CS4220
Computer Networks

Lecture 2 Physical Layer

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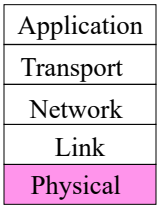
The Physical Layer
Chapter 2

- Theoretical Basis for Data Communications
- Guided Transmission Media
- Wireless Transmission
- Communication Satellites
- Digital Modulation and Multiplexing
- Public Switched Telephone Network
- Mobile Telephone System
- Cable Television

The Physical Layer

- Foundation on which other layers build
  - Properties of wires, fiber, wireless limit what the network can do
- Key problem is to send (digital) bits using only (analog) signals
  - This is called modulation



The Theoretical Basis for Data Communication

Data information can be transmitted on wires by varying some physical property as voltage.

- Fourier Analysis
- Bandwidth-Limited Signals
- Maximum Data Rate of a Channel
  - Shannon's theorem

Guided Transmission (Wires & Fiber)

- Media have different properties, hence performance
  - Reality check
    - Storage media »
  - Wires:
    - Twisted pairs »
    - Coaxial cable »
    - Power lines »
  - Fiber cables »

Storage Media

- Given a 200GB tape, a box 60 X 60 X 60cm can hold about 1000 of these tapes. A box can be delivered anywhere domestically in 24 hours. What is the effective bandwidth?

What are the major problems with storage media?

Twisted Pair

- A twisted pair consists of two insulated copper wires, typically about 1mm thick. Very Common (phone lines)
  - More twists per cm leads to less crosstalk and better quality over longer distance

(a)

Why twisted pairs are widely used?

(b)

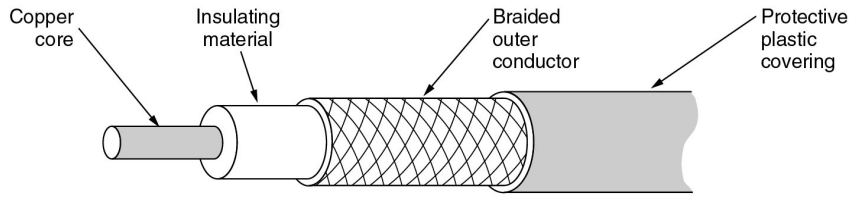
(a) Category 3 UTP (16 MHz). (b) Category 5 UTP (100 MHz).

Link Terminology

- Full-duplex link
  - Used for transmission in both directions at once
  - e.g., use different twisted pairs for each direction
- Half-duplex link
  - Both directions, but not at the same time
  - e.g., senders take turns on a wireless channel
- Simplex link
  - Only one fixed direction at all times; not common

Coaxial Cable

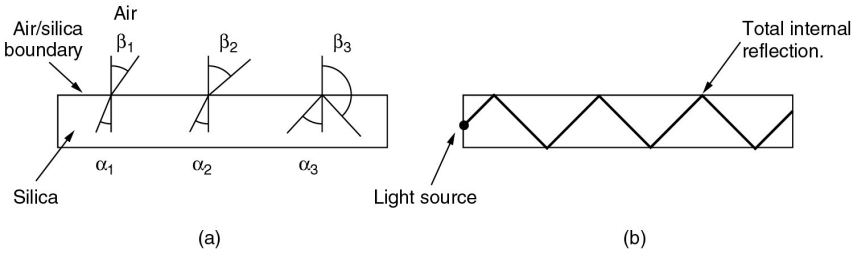
- **A good combination of high bandwidth and excellent noise immunity.**
  - **Used to be in telecom for long-distance lines (replaced by fiber optics), but still widely used in cable TV and MANs.**



A coaxial cable.

