EC 745 Telecommunication Networks

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Introduction

- Course website:

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- Textbook:

  Communication Networks: Fundamental Concepts and Key Architectures, Alberto-Leon Garcia and I. Widjaja, 2nd ed, McGraw-Hill, 2004.

Chapter 1
Communication Networks and Services

Network Architecture and Services
Telegraph Networks & Message Switching
Telephone Networks and Circuit Switching
Computer Networks & Packet Switching
Future Network Architectures and Services
Key Factors in Network Evolution

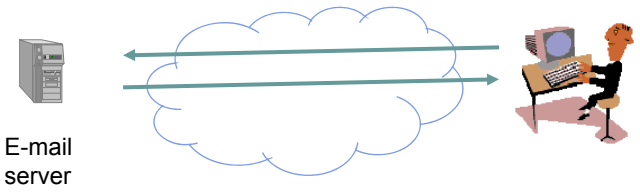
Chapter 1
Communication Networks and Services

Network Architecture and Services

Communication Services & Applications

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

E-mail



Exchange of text messages via servers

Communication Services & Applications

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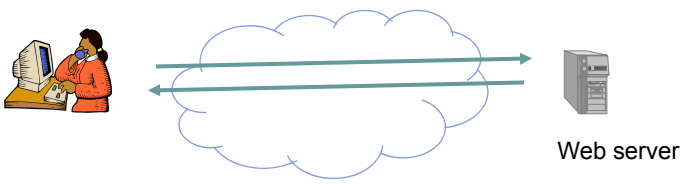
Web Browsing



Retrieval of information from web servers

Communication Services & Applications

- A communication service enables the exchange of information between users at different locations.
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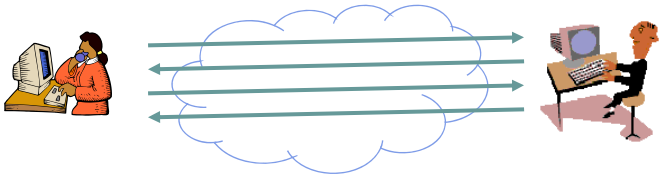
Instant Messaging



Direct exchange of text messages

Communication Services & Applications

- A communication service enables the exchange of information between users at different locations.
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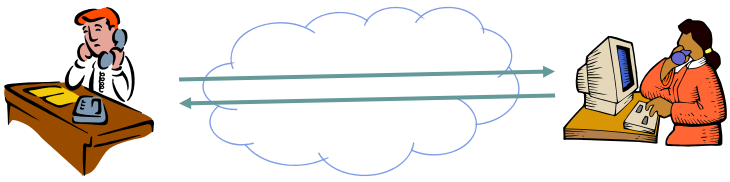
Telephone



Real-time bidirectional voice exchange

Communication Services & Applications

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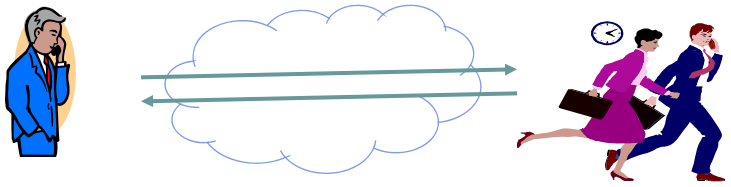
Cell phone



Real-time voice exchange with mobile users

Communication Services & Applications

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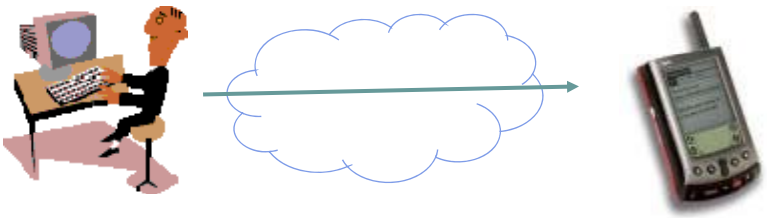
Short Message Service



Fast delivery of short text messages

Many other examples!

