Chapter 2

The Physical Layer

The Theoretical Basis for Data Communication

- Fourier Analysis
- Bandwidth-Limited Signals
- Maximum Data Rate of a Channel

Fourier Series Decomposition

Reminder:

Any (reasonably behaved) periodic signal *g*(*t*), of period *T*, can be constructed by summing a (possibly infinite) number of sines and cosines (called a Fourier series):

$$g(t) = \frac{1}{2}c + \sum_{n=1}^{\infty} a_n \sin(2\pi nft) + \sum_{n=1}^{\infty} b_n \cos(2\pi nft) \qquad (2-1)$$

where

$f = 1/T$ is the fundamental frequency

a_n and b_n are the sine and cosine amplitudes of the *n*th harmonics

(For nonperiodic signals, refer to Fourier transforms, but the intuition is the same)

$$a_n = \frac{2}{T}\int_0^T g(t)\sin(2\pi nft)\,dt$$

$$b_n = \frac{2}{T}\int_0^T g(t)\cos(2\pi nft)\,dt$$

$$c = \frac{2}{T}\int_0^T g(t)\,dt$$

Fourier Transform

Let $g(t)$ denote a *nonperiodic deterministic signal*, expressed as some function of time t. By definition, the *Fourier transform* of the signal $g(t)$ is given by the integral

$$G(f) = \int_{-\infty}^{\infty} g(t) \exp(-j2\pi ft)\, dt$$

where $j = \sqrt{-1}$, and the variable f denotes *frequency*. Given the Fourier transform $G(f)$, the original signal $g(t)$ is recovered exactly using the formula for the *inverse Fourier transform*:

$$g(t) = \int_{-\infty}^{\infty} G(f) \exp(j2\pi ft)\, df$$

For the Fourier transform of a signal $g(t)$ to exist, it is sufficient but not necessary that $g(t)$ satisfies three conditions known collectively as *Dirichlet's conditions*:

1. The function $g(t)$ is single-valued, with a finite number of maxima and minima in any finite time interval.
2. The function $g(t)$ has a finite number of discontinuities in any finite time interval.
3. The function $g(t)$ is absolutely integrable, that is,

$$\int_{-\infty}^{\infty} |g(t)|\, dt < \infty$$

Fourier Transform (2)

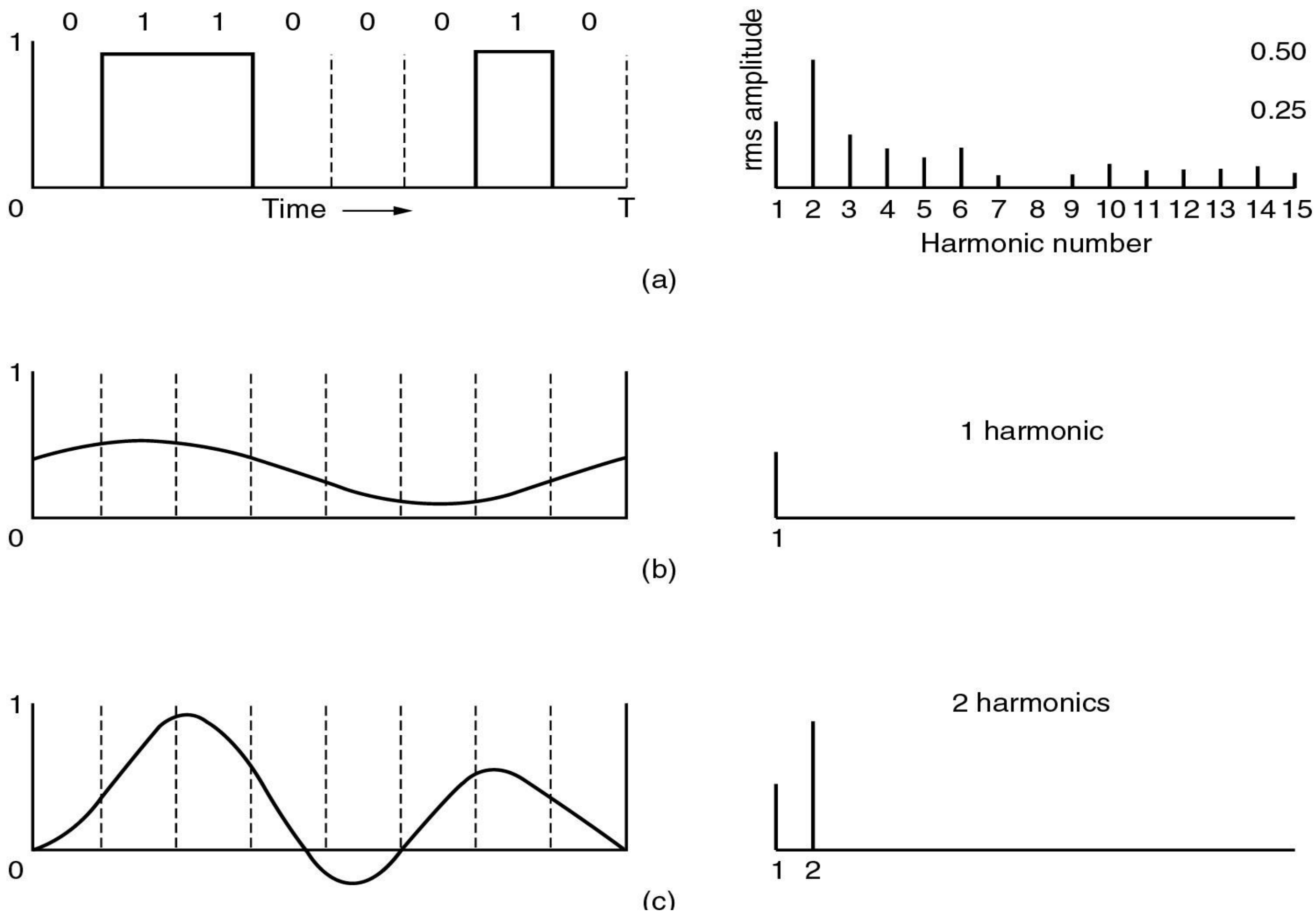
Indeed, we may go one step further and state that all energy signals, that is, signals $g(t)$ for which

$$\int_{-\infty}^{\infty} |g(t)|^2 \, dt < \infty$$

are Fourier transformable.

We refer to $|G(f)|$ as the magnitude spectrum of the signal $g(t)$, and refer to $\arg\{G(f)\}$ as its phase spectrum.

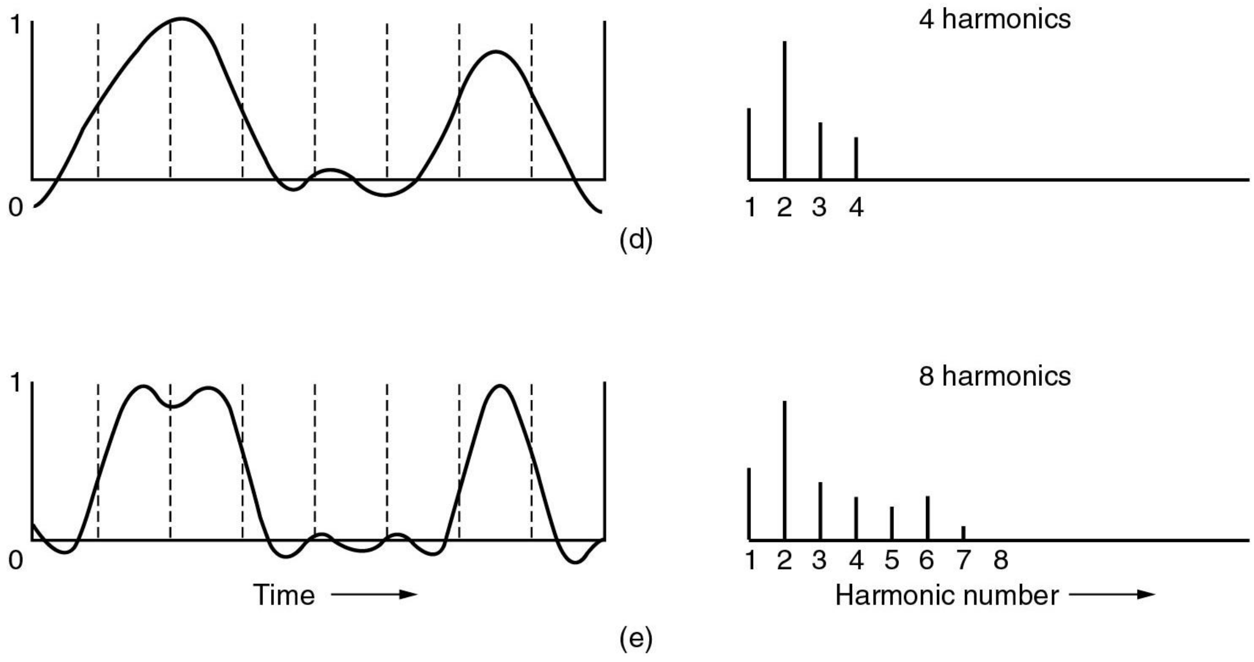
Bandwidth-Limited Signals



A binary signal and its root-mean-square Fourier amplitudes.