Fiber Optics

- **An optical transmission system has three key components: the light source, transmission medium, and the detector**
  - **Main issue: light leaking**



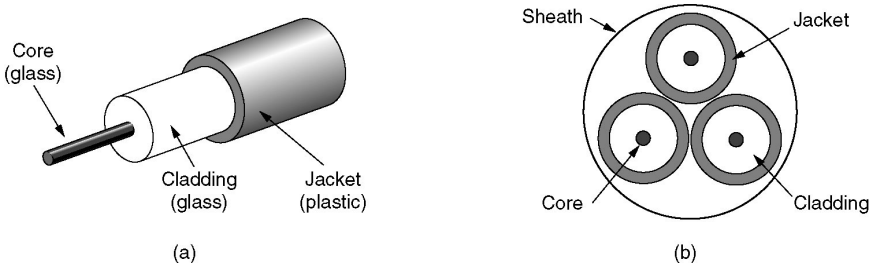
(a) Three examples of a light ray from inside a silica fiber impinging on the air/silica boundary at different angles.

(b) Light trapped by total internal reflection (multimode fiber).

Fiber Cables

(a) Side view of a single fiber.

(b) End view of a sheath with three fibers.



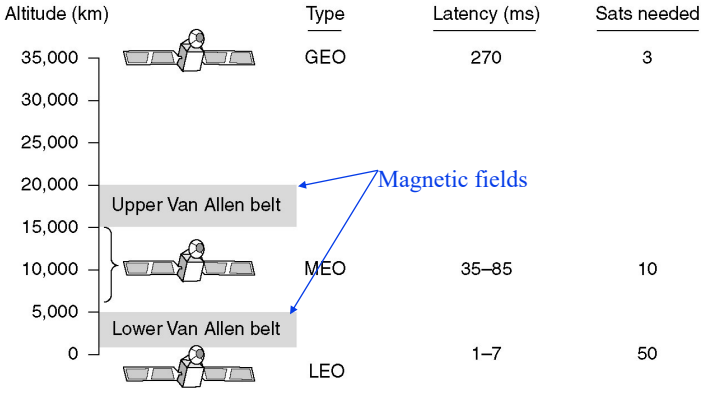
Wireless Transmission

- The Electromagnetic Spectrum
- Radio Transmission
- Microwave Transmission
- Infrared and Millimeter Waves
- Lightwave Transmission

Communication Satellites

- Geostationary Satellites
- Medium-Earth Orbit Satellites
- Low-Earth Orbit Satellites
- Satellites versus Fiber

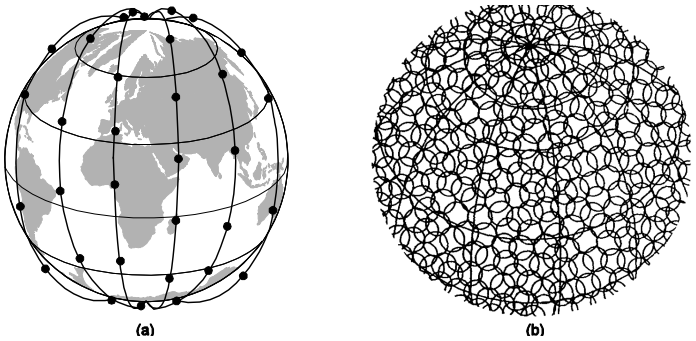
Communication Satellites



Communication satellites and some of their properties, including altitude above the earth, round-trip delay time and number of satellites needed for global coverage.

Low-Earth Orbit Satellites Iridium

- Iridium: to provide worldwide telecommunication service using hand-held devices that communicate directly with the (66) Iridium satellites.



(a) The Iridium satellites from six necklaces around the earth.

(b) 1628 moving cells cover the earth.

Why Iridium lost business?

Multiplexing

Multiplexing many conversations into a single physical trunk

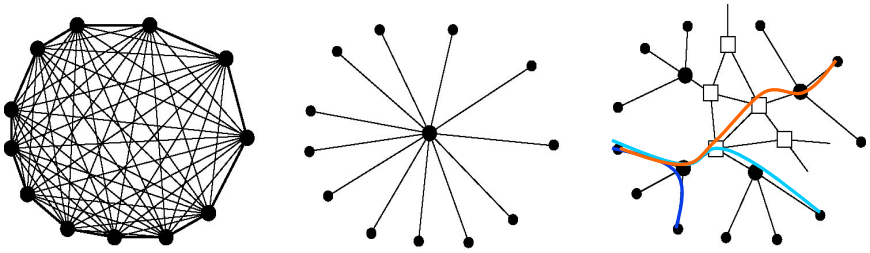
- FDM (Frequency Division Multiplexing)
  - The overall frequency spectrum is divided into frequency bands, with each user having exclusive possession of some band.
- TDM (Time Division Multiplexing)
  - The users take turns (Round-Robin), each one periodically getting the entire bandwidth for a little burst of time.