- Peer-to-peer applications
- Audio & video streaming
- Network games
- On-line purchasing
- Text messaging in PDAs, cell phones (SMS)
- Voice-over-Internet

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
  - Fax and modems build on basic telephone service
- New applications build on multiple networks
  - 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 …

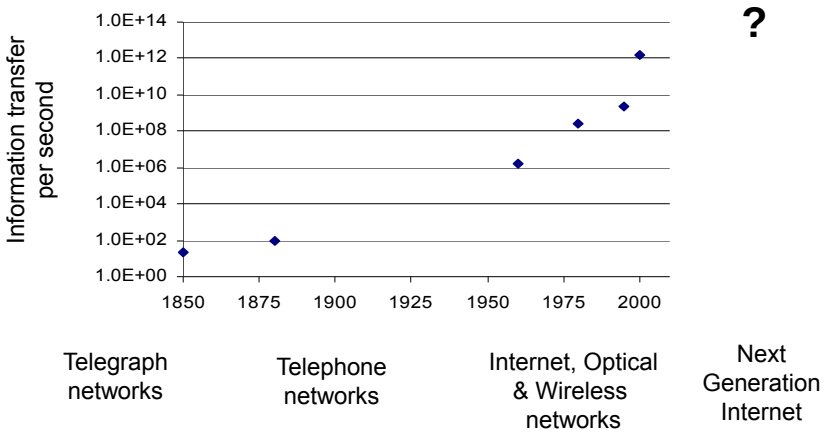
How are communication networks designed and operated?

Communication Network Architecture

- *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*

Next we will trace evolution of three network architectures: telegraph, telephone, and computer networks

Network Architecture Evolution



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
  - Multiservice packet switching network

Chapter 1
Communication Networks and Services

Telegraph Networks & Message Switching

Telegraphs & Long-Distance Communications

Approaches to long-distance communications

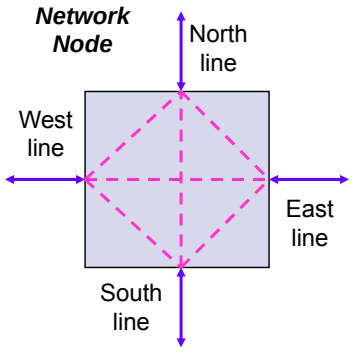
- Courier: physical transport of the message
  - DHL, Aramex, FedEx
- Telegraph: message is transmitted across a network using signals
  - Drums, beacons, mirrors, smoke, flags, semaphores…
  - Electricity, light
- Telegraph delivers message much sooner

Optical (Visual) Telegraph

- Claude Chappe invented optical telegraph in the 1790's
- Semaphore mimicked a person with outstretched arms with flags in each hand
- Different angle combinations of arms & hands generated 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 each line were decoded
  - Next-hop in ***route*** determined by destination ***address*** of a message
  - Each message was carried by hand to next line, and stored until operator became available for next 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

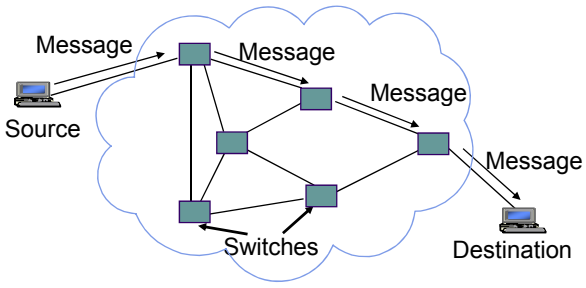
Digital Communications

- Morse code converts text message into sequence of dots and dashes
- Use transmission system designed to convey dots and dashes

	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

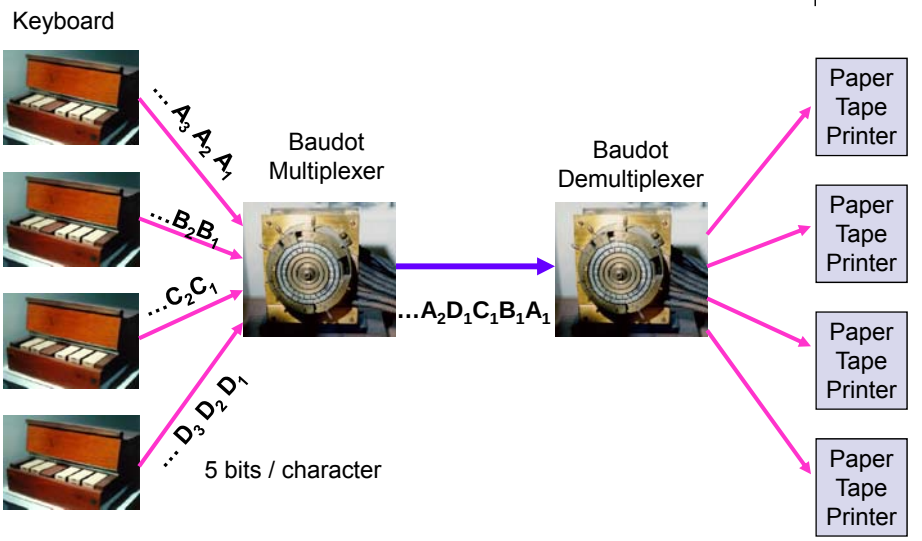
- Electric telegraph networks exploded
  - Message switching & Store-and-Forward operation
  - Key elements: Addressing, Routing, Forwarding
- Optical telegraph networks disappeared



