CPE 490: Information Systems Engineering I: Computer Networking

Chapter 2 - The Physical Layer

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Outline

- Physical Transmission Medium
  - Twisted Pair
  - Coaxial Cable
  - Fiber Optics
- Wireless Transmissions
  - The Electromagnetic Spectrum
  - Radio Transmission; Microwave Transmission
  - Infrared and Millimeter Waves; Lightwave Transmission
  - Communication Satellites
- Public Switched Telephone System (PSTN)
  - PSTN
  - Multiplexing: FDM, WDM, TDM, CDM
- The Mobile Telephone System:
  - 1G - Analog
  - 2G, 3G - Digital

The Theoretical Basis for Data Communication

- Maximum Data Rate of a Channel
  - ✓ Nyquist's Theorem:
    - ✓ Maximum data rate = $2H \log_2 V$ bits/sec
    - H – bandwidth of the filter (channel).
    - V – number of discrete levels (e.g., binary – 2).
  - ✓ Shannon's result for a noise channel:
    - Maximum data rate = $H \log_2 (1 + S/N)$ bits/sec
    - S/N – the ratio of signal power to noise power .

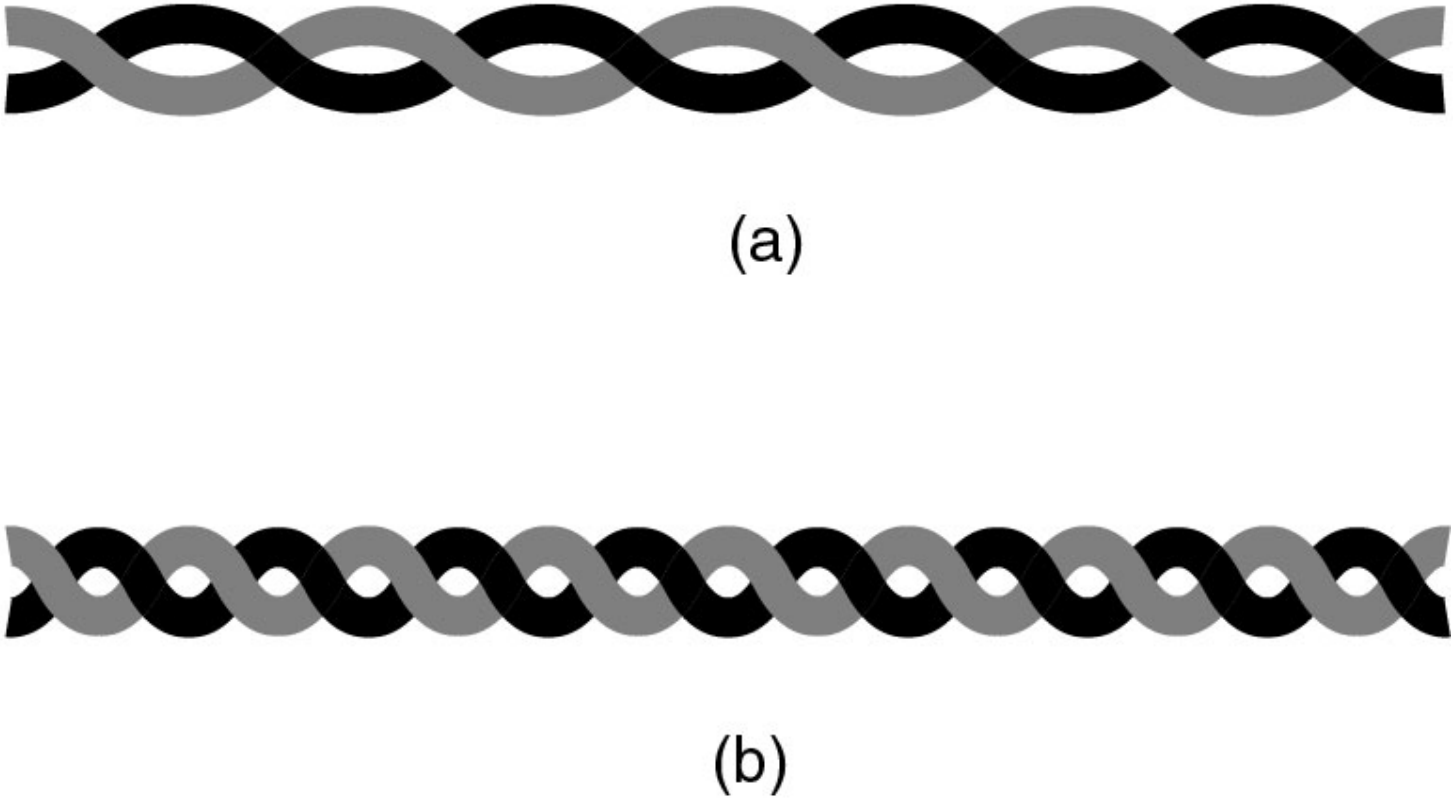
Physical Transmission Medium

- Twisted Pair
- Coaxial Cable
- Fiber Optics

Twisted Pair

- A twisted pair consists of two insulated copper wires
  - 1mm thick.
- When two wires are twisted, the waves cancel out,
  - so the wire radiates less effectively – less interference.
- Twisted pairs are commonly used in telephone system.
  - from telephones to the switching office.
- Twisted pairs can be used to transmit both analog and digital signals.
  - The bandwidth depends on the thickness of the wire and the distance.
  - Several megabits/sec. for a few kilometers.
- Two typical twisted pairs.
  - Category 3 UTP (Unshielded Twisted Pair)
    - Shielded Twisted Pair: The expensive shielded twisted pair cables by IBM in 1980s.
  - Category 5 UTP
    - More twists per centimeter
    - Less crosstalk and better-quality signal over longer distance.

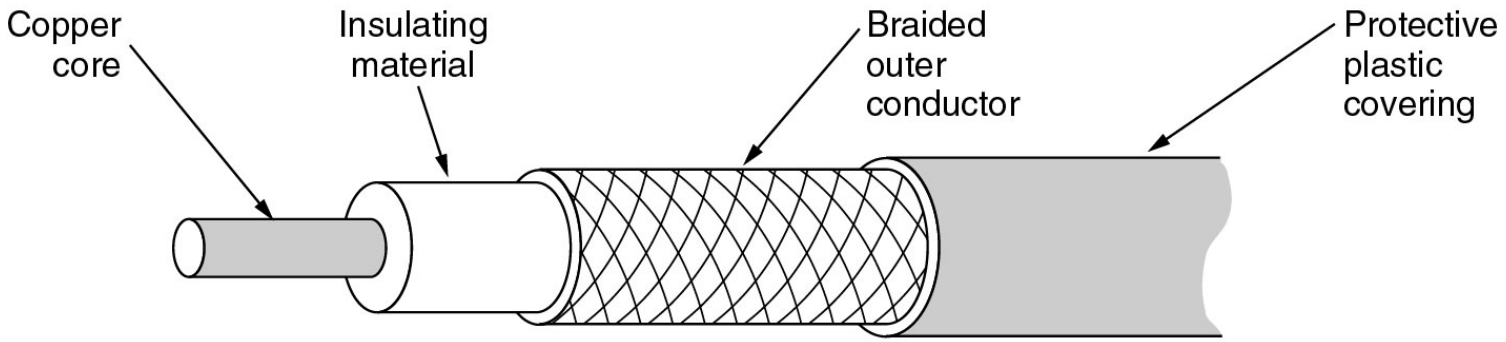
Twisted Pair



(a) Category 3 UTP. (b) Category 5 UTP.

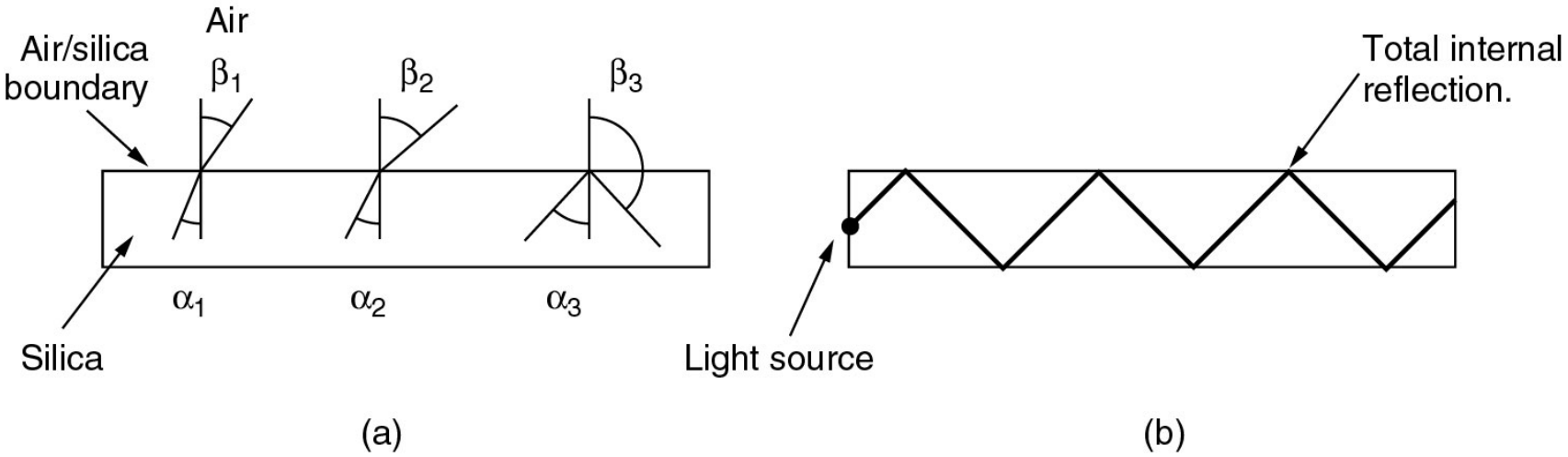
Coaxial Cable

- Coaxial Cable has better shielding than twisted pairs
  - ✓ so it can span longer distances at higher speeds.
- Two kinds of coaxial cables are widely used
  - ✓ 50-ohm cable – digital signal.
  - ✓ 75- ohm cable – analog transmission, cable TV, and Internet over cable.



A coaxial cable.

Fiber Optics

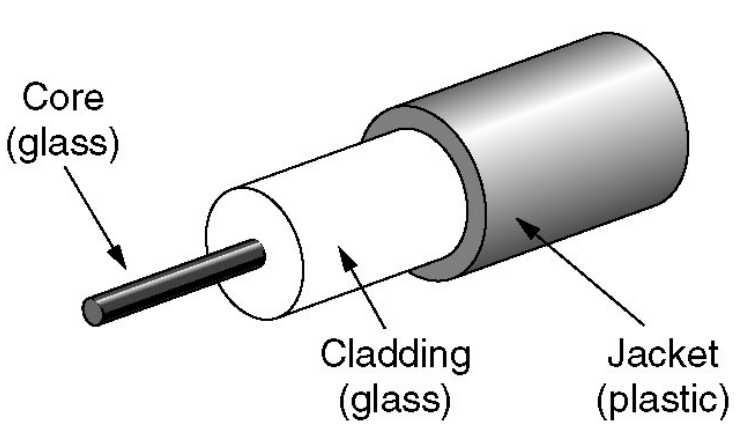


(a) Three examples of a light ray from inside a silica fiber impinging on the air/silica boundary at different angles.

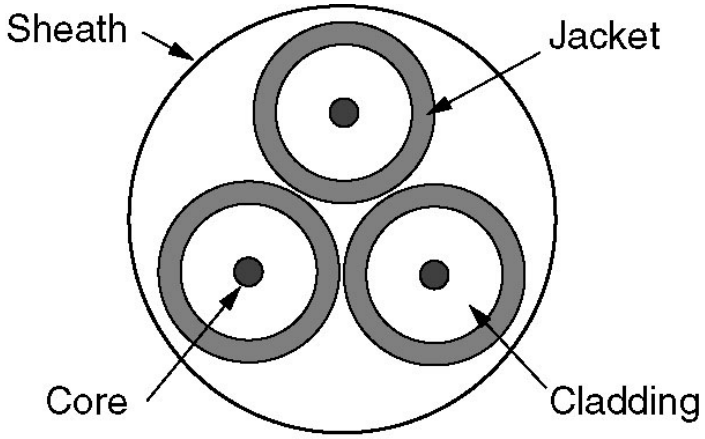
(b) Light trapped by total internal reflection.

Fiber Cables

- The light propagates through the core glass.
- The core is surrounded by a glass cladding with a lower index of refraction.



(a)



(b)

(a) Side view of a single fiber.

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

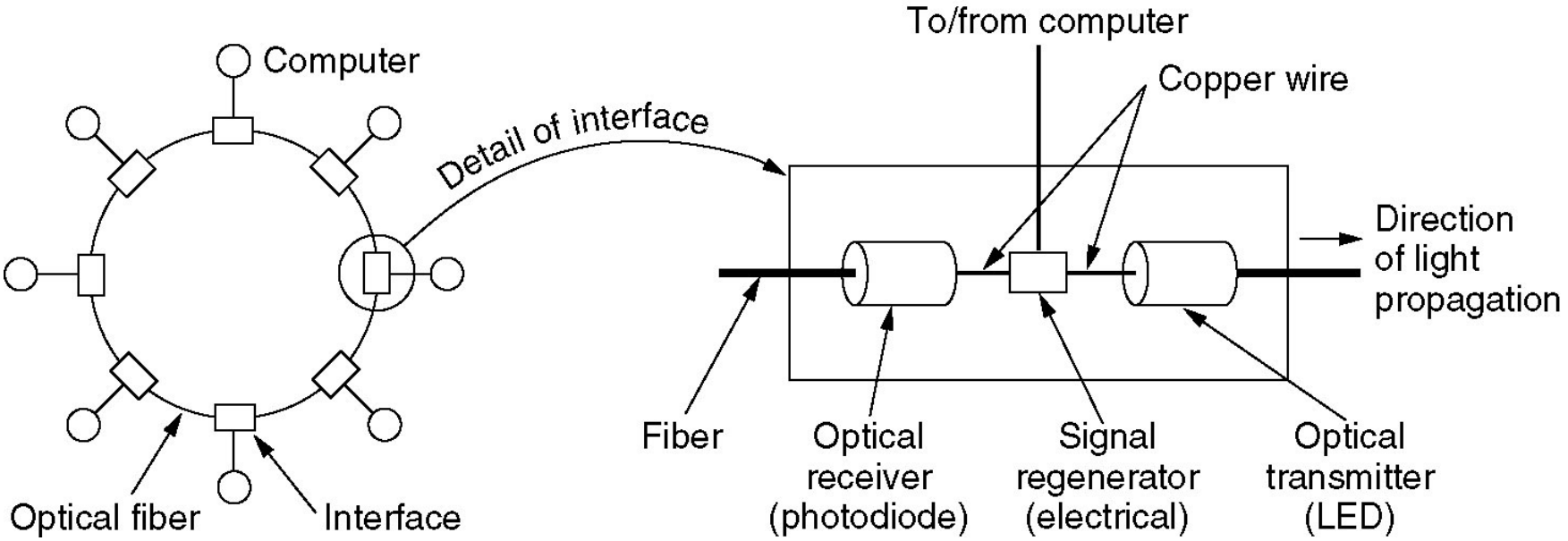
Light Sources

Item	LED	Semiconductor laser
Data rate	Low	High
Fiber type	Multimode	Multimode or single mode
Distance	Short	Long
Lifetime	Long life	Short life
Temperature sensitivity	Minor	Substantial
Cost	Low cost	Expensive

A comparison of LEDs (Light Emitting Diode) and semiconductor diodes as light sources

Fiber Optic Networks

- A photodiode gives off an electrical pulse when struck by light.
- A LED (Light Emitting Diode) or laser diode gives off light based on the input electrical pulse.