(b) – (c) Successive approximations to the original signal.

Bandwidth-Limited Signals (2)



(d) – (e) Successive approximations to the original signal.

Bandwidth-Limited Signals (3)

Suppose we transmit the previous binary signal (of 8 bits) infinitely often, we have a periodic signal.
Suppose the transmission is done on a telephone line (cut-off frequency = ± 3000 Hz)

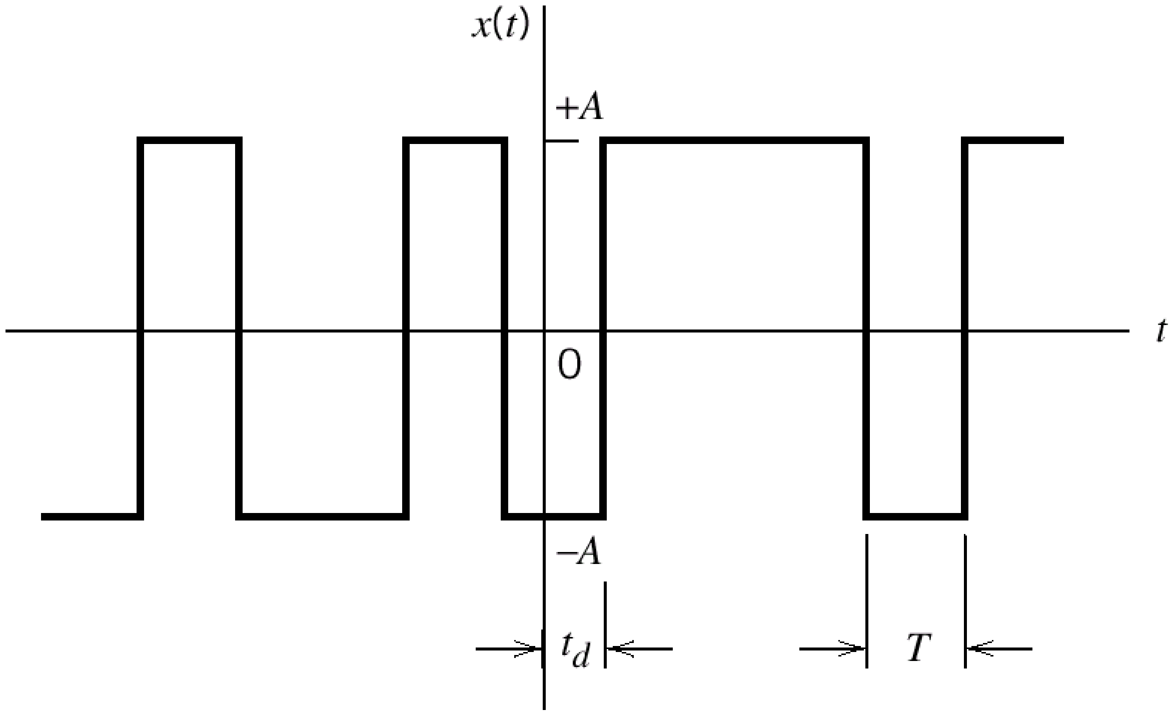
Data rate= D **T = 8/D** **f = 1/T** **greatest int ≤ 3000 × T**

Bps	T (msec)	First harmonic (Hz)	# Harmonics sent
300	26.67	37.5	80
600	13.33	75	40
1200	6.67	150	20
2400	3.33	300	10
4800	1.67	600	5
9600	0.83	1200	2
19200	0.42	2400	1
38400	0.21	4800	0

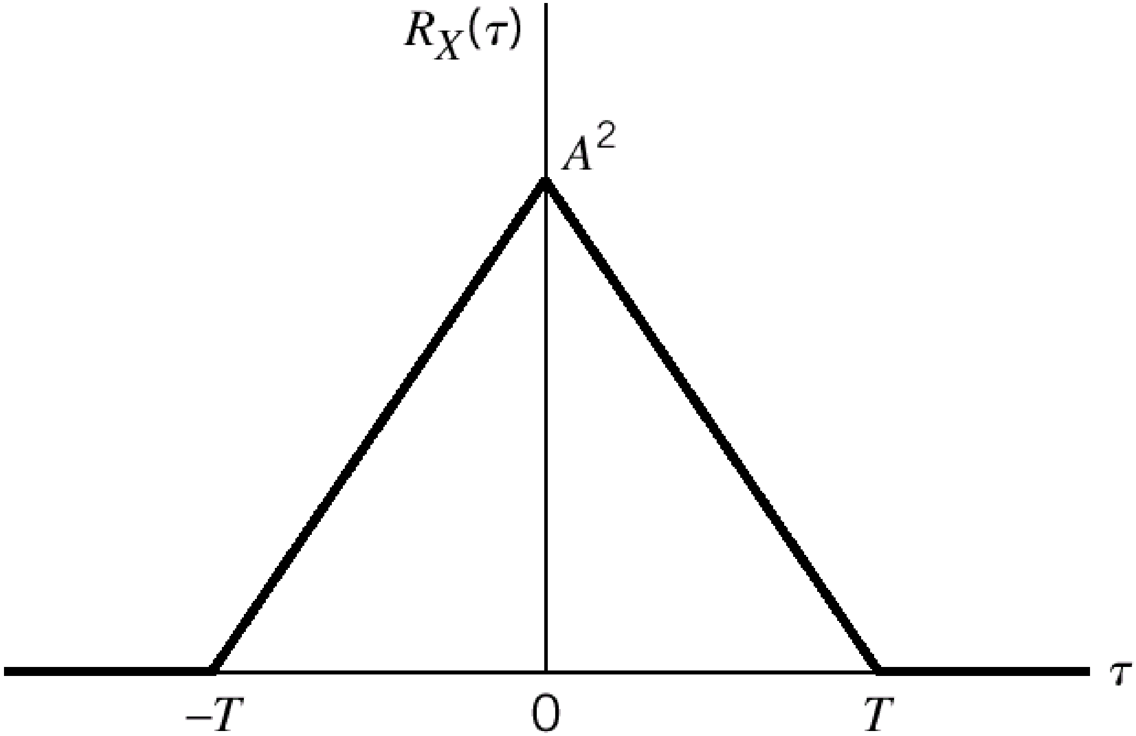
OK

Not OK

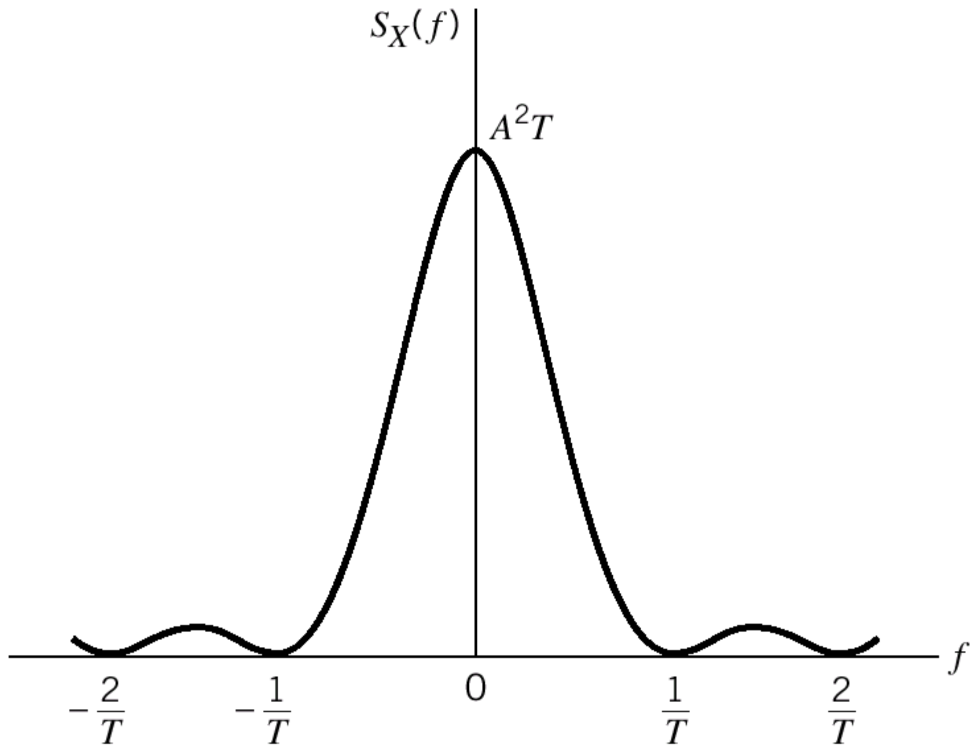
Relation between data rate and harmonics.