Public Switched Telephone System

- Structure of the Telephone System
- The Politics of Telephones
- The Local Loop: Modems, ADSL and Wireless
- Trunks and Multiplexing
- Switching

Structure of the Telephone System

- PSTN (Public Switched Telephone Network):
  - voice or data (56 kbps vs. 1 Gbps)



(a) (b) (c)

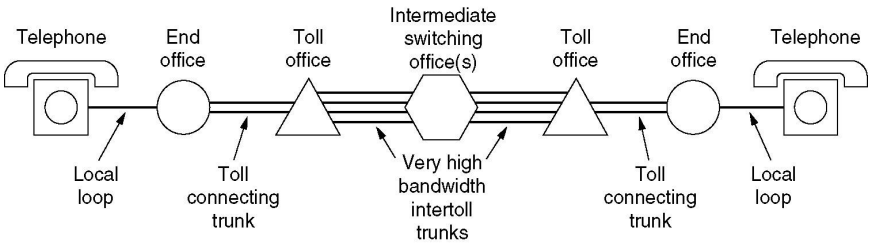
(a) Fully-interconnected network.

(b) Centralized switch.

(c) Two-level hierarchy.

Structure of the Telephone System (2)

- Three major components in the telephone system
  - Local loops ("last mile", analog - > digital)
  - Trunks (Multiplexing)
  - Switching offices



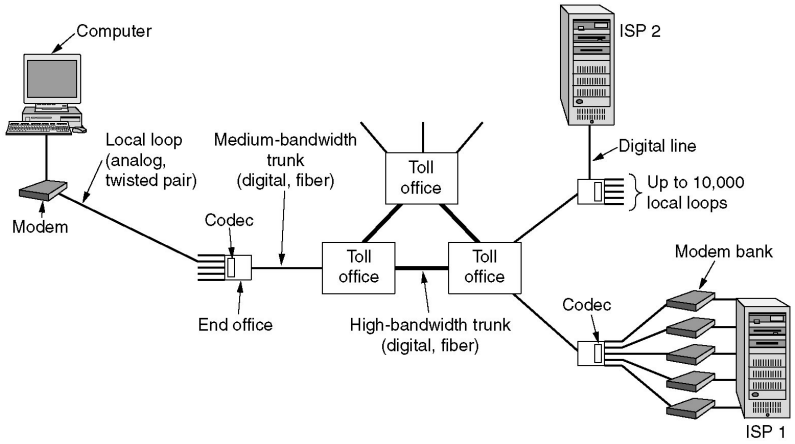
A typical circuit route for a medium-distance call.

Major Components of the Telephone System

- **Local loops**
  - Analog twisted pairs going to houses and businesses
- **Trunks**
  - Digital fiber optics connecting the switching offices
- **Switching offices**
  - Where calls are moved from one trunk to another

The Local Loop: Modems, ADSL, and Wireless

The use of both analog and digital transmissions for a computer to computer call. Conversion is done by the modems and codecs.



Topology Impact on Transmission Paths

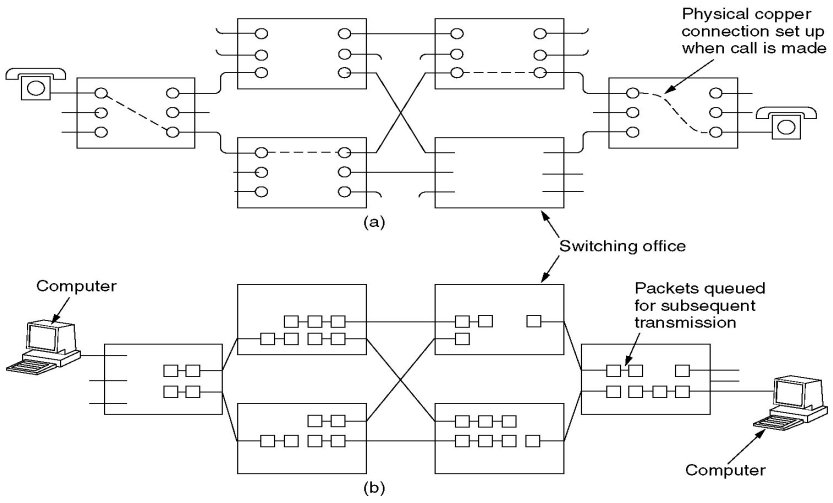
- **A packet-switching network has a star topology with a central switch. It has n nodes. What are the best-, average-, and worst-case transmission paths in hops?**