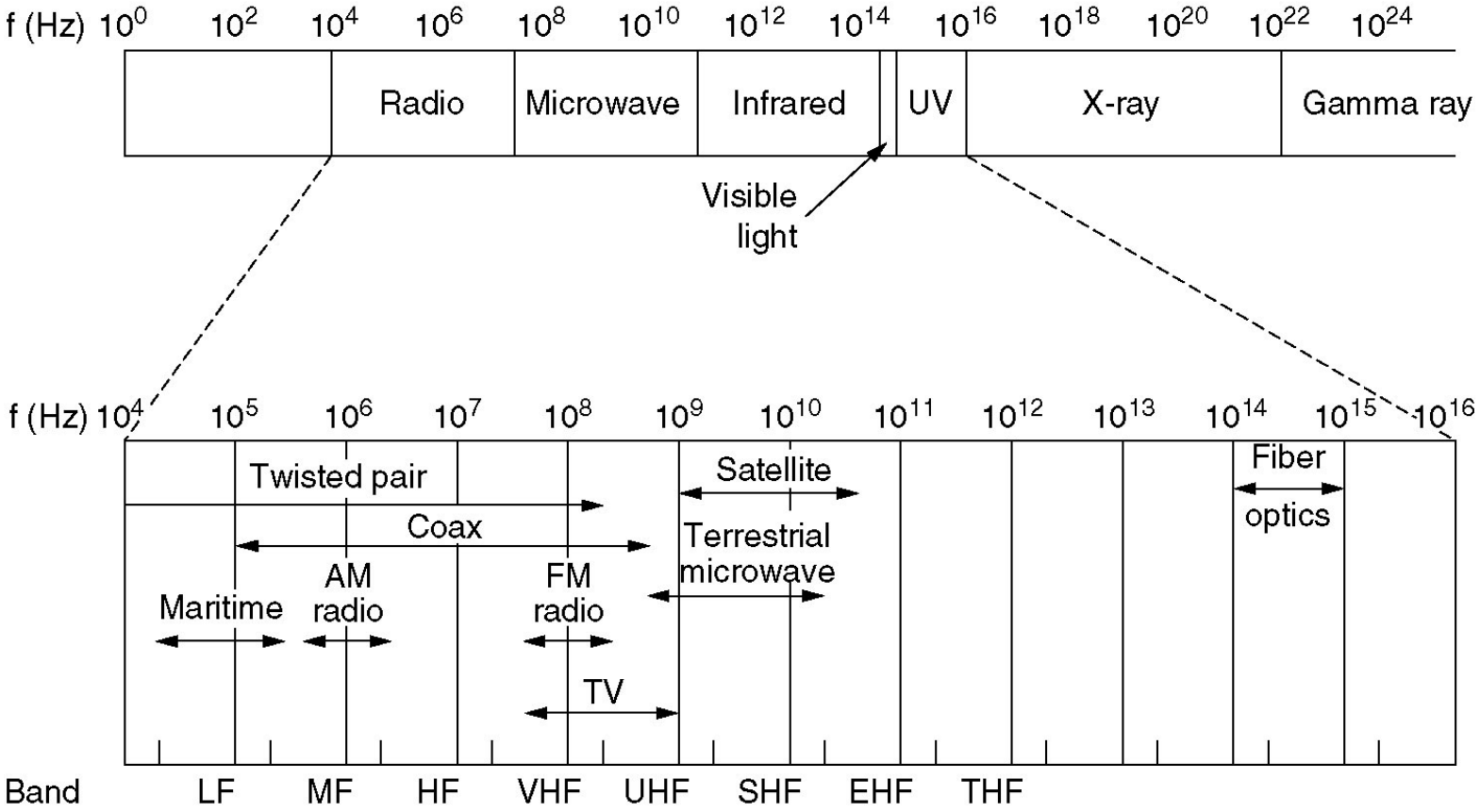
A fiber optic ring with active repeaters.

Wireless Transmission

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

The Electromagnetic Spectrum

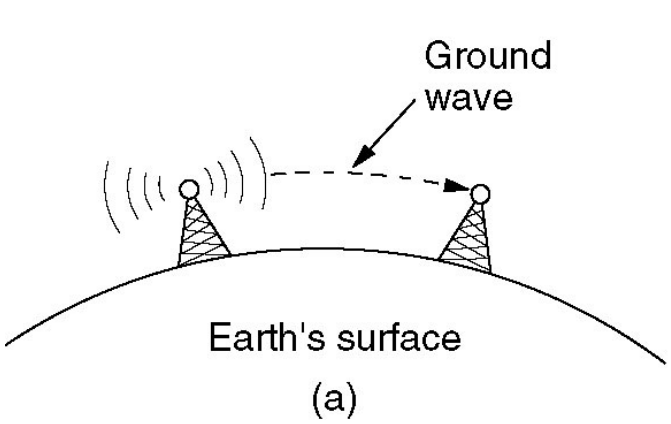
- Frequency f - the number of oscillations per second of a wave.
- Wavelength λ – the distance between two consecutive maxima of a wave.
- The speed of light c in vacuum is 300,000,000 meter/sec. $\lambda f = c$

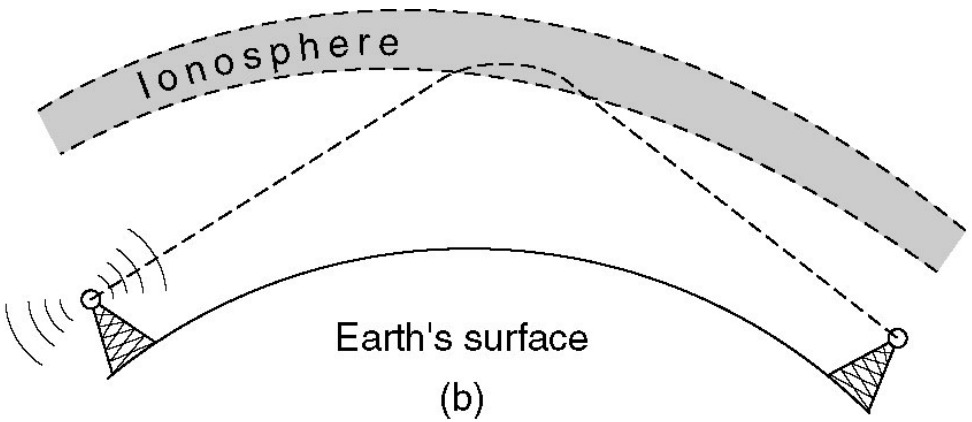


The electromagnetic spectrum and its uses for communication.

Radio Transmission

- Radio waves are easy to generate, can travel long distances, and can penetrate buildings easily.
- In the VLF, LF, and MF bands, radio waves follow the curvature of the earth.
  - ✓ Less than 1,000 km. (AM radio use MF band)
- In the HF and VHF bands, the ground waves tend to be absorbed.
  - They bounce off the ionosphere (a layer of charged particles at the height of 100~500km).
  - The signals can bounce several times. (Amateur radio uses these bands)



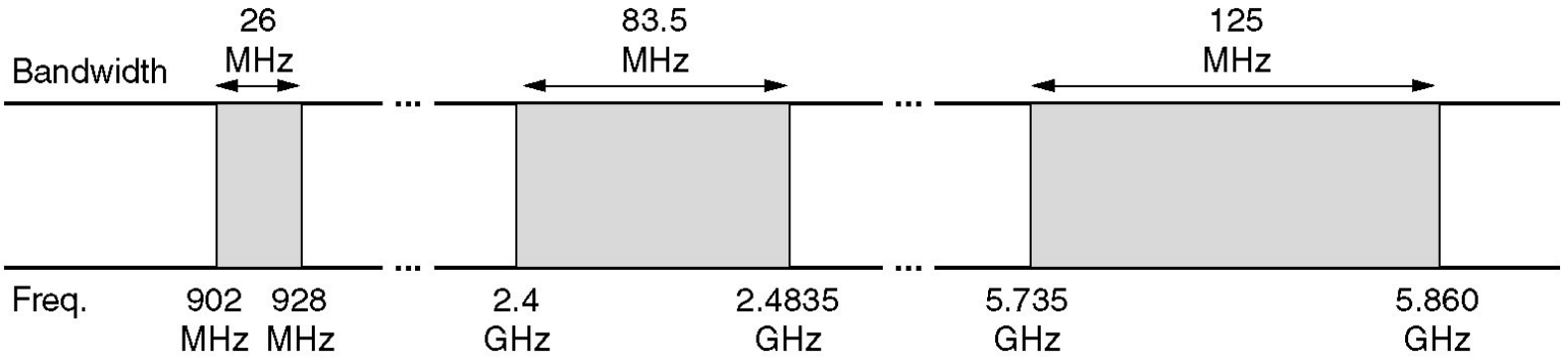


Microwave Transmission

- Microwave – Above 100 MHz, the waves travel in nearly straight lines can be narrowly focused.
- The transmitting and receiving antennas must be accurately aligned with each other.
- Microwaves formed the backbone of the long-distance TV transmission system before fiber optics.

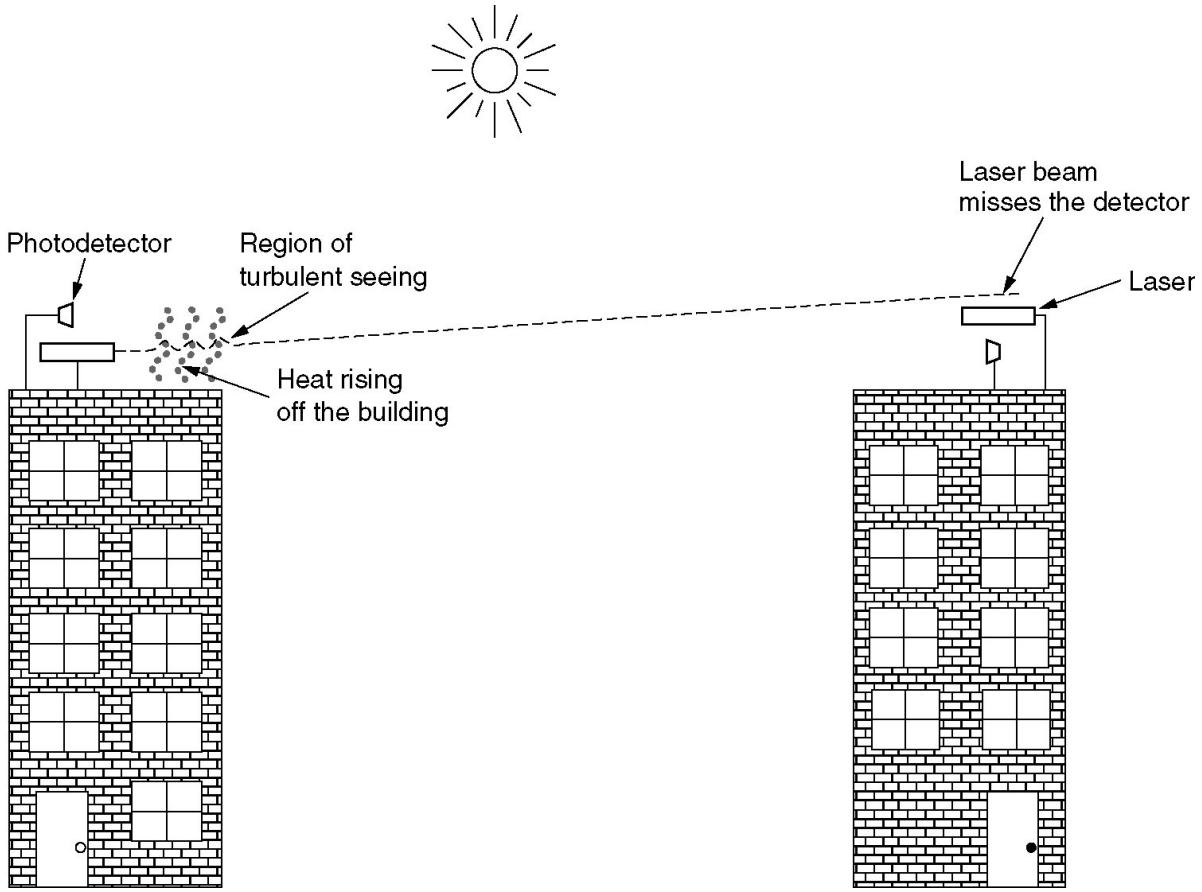
Allocations of the Electromagnetic Spectrum

- There are national and international agreements about who gets to use which frequencies.
- Spectrum is allocated for AM, FM radios, TV, mobile phones navigation, etc.
- The ISM (Industrial, Scientific, Medical) bands are set aside for unlicensed usage.
  - ✓ The ISM bands vary from country to country.
  - ✓ E.g., cordless phones, garage door openers, wireless mice.



The ISM bands in the United States.