Sample function of random binary wave

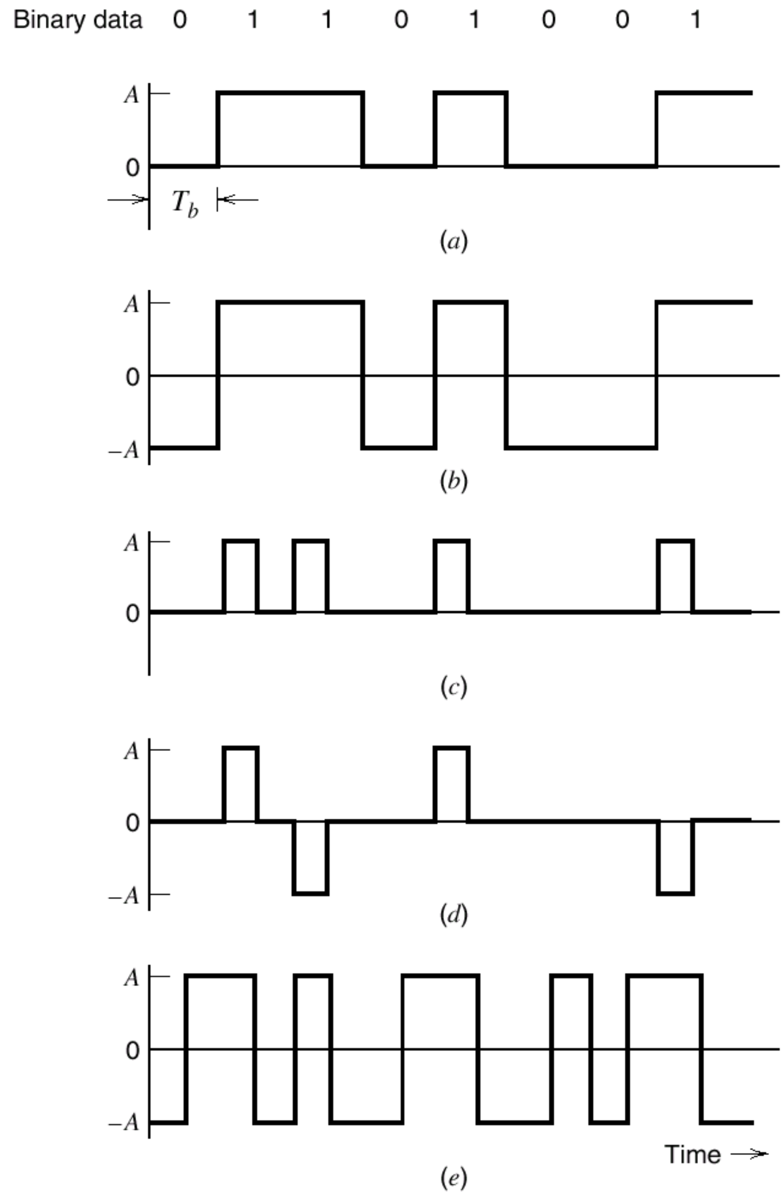


Autocorrelation function of random binary wave



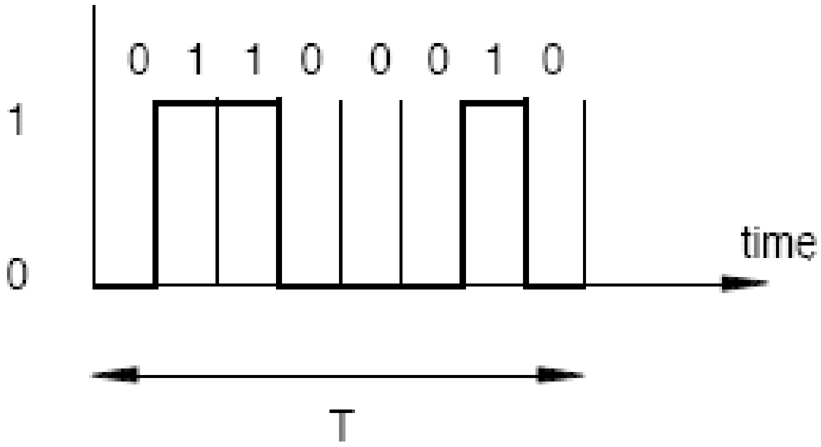
Power spectral density of random binary wave

$$S_x(f) = \int_{\infty}^{\infty} R_x(\tau)\exp(-j2\pi f\tau)\,d\tau$$



Line codes for the electrical representations of binary data.
(a) Unipolar NRZ signaling. (b) Polar NRZ signaling. (c) Unipolar RZ signaling.
(d) Bipolar RZ signaling. (e) Split-phase or Manchester code.

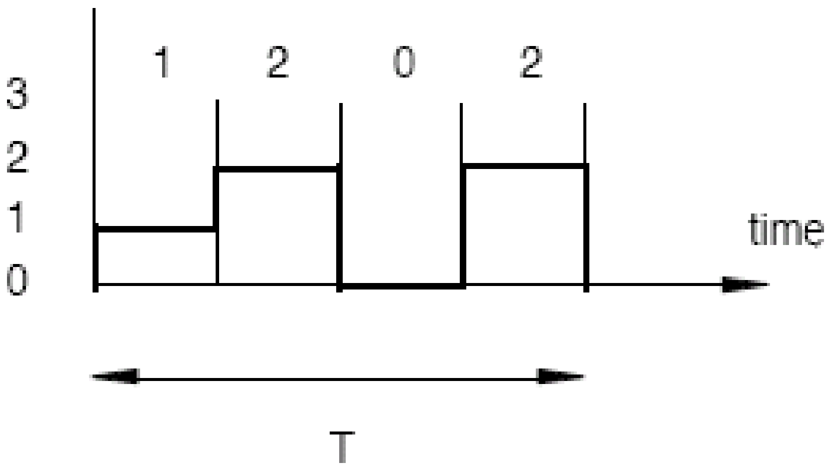
Coding: baud vs. bps



Data rate: D = 8 / T (bps)

Elementary interval: Δ = T / 8 (sec)

Modulation speed: R = 8 / T (bauds)



Data rate: D = 8 / T (bps)

Elementary interval: Δ = T / 4 (sec)

Modulation speed: R = 4 / T (bauds)

baud=Symbol/sec

Maximum Data Rate of a Channel

- **Nyquist's Theorem**

Max. data rate = $2H \log_2 V$ bits/sec

(Noiseless Channel)

where V represent No. of discrete level of signals.

- **Shannon's Theorem**

Max. data rate = $H \log_2 (1 + \frac{S}{N})$ bits/sec

(Noisy Channel)

where S/N represent signal-to-noise ratio.