Baudot Telegraph Multiplexer

- Operator 25-30 words/minute
  - but a wire can carry much more
- Baudot multiplexer: Combine 4 signals in 1 wire
  - Binary block *code* (ancestor of ASCII code)
    - A character represented by 5 bits
  - Time division *multiplexing*
    - Binary codes for characters are interleaved
  - *Framing* is required to recover characters from the binary sequence in the multiplexed signal
  - *Keyboard* converts characters to bits

Baudot Telegraph Multiplexer



Elements of Telegraph Network Architecture

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

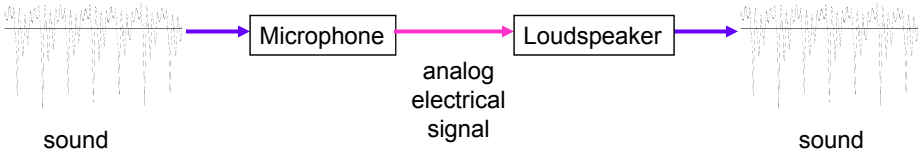
Chapter 1
Communication Networks and Services

Telephone Networks and Circuit Switching

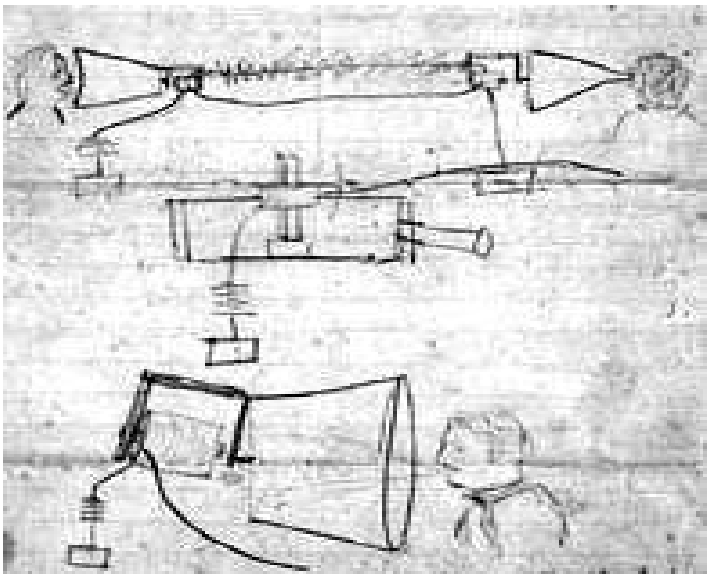
Bell's Telephone

- Alexander Graham Bell (1875) working on harmonic telegraph to multiplex telegraph signals
- 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

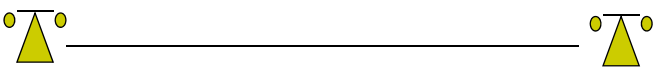


Bell's Sketch of Telephone



Signaling

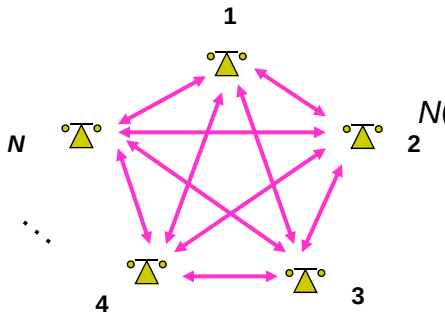
- Signaling required to establish a call
  - Flashing light and ringing devices to alert the called party of incoming call
  - Called party information to operator to establish calls



Signaling + voice signal transfer

The N^2 Problem

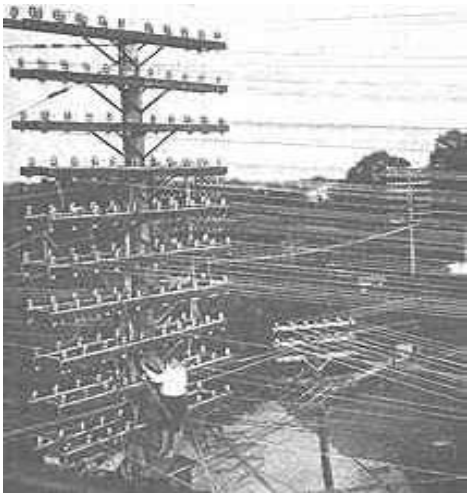
- For N users to be fully connected *directly*
- Requires $N(N-1)/2$ connections
- Requires too much space for cables
- Inefficient & costly since connections not always on



