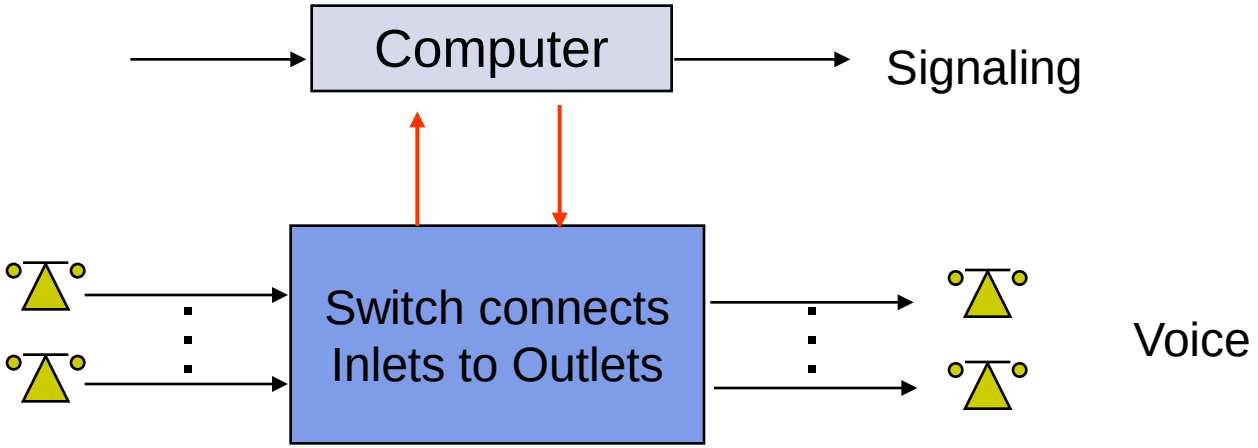
Tandem & Toll switches connect CO's

Three Phases of a Connection



Computer Connection Control

- A computer controls connection in telephone switch
- Computers exchange *signaling messages* to:
  - Coordinate setup of telephone connections
  - To implement new services such as caller ID, voice mail, . . .
  - To enable *mobility and roaming in* cellular networks
- "Intelligence" inside the network
- A separate *signaling network* is required