Guided Transmission Media

- Magnetic Media
- Twisted Pairs
- Coaxial Cable
- Power Lines
- Fiber Optics

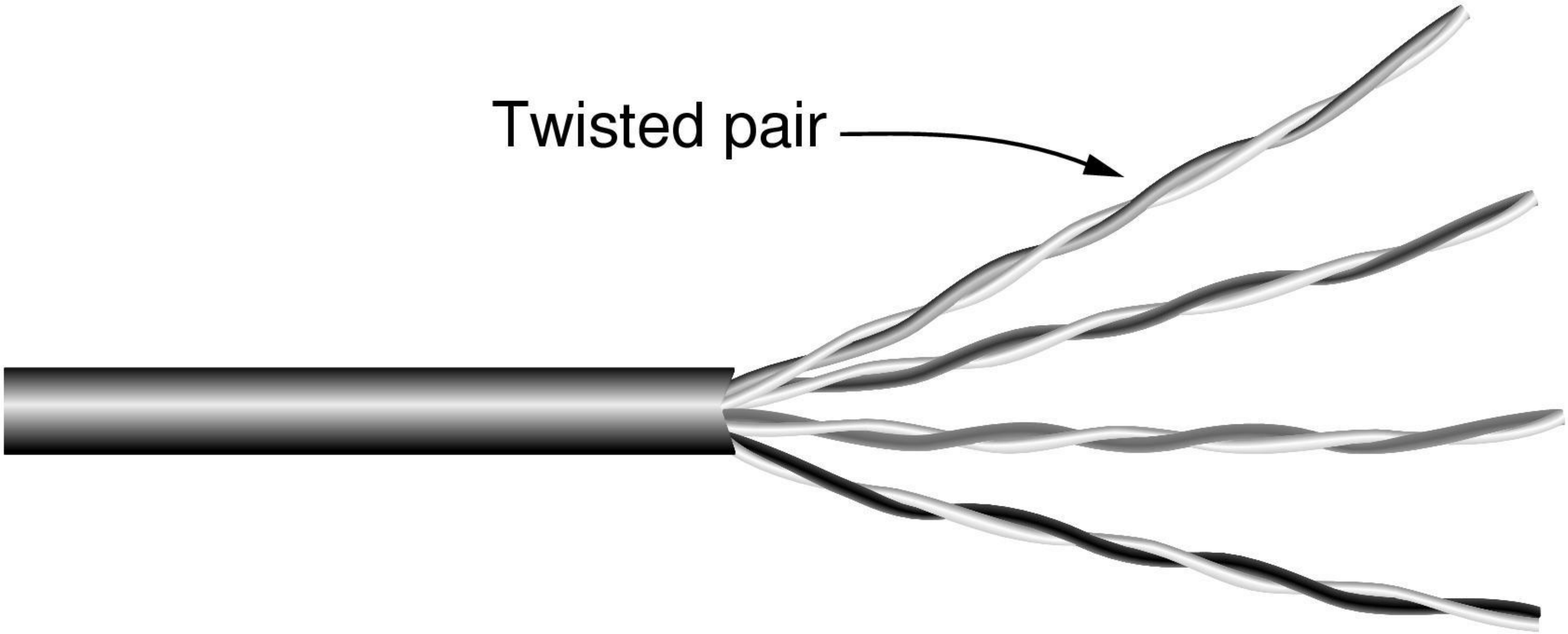
Magnetic Media

- Write data onto magnetic media
  - Disks
  - Tapes
- Data transmission speed
  - Never underestimate the bandwidth of a station wagon full of tapes hurtling down the highway.

Twisted Pair

- **Twisted pair**
  - two insulated copper wires, 1mm thick
  - to reduce electrical interference from similar pairs close by
  - low cost
- **Application**
  - telephone system: nearly all telephones
  - several km without amplification
- **Bandwidth**
  - thickness of the wire, and distance
  - Typically, several Mbps for a few km

Twisted Pairs



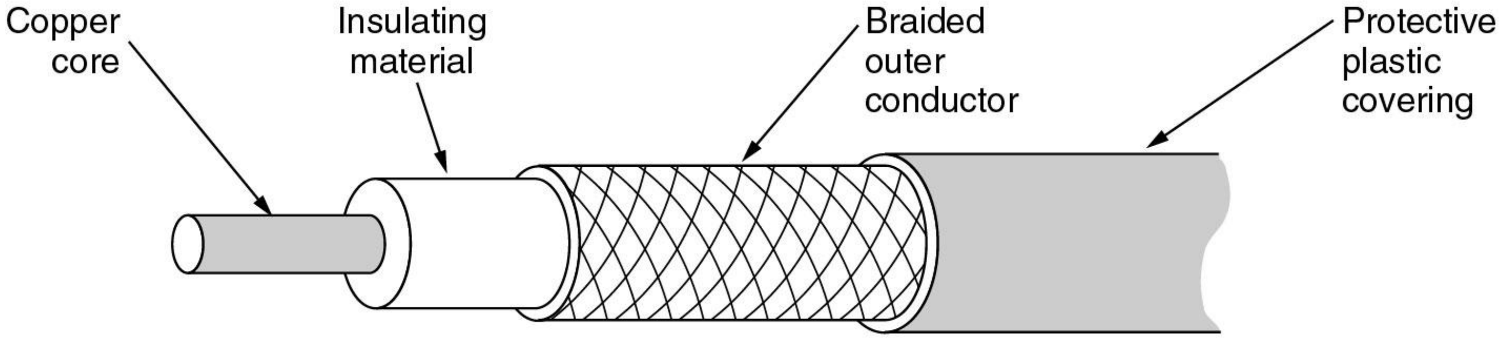
Category 5 UTP cable with four twisted pairs

(a) Category 3 Unshielded Twisted Pair (UTP). BW.=16MHz

(b) Category 5 Unshielded Twisted Pair (UTP). BW.=100MHz

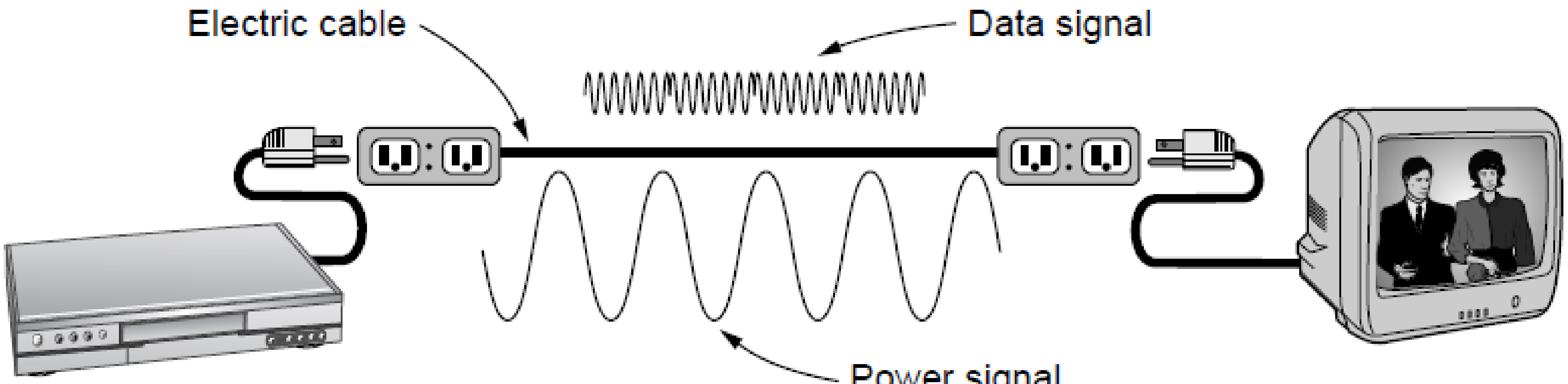
(c) Cat. 6 BW.=250MHz, Cat.7 BW.= 600MHz

Coaxial Cable



A coaxial cable.

Power Lines



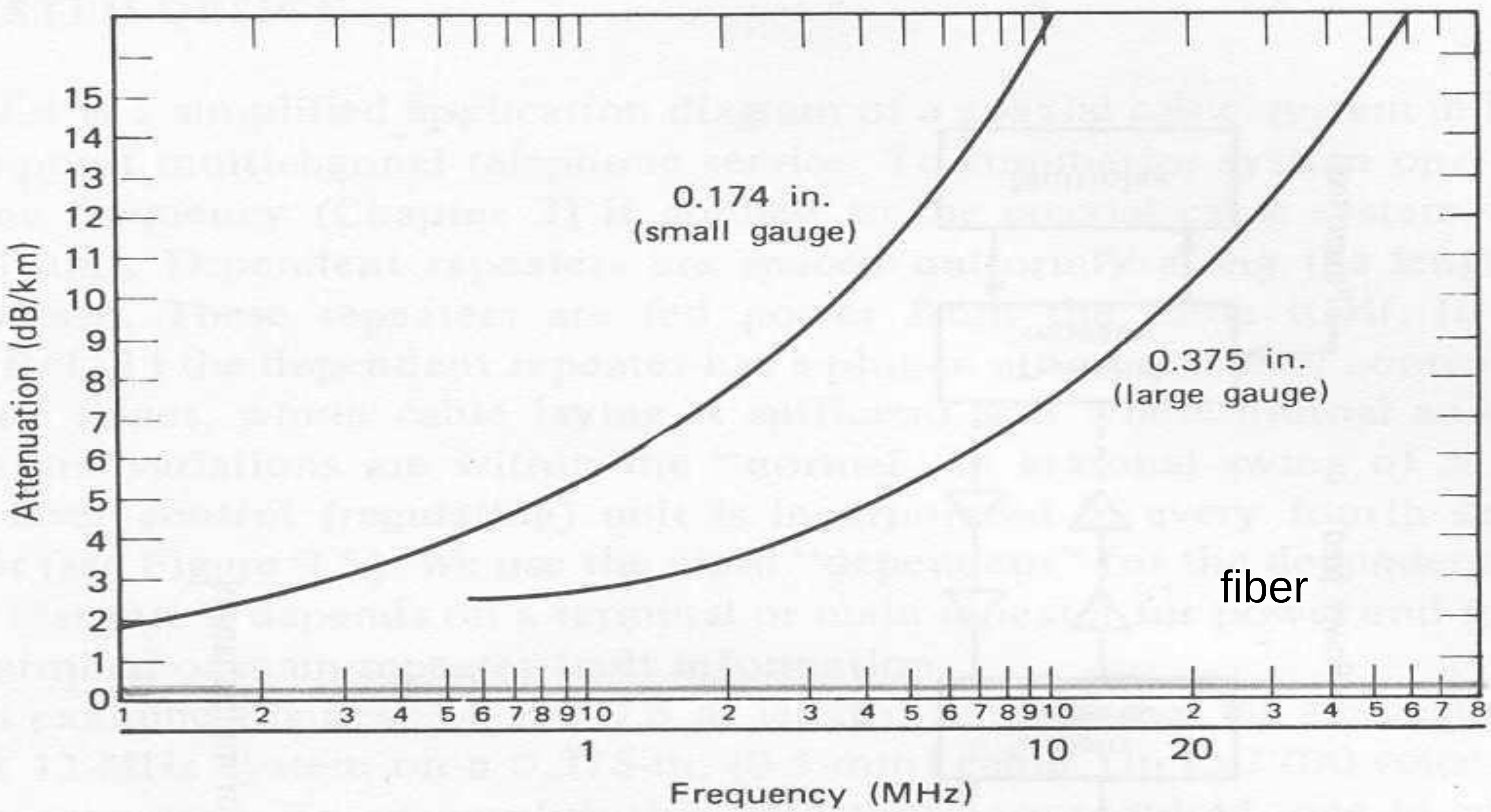
A network that uses household electrical wiring.