How about a bidirectional ring, and a fully interconnected packet-switching networks?

Switching

- Circuit Switching
- Message Switching
- Packet Switching

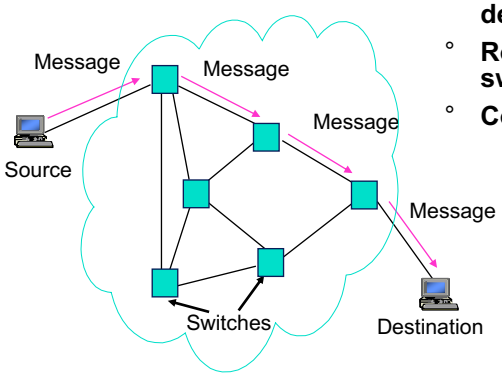
Circuit Switching vs. Packet Switching



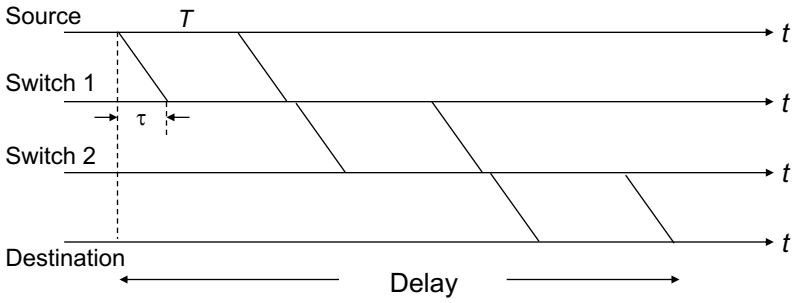
(a) Circuit switching. (b) Packet switching.

Message Switching

- Message switching invented for telegraphy
- Entire messages multiplexed onto shared lines, stored & forwarded
- Headers for source & destination addresses
- Routing at message switches
- Connectionless



Message Switching Delay

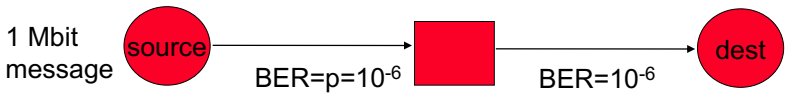


Minimum delay = $3\tau + 3T$

Additional queueing delays possible at each link

What are the major problems?

Long Messages vs. Packets



How many bits need to be transmitted to deliver message?

- Approach 1: send 1 Mbit message
- Probability message arrives correctly

$$P_c = (1-10^{-6})^{10^6} \approx e^{-10^6 10^{-6}} = e^{-1} \approx 1/3$$

- On average it takes about 3 transmissions/hop
- Total # bits transmitted ≈ 6 Mbits

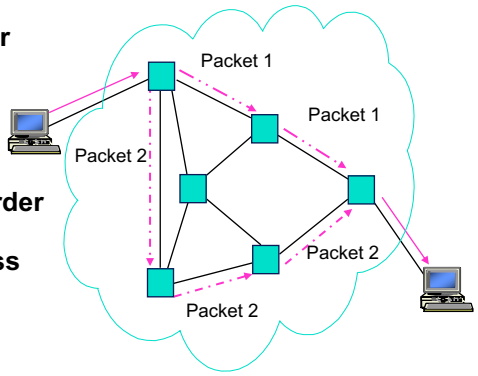
- Approach 2: send 10 100-kbit packets
- Probability packet arrives correctly

$$P_c' = (1-10^{-6})^{10^5} \approx e^{-10^5 10^{-6}} = e^{-0.1} \approx 0.9$$

- On average it takes about 1.1 transmissions/hop
- Total # bits transmitted ≈ 2.2 Mbits