Lightwave Transmission

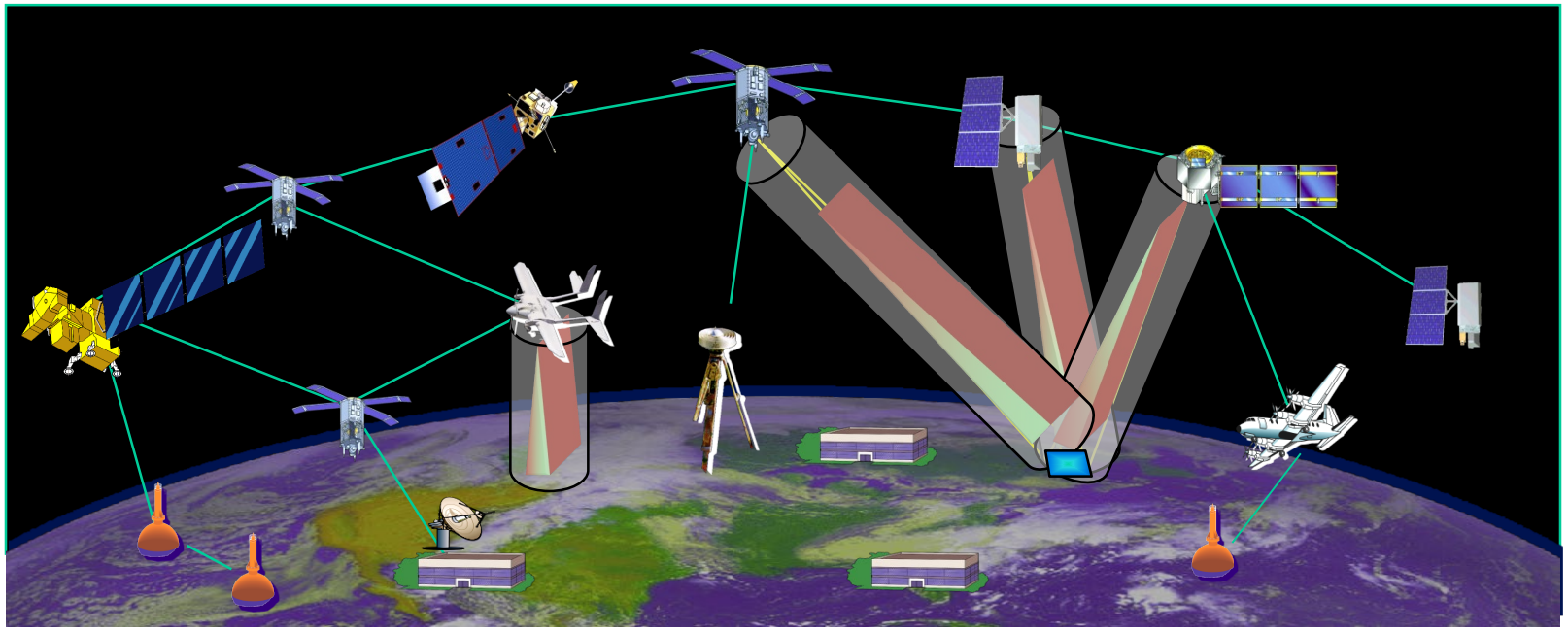


Convection currents can interfere with laser communication systems. A bidirectional system with two lasers is pictured here.

Communication Satellites

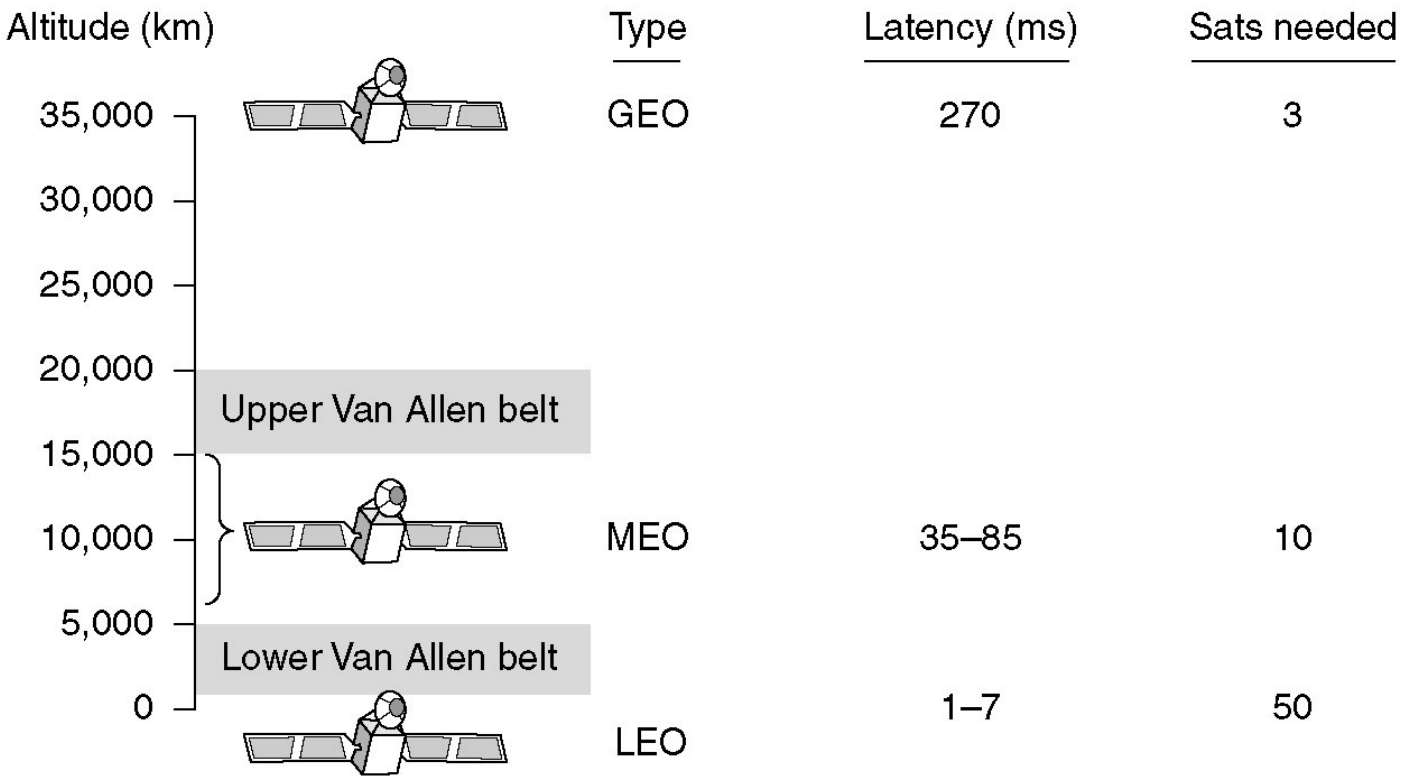
- Geostationary –Earth Orbit (GEO) Satellites
  - ✓ Stationary to the Earth
- Medium-Earth Orbit (MEO) Satellites
  - ✓ E.g., GPS satellites orbiting at 18,000 km.
- Low-Earth Orbit (LEO) Satellites
  - ✓ Closer to the earth
  - ✓ The ground stations do not need much power.
  - ✓ The round-trip delay is small.
  - ✓ Need a large number of satellites to cover the earth.

Communication Satellites



Graphic Credit: *NASA/GSFC: 2000 Survey of Distributed Spacecraft Technologies and Architectures for NASA's Earth Science Enterprise in the 2010-2025 Timeframe*

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.

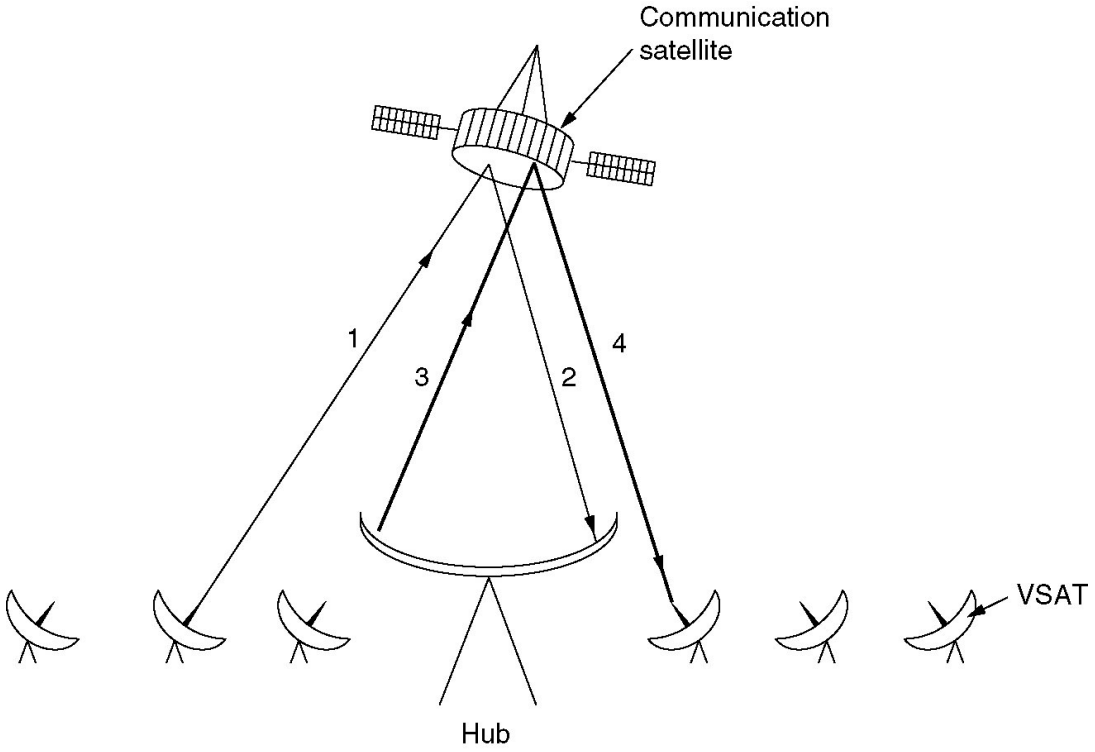
Communication Satellites (2)

Band	Downlink	Uplink	Bandwidth	Problems
L	1.5 GHz	1.6 GHz	15 MHz	Low bandwidth; crowded
S	1.9 GHz	2.2 GHz	70 MHz	Low bandwidth; crowded
C	4.0 GHz	6.0 GHz	500 MHz	Terrestrial interference
Ku	11 GHz	14 GHz	500 MHz	Rain
Ka	20 GHz	30 GHz	3500 MHz	Rain, equipment cost

The principal satellite bands.

Communication Satellites (3)

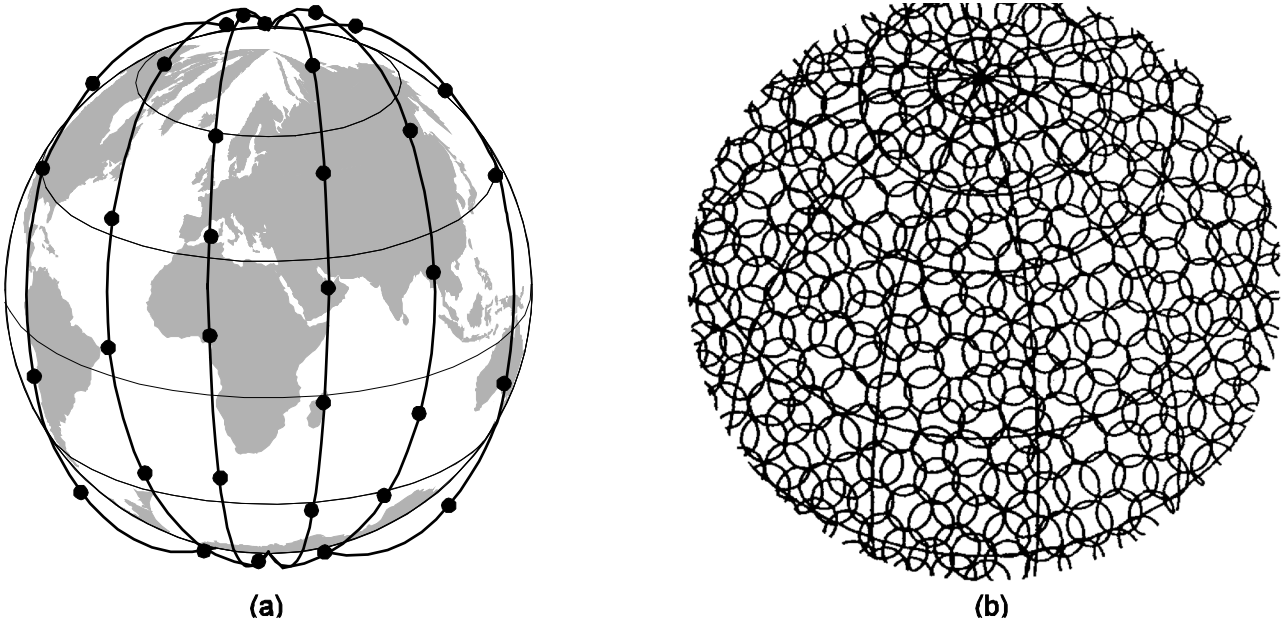
- VSATs (Very Small Aperture Terminals)
  - ✓ Low-cost microstation with small antennas – 1 m (vs 10 m for standard GEO station antenna).
  - ✓ A hub (with large antenna) is used to relay traffic between VSATs.



VSATs using a hub.

Low-Earth Orbit Satellites Iridium

- Iridium Satellites: 66 low-orbit (750 km) satellites
  - ✓ Each satellite has 48 cells (spot beams) – totally 1628 cells.
  - ✓ Providing worldwide telecommunication services
    - Voice, data, paging, fax and navigation services.