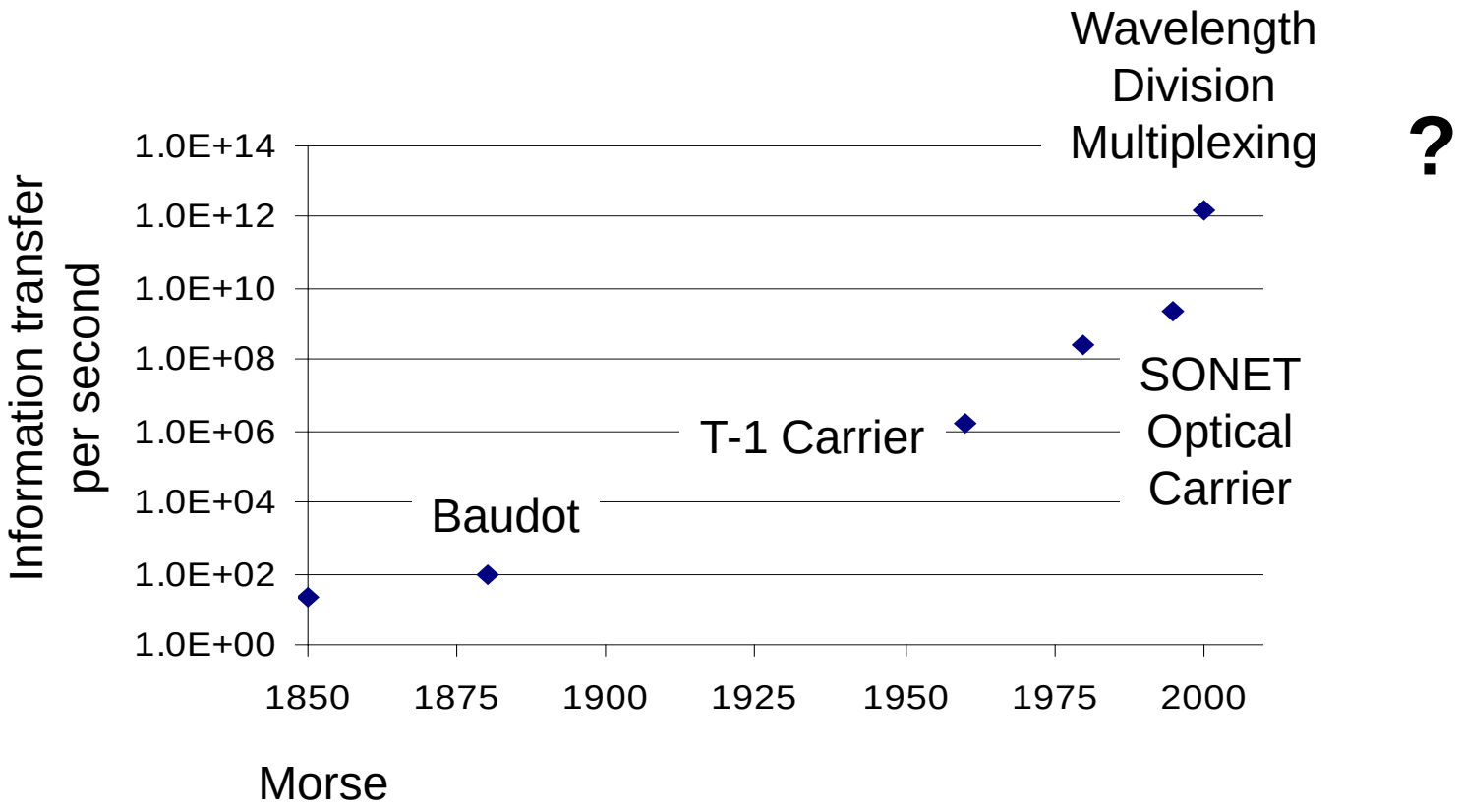


Digitization of Telephone Network

- Pulse Code Modulation digital voice signal
  - Voice gives 8 bits/sample x 8000 samples/sec = 64×10^3 bps
- Time Division Multiplexing for digital voice
  - T-1 multiplexing (1961): 24 voice signals = 1.544×10^6 bps
  - Math time: 64K x 24 = ? What is the difference and why?
    - 8 Kbit/s of framing information which facilitates the **synchronization** and **demultiplexing** at the receiver
- Digital Switching (1980s) *<What company invented this?>*
  - Switch TDM signals without conversion to analog form
  - Who invented digital telephone switches?
- Digital Cellular Telephony (1990s)
- Optical Digital Transmission (1990s)
  - One OC-192 optical signal = 10×10^9 bps (10G)
  - One optical fiber carries 160 OC-192 signals = 1.6×10^{12} bps!
  - Now 40G and 100G!

All digital transmission, switching, and control

Digital Transmission Evolution



Elements of Telephone Network Architecture

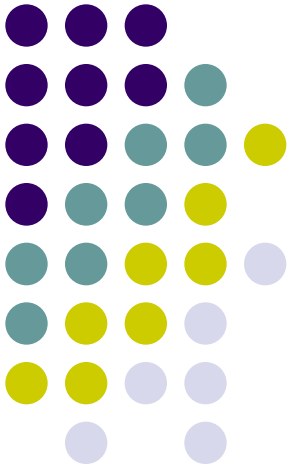
- Digital transmission & switching
  - Digital voice; ***Time Division Multiplexing***
- ***Circuit switching***
  - User signals for call setup and tear-down
  - Route selected during connection setup
  - **End-to-end connection across network**
  - Signaling coordinates connection setup
- ***Hierarchical*** Network
  - Decimal numbering system
  - Hierarchical structure; simplified routing; scalability
- ***Signaling Network***
  - Intelligence inside the network, e.g., Pizza Pizza, 1-800-…

Circuit Switching

- What is the main advantage?

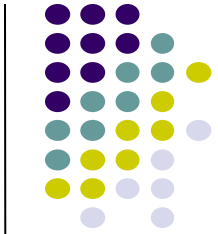
- Disadvantage?

Introduction: Communication Networks and Services



Computer Networks & Packet Switching

Computer Network Evolution Overview



- *1950s*: Telegraph technology adapted to computers
- *1960s*: Dumb terminals access shared host computer
  - SABRE airline reservation system
- *1970s*: Computers connect directly to each other
  - ARPANET **packet switching network**
  - **TCP/IP** internet protocols
  - **Ethernet** local area network
- *1980s & 1990s*: New applications and Internet growth
  - Commercialization of Internet
  - E-mail, file transfer, web, P2P, . . .
  - Internet traffic surpasses voice traffic

What is a protocol?

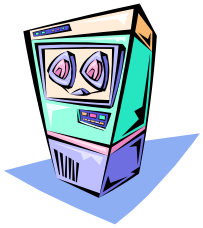
- The customs and regulations dealing with diplomatic formality diplomatic formality (Dictionary.com)
  - Hand shakes
- Communications between computers requires very ***specific unambiguous rules***
- A ***protocol*** is a set of rules that governs how two or more communicating parties are to interact
  - Internet Protocol (IP)
  - Transmission Control Protocol (TCP)
  - HyperText Transfer Protocol (HTTP)
  - Simple Mail Transfer Protocol (SMTP)

A familiar protocol

Caller

Dials 411

System replies



"What city"?

Caller replies

"Springfield"

System replies

"What name?"

Caller replies

"Simpson"

System replies

"Thank you, please hold"

Caller waits

"Do you have a first name or street?"

Operator replies

Caller replies

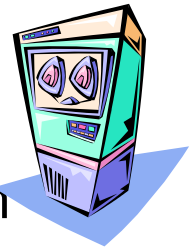
"Evergreen Terrace"

"Thank you, please hold"