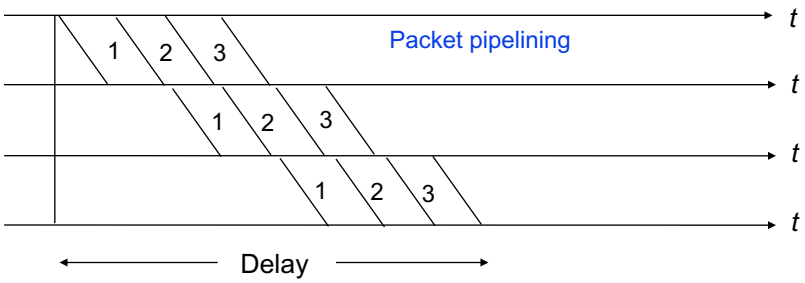
Packet Switching - Datagram

- Messages broken into smaller units (packets)
  - A packet has maximum size
- Source & destination addresses in packet header
- Connectionless, packets routed independently (datagram)
- Packet may arrive out of order
- Pipelining of packets across network can reduce delay, increase throughput
- Lower delay that message switching, suitable for interactive traffic



Packet Switching Delay

Assume three packets corresponding to one message traverse same path

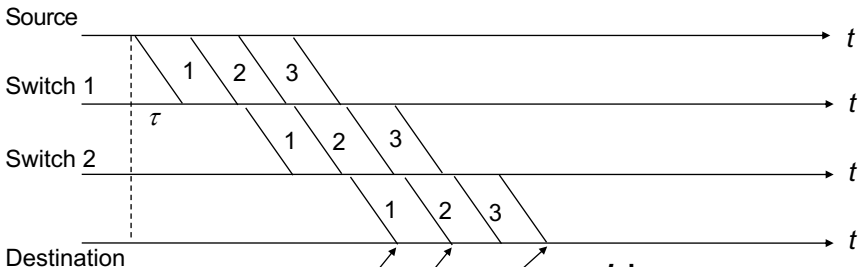


Minimum Delay = $3\tau + 5(T/3)$ (single path assumed)