$N = 1000$

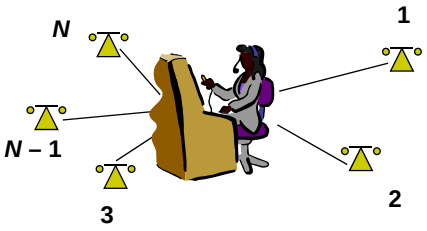
$N(N-1)/2 = 499500$

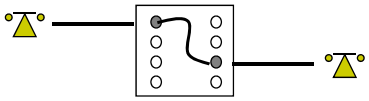
Telephone Pole Congestion



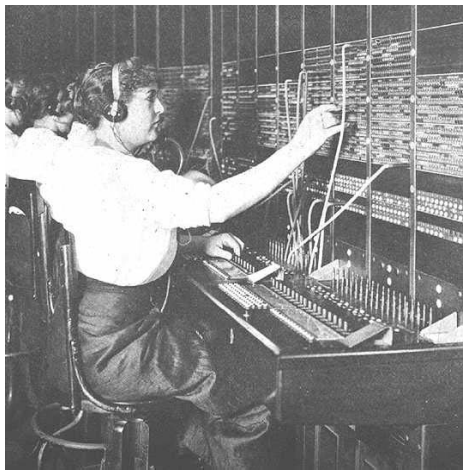
Circuit Switching

- 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



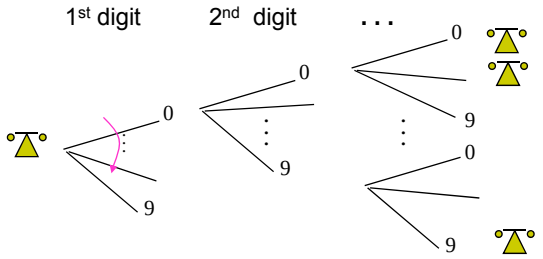


Manual Switching



Strowger Switch

- Human operators intelligent & flexible
  - But expensive and not always discreet
- Strowger invented automated switch in 1888
  - Each current pulse advances wiper by 1 position
  - User dialing controls connection setup
- Decimal telephone numbering system
- Hierarchical network structure simplifies routing
  - Area code, exchange (CO), station number



Strowger Switch

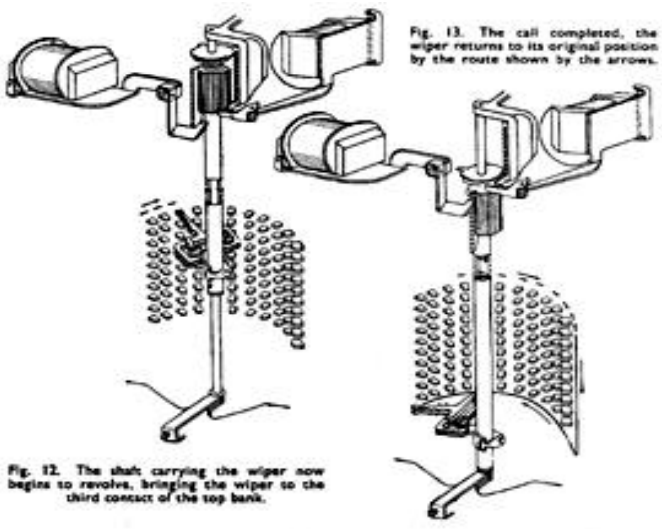
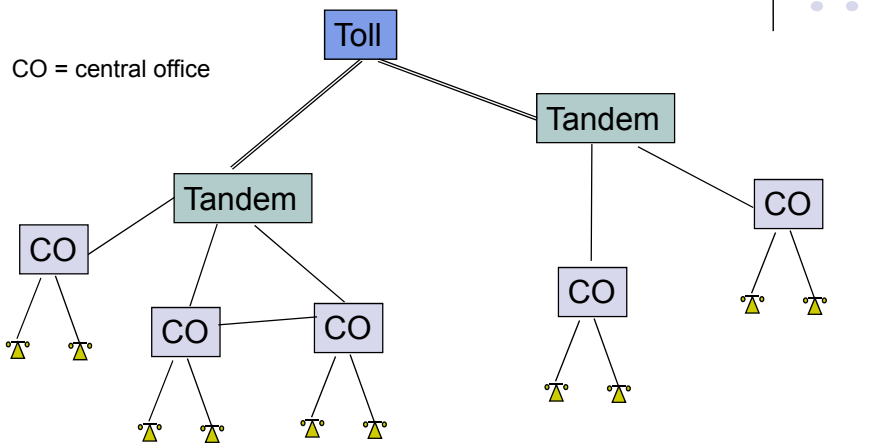


Fig. 13. The call completed, the wiper returns to its original position by the route shown by the arrows.