Baseband Coaxial Cable

- **Coaxial cable (coax)**
  - better shielding (Fig. 2-4)
  - longer distances at higher speeds
  - two kinds
    - 50-ohm cable: digital transmission
    - 75-ohm cable: analog transmission (Cable TV)
- **Bandwidth**
  - 1-km cable: 1-2 Gbps
- **Application**
  - telephones system: coaxial cable are being replaced by fiber optics
  - widely used for cable TV

Broadband Coaxial Cable

- **Broadband cable**
  - any cable network using analog transmission
  - 300 MHz (1bps ~ 1 Hz of bandwidth)
  - 100 km
  - multiple channels: 6-MHz channels
- **Difference between baseband and broadband**
  - broadband covers a large area
  - analog amplifiers are needed
- **Broadband cable**
  - inferior to baseband (single channel) for sending digital data
  - advantage: a huge amount is installed
  - In US, TV cable more than 80% of all homes
  - cable TV systems will operate as MANs and offer telephone and other service



Attenuation–frequency response per kilometer

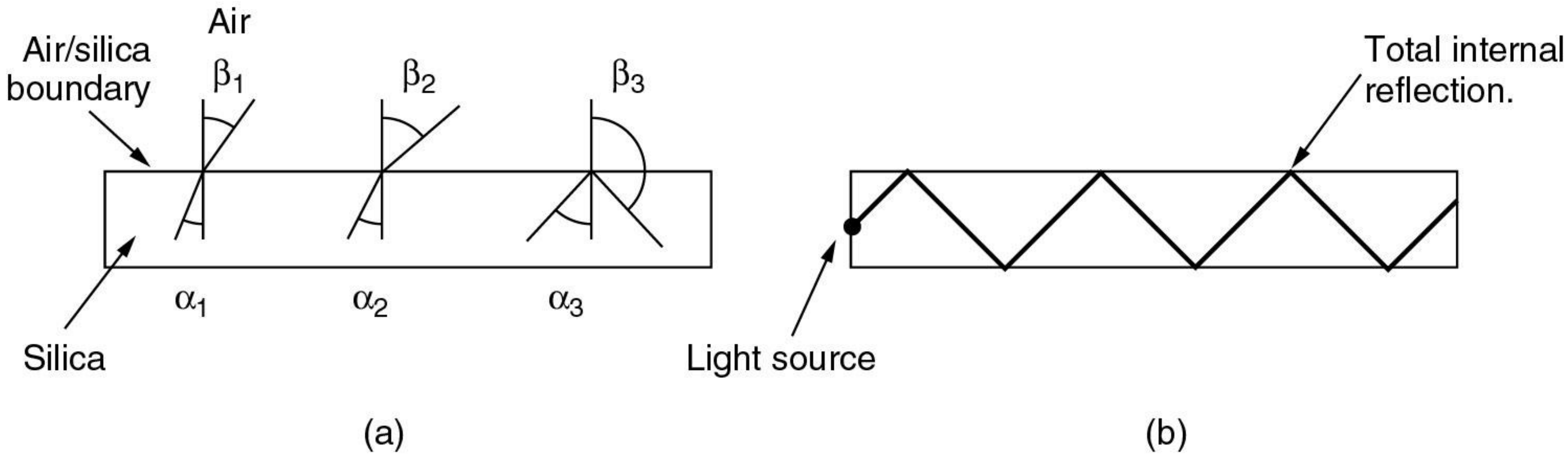
Fiber Optics

- Achievable bandwidth with fiber: more than 50,000 Gbps
  - 40 Gbps/wavelength : due to inability to convert electrical -> optical signals faster
  - 100 Gbps: in lab
- CPUs' physical limits
  - speed of electron
  - heat dissipation
- Communication (100 times/decade) won the race with computation (10 times/decade)
  - use network, and avoid computations at all

Fiber Optics (2)

- **Optical Transmission Systems**
  - light source
  - transmission medium: ultra-thin fiber of glass
  - detector: light -> electrical pulse
- **Refraction (See Fig. 2.5)**
- **Multimode fiber**
  - many different rays are bounced at different angles
- **Single-mode fiber**
  - fiber's diameter: a few wavelengths of light
  - for longer distances
  - lasers: 100 km without repeaters

Fiber Optics (3)



(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.

Snell's law: $n_1 \sin\alpha = n_2 \sin\beta$

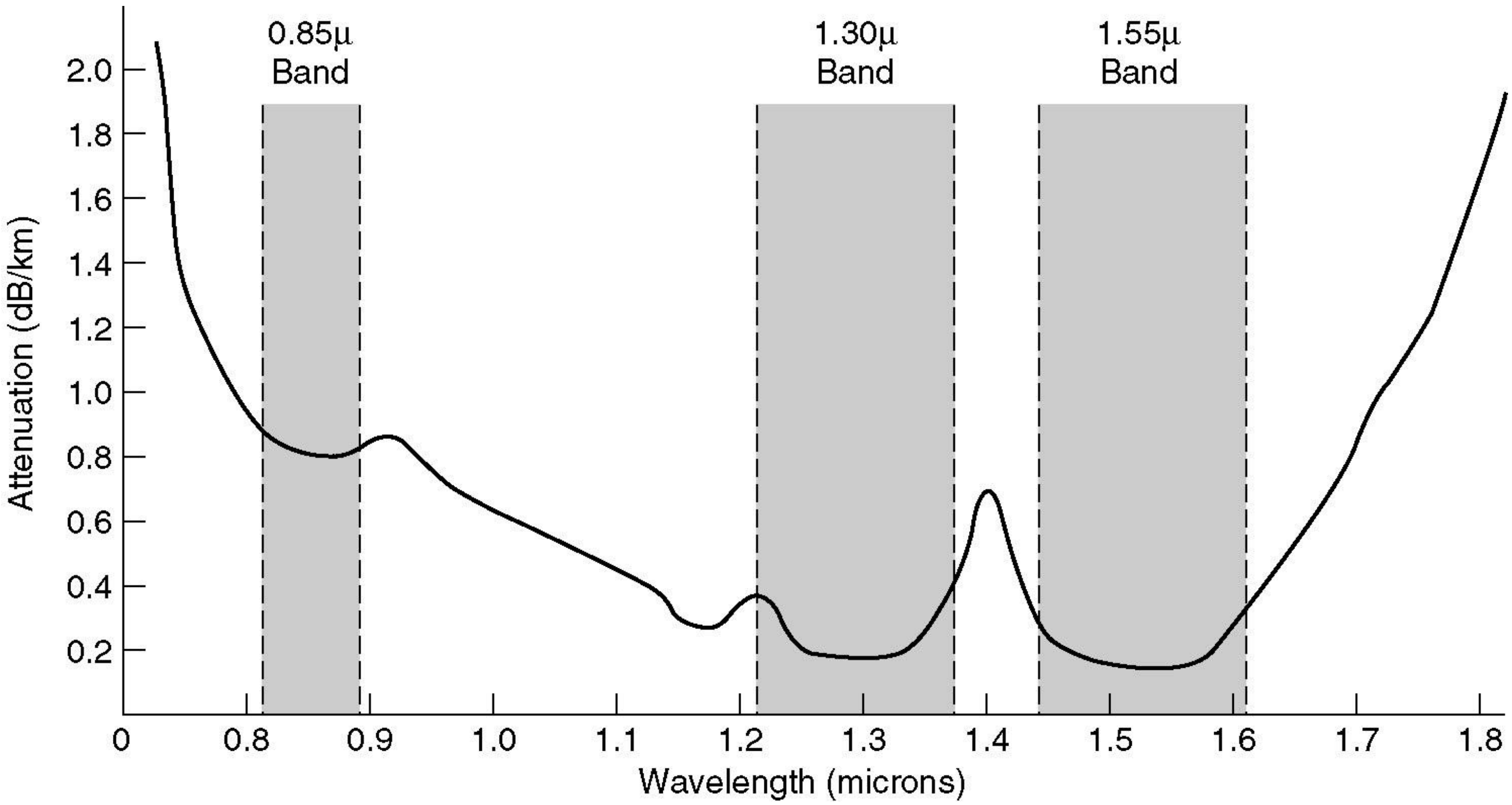
n (refraction index) $= c / v$

c is the speed of light in vacuum, v in the medium

When $\beta = 90°$, we get $\sin\alpha_c = n_2 / n_1$ (with $n_2 < n_1$)