Operator replies

Caller waits

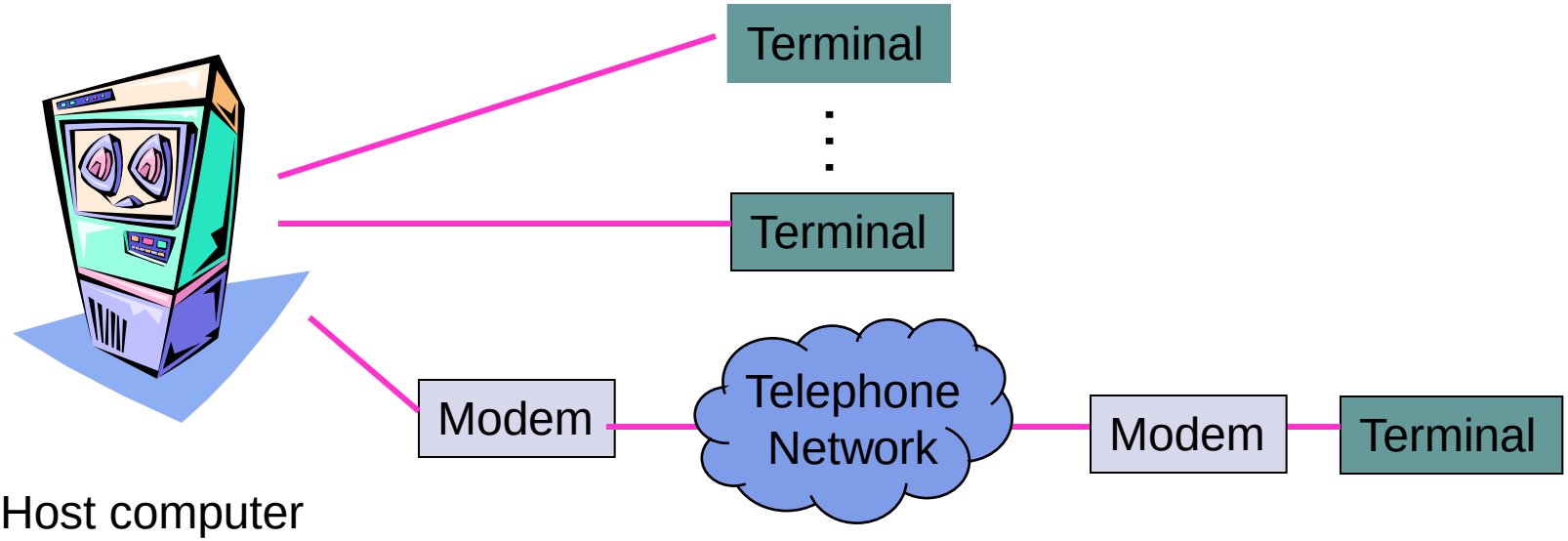
System replies with number



Caller dials

Terminal-Oriented Networks

- ***Early computer systems*** very expensive
- Time-sharing methods allowed multiple terminals to share local computer
- Remote access via ***telephone*** modems

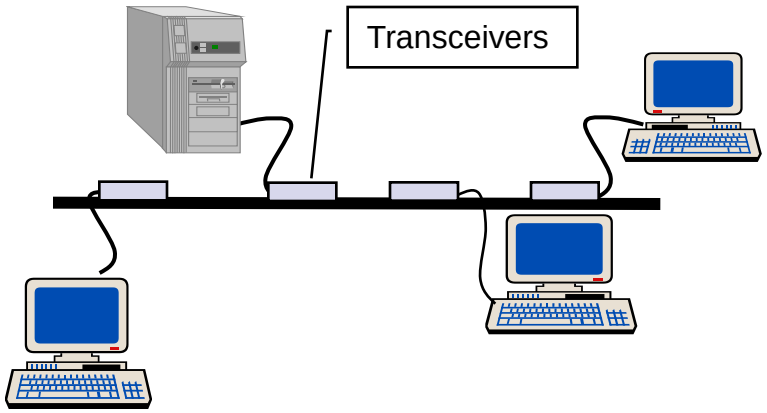


Ethernet Local Area Network

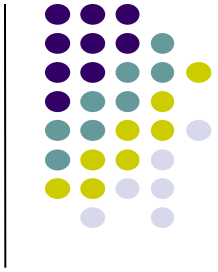
- In 1980s, affordable workstations available
- Need for low-cost, high-speed networks
  - To interconnect local workstations
  - To access local shared resources (printers, storage, servers)
- Low cost, high-speed communications with low error rate possible using coaxial cable
- Ethernet is the standard for high-speed wired access to computer networks

Ethernet Medium Access Control

- Network interface card (NIC) connects workstation to LAN
- Each NIC has globally unique address
- Frames are broadcast into coaxial cable
- NICs listen to medium for frames with their address
- Transmitting NICs listen for collisions with other stations, and abort and reschedule retransmissions



Packet Switching



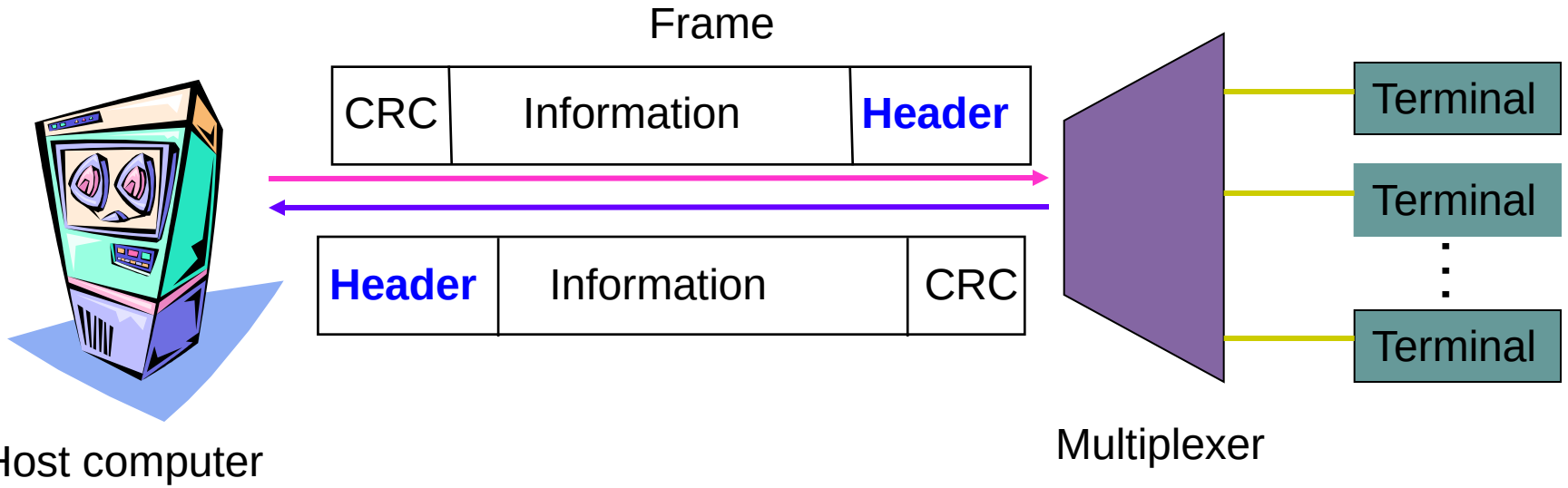
- Network should support multiple applications
  - Transfer arbitrary message size
  - Low delay for interactive applications
  - In store-and-forward operation, long messages induce high delay on interactive messages
- Packet switching introduced
  - Network transfers packets using store-and-forward
  - Break long messages into multiple packets
- ARPANET testbed led to many innovations