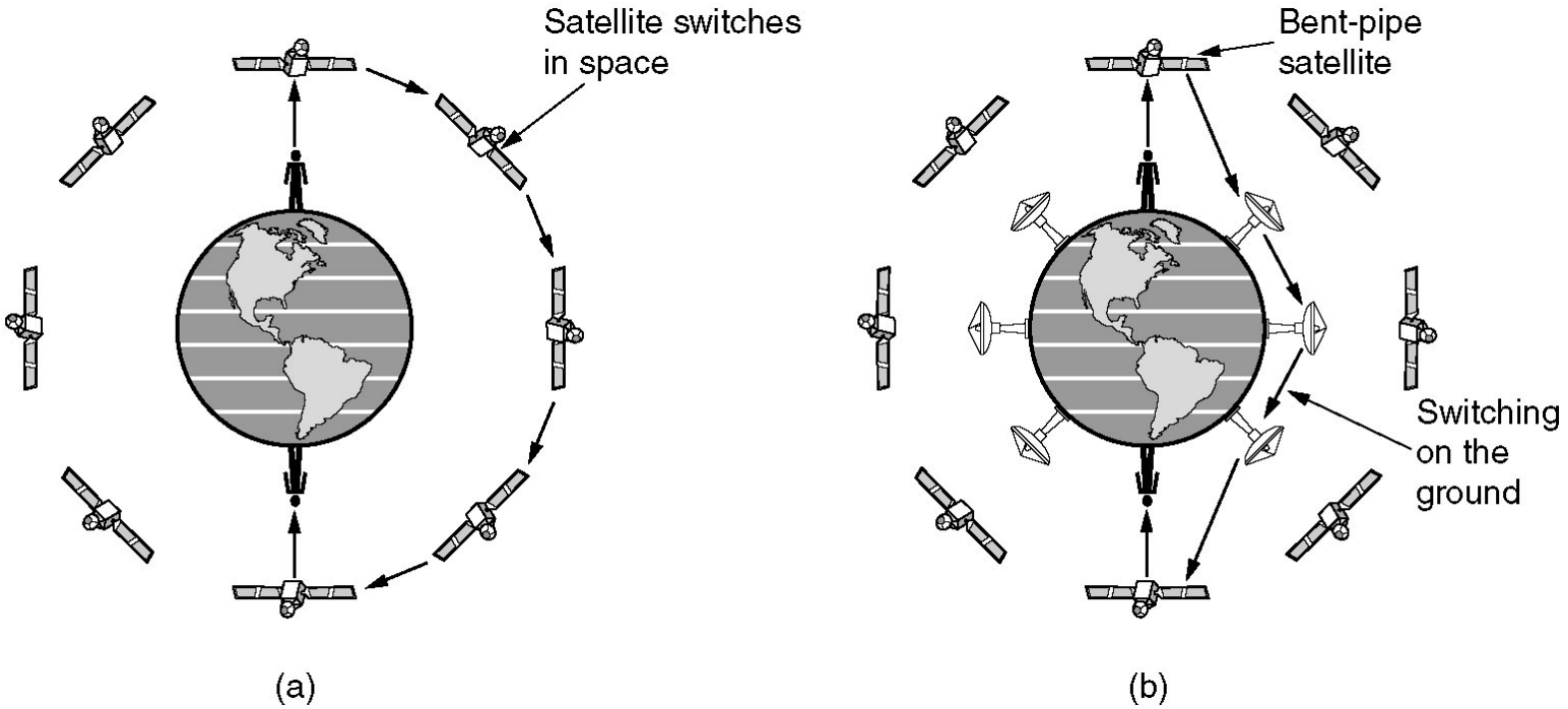


(a) The Iridium satellites from six necklaces around the earth.

(b) 1628 moving cells cover the earth.

Globalstar

- Globalstar: 48 LEO satellites
  - ✓ Relaying on the ground.
- Iridium Satellites relay in space



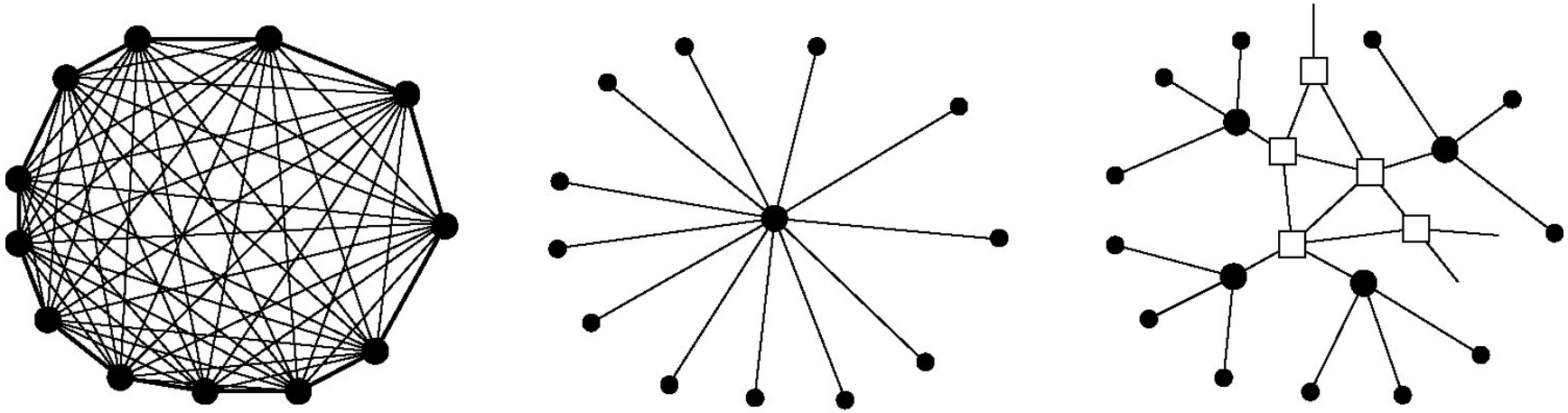
(a) Relaying in space.

(b) Relaying on the ground.

Public Switched Telephone System (PSTN)

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

Structure of the Telephone System

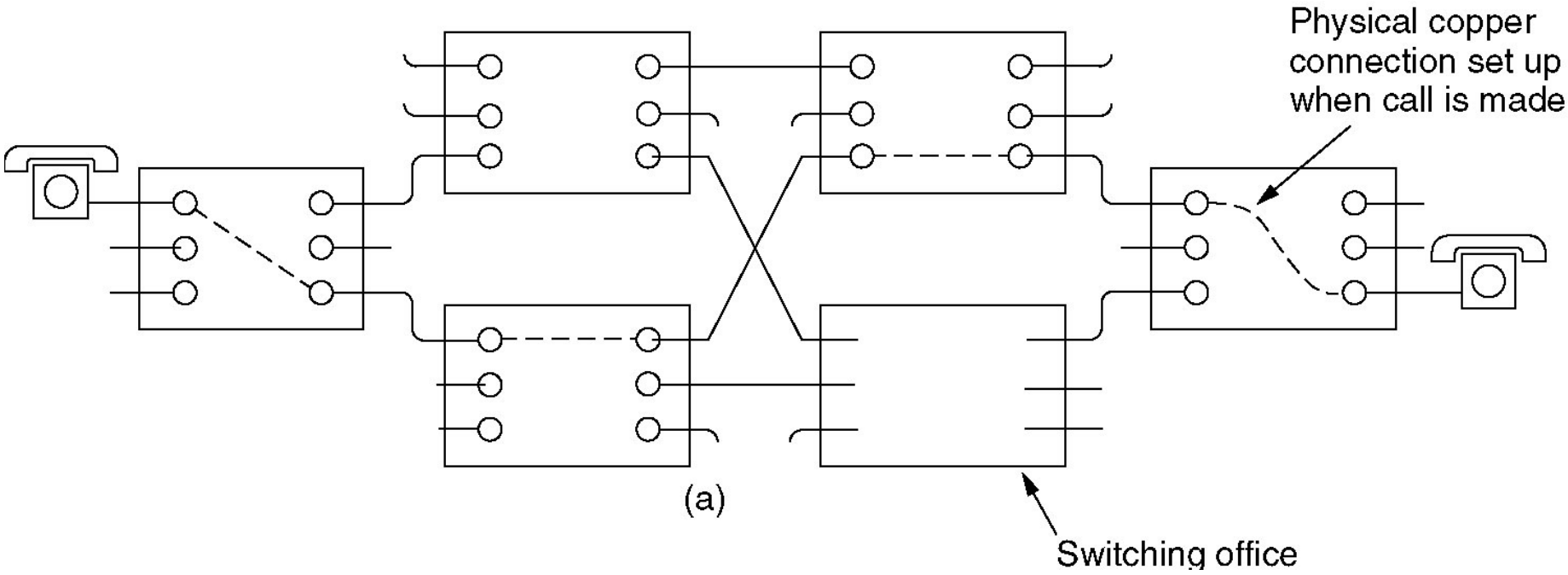


(a) Fully-interconnected network.

(b) Centralized switch.

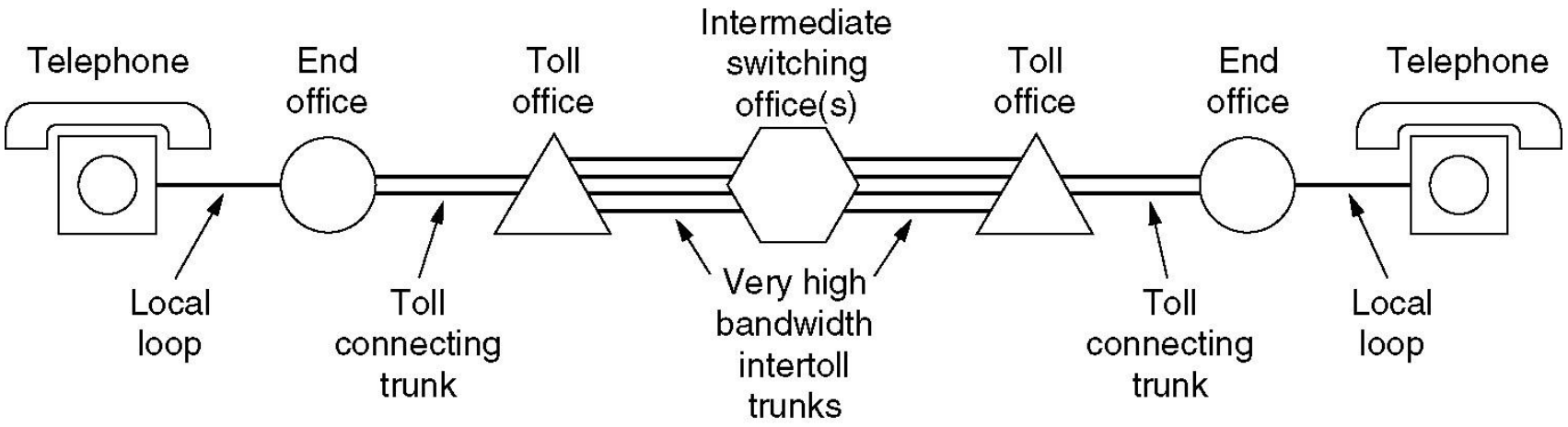
(c) Two-level hierarchy.

Circuit Switching



Structure of the Telephone System (2)

- End office – local central office
- Toll office – local switching center

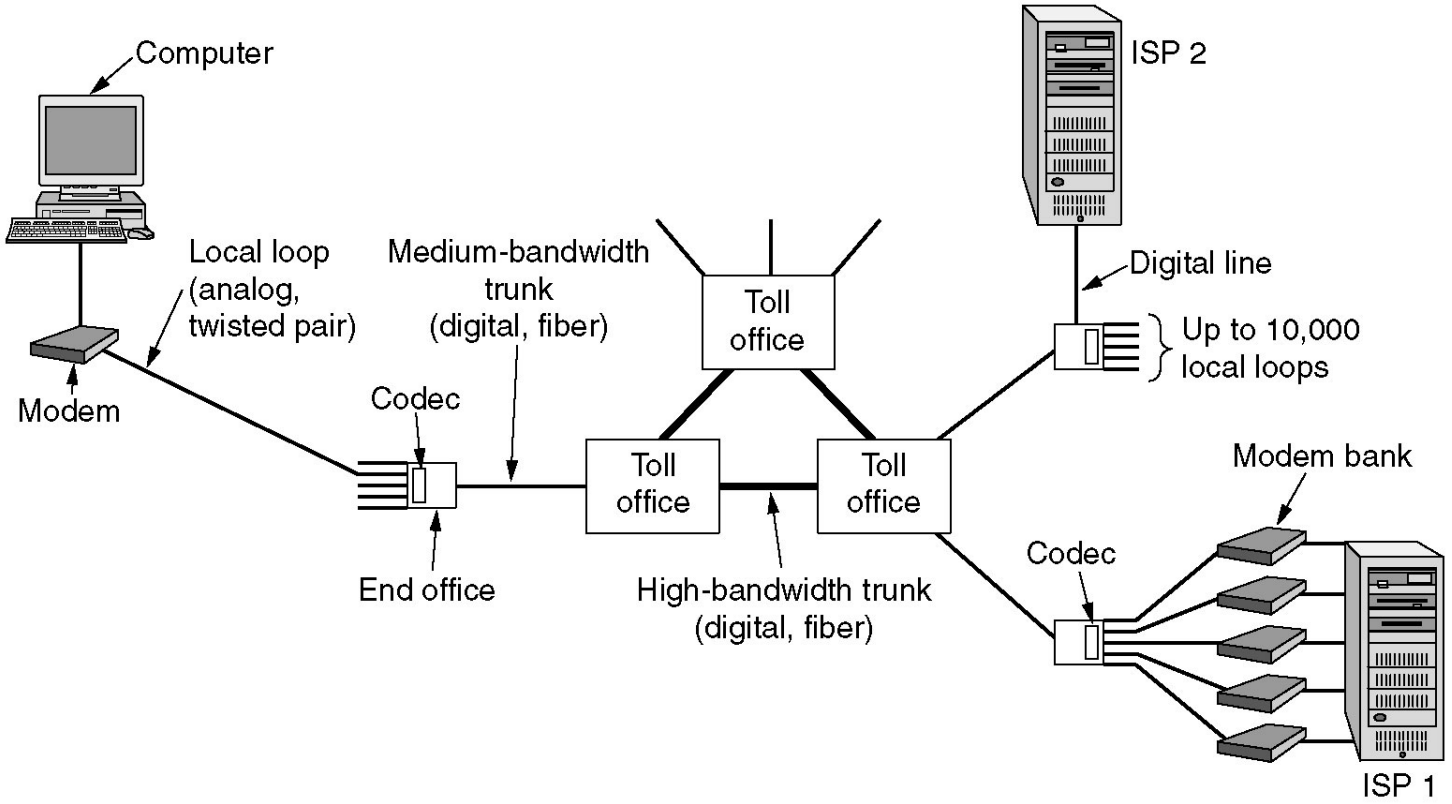


A typical circuit route for a medium-distance call.