Additional queueing delays possible at each link

Packet pipelining enables message to arrive sooner

Delay for k-Packet Messge over L Hops



3 hops

$3\tau + 2(T/3)$ first bit received

$3\tau + 3(T/3)$ first bit released

$3\tau + 5(T/3)$ last bit released

***L* hops**

$L\tau + (L\text{-}1)P$ first bit received

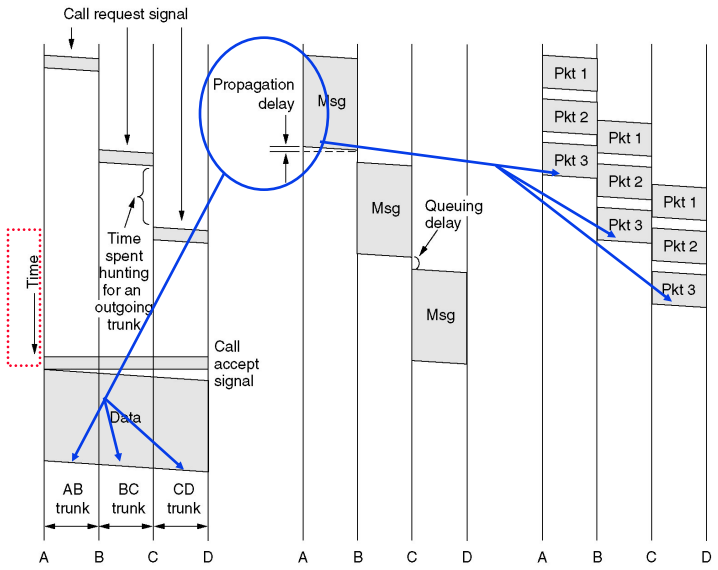
$L\tau + LP$ first bit released

$L\tau + LP + (k\text{-}1)P$ last bit released

or $L\tau + (L\text{-}1)P + kP$

where $T = k\,P$ *(what is P indeed?)*

Circuit, Message, Packet Switchings



(a) Circuit switching. **(b)** Message switching. **(c)** Packet switching

Switching Performance

- What is the delay of sending an *X*-bit message over a *L*-hop path in a circuit-switched network? The circuit setup time is *s* sec, the propagation delay is τ sec per hop, and the data rate is *b* bps.
- What is the delay of sending an *X*-bit message over a *L*-hop path in a lightly-loaded packet-switched network? The propagation delay per packet is τ sec per hop, the packet size is *p* bits, and the data rate is *b* bps.

Packet Switching

Item	Circuit-switched	Packet-switched
Call setup	Required	Not needed
Dedicated physical path	Yes	No
Each packet follows the same route	Yes	No
Packets arrive in order	Yes	No
Is a switch crash fatal	Yes	No
Bandwidth available	Fixed	Dynamic
When can congestion occur	At setup time	On every packet
Potentially wasted bandwidth	Yes	No
Store-and-forward transmission	No	Yes
Transparency	Yes	No
Charging	Per minute	Per packet

A comparison of circuit switched and packet-switched networks.

Bit Rates of Digital Transmission Systems

System	Bit Rate	Observations
Telephone twisted pair	33.6-56 kbps	4 kHz telephone channel
Ethernet twisted pair	10 Mbps, 100 Mbps	100 meters of unshielded twisted copper wire pair
Cable modem	500 kbps-4 Mbps	Shared CATV return channel
ADSL twisted pair	64-640 kbps in, 1.536-6.144 Mbps out	Coexists with analog telephone signal
2.4 GHz radio	2-11 Mbps	IEEE 802.11 wireless LAN
28 GHz radio	1.5-45 Mbps	5 km multipoint radio
Optical fiber	2.5-10 Gbps	1 wavelength
Optical fiber	>1600 Gbps	Many wavelengths

Summary: Questions of Interests

- How long will it take to transmit a message?
  - How many bits are in the message (text, image)?
  - How fast does the network/system transfer information?
- Can a network/system handle a voice (video) call?
  - How many bits/second does voice/video require? At what quality?
- How long will it take to transmit a message without errors?
  - How are errors introduced?
  - How are errors detected and corrected?
- What transmission speed is possible over radio, copper cables, fiber, …?

Summary: A Transmission System

Transmitter

- Converts information into *signal* suitable for transmission
- Injects energy into communications medium or channel
  - Telephone converts voice into electric current
  - Modem converts bits into tones

Receiver

- Receives energy from medium
- Converts received signal into form suitable for delivery to user
  - Telephone converts current into voice
  - Modem converts tones into bits

Summary: Transmission Impairments

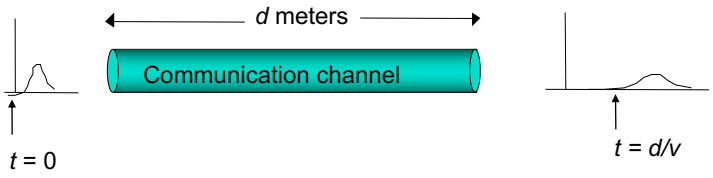
Communication Channel

- Pair of copper wires
- Coaxial cable
- Radio
- Light in optical fiber
- Light in air
- Infrared

Transmission Impairments

- Signal attenuation
- Signal distortion
- Spurious noise
- Interference from other signals

Summary: Fundamental Issues in Transmission Media



- **Propagation speed of signal**
  - **c = 3 x 10^8 meters/second in vacuum**
  - **$\nu = c/\sqrt{\varepsilon}$ speed of light in medium where $\varepsilon > 1$ is the dielectric constant of the medium**
  - **ν = 2.3 x 10^8 m/sec in copper wire; ν = 2.0 x 10^8 m/sec in optical fiber**

Reading and Homework

- Chapter 2 of the textbook.
- Homework
  - Posted on the course web site.