The Internet

- Different network types emerged for data transfer between computers
- Each network has its protocols and is possibly built on different technologies
- *Internetworking protocols* required to enable communications between computers attached to *different* networks
- ***Internet***: a network of networks

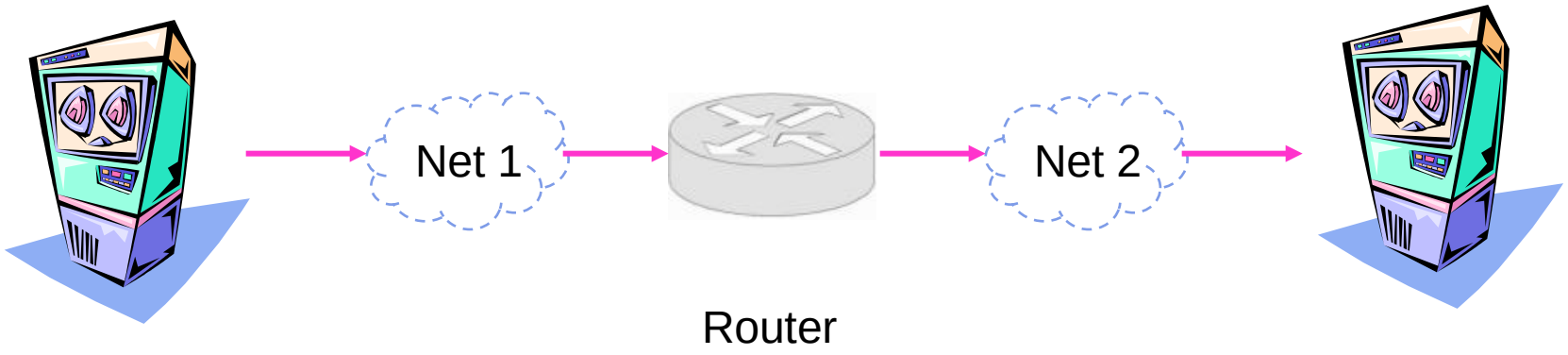
Statistical Multiplexing

- Statistical multiplexer allows a line to carry *frames* that contain messages to/from *multiple terminals*
- Frames may be buffered at *multiplexer* until line becomes available, i.e. store-and-forward
- *Address* in frame header identifies terminal
- Header carries other *control* information



Internetworking- Internet Protocol (IP)

- *Routers* interconnect different networks
- Host computers prepare IP packets and transmit them over their attached network
- Routers forward IP packets across networks
- *Best-effort* IP transfer service, no retransmission



Internet: Packet Switching

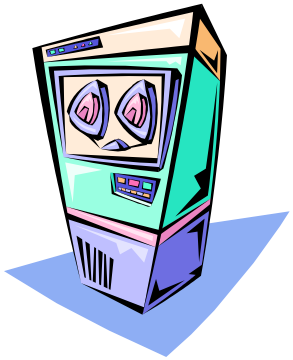
Host generates message

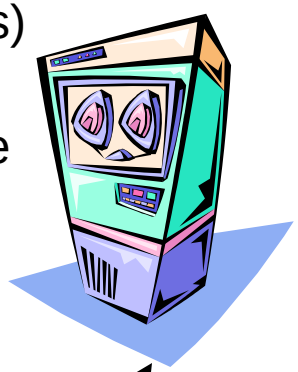
Source packet switch converts message to packet(s)