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

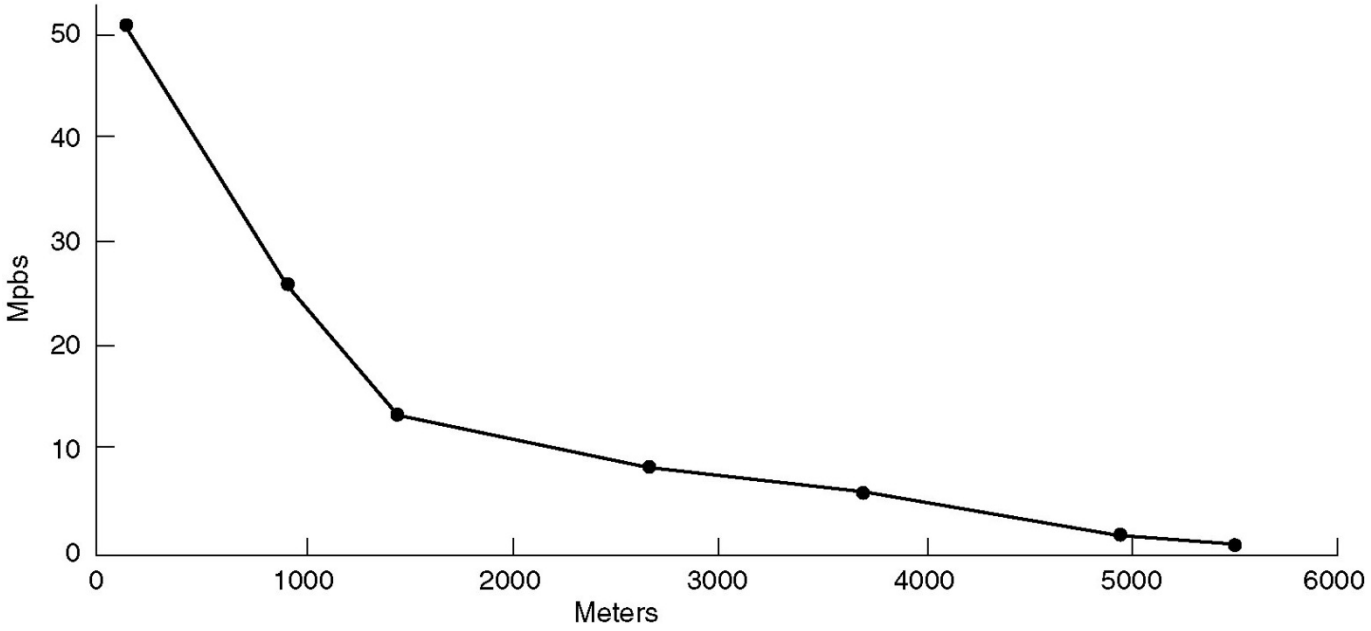
The Local Loop: Modems and ADSL



- The use of both analog and digital transmissions for a computer to computer call.
- Conversion is done by the modems and codecs.
- Codec (coder-decoder) is a device that convert analog signals to digital signals (digitize).

Digital Subscriber Lines (DSL)

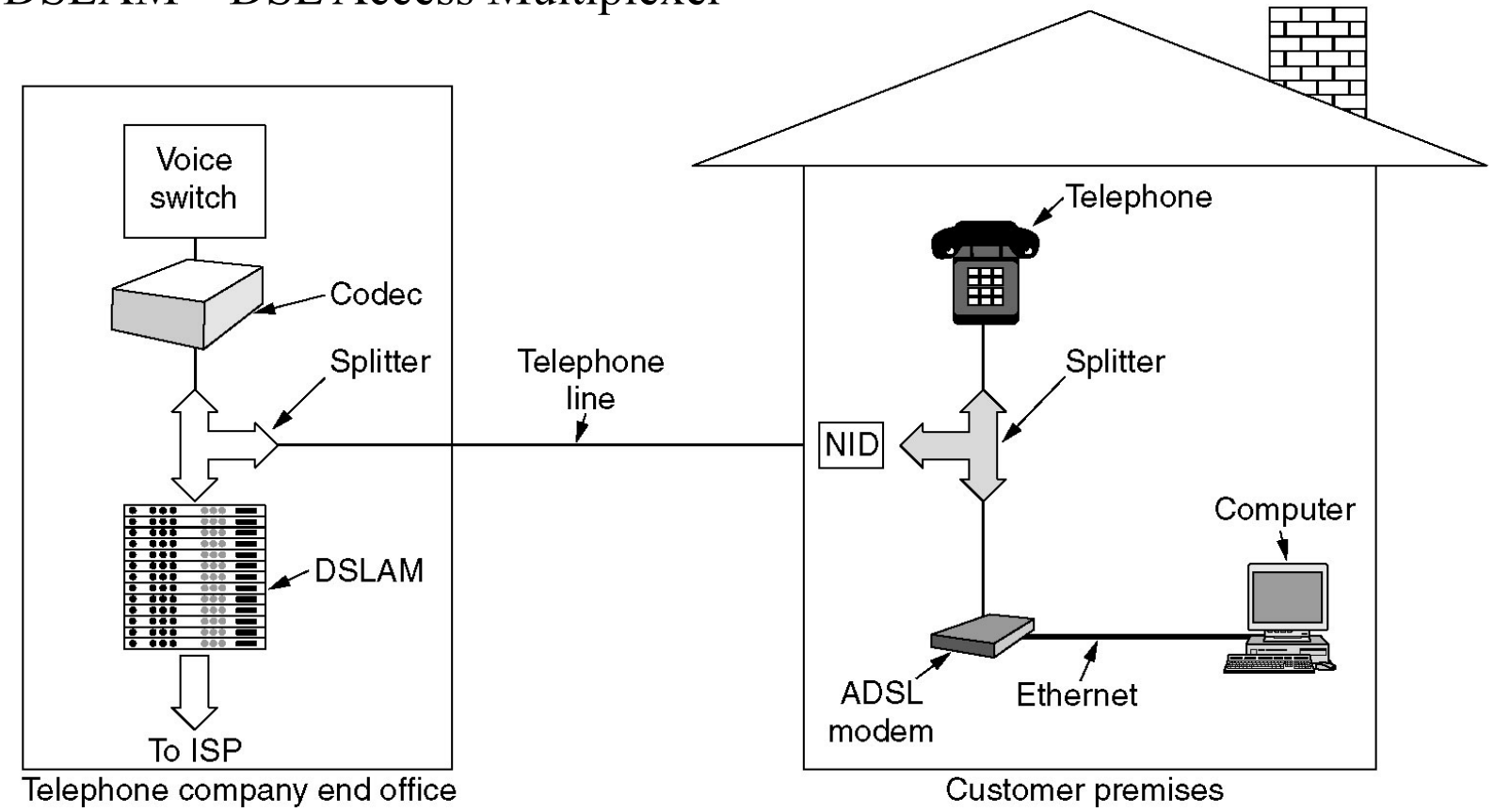
- Modems are slow (56 ~ 92 kbps) since telephones were designed for carrying human voice.
  - ✓ The local loop runs through a bandpass filter (300 Hz ~ 3400 Hz).
- In xDSL (use phone line), the line does not go through the filter
  - ✓ Making the entire capacity of the local loop (e.g., twisted pair) available.
  - ✓ The capacity of the local loop depends on its length, thickness, and quality.



Bandwidth versus distance over category 3 UTP for DSL.

Digital Subscriber Lines (2)

- NID – Network Interface Device
- DSLAM – DSL Access Multiplexer

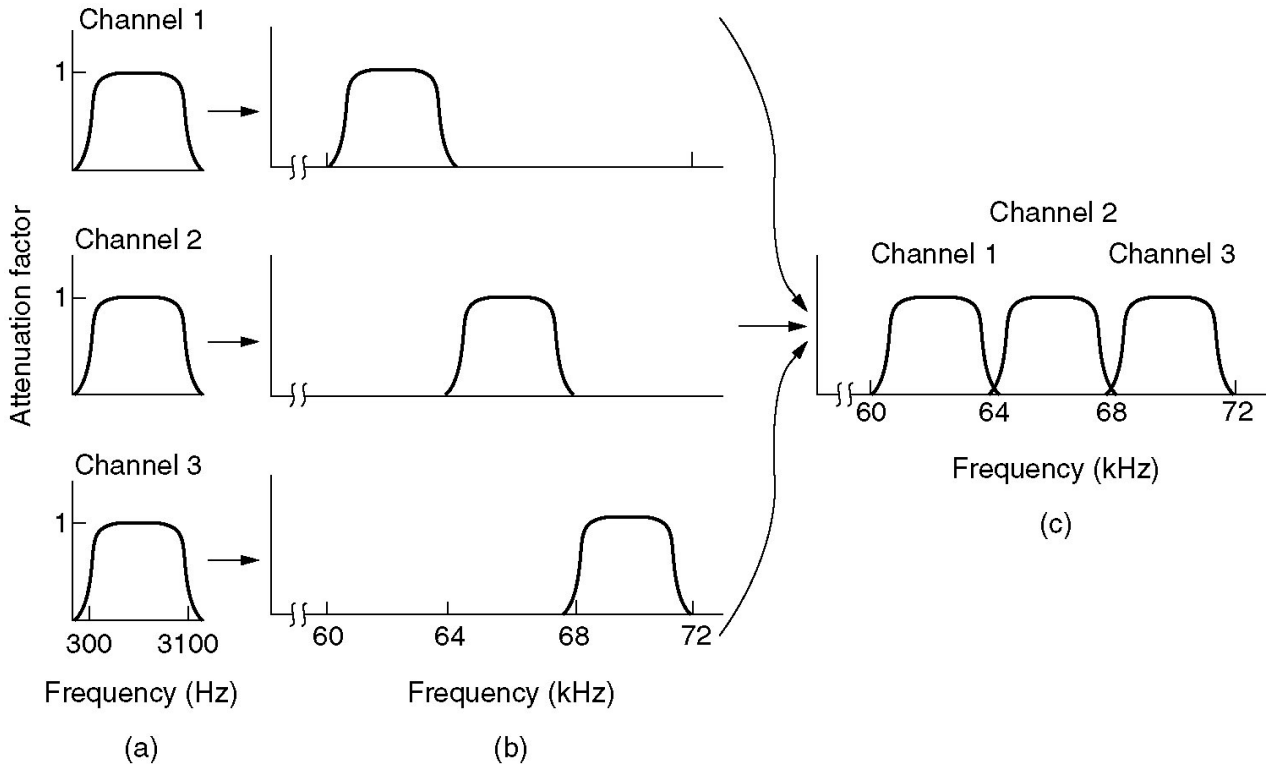


A typical ADSL equipment configuration.

Multiplexing Techniques

- Frequency Division Multiplexing (FDM)
- Wavelength Division Multiplexing (WDM)
- Time Division Multiplexing (TDM)
- Code Division Multiplexing (CDM)

Frequency Division Multiplexing (FDM)



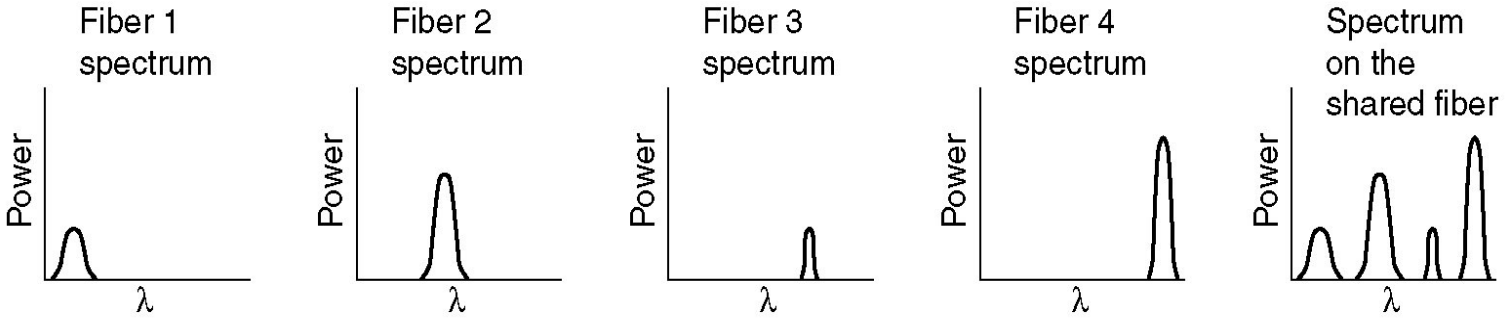
(a) The original bandwidths – 3 voice-grade channels.

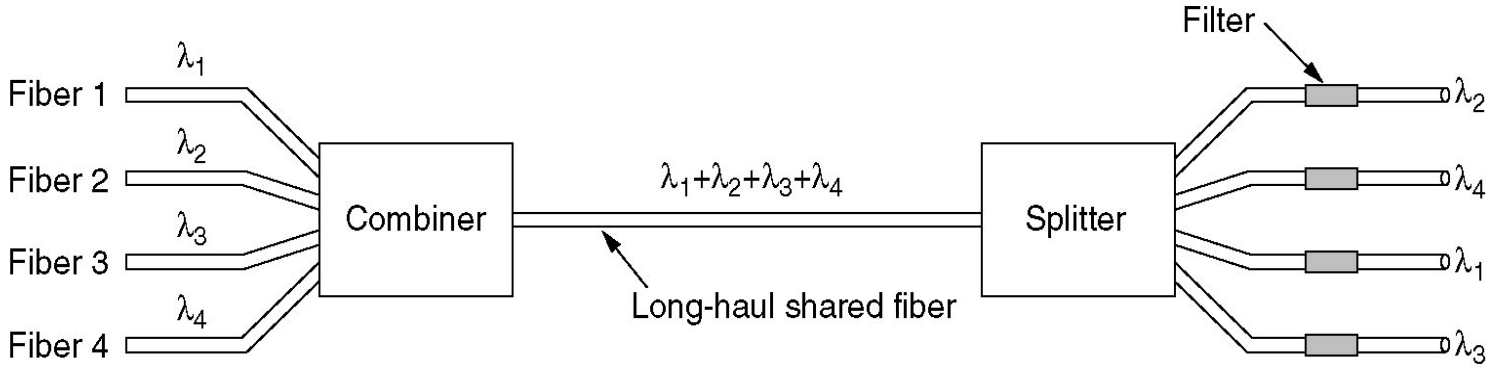
(b) The bandwidths raised in frequency - 4 kHz is allocated to each channel.

(c) The multiplexed channel.

Wavelength Division Multiplexing (WDM)

- For fiber optic channels, a variation of FDM is used - WDM. $\lambda f = c$
- DWDM – Dense WDM
  - ✓ the number of channels is very large and the wavelengths are spaced close.
  - ✓ E.g., 96 channels of 10 Gbps, for a total of 960 Gbps over one fiber.