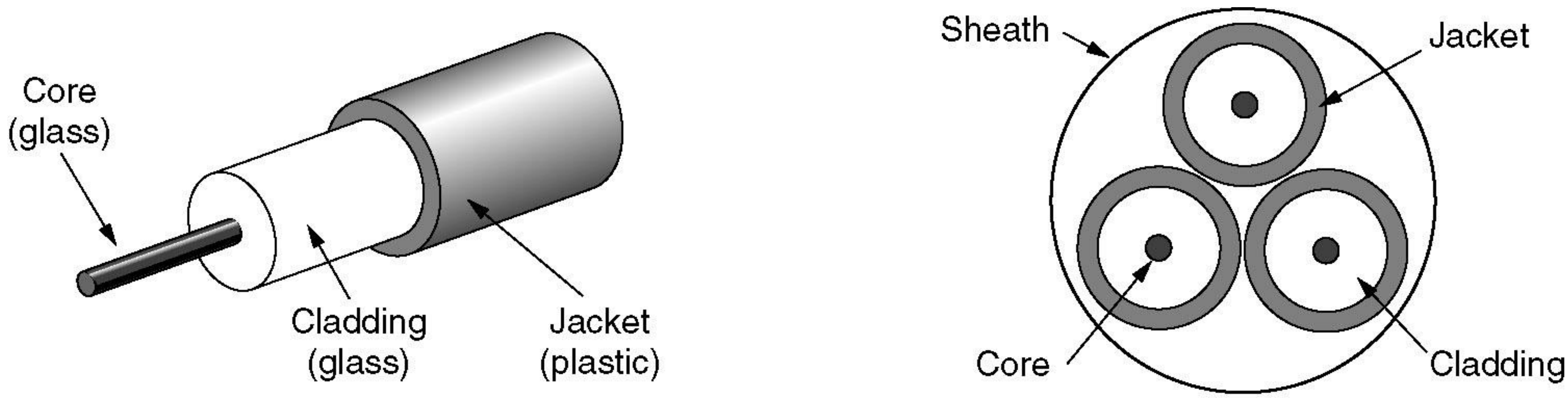
For $\alpha > \alpha_c$, there is no refraction (total internal reflection)

Transmission of Light through Fiber



Attenuation of light through fiber in the infrared region.

Fiber Cables



(a) (b)

(a) Side view of a single fiber.

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

Fiber Cables (2)

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

A comparison of semiconductor diodes and LEDs as light sources.

Comparison Between Fiber Optics and Copper Wire

- **Fiber Optics**
  - Much higher bandwidths
  - Low attenuation: amplifiers for every 30 km
  - Not affected by power surges, electromagnetic interference, power failures, corrosive chemicals
  - Telephone systems like it: thin and lightweight
    - copper has excellent resale value
    - fiber has much lower installation cost
  - Quite difficult to tap: do not leak light
  - Disadvantage
    - two-way communication: two fibers or two frequency bands on one fiber
    - fiber interfaces are more expensive than electrical interfaces
- **Copper Wire**
  - Amplifiers : ~ every 5 km

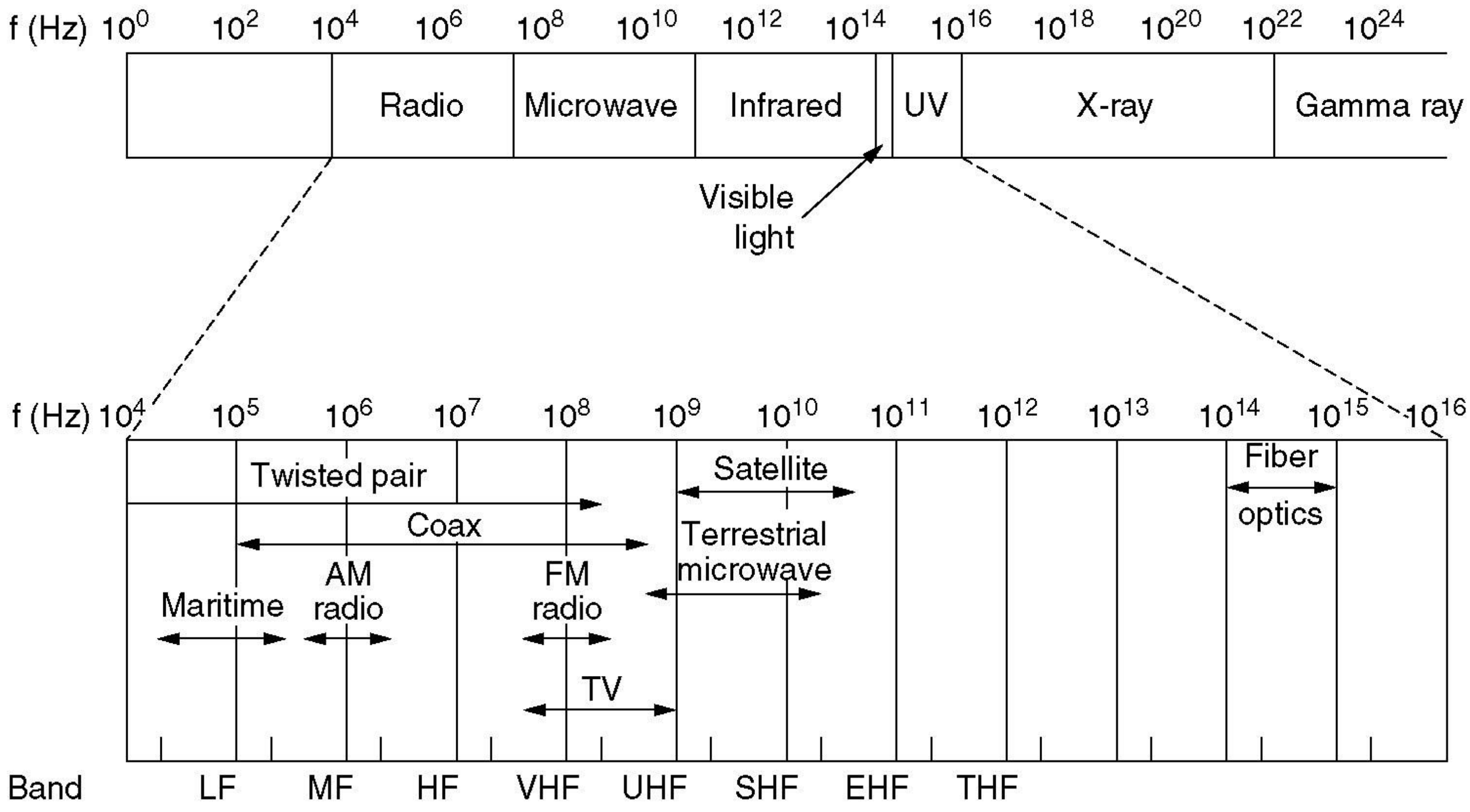
Wireless Transmission

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

Electromagnetic Spectrum

- $\lambda f = c,$ $$\frac{df}{d\lambda} = -\frac{c}{\lambda^2} \Rightarrow \Delta f = \frac{c\Delta\lambda}{\lambda^2} \quad (2-3)$$
  - c: $3 * 10^8$ m/sec
  - copper or fiber: 2/3 speeds
- Can be used for transmitting information
  - radio, microwave, infrared, and visible light
  - by modulating the amplitude, frequency, or phase of the waves
- The others
  - Ultraviolet light, X-rays, and gamma rays
  - they are better due to their higher frequencies
  - disadvantages
    - hard to produce
    - hard to modulate
    - do not propagate well through buildings
    - dangerous to living things
- National and International agreements about who can use which frequencies.