Packets transferred independently across network

Destination packet switch **reassembles** message

Destination packet switch delivers message





Message

Packet 2

Packet Switch

Packet 2

Message

Packet Switch

Packet Switch

Packet 1

Packet Switch

Packet 1

Packet Switch

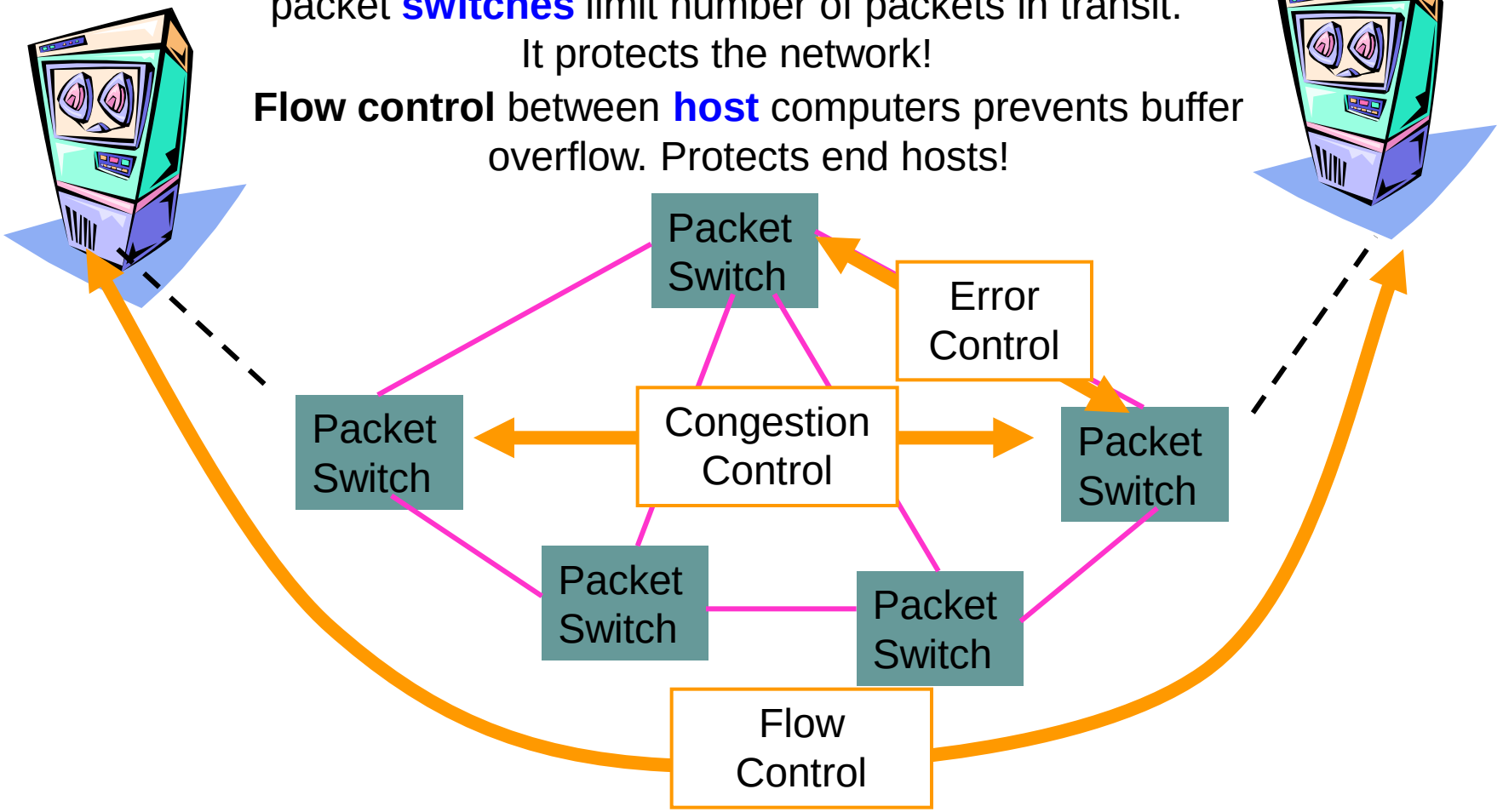
Packet 1

Other Internet Features

Error control between adjacent packet switches

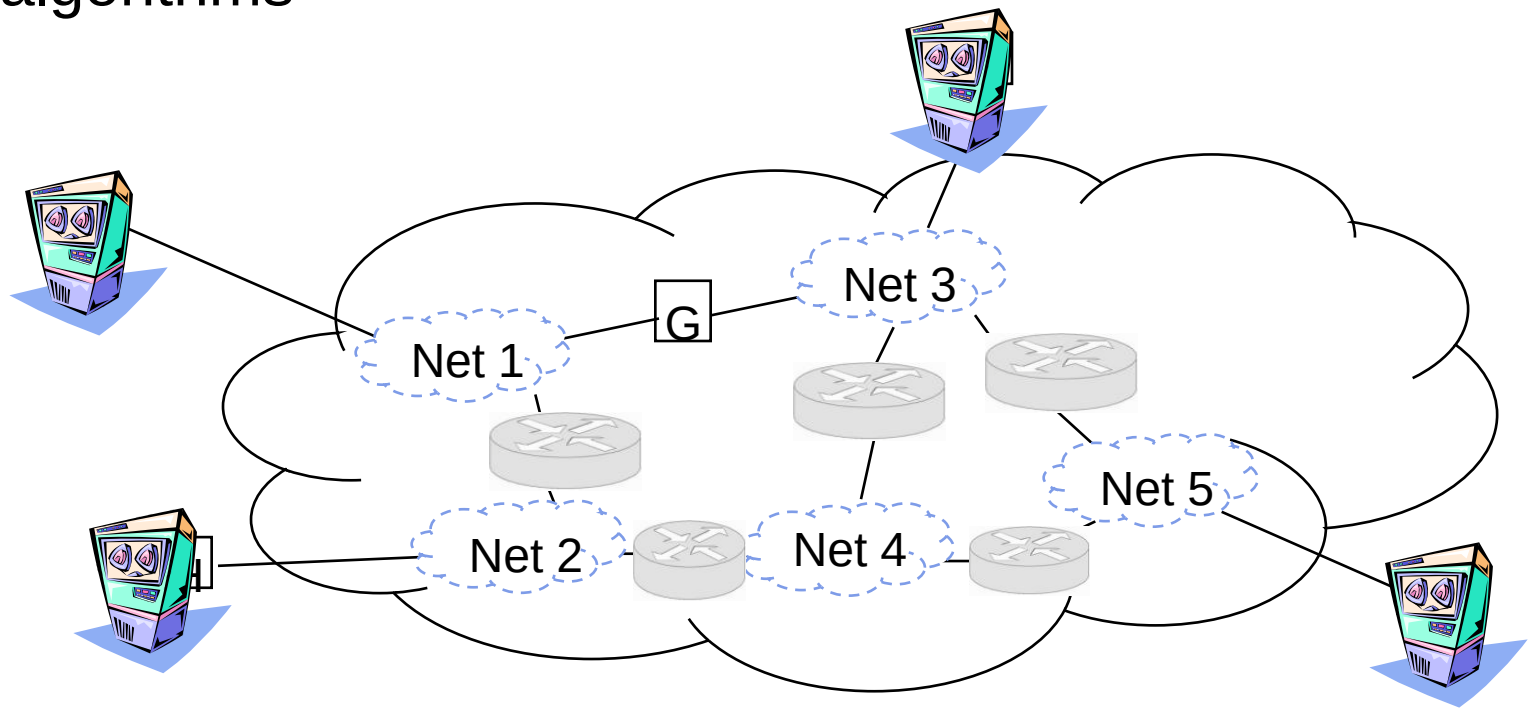
Congestion control between source & destination packet **switches** limit number of packets in transit. It protects the network!

Flow control between **host** computers prevents buffer overflow. Protects end hosts!



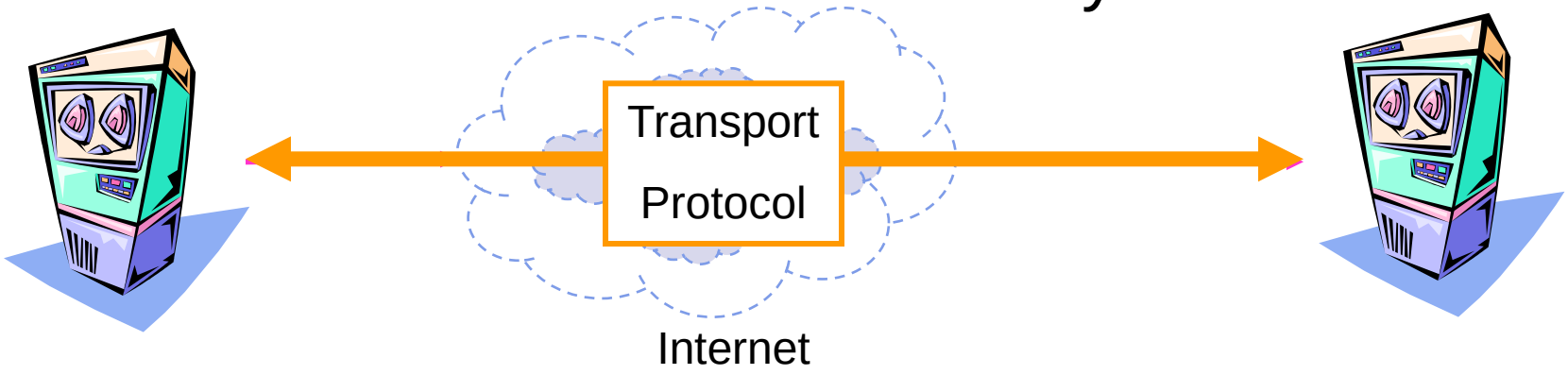
Addressing & Routing

- Hierarchical address: Net ID + Host ID
- IP packets routed according to Net ID
- Routers compute routing tables using distributed algorithms



Transport Protocols

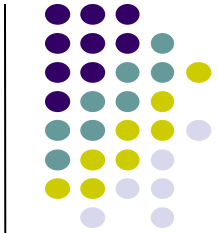
- Host computers run two transport protocols on top of IP to enable process-to-process communications
- *User Datagram Protocol* (UDP) enables **best-effort transfer** of individual block of information
- *Transmission Control Protocol* (TCP) enables **reliable transfer** of a stream of bytes



Names and IP Addresses

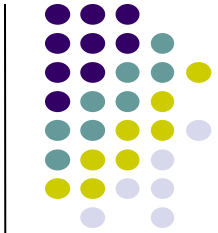
- Routing is mostly done based on 32-bit IP addresses (IPv4)
- Dotted-decimal notation
  - 128.100.11.1
- Hosts are also identified by name
  - Easier to remember
  - Hierarchical name structure
  - alexander.sce.carleton.ca
- Domain Name System (DNS) provided conversion between names and addresses

Summary: Elements of Computer Network Architecture



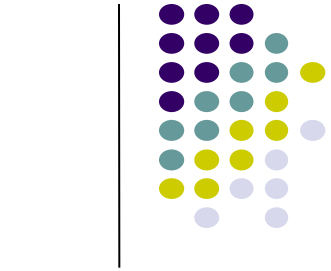
- *Digital transmission*
- Exchange of *frames* between adjacent equipment
  - Framing and error control
- *Medium access control* (*MAC*) regulates sharing of broadcast medium.
- *Addresses* identify attachment to network or internet.
- Transfer of *packets* across a packet network
- Distributed calculation of *routing tables*

Summary: Elements of Computer Network Architecture

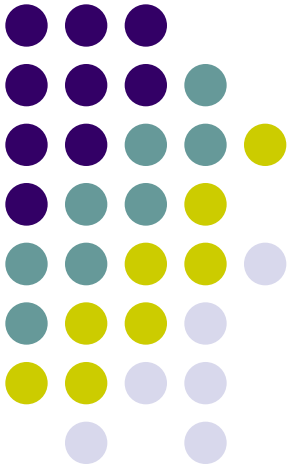


- *Congestion control* regulates no of packets inside the network; *flow control* regulates end-to-end traffic.
- *Internetworking* across multiple networks using routers
- *Segmentation and reassembly* of messages into packets at the ingress to and egress from a network or internetwork
- *End-to-end transport protocols* for process-to-process communications
- *Applications* that build on the transfer of messages between computers.
- *Intelligence is at the edge of the network.*

Introduction:Communication Networks and Services



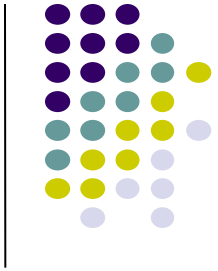
Future Network Architectures and Services



Trends in Network Evolution

- Network evolution is driven by new services
  - Services that generate revenues drive the development of new network architectures
- Current trends
  - Integration and Multimedia applications
  - Mobile Apps / networks, e.g., 4G, 5G wireless net.
  - Cloud computing / networking
  - Software-defined networking (SDN)
  - Content-centric (Information-centric) networking
  - Security & privacy

Packet vs. Circuit Switching



- Packet switching at the edge
  - IP enables rapid introduction of new applications
  - New cellular voice networks packet-based
  - Voice and telephone network has been gradually replaced
- However, large packet flows easier to manage by circuit-like methods
  - ***Optical circuit switching***

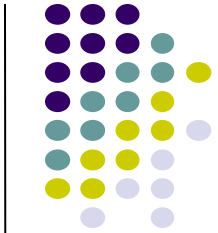
Optical Circuit Switching

- Optical signal transmission over fiber can carry huge volumes of information (Tbps)
- Optical signal processing very limited
  - Optical logic circuits bulky and costly
- Optical packet switching will not happen soon
  - Optical-to-Electronic conversion is expensive
- Thus trend towards optical circuit switching in the core of the network
  - (Technologies may evolve quickly.)

Multimedia Applications-Integration

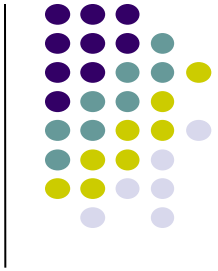
- Trend towards digitization of *all* media
- Digital voice standard in cell phones
- Music cassettes/CDs replaced by MP3's
- Digital cameras replacing photography
- Video: digital storage and transmission
  - Analog VCR cassettes replaced by DVDs which replaced by Youtube
  - Analog broadcast TV is being replaced by digital TV
- Integration of all applications over one network: voice communications, gaming, tv/entertainment, shopping etc.

End of Trust



- Security Attacks
  - Spam
  - Denial of Service attacks
  - Viruses
- Firewalls & Filtering
  - Control flow of traffic/data from Internet
- Protocols for privacy, integrity and authentication

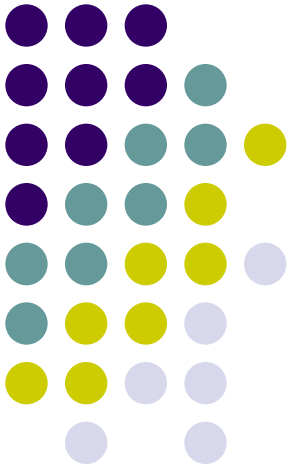
P2P and Overlay Networks



- A peer-to-peer (or P2P) computer network is a network that relies on computing power at the edges (ends) of a connection rather than in the network itself.
  - Bit Torrent, Napster, Gnutella, Kazaa
  - Processing & storage (SETI@home)
  - Information & files (MP3s)
  - Creation of virtual distributed servers
- P2P creates transient overlay networks
  - Users (computers) currently online connect directly to each other to allow sharing of their resources
  - Huge traffic volumes a challenge to network management

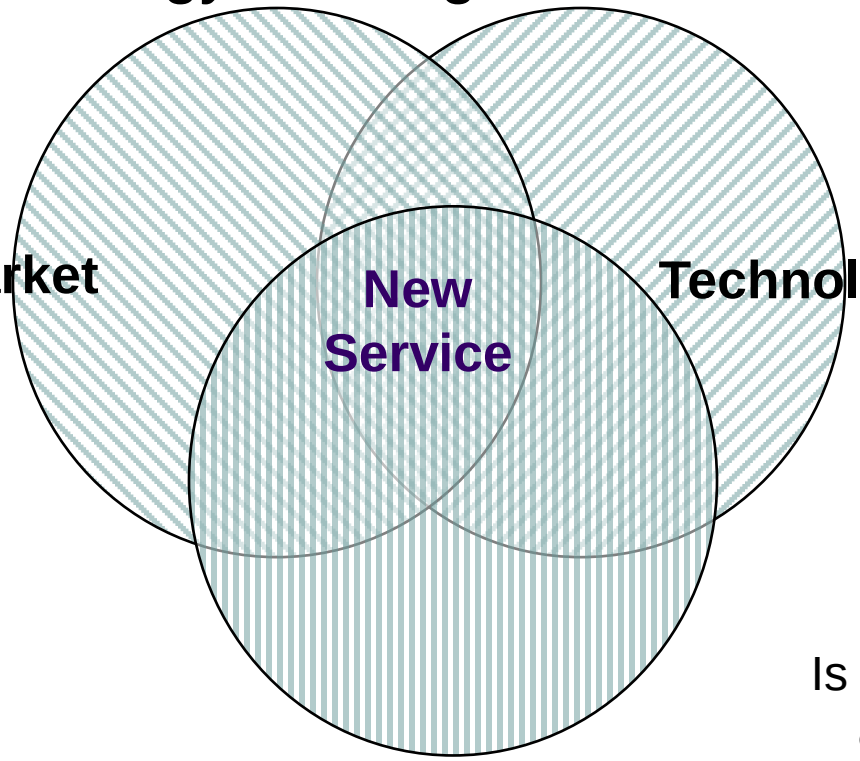
Introduction:Communication Networks and Services

Key Factors in Network Evolution



Success Factors for New Services

- Technology not only factor in success of a new service
- Three factors considered in new telecom services: Market, technology and regulation

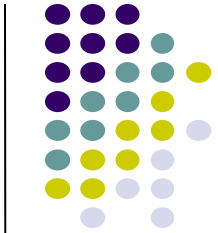


Can there be demand for the service?

Can it be implemented cost-effectively?

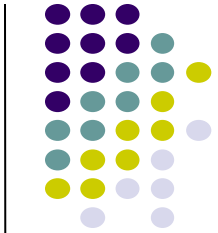
Is the service allowed?

Technology



- Relentless improvement in transmission
  - High-speed transmissions in copper pairs/optical networks
  - Higher call capacity in cellular networks
- Relentless improvement in processing & storage
  - RAM: larger tables, larger systems
  - Network processors: hardware for routing, switching, forwarding, and traffic management and error control
  - Microprocessors: higher layer protocols and applications
- Improvement in network architecture / protocols
  - SDN
  - CCN/ICN

Market

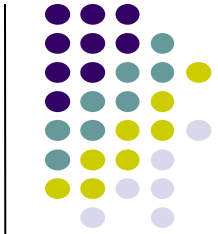


- Usefulness of a service increases with size of community
  - Critical mass is needed
- *Economies of scale*: per-user cost drops with increased volume
  - Smart devices
  - Efficiencies from multiplexing

Standards

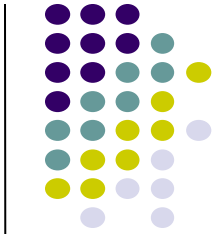
- New technologies may be costly and risky
- Standards allow players to share risk and benefits of a new market
  - Interoperability and network effect
  - Healthy high-tech competition towards well defined innovations
- Example
  - 802.11 wireless LAN products
  - SDN (evolution vs. revolution?)