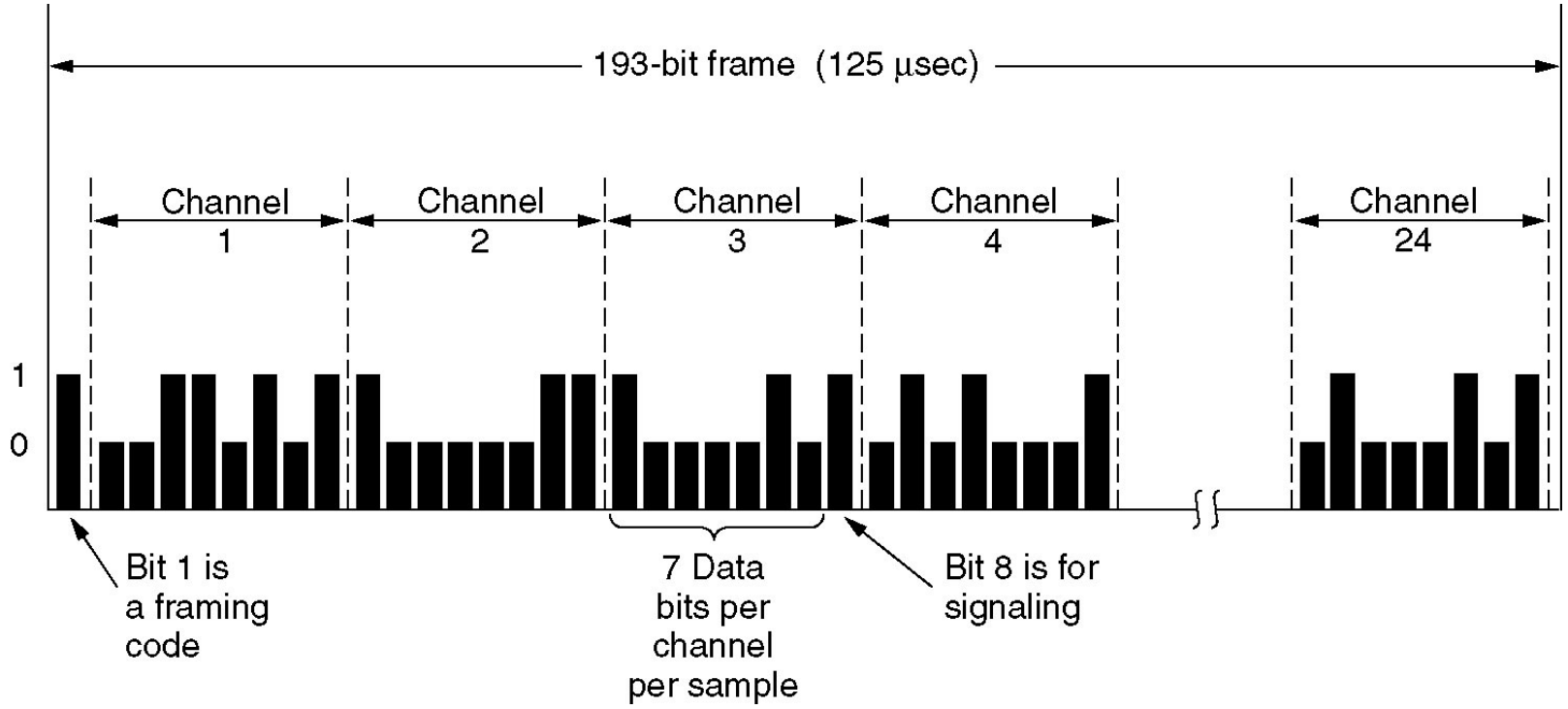




Wavelength Division Multiplexing (WDM).

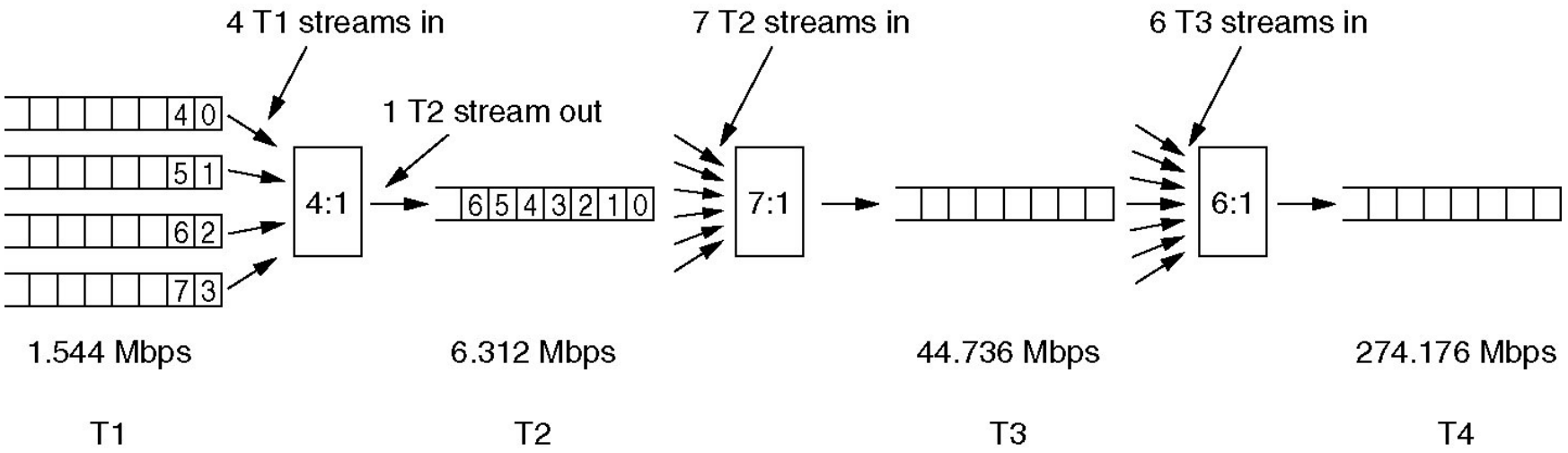
Time Division Multiplexing (TDM)

- TDM can be handled entirely by digital electronics.
- Codec (coder-decoder) is a device that convert analog signals to digital signals (digitize).
  - ✓ For voice traffic, a codec makes 8000 samples per second (125 μ sec/sample)
  - ✓ T1 is a typical frame for voice traffic – 193 bit / 125 μ sec = 1.544 Mbps.



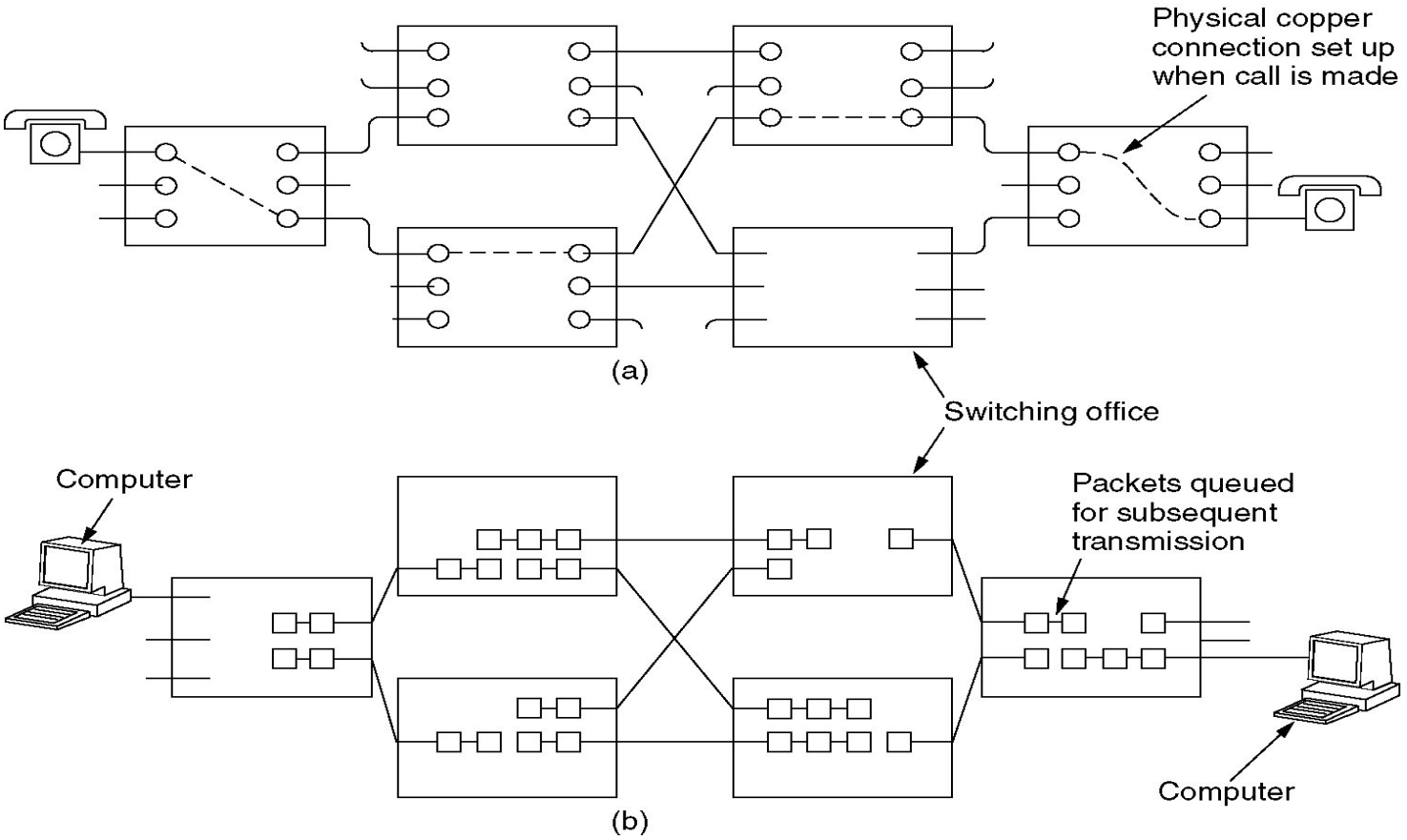
The T1 carrier (1.544 Mbps).

Time Division Multiplexing (2)



Multiplexing T1 streams into higher carriers.

Switching



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

Message Switching

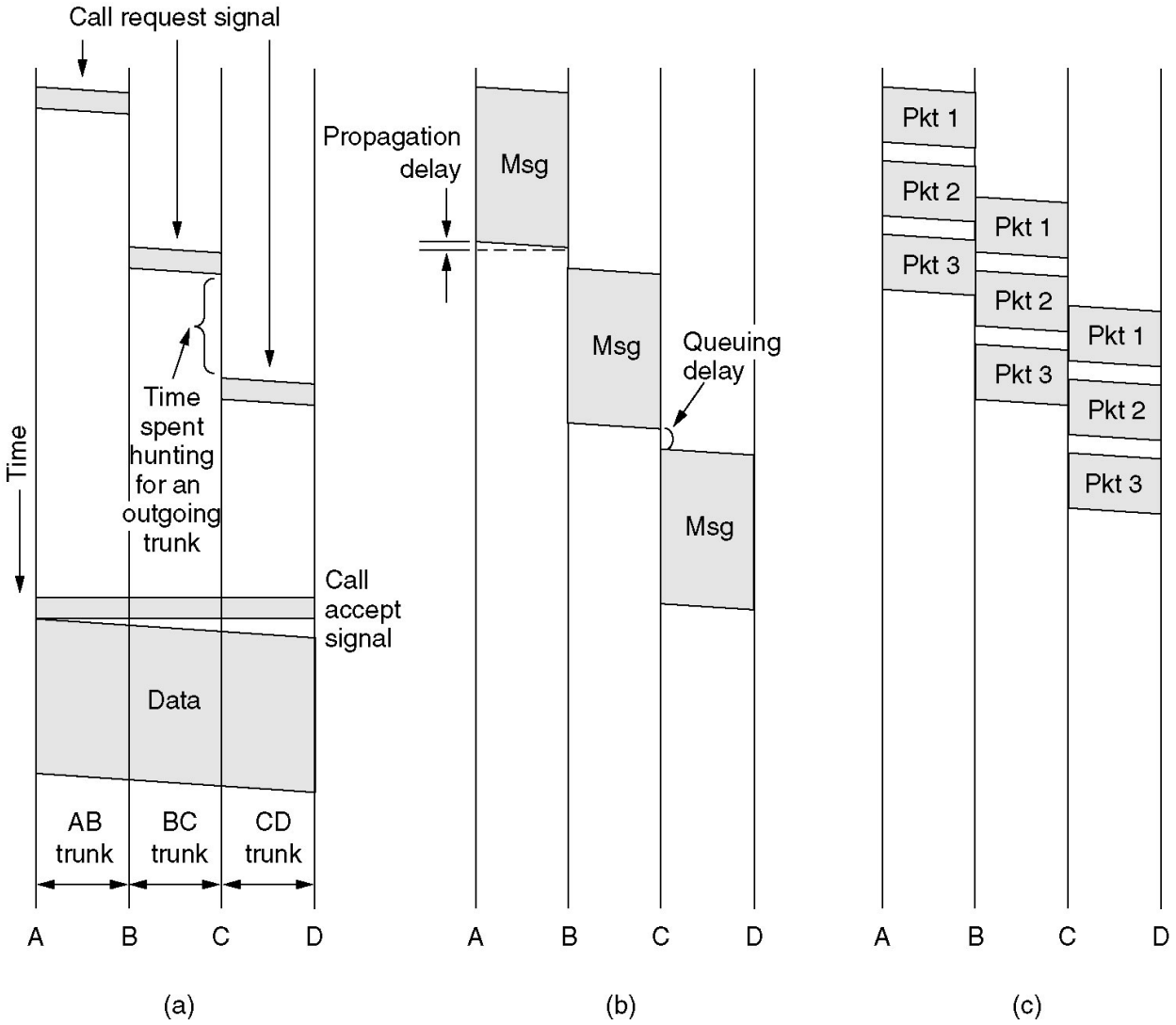
(a) Circuit switching

(b) Message switching

- No limit on message size
- Messages are stored on disk.
- A single message could tie up a link for minutes – useless for interactive traffic.
- Message switching is not used anymore.

(c) Packet switching

- Tight upper limit on packet size.
- Packets are stored in router memory.