Fig. 12. The shaft carrying the wiper now begins to revolve, bringing the wiper to the third contact of the top bank.

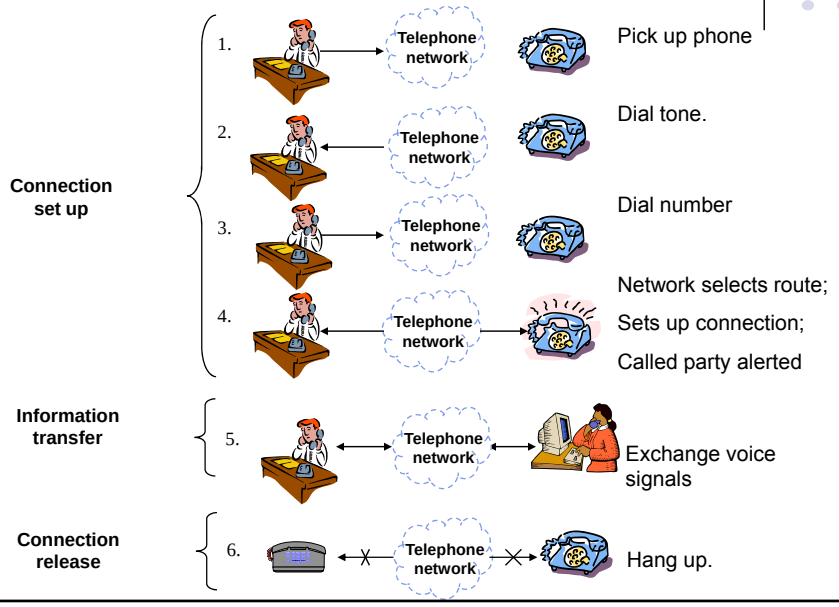
Hierarchical Network Structure



Telephone subscribers connected to local CO (central office)

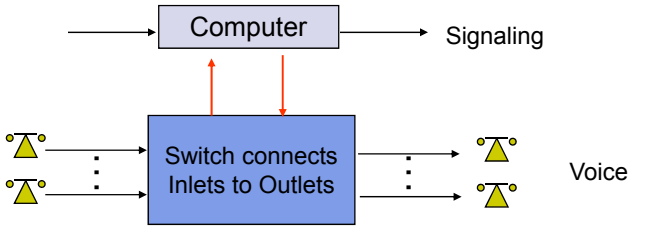
Tandem & Toll switches connect CO's

Three Phases of a Connection



Computer Connection Control

- A computer controls connection in telephone switch
- Computers exchange *signaling messages* to:
  - Coordinate set up 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

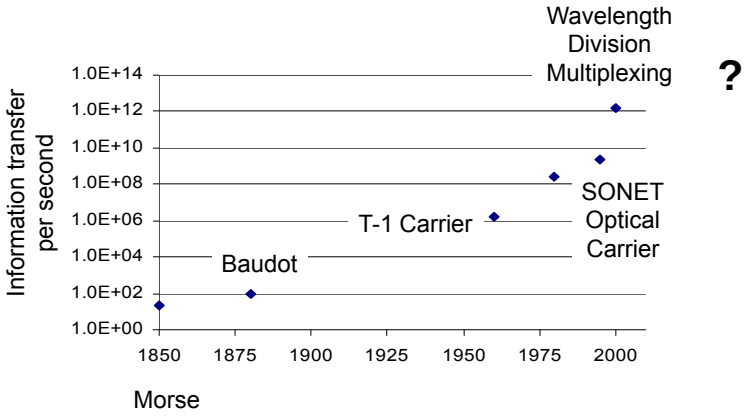


Digitization of Telephone Network

- 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
- Digital Switching (1980s)
  - Switch TDM signals without conversion to analog form
- Digital Cellular Telephony (1990s)
- Optical Digital Transmission (1990s)
  - One OC-192 optical signal = 10×10^9 bps
  - One optical fiber carries 160 OC-192 signals = 1.6×10^{12} bps!

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