Electromagnetic Spectrum (1)



The electromagnetic spectrum and its uses for communication.

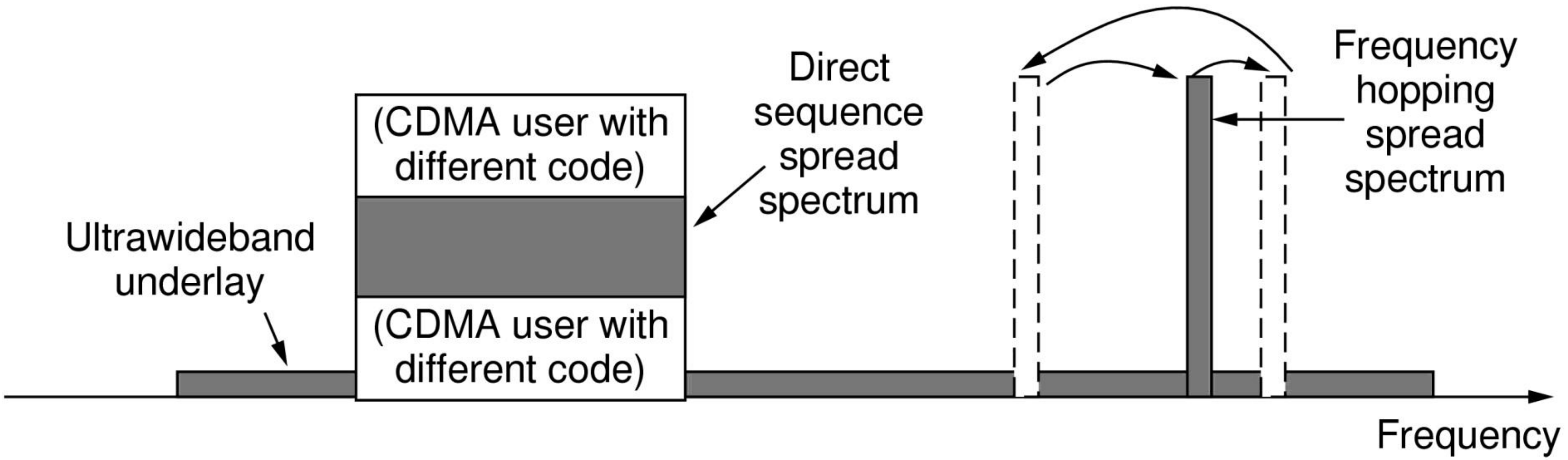
Radio Transmission

- **Radio waves**
  - easy to generate
  - travel long distances
  - penetrate buildings easily (< 2.0GHz)
  - omnidirectional (travel in all directions)
- **Properties**
  - at low frequencies
    - pass through obstacles well
    - power falls off sharply with distance (1 / r^3 in air)
  - at high frequencies
    - tend to travel in straight lines
    - bounce off obstacles
    - absorbed by rain
  - subject to interference from motors and electrical equipment

Radio Transmission (2)

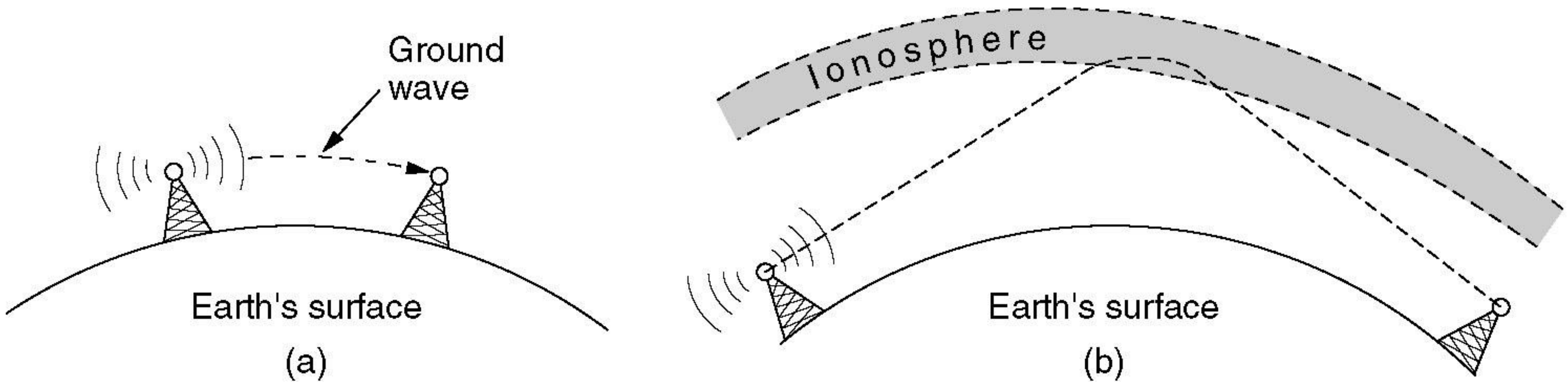
- **VLF, LF, and MF Bands (See Fig. 2-12a)**
  - radio waves follow the ground
  - can be detected for 1000 km at the lower frequencies
  - offer relatively low bandwidth
- **HF and VHF Bands**
  - the waves reaching the ionoshpere (電離層) are refracted back to the earth
  - Hams (amateur radio operators) use them to talk long distances

The Electromagnetic Spectrum (2)



Spread spectrum and ultra-wideband (UWB) communication

Radio Transmission (3)



(a) In the VLF, LF, and MF bands, radio waves follow the curvature of the earth.

(b) In the HF band, they bounce off the ionosphere.

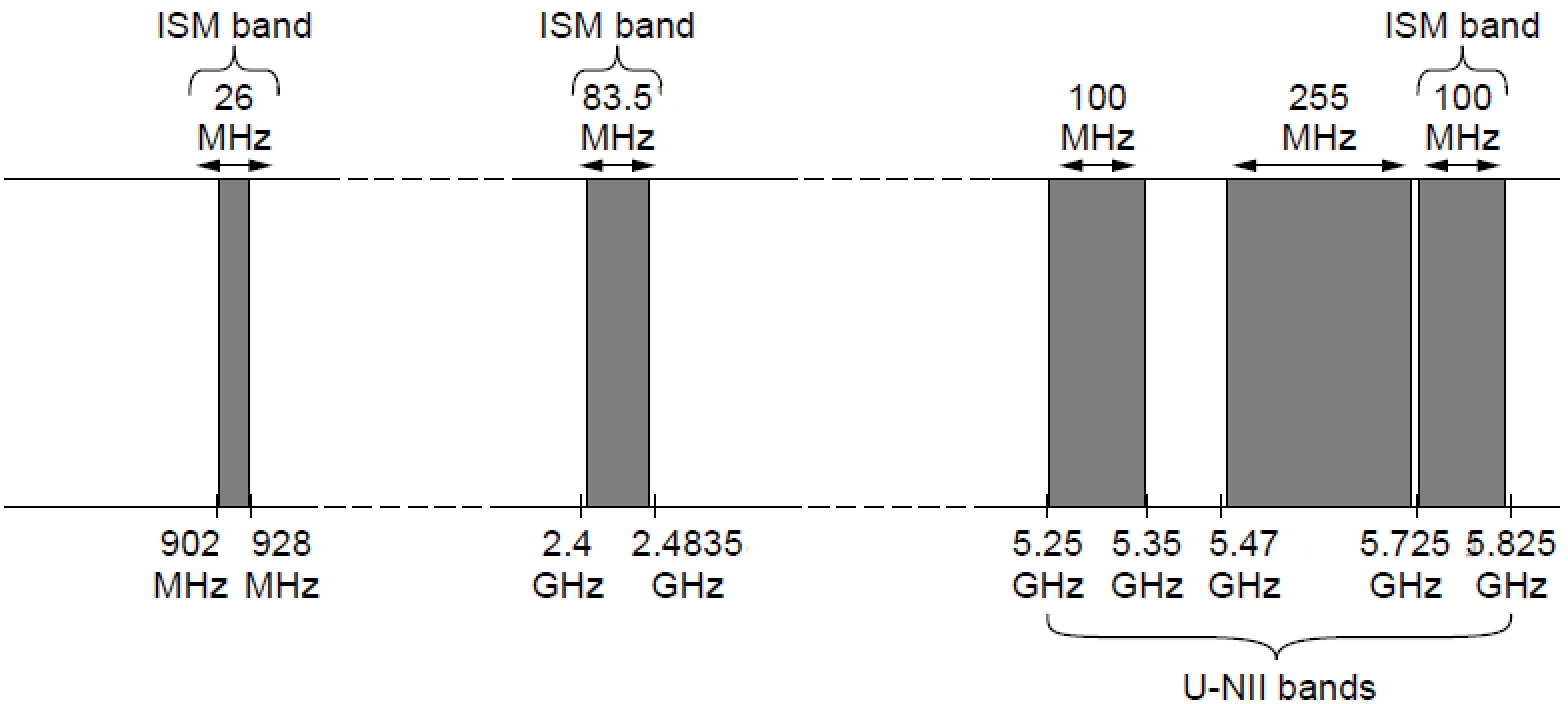
Microwave Transmission

- **Microwaves**
  - above 100 Mhz
  - travel in straight lines, narrowly focused
  - long distance telephone transmission systems (before fiber optics)
  - MCI: Microwave Communications, Inc. (A company was competing with AT&T)
  - repeaters needed periodically
  - do not penetrate buildings well
  - Multipath fading: some divergence, some refracted
  - problem at 4 GHz: absorption by water (rain)
- **Usage**
  - widely used by long-distance telephone, cellular telephones, TV
- **Advantages over Fiber Optics**
  - do not need right of way: microwave tower for every 50 km (MCI)
  - relatively inexpensive (towers and antennas)