Circuit Switched and 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

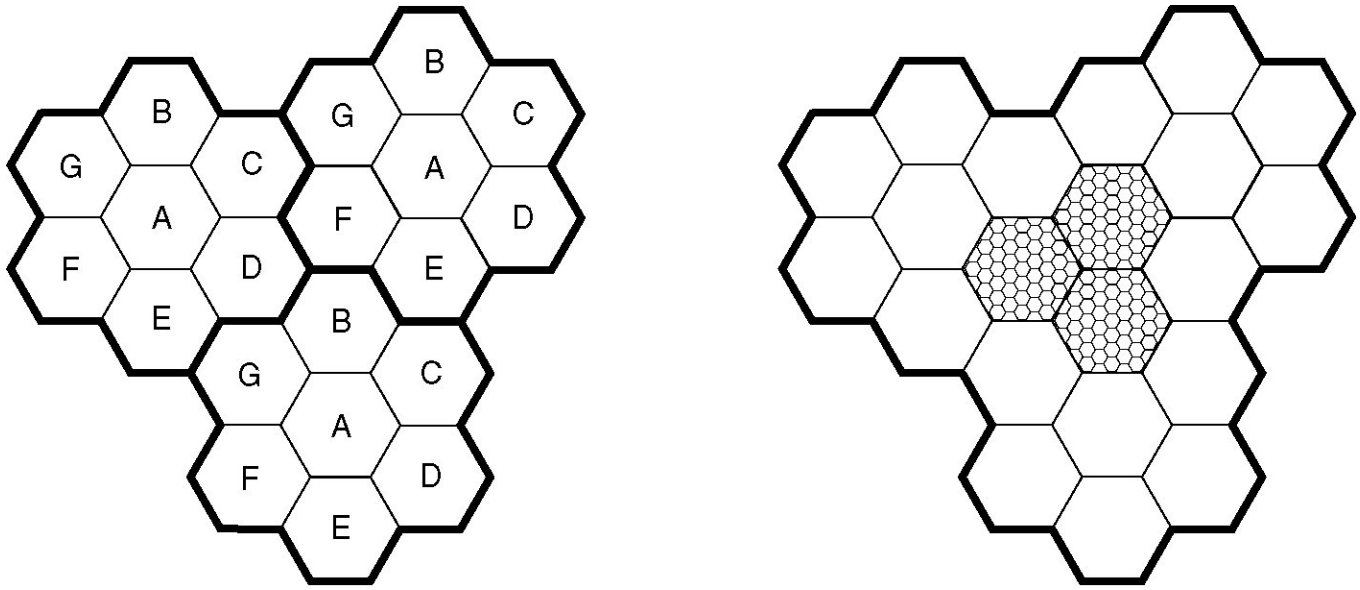
A comparison of circuit switched and packet-switched networks.

The Mobile Telephone System

- First-Generation Mobile Phones: Analog Voice
  - ✓ Using analog modulation - The traditional method of modulating radio signals so that they can carry information.
  - ✓ E.g., AM (amplitude modulation) and FM (frequency modulation).
- Second-Generation (2G) Mobile Phones: Digital Voice
  - ✓ Using digital modulation - reduces voice to binary code - the zeros and ones.
  - ✓ At the receiving end, the information is reconverted.
  - ✓ Digital transmission offers stronger reception, less static, greater call handling capacity, fewer dropped calls, and improved call privacy.
- Third-Generation (3G) Mobile Phones: Digital Voice and Data.
  - E.g., Sprint and Verizon offer EVDO (Evolution-Data Optimized) 3G data service for cell phones.

Advanced Mobile Phone System

- In AMPS, a cell is about 10 to 20 km across.
- Each cell uses some set of frequencies not used by its neighbors.
  - ✓ Frequency reuse.
- Handoff – When cell phone travels across cells, a new channel is used.
- Totally 832 full-duplex channels in AMPS, each simplex channel is 30 kHz.



(a) (b)

(a) Frequencies are not reused in adjacent cells.
(b) To add more users, smaller cells can be used.

AMPS Channel Categories

The 832 channels of AMPS are divided into four categories:

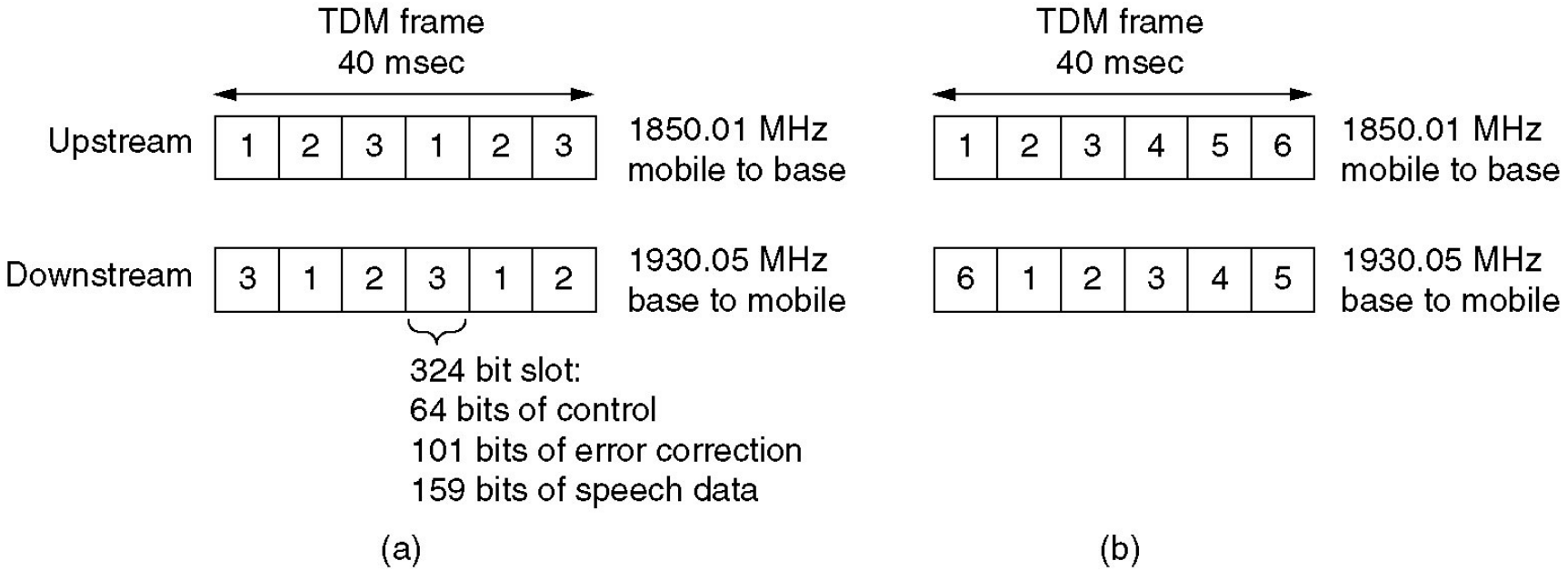
- Control (base to mobile) to manage the system
- Paging (base to mobile) to alert users to calls for them
- Access (bidirectional) for call setup and channel assignment
- Data (bidirectional) for voice, fax, or data

Digital Voice: D-AMPS (Digital Advanced Mobile Phone System)

- Four systems in use now: D-AMPS, GSM, CDMA, and PDC (Personal Digital Cellular).

2G: Digital Advanced Mobile Phone System

- D-AMPS is fully digital – back compatible with AMPS.
  - ✓ Uses the same 30 kHz channels at the same frequencies as AMPS.
  - ✓ One channel could be analog (for AMPS) and the adjacent one be digital.
  - ✓ Upstream channels: 1850 – 1910 MHz. Downstream channels: 1930 – 1990 MHz.

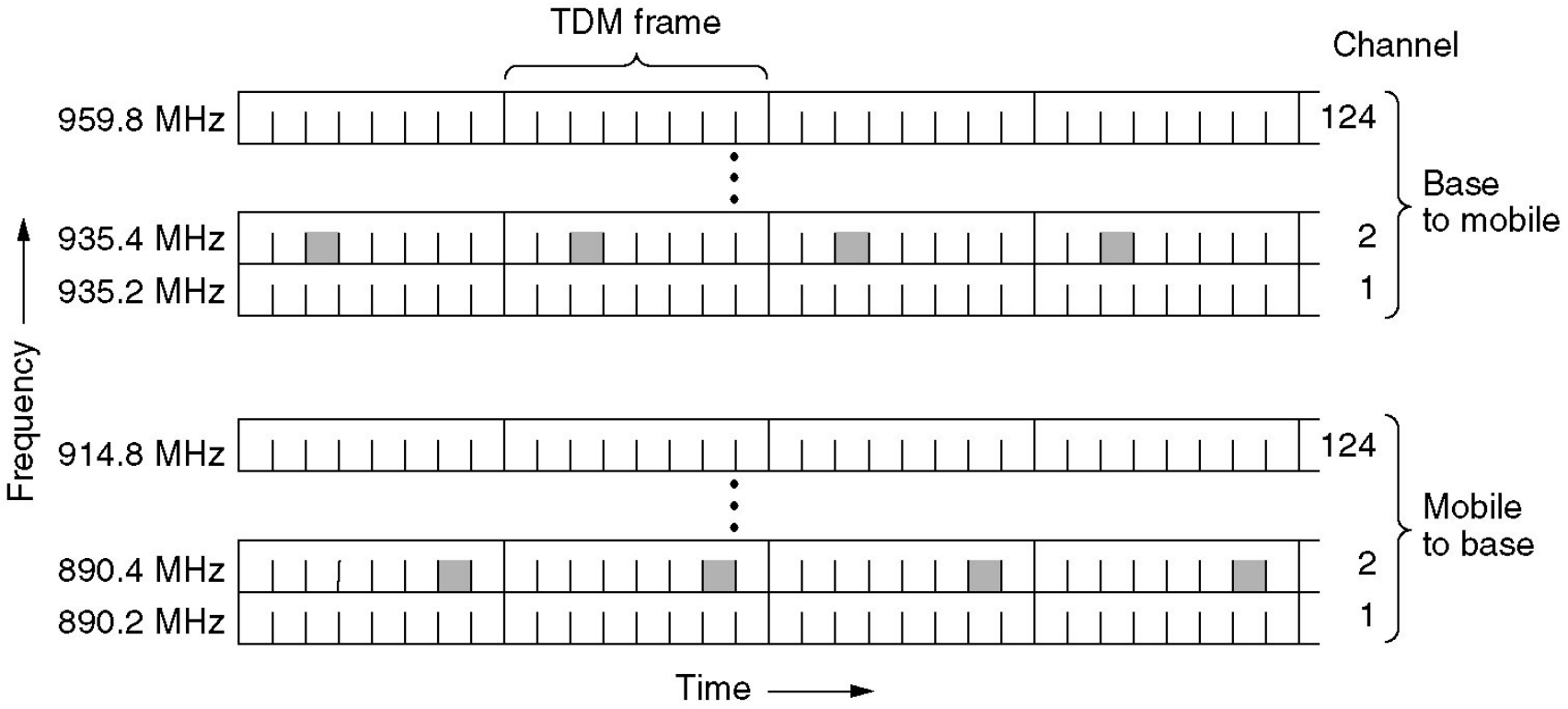


(a) A D-AMPS channel with three users.

(b) A D-AMPS channel with six users.

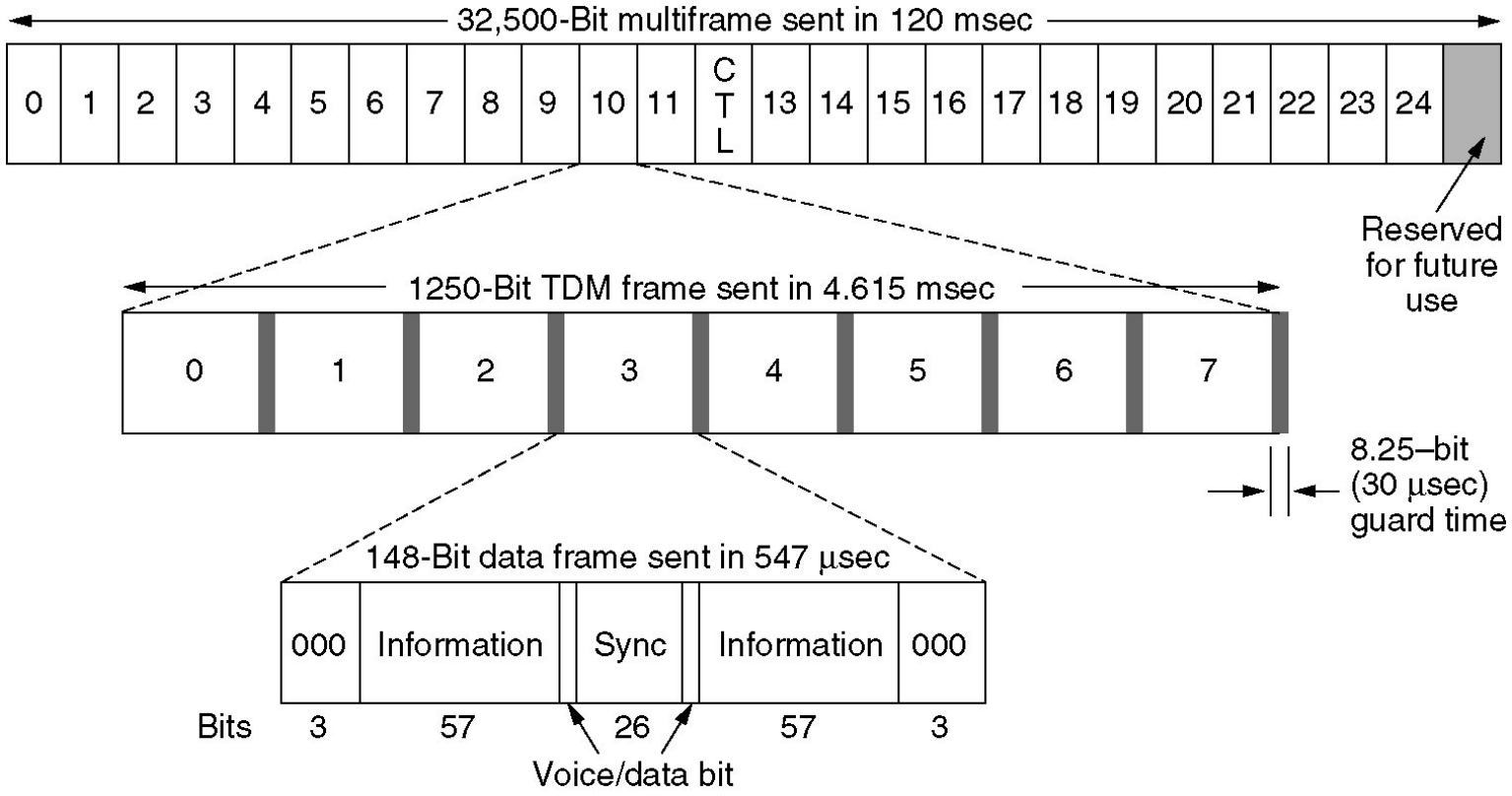
Global System for Mobile Communications (GSM)

- D-AMPS is used in the U.S. and Japan, while GSM is used everywhere else.
- Both D-AMPS and GSM use FDM + TDM (for each frequency channel).
- A channel in GSM is 200 kHz – higher data rate per user.
  - ✓ A channel in D-AMPS is 30 kHz.