Standards Bodies



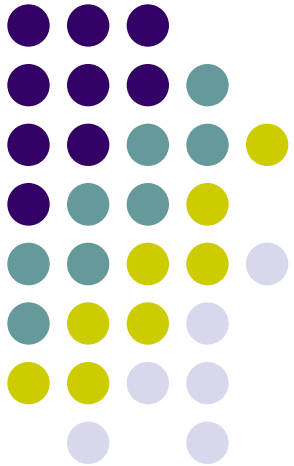
- Internet Engineering Task Force
  - Internet standards development
  - Request for Comments (RFCs): www.ietf.org
- International Telecommunications Union
  - International telecom standards
- IEEE 802 Committee
  - Local area and metropolitan area network standards
- Industry Organizations
  - MPLS Forum, WiFi Alliance, World Wide Web Consortium, ZIGBEE (802.15.4) alliance, SDN, CCN/ICN, etc.

Introduction:Communication Networks and Services

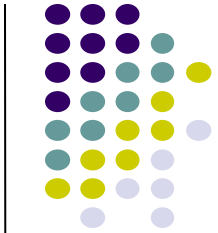


Network Classification

(Good overview and what you should primarily remember!)



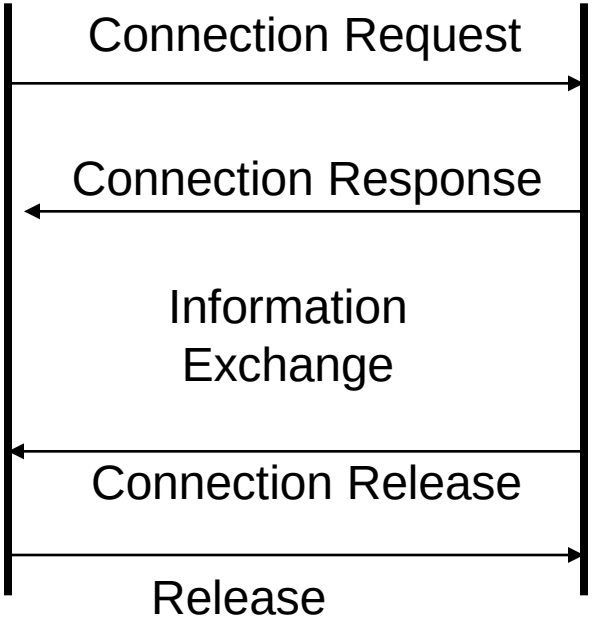
Network Classification



- Based on connection model
  - Connection oriented (CO) and connectionless (CLS) networks
- Based on switching technology
  - Circuit Switching (CS) and Packet Switching (PS) networks
- Based on geographical coverage
  - Local Area Networks (LAN), Metropolitan Area Networks (MAN), and Wide Area Networks (WAN)
    - More recently personal area networks (PAN) and home networks
- Based on ownership model
  - Enterprise networks (EN) and Carrier Networks (CN)

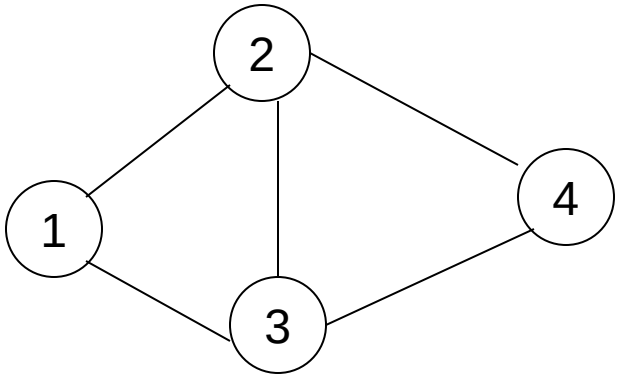
Connection-Oriented (CO) Networks

- In Connection-Oriented (CO) networks a **connection is established** between the source and the destination **before the exchange** of the information
  - Requires **signaling** for the connection establishment with the desired attributes
  - A prominent example is PSTN using signaling system 7 (SS7) for connection establishment



Connectionless (CLS) Networks

- Each unit of transmission includes a source and a destination information
  - This information is used to route the packet from source to destination
  - No explicit signaling is needed. However control information is needed to establish routing tables (routing protocols)
  - Classic example is IP network.



Dest	Next Hop

Circuit Switching (CS) Networks

- Circuit Switching Networks
  - A physical circuit is allocated to each session end-to-end.
  - A circuit-switched network is a connection oriented network
- A circuit can be a time slot, a frequency band, or a wavelength

Packet-Switching (PS) Networks

- Information is fragmented into units of information called packets
  - Packets may be of fixed length for variable length
    - Asynchronous Transfer Model (ATM) is an example of fixed-size packet technology
    - IP (Internet) allows variable length packets
- PS networks can be either connection oriented or connectionless
  - ATM virtual circuit is an example of PS-CO network
  - IP (Internet) is an example of PS-CL network.

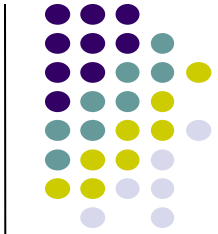
Local Area Networks (LAN)

- Covers a geographical diameter in the order of 10 meters (within a building or a department)
- Usually employs a bus or a ring topology
  - Ethernet (IEEE 802.2) is an example of a bus topology
  - Token ring (IEEE 802.5) is an example of ring topology

Metropolitan Area Networks (MAN)

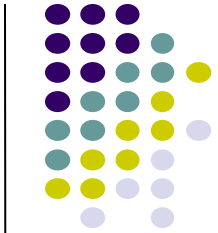
- Covers a geographical distance of about 50 km (spans a single city)
- May have a ring, a bus, or a mesh topology
  - Distributed Queue Dual Bus (DQDB) or IEEE 802.6 is an example of MAN using a bus architecture

Wide Area Network (WAN)



- Covers a wider geographical areas between cities

Enterprise Networks



- Serves a single organization, e.g. Carleton University
  - Could be owned and operated by the organization
  - Or its operation can be outsourced to a service provider
- Extends between multiple sites that are geographically dispersed.