Microwave Transmission (2)

- **Industrial/Scientific/Medical Bands (ISM)**
  - do not require government licensing
  - cordless telephones, garage door openers, wireless hi-fi speakers, security gates
  - higher bands
    - more expensive electronics
    - interference from microwave and radar installations

The Politics of the Electromagnetic Spectrum



ISM and U-NII bands used in the United States by wireless devices

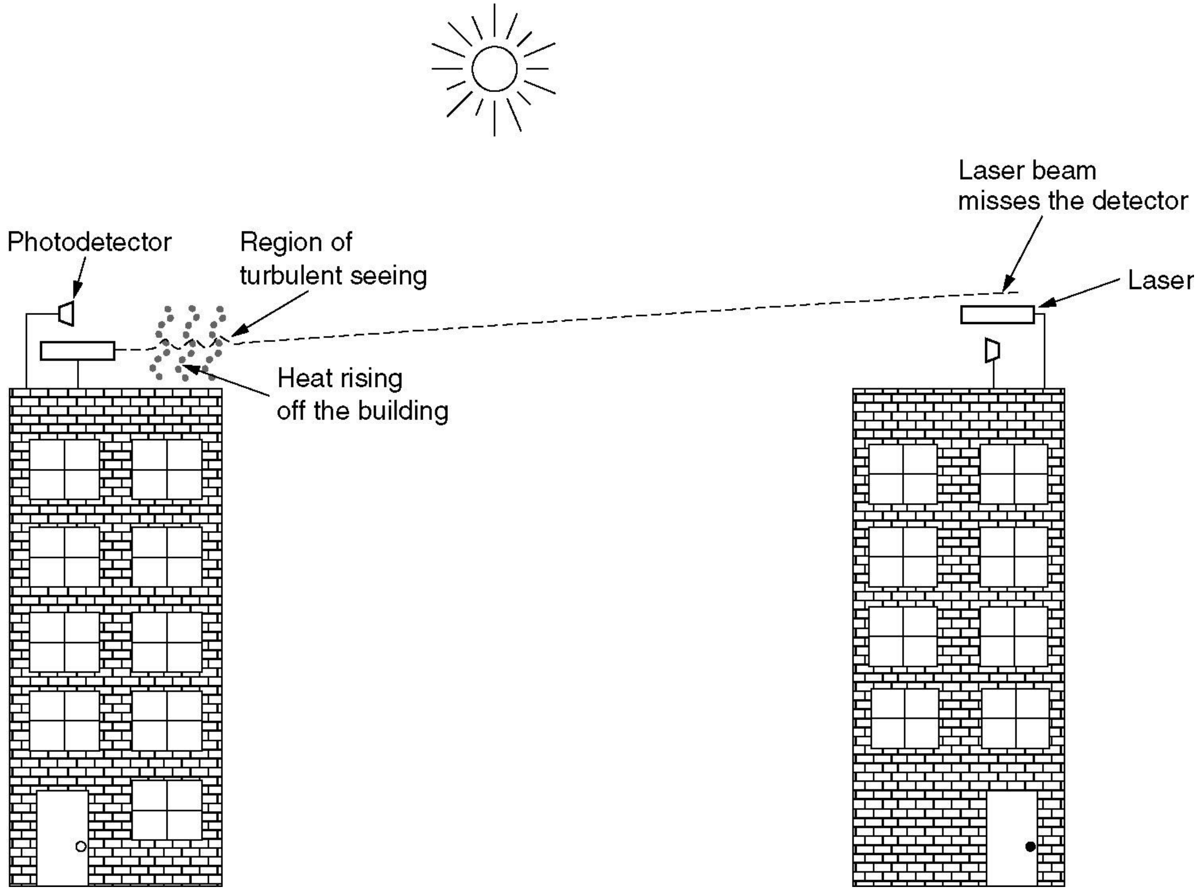
Infrared and Millimeter Waves

- **short range communications:**
  - remote controllers for TVs, VCRs, and stereos
- **relatively directional, cheap, easy to build**
- **do not pass through solid objects**
  - no interference between rooms
  - security is better than radio systems
  - no government license is needed
- **Indoor wireless LAN**

Lightwave Transmission

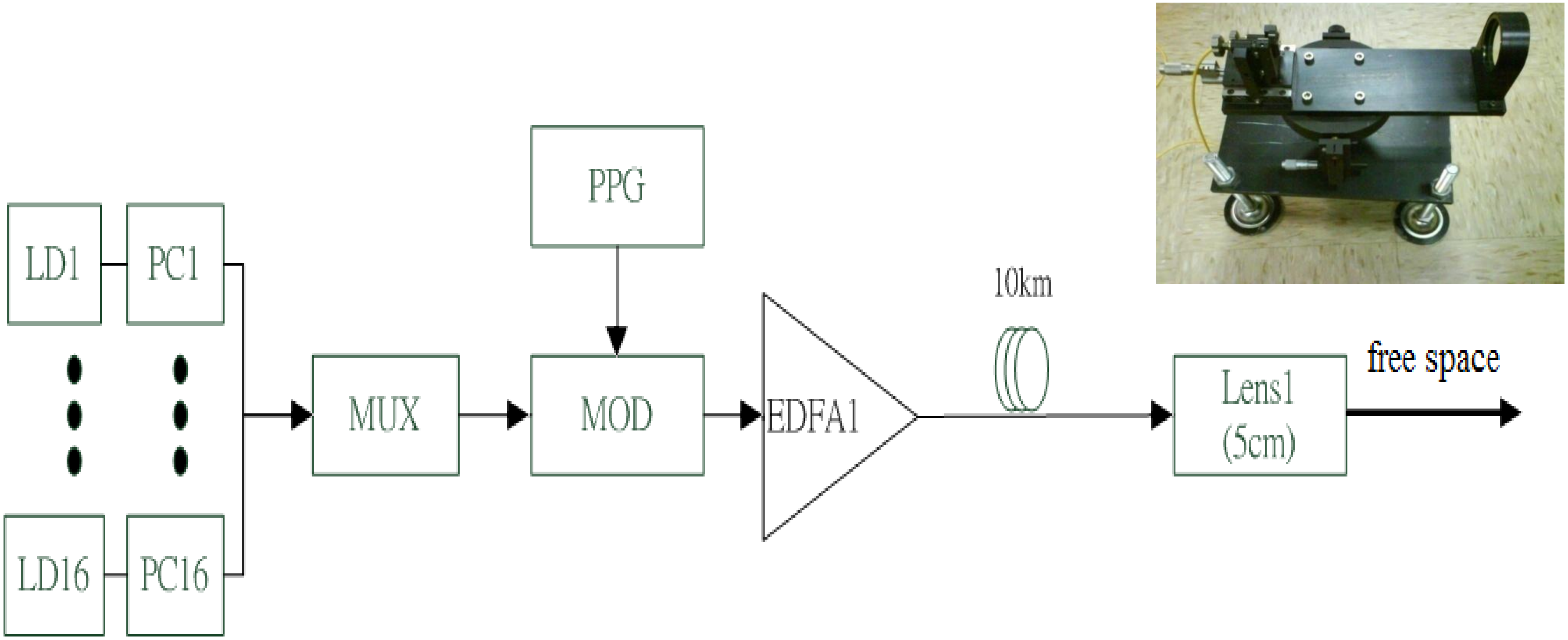
- **Unguided optical signaling**
  - to connect LANs in two buildings via lasers mounted on rooftops
    - very high bandwidth
    - very low cost
    - Relatively easy to install
    - does not require FCC license
    - need to aim accurately
    - disadvantage: laser beams cannot penetrate rain or thick fog
- **An example interference with convection currents**
  - See Fig. 2-14

Lightwave Transmission (2)