GSM uses 124 frequency channels, each of which uses an eight-slot TDM system

GSM (2)



A portion of the GSM framing structure.

3G Mobile Phones: Digital Voice and Data

Basic services a 3G Mobile Phone network should provide

- High-quality voice transmission
- Messaging (replace e-mail, fax, SMS, chat, etc.)
- Multimedia (music, videos, films, TV, etc.)
- Internet access (web surfing, w/multimedia.)

CDMA (Code Division Multiplexing Access)

- Multiple simultaneous transmissions are separated by using different coding schemes.

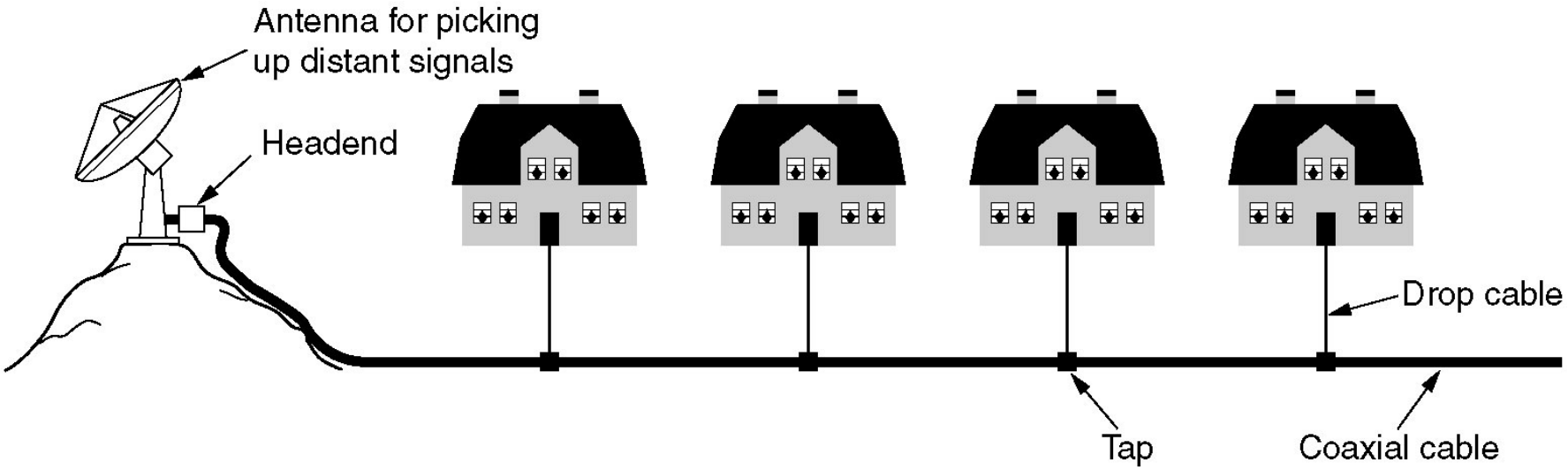
3G Mobile Phone Systems:

- W-CDMA (Wideband CDMA) – Ericsson
- CDMA2000 – Qualcomm
  - ✓ Does not interwork with GSM
  - ✓ Different from W-CDMA in: chip rate (number of time intervals per bit), frame time, spectrum used, time synchronization approach.

Cable Television

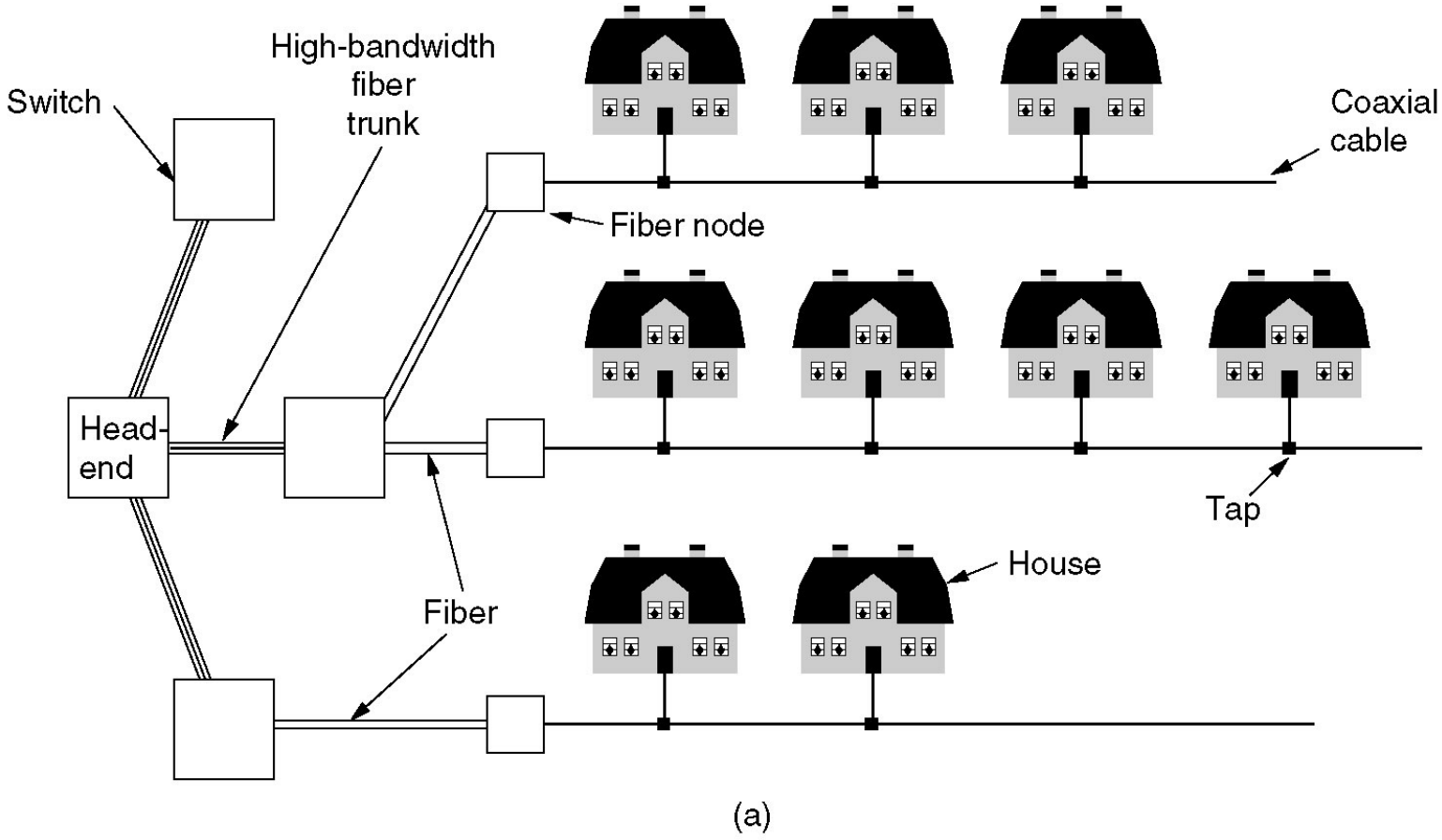
- Community Antenna Television
- Internet over Cable
- Spectrum Allocation

Community Antenna Television



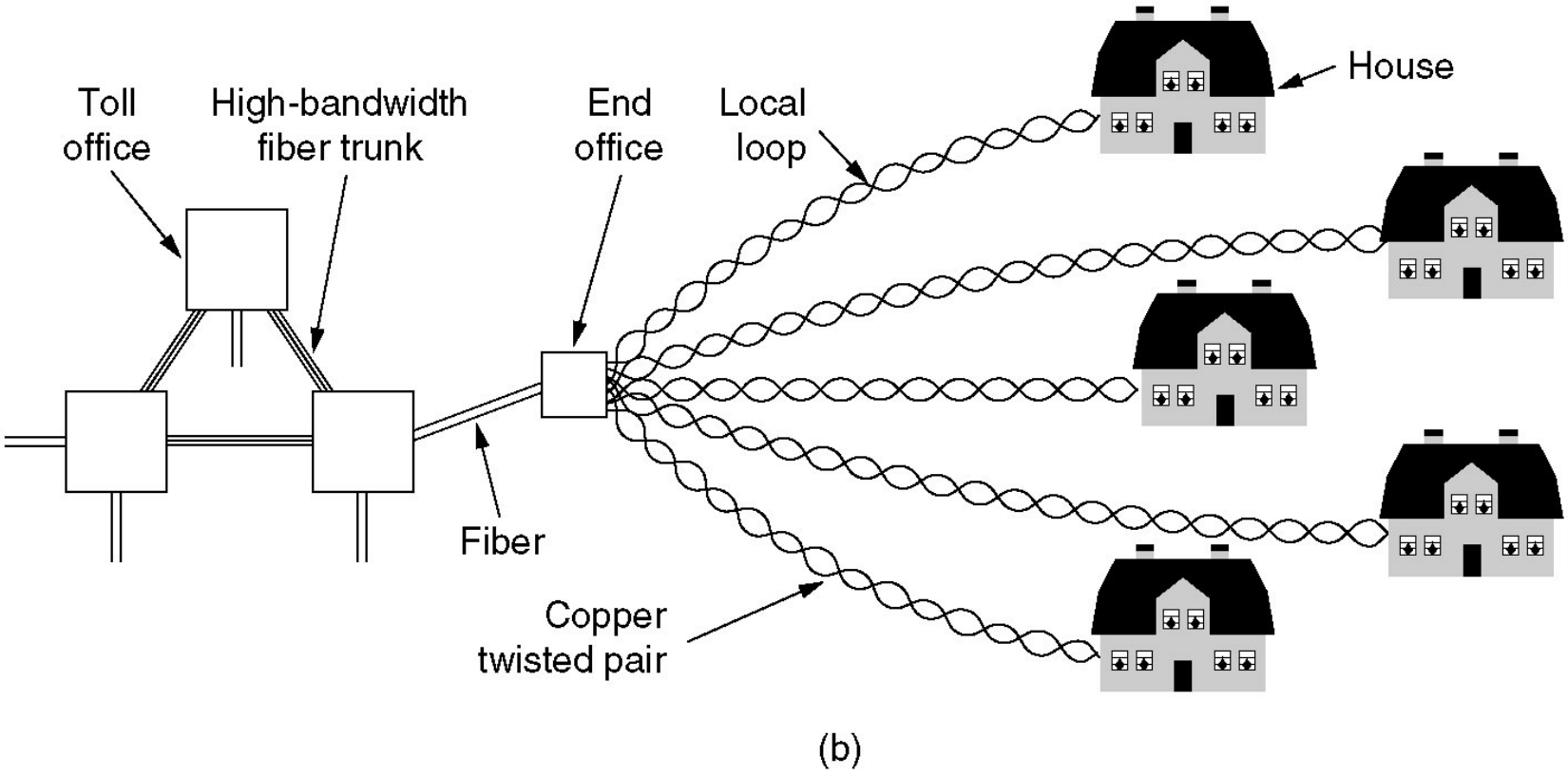
An early cable television system.

Internet over TV Cable



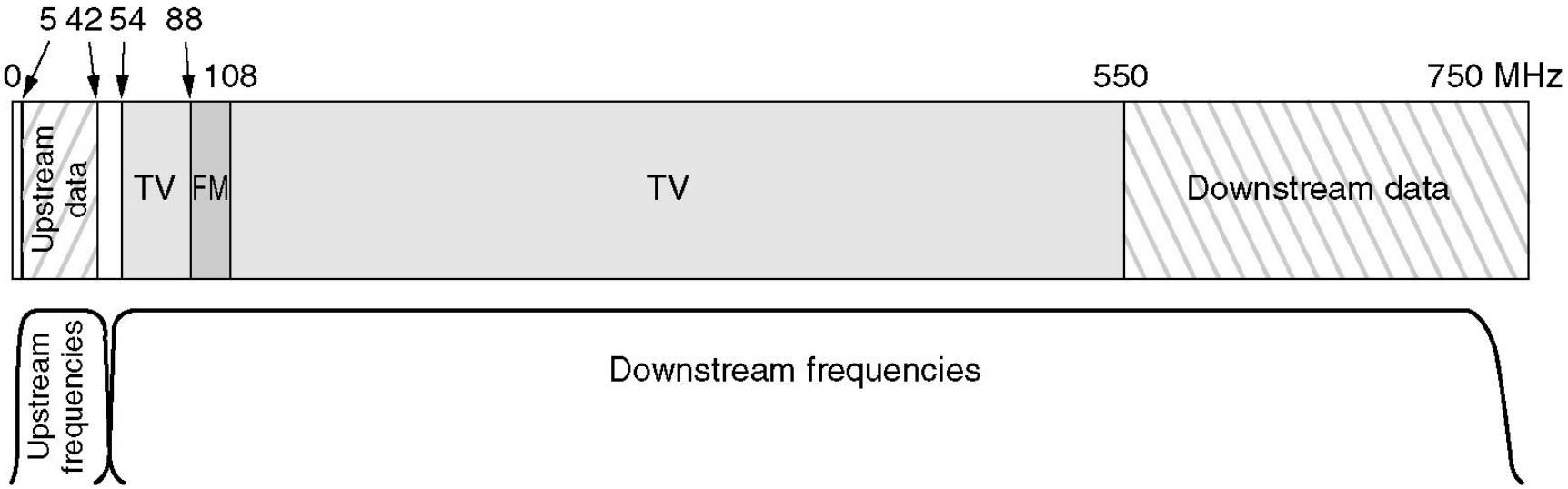
Cable television

Internet over Telephone System



The fixed telephone system.

Spectrum Allocation



Frequency allocation in a typical cable TV system used for Internet access