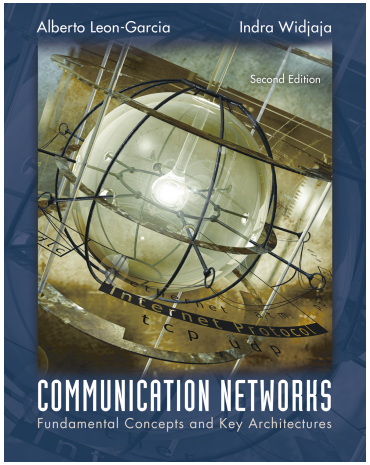
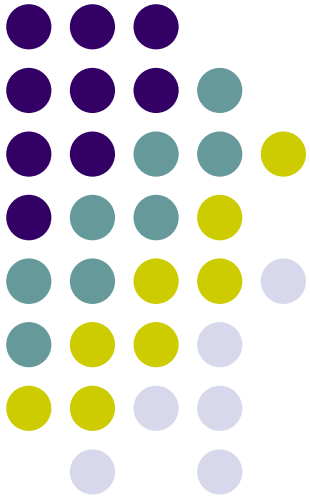
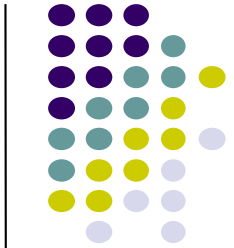
Communication Networks and Services



Introduction to Message & Circuit Switching

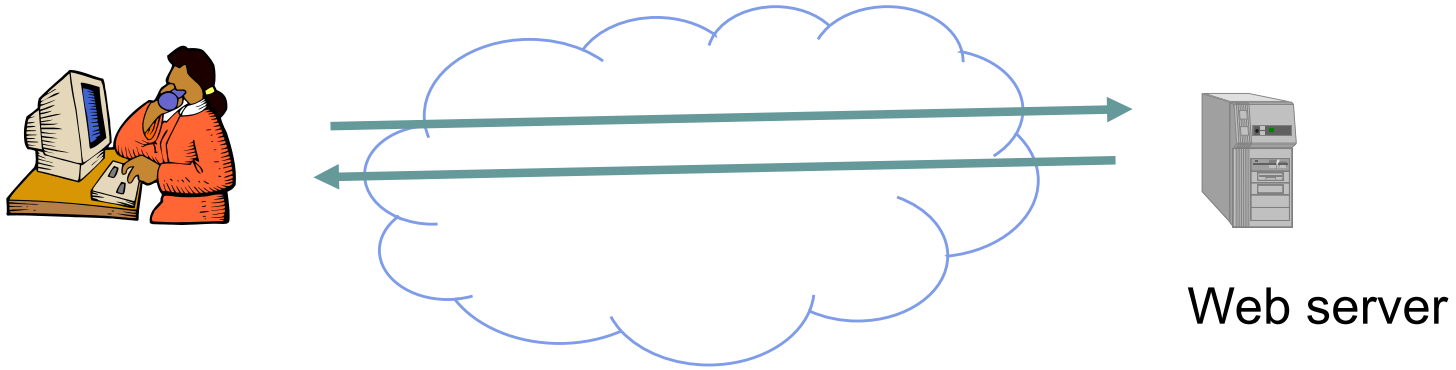


Communication Services & Applications



- A web browsing *application* enables retrieval of information from a server.
- Uses TCP reliable stream *service* provided by the Internet to retrieve files

Web Browsing

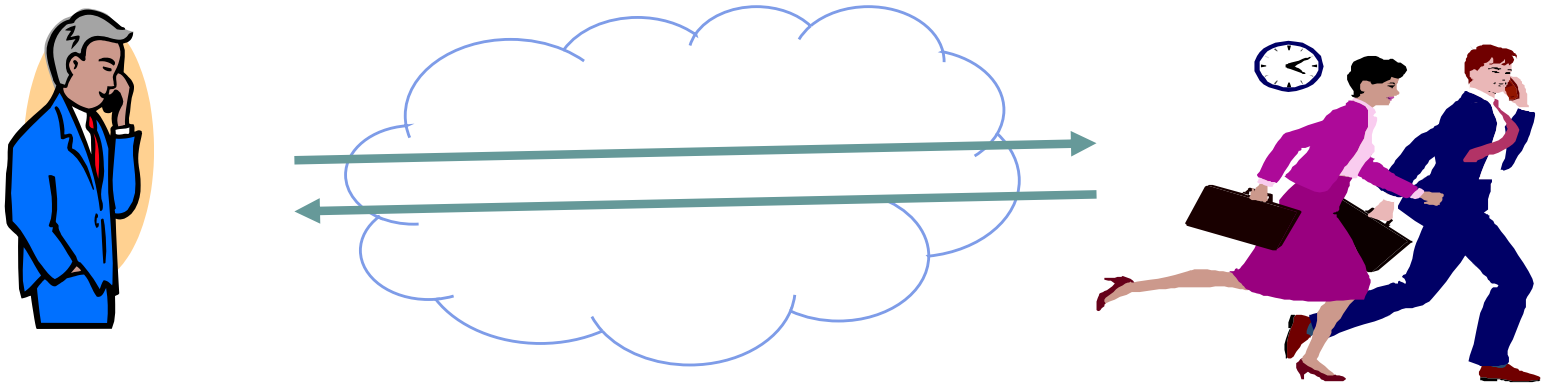


Retrieval of information from web servers

Communication Services & Applications

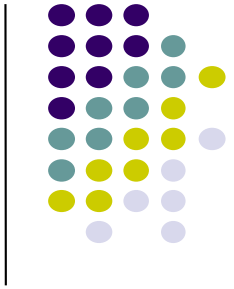
- Mobile phone *application* enables two-way communications between two mobile users.
- Uses UDP datagram *service* provided by the Internet to transfer clips of voice

Cell phone



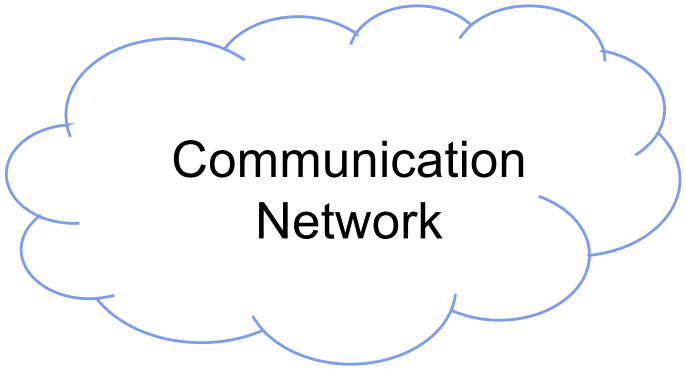
Real-time voice exchange with mobile users

Services & Applications



- Service: Basic information transfer capability
  - Internet transfer of individual block of information
  - Internet reliable transfer of a stream of bytes
  - Real-time transfer of a voice signal
- Applications build on communication services
  - E-mail & web build on reliable stream service
  - Voice Telephony builds on real-time transfer

What is a communication network?

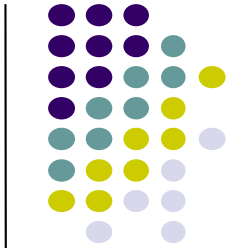


- The equipment (hardware & software) and facilities that provide the basic communication service
- Virtually invisible to the user; Represented by a cloud
- Applications run on user or terminal devices
- Equipment
  - Routers, servers, switches, multiplexers, hubs, modems, access points …
- Facilities
  - Copper wires, coaxial cables, optical fiber
  - Ducts, conduits, telephone poles …

How are networks designed and operated?

- *Network architecture:* the plan that specifies how the network is built and operated
- Architecture is driven by the network services
- Overall communication process is complex
- Network architecture partitions overall communication process into separate functional areas called *layers*

Telegraphs & Message Switching



Message Transfer Service

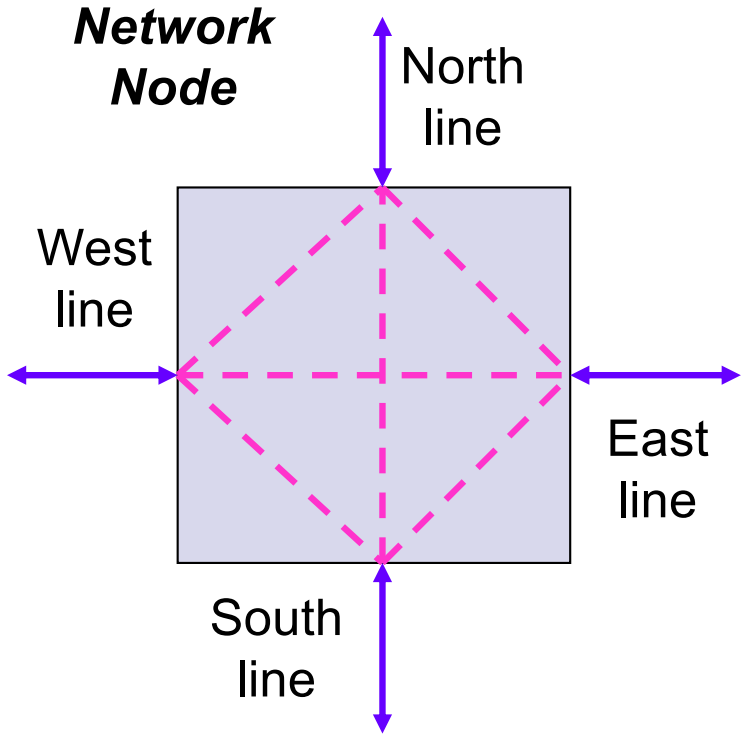
- Courier: physical transport of the message
  - Messenger pigeons, pony express, UPS, drones
- Telegraph: message is transmitted across a network using signals
  - Drums, beacons, mirrors,, flags, semaphores…
  - Electricity, light
- Telegraph delivers message much sooner

Optical (Visual) Telegraph

- Claude Chappe, 1790's
- Semaphore mimics person with flags in each hand
- Different angle combinations of arms & hands generates hundreds of possible signals
- Code for enciphering messages kept secret
- Signal could propagate 800 km in 3 minutes!

Message Switching

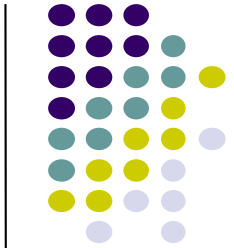
- Network nodes were created where several optical telegraph lines met (Paris and other sites)
- *Store-and-Forward* Operation:
  - Messages arriving on a line are recorded
  - Next-hop in ***route*** determined by destination ***address*** of a message
  - Each message carried by hand to next line, and stored until operator is available for transmission



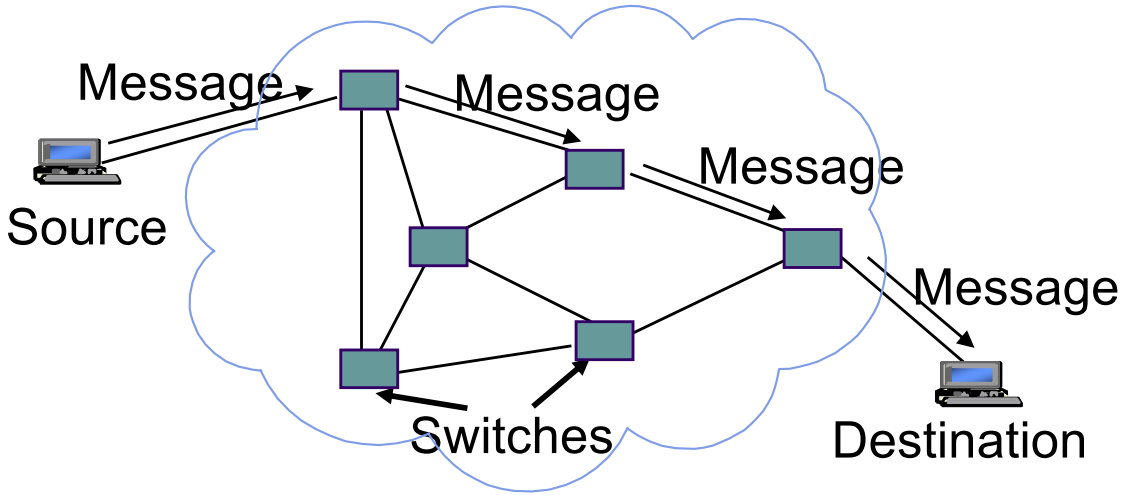
Electric Telegraph

- William Sturgeon Electro-magnet (1825)
  - Electric current in a wire wrapped around a piece of iron generates a magnetic force
- Joseph Henry (1830)
  - Current over 1 mile of wire to ring a bell
- Samuel Morse (1835)
  - Pulses of current deflect electromagnet to generate dots & dashes
  - Experimental telegraph line over 40 miles (1840)
- Signal propagates at the speed of light!!!
  - Approximately 2 x 10^8 meters/second in cable

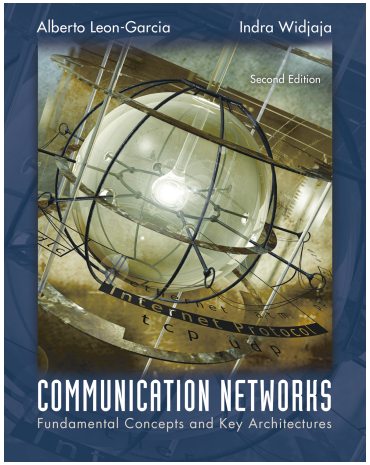
Elements of Telegraph Network Architecture



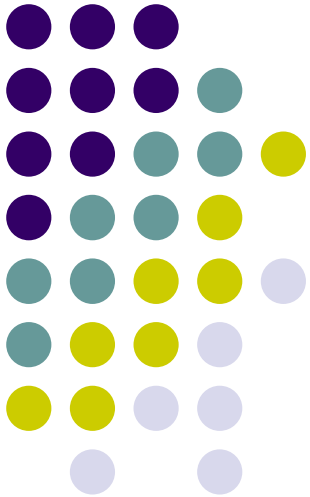
- Digital transmission
  - Text messages converted into dots/dashes or zeros/ones
- Message Switching Service
  - Messages contain source & destination *addresses*
  - *Store-and-Forward:* Messages forwarded hop-by-hop across network
  - *Routing* determines path followed according to destination address



Communication Networks and Services



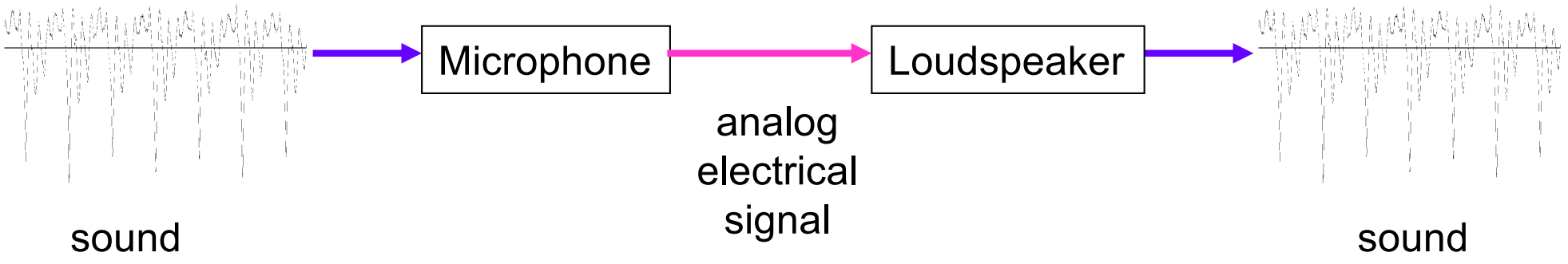
Telephone Networks and Circuit Switching



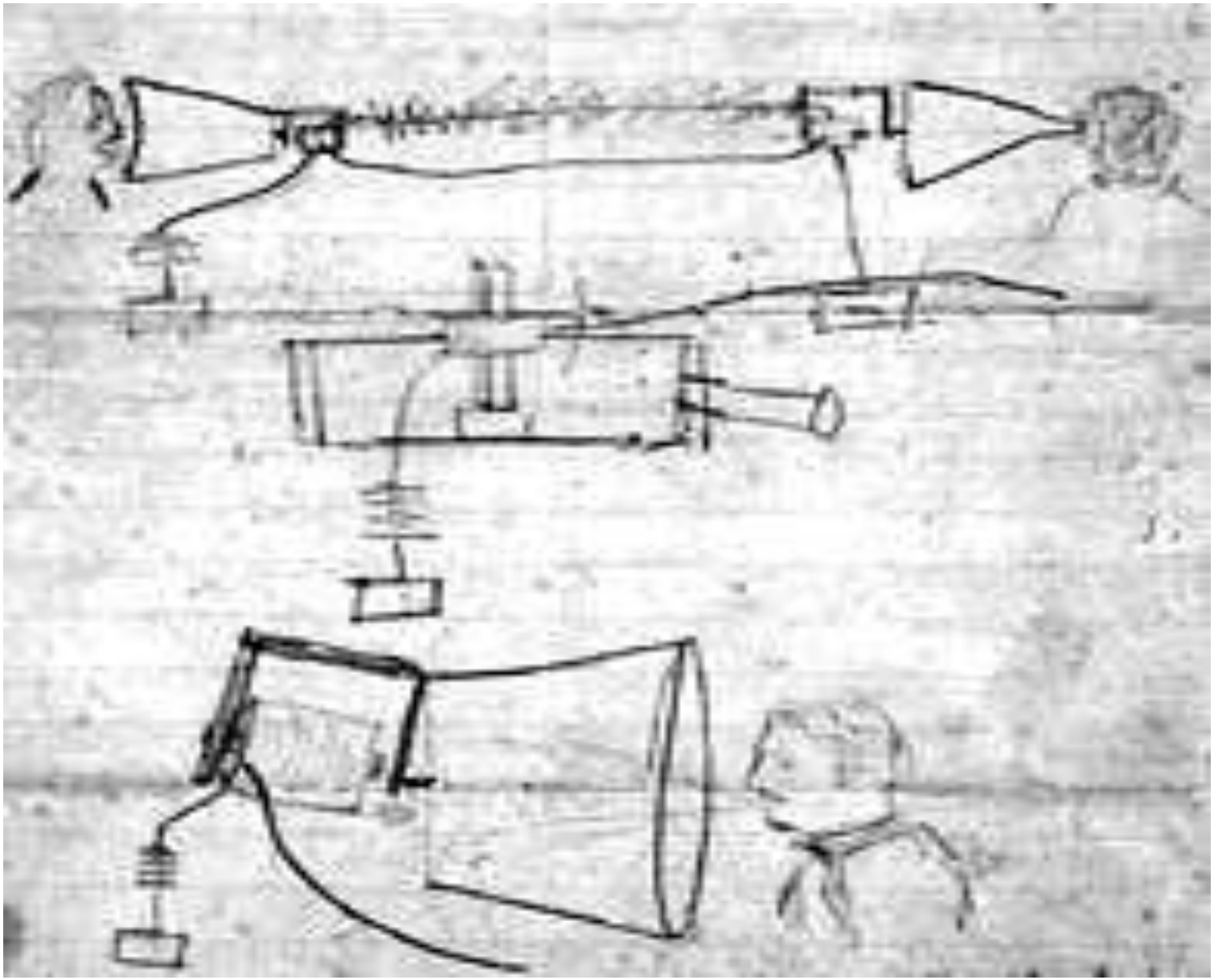
Bell's Telephone

- Alexander Graham Bell (1875) discovered voice signals can be transmitted directly
  - 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

Signal for "ae" as in cat

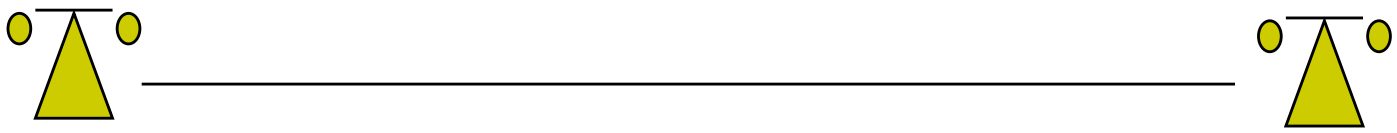


Bell's Sketch of Telephone



Signaling

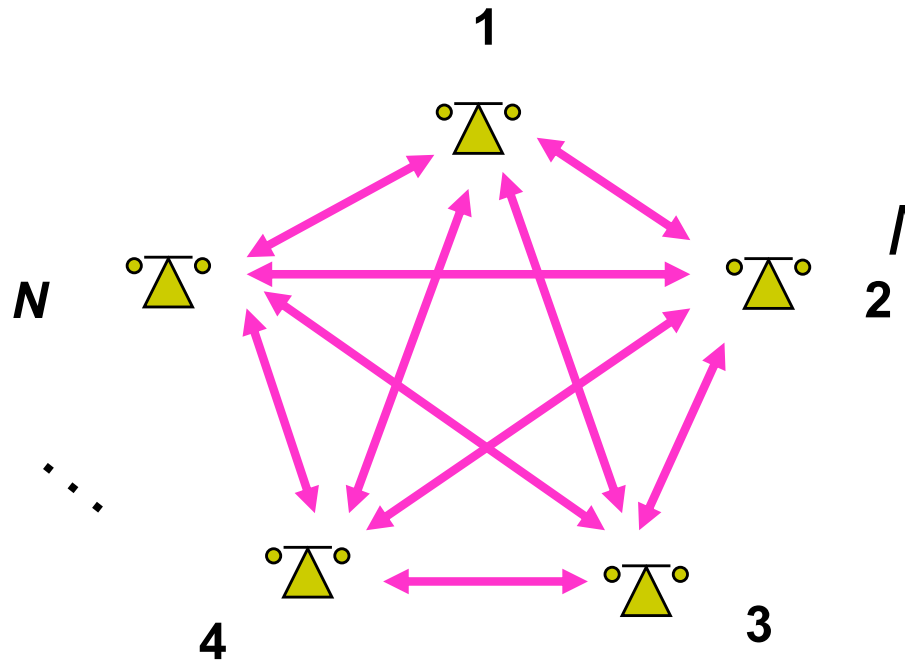
- Signaling required to establish a call
  - Flashing light and ringing devices to alert the called party of incoming call
  - Called party information to operator to establish calls



Signaling + voice signal transfer

The N^2 Problem

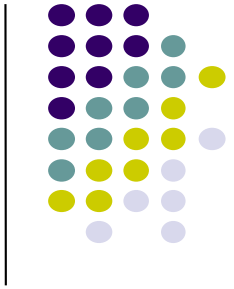
- For N users to be fully connected *directly*
- Requires $N(N-1)/2$ connections
- Requires too much space for cables
- Inefficient & costly since connections not always on



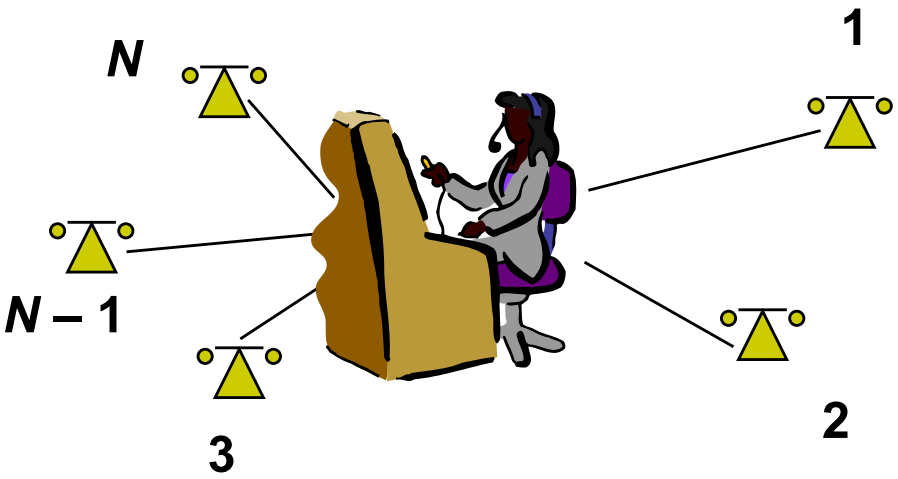
$N = 1000$

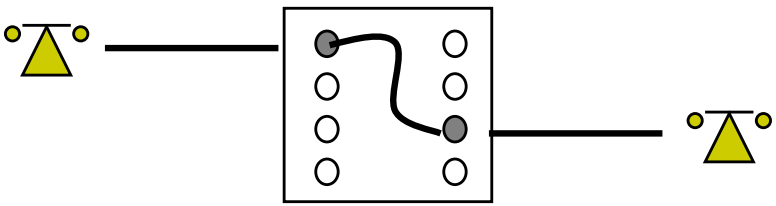
$N(N-1)/2 = 499500$

Circuit Switching

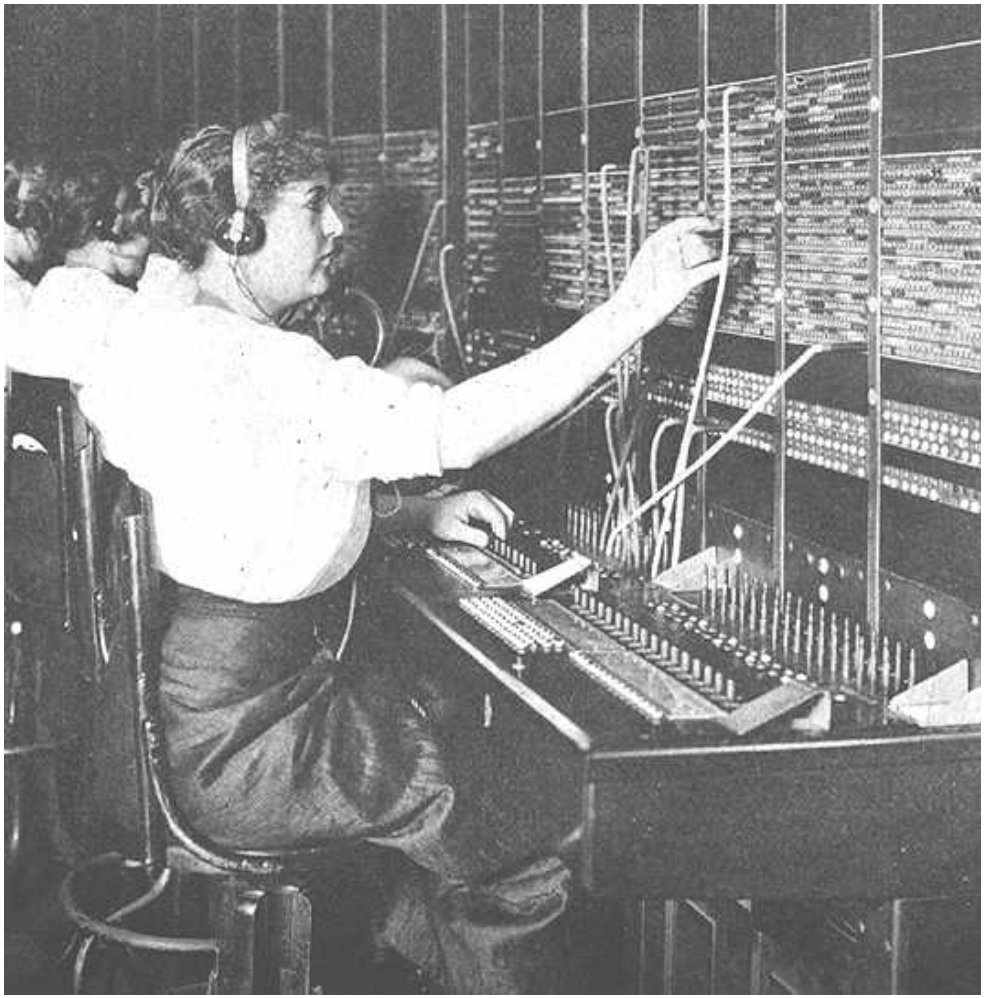


- Patchcord panel switch invented in 1877
- Operators connect users on demand
  - Establish *circuit* to allow electrical current to flow from inlet to outlet
- Only *N* connections required to central office

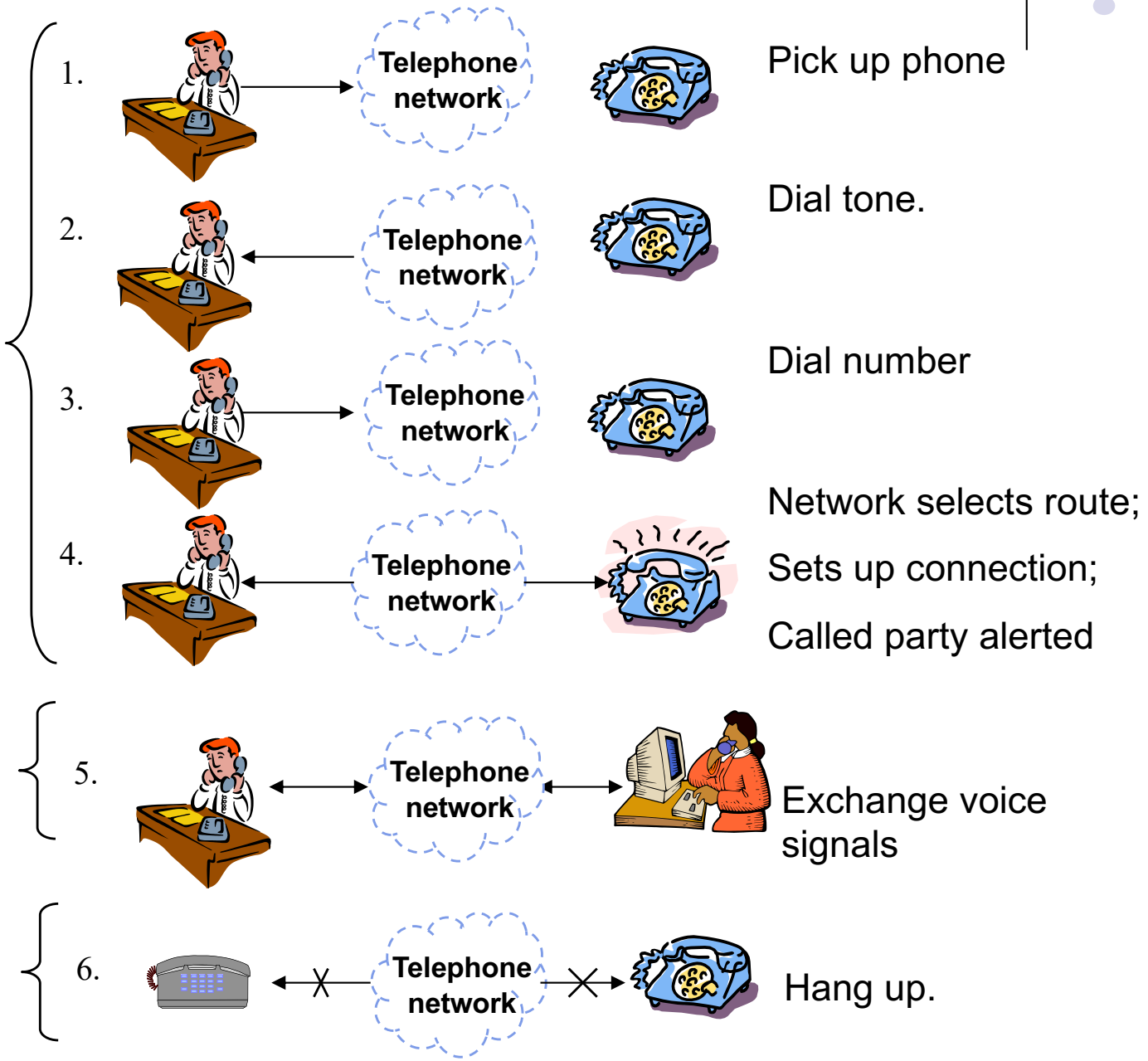




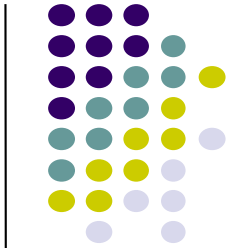
Manual Switching



Three Phases of a Connection

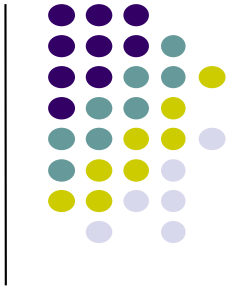


Elements of Telephone Network Architecture



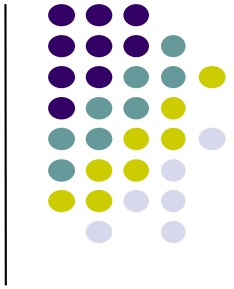
- Circuit switching service
  - User signals for call setup and tear-down
  - Route selected during connection setup
  - End-to-end connection across network
  - Signaling coordinates connection setup
- Hierarchical Network
  - Decimal numbering system
  - Hierarchical structure; simplified routing; scalability
- Signaling Network
  - Intelligence inside the network

ECE 361 Learning Objectives



- Architecture (logical design) of networks
  - Networks provide services to support applications
  - Networks are designed in ***layered architectures***
  - ***Protocols*** govern operation of each layer
  - Focus on Internet Architecture
- Some aspects of physical design of network
  - Broadband, WiFi, Ethernet, IP Routers, Sensors, Smart Phones, Servers, Datacenters

Syllabus

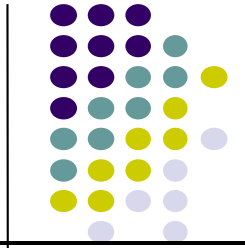


ECE 361	**Computer Networks**	**Winter 2019**	
Professor	A. Leon-Garcia, Bahen 4120, alberto.leongarcia@utoronto.ca (LEC 101) Hamid Timorabadi LP371, lh.timorabadi@utoronto.ca (LEC 102)		
TAs	Sayed Ehsan Etesami (mailto:ehsan.etesami@mail.utoronto.ca), Pooyan Habibi (mailto:pooyan.habibi@mail.utoronto.ca), Yihuan Huang (yihuan.huang@alum.utoronto.ca), Simona Marinova (mailto:simona.marinova@mail.utoronto.ca), Morteza Moghaddassian (mailto:m.moghaddassian@mail.utoronto.ca), Beibei Zhang (mailto:benjamin.zhang@mail.utoronto.ca)		
Textbook	*Communications Networks: Fundamental Concepts and Key Architectures, McGraw-Hill, Second Edition,* by Leon-Garcia & Widjaja		
Mark Distribution	Term Test (February 14, 2019 8-10 pm, Exam Centre, Room 10(	35%	Closed Book; Formulas Provided
	Labs (Labs 3 pts each)	15%	
	Final Exam	50%	Closed Book; Formulas Provided
Tutorial	TA guides students through selected homework-related exercises; Homework solutions will be posted weekly		
Lab	Students will work in teams of 2; students are free to form teams from the same lab section.		
Time & Place	LEC101: TuWF 1pm, GB248; LEC102, TuThF, 9am, GB248 PRA101/102, Mon 3-6pm , PRA103/104, Mon noon-15:00am, GB243; TUT 101/103 Th 11am-noon, MY315/MY360; TUT102 Tu noon-1 pm		

Syllabus

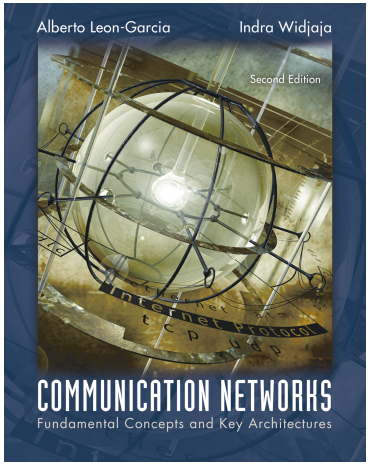
Date	Lecture Topic (MWF)	Reading	Tutorial	Lab
The schedule is subject to change because of unexpected events such as class cancellations, snowstorms, etc.				
January 7, 2019	**WEEK 1**			
January 8, 2019	Introduction to Message & Circuit Switching; Course Overview		No Tutorial	No Lab
January 9, 2019	Introduction to Packet Switching Networks			
January 11, 2019	Layered Network Architectures			
January 14, 2019	**WEEK 2**			
January 15, 2019	TCP/IP Architecture Overview		Layered Architectures: Encapsulation;	PRA02 Lab #1 WireShark Exercises
January 16, 2019	HTTP			
January 18, 2019	Voice over IP; RTP and UDP			
January 21, 2019	**WEEK 3**			
January 22, 2019	Berkeley Sockets		TCP & UDP	PRA01/03/04 Lab #1 Wireshark Exercises
January 23, 2019	Digital Transmission			
January 25, 2019	Communications Media			
January 28, 2019	**WEEK 4**			
January 29, 2019	Error Detection: Check Sums & Polynomial Codes		Bit Rates, Propagation Delay, Message Delays	PRA02 Lab #2 TCP/IP Utilities Read Section 2.5
January 30, 2019	Stop-and-Wait ARQ			
February 1, 2019	Selective ARQ			
February 4, 2019	**WEEK 5**			
February 5, 2019	TCP Reliable Stream Service and Flow Control		ARQ Performance	PRA01/03/04 Lab #2 TCP/IP Utilities Read Section 2.5
February 6, 2019	TCP Congestion Control			
February 8, 2019	Review for Midterm			
February 11, 2019	**WEEK 6 Midterm on February 14, 2019 8-10 pm, Exam Centre, Room 100**			
February 12, 2019	Packet Buffering and Statistical Multiplexing		Review Questions	
February 13, 2019	Packet Delay and Packet Loss Models			
February 15, 2019	Framing: HDLC, PPP, and Ethernet			
February 18, 2019	**WEEK 7 Reading Week**			

Syllabus

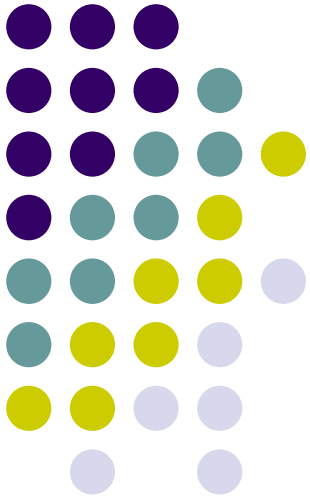


February 25, 2019		**WEEK 8**		
February 26, 2019	Aloha Random Access		Statistical Multiplexing	PRA01/03/04 Lab #3 UDP Sockets
February 27, 2019	CSMA/CD & CSMA/CA			
March 1, 2019	Ethernet LANs			
March 4, 2019		**WEEK 9**		
March 5, 2019	Spanning Tree Protocol & VLANs		MAC & Ethernet	PRA02 Lab #3 UDP Sockets
March 6, 2019	WIFI LANs			
March 8, 2019	LTE Cellular Mobile Networks			
March 11, 2019		**WEEK 10**		
March 12, 2019	Router and Switch Design		WIFI & LTE	PRA01/03/04 Lab #4 TCP Sockets
March 13, 2019	Routing Tables: Datagrams & Virtual Circuits			
March 15, 2019	Packet Scheduling and Quality of Service			
March 18, 2019		**WEEK 11**		
March 19, 2019	Distance Vector Routing		Routers & Switches	PRA02 Lab #4 TCP Sockets
March 20, 2019	Link-State Routing			
March 22, 2019	MPLS and SDN			
March 25, 2019		**WEEK 12**		
March 26, 2019	Segment Routing		Routing Protocols	PRA01/03/04 has Lab #5 OpenFlow Pt-Pt & Multipoint
March 27, 2019	IPv6 and CIDR			
March 29, 2019	DHCP, NAT, and IP mobility			
April 1, 2019		**WEEK 13**		
April 2, 2019	Cryptographic Algorithm Overview		IP Topics	PRA02 has Lab #5 OpenFlow Pt-Pt & Multipoint Circuits
April 3, 2019	Private Key and Public Key Cryptography			
April 5, 2019	TLS , HTTPS, SSH			
April 8, 2019		**WEEK 14**		
April 9, 2019	Course Review		Review Questions	
April 10, 2019	Course Review			
April 12, 2019				

Communication Networks and Services

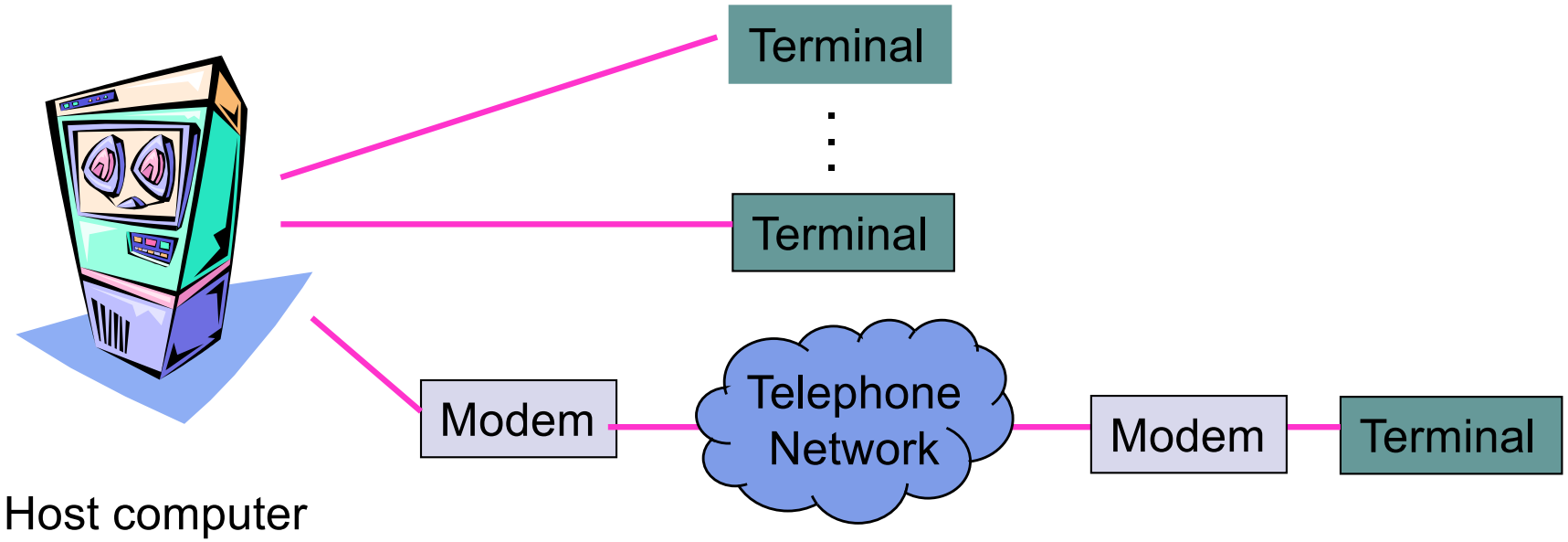


Computer Networks & Packet Switching



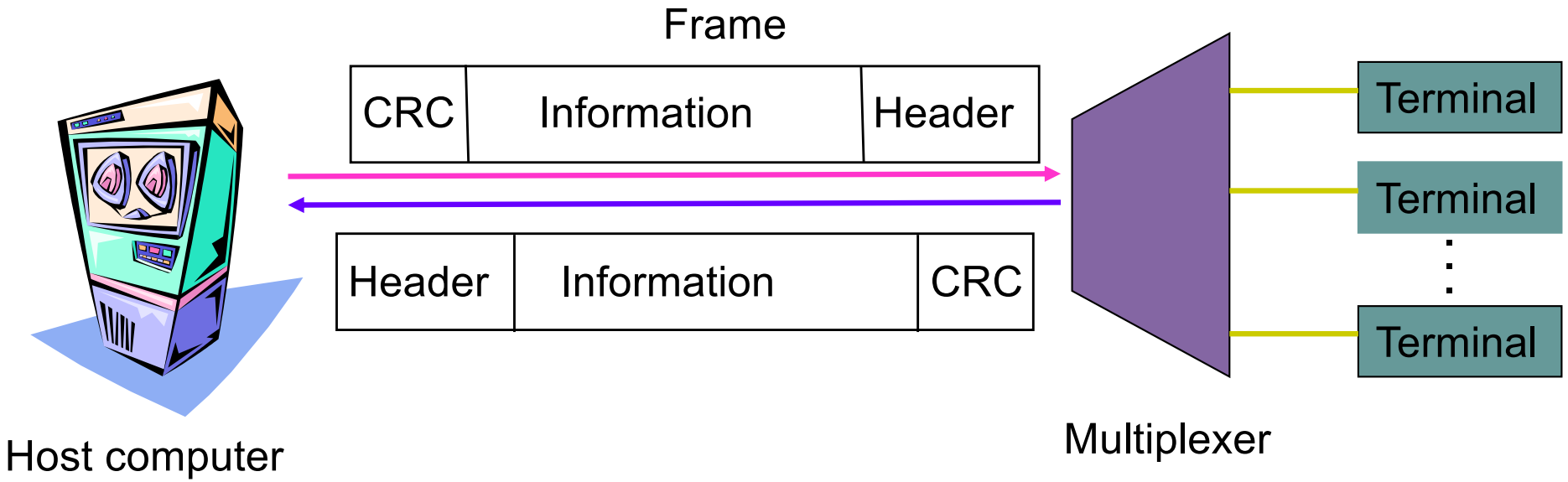
Terminal-Oriented Networks

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

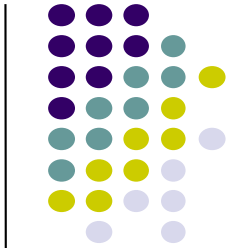


Multiplexing

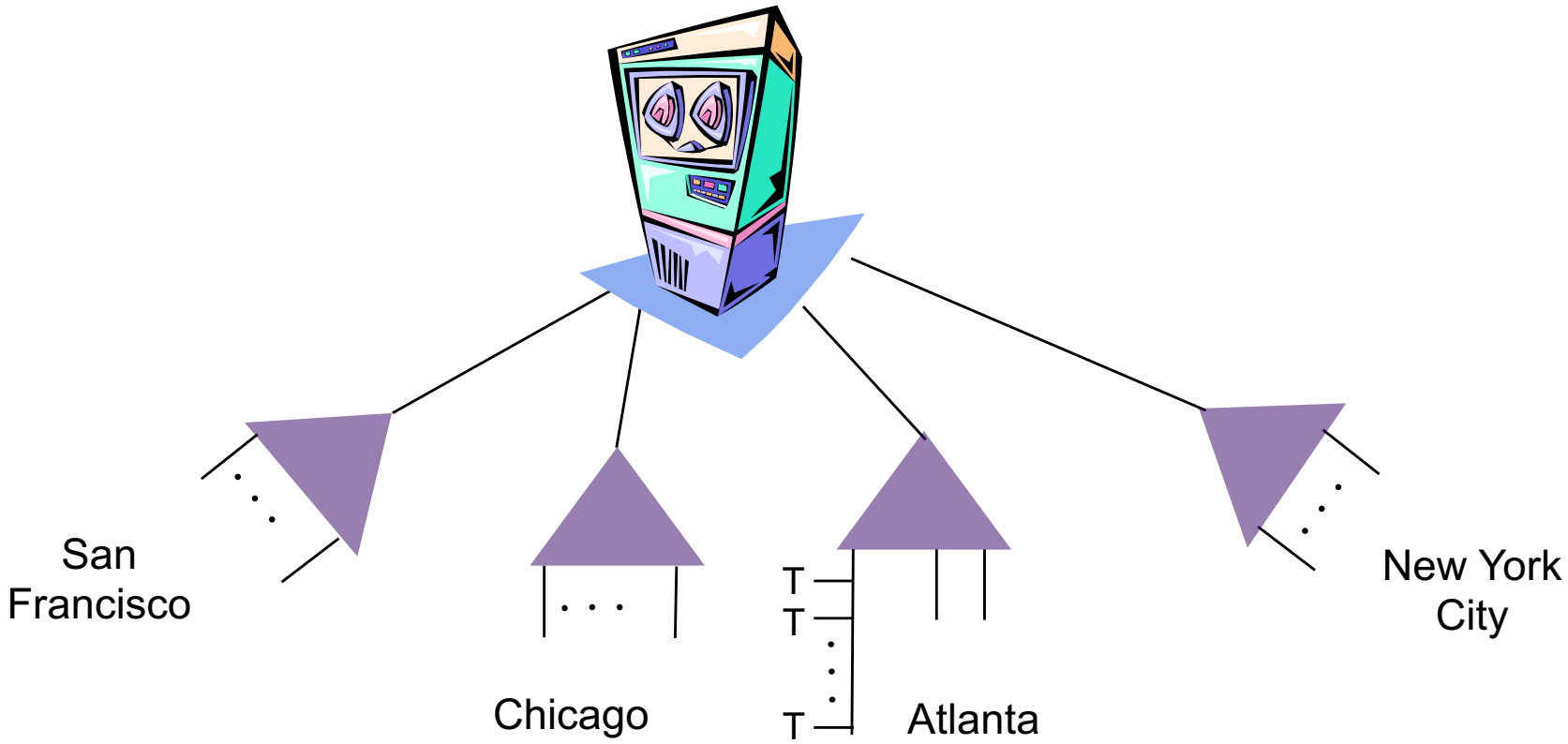
- Multiplexer allows a line to carry *frames* that contain messages to/from multiple terminals
- Frames are buffered at *multiplexer* until line becomes available, i.e. store-and-forward
- *Address* in frame header identifies terminal
- Header carries other *control* and error checking information



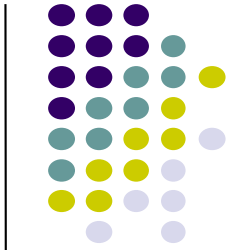
Tree Topology Networks



- National & international terminal-oriented networks
- Routing was very simple (to/from host)
- Each network typically handled a single application



Computer-to-Computer Networks



- As cost of computing dropped, terminal-oriented networks viewed as too inflexible and costly
- Needed flexible computer networks
  - Interconnect computers as required
  - Support many applications
- Application Examples
  - File transfer between arbitrary computers
  - Execution of a program on another computer
  - Multiprocess operation over multiple computers

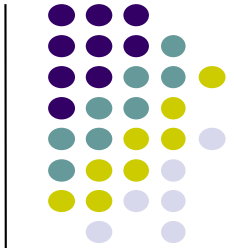
Origins of Internet

Larry Roberts: ARPANET

Vint Cerf & Bob Kahn: TCP/IP

Tim Berners-Lee: World-Wide Web

Packet Switching



- Network should support multiple applications
  - Transfer arbitrary-size messages
  - Low-delay short messages for interactive applications
  - But in store-and-forward operation, long messages induce high delay on interactive messages
- Packet switching
  - Network transfers packets using store-and-forward
  - Packets have maximum length
  - Break long messages into multiple packets
- ARPANET testbed led to many innovations

ARPANET Packet Switching

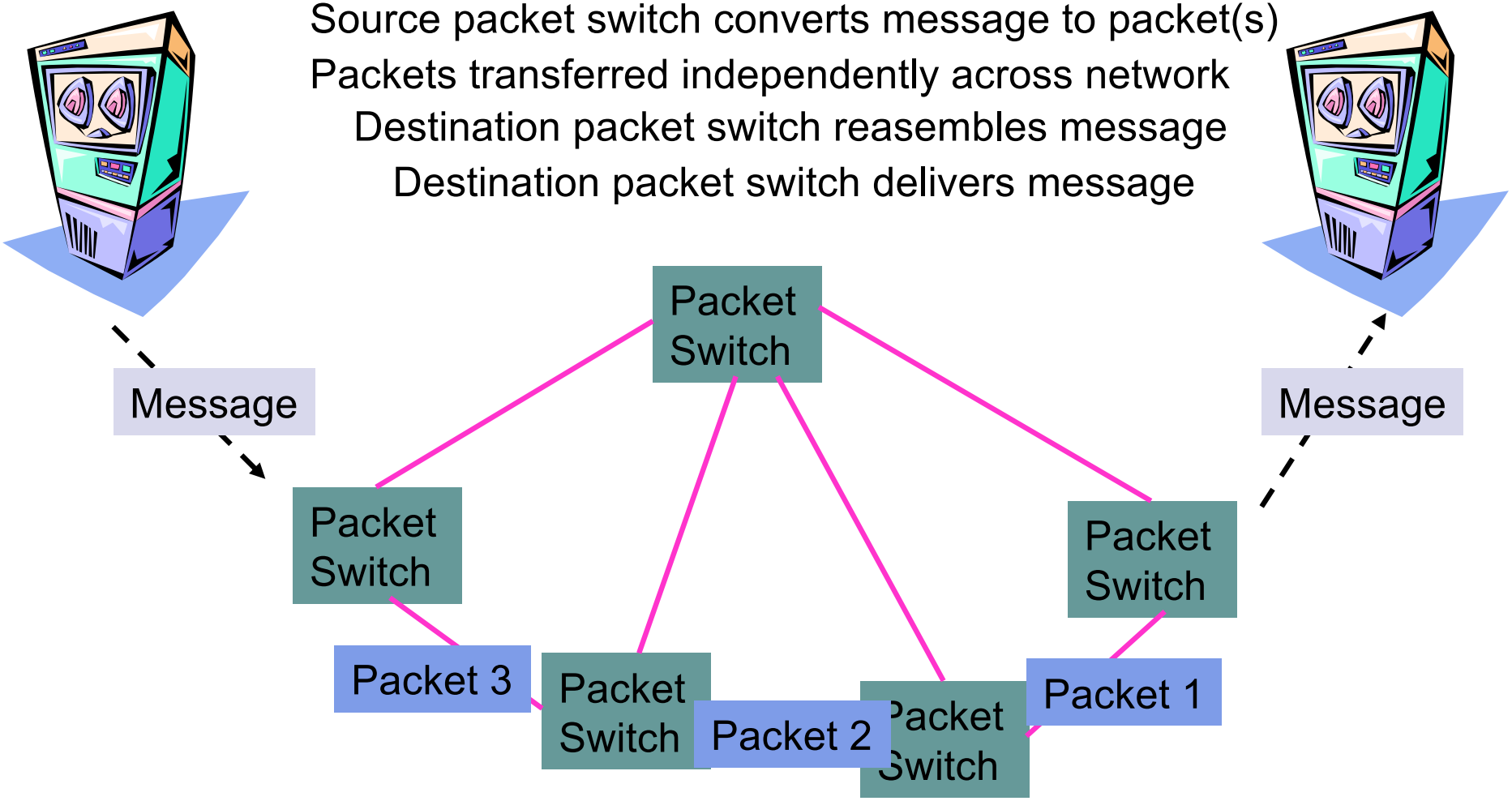
Host generates message

Source packet switch converts message to packet(s)

Packets transferred independently across network

Destination packet switch reasembles message

Destination packet switch delivers message



ARPANET Routing

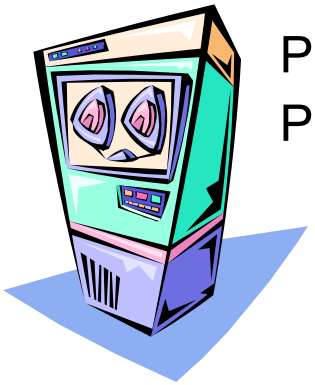
Routing is highly nontrivial in large mesh networks

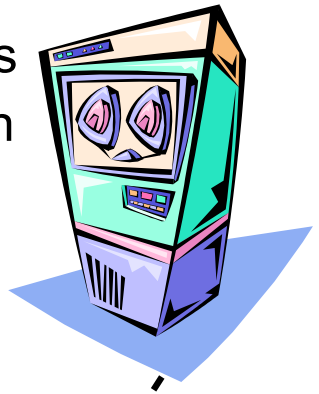
No connection setup prior to packet transmission

Packets header includes source & destination addresses

Packet switches have table with next hop per destination

Routing tables calculated by packet switches using distributed algorithm





Packet Switch

Packet Switch

Packet Switch

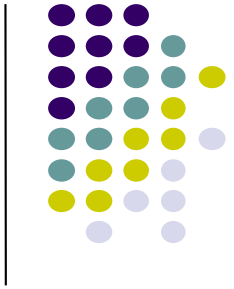
Packet Switch

Packet Switch

Hdr Packet

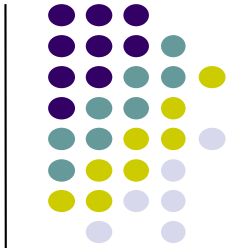
Dest:	Next Hop:
xyz	abc
wvr	edf

The Internet

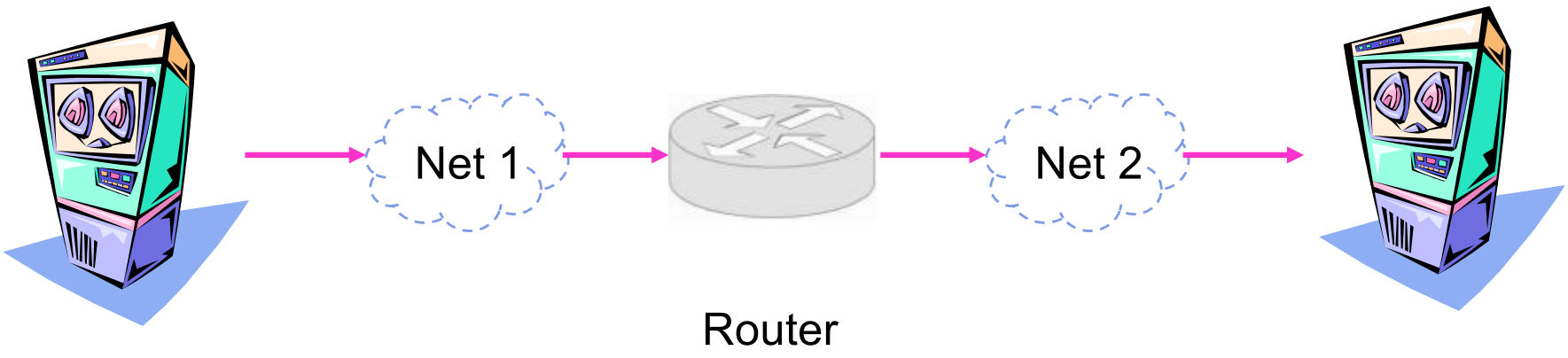


- *Different* packet switching networks emerged for data transfer between computers
  - Wired, satellite, radio packet networks
- Each network has its protocols and uses different technologies
- *Internetworking protocols* invented to enable communications between computers attached to *different* networks
- ***Internet***: a network of networks

Internet Protocol (IP)

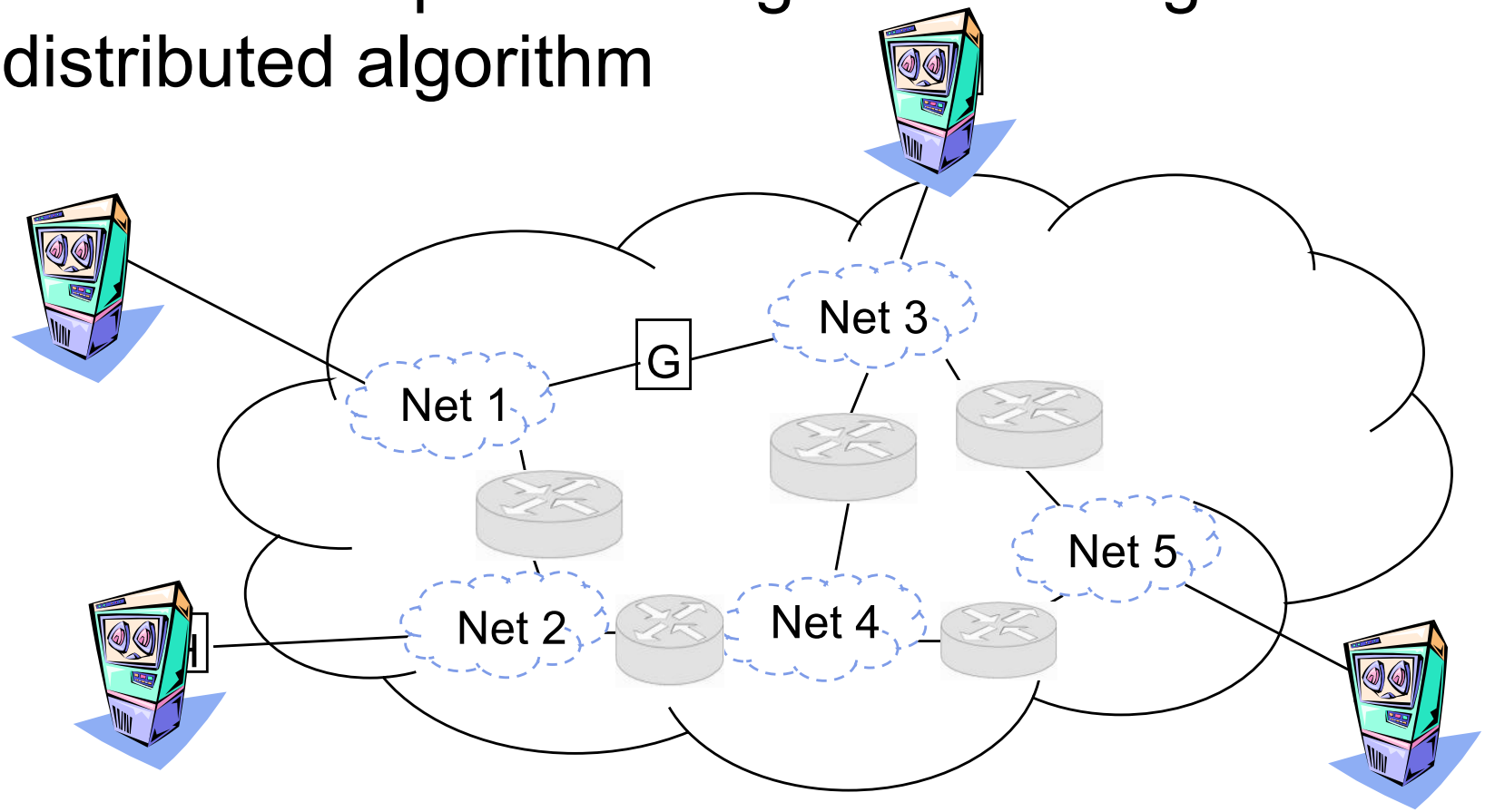


- *Routers (gateways)* interconnect networks
- Host computers prepare IP packets and transmit them over their attached network
- Each network has own addresses & protocols
- Routers forward IP packets across networks
- *Best-effort* IP transfer service, no retransmission

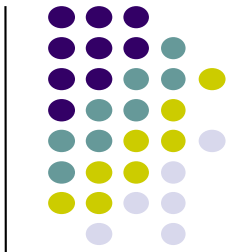


Addressing & Routing

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



Elements of Computer Network Architecture



- Transfer packets across a network of networks
- Each packet transferred across sequence of networks (that possibly use different technology)
- *Hierarchical addresses* identify
  - attachment to a network
  - host within the network
- Distributed calculation of *routing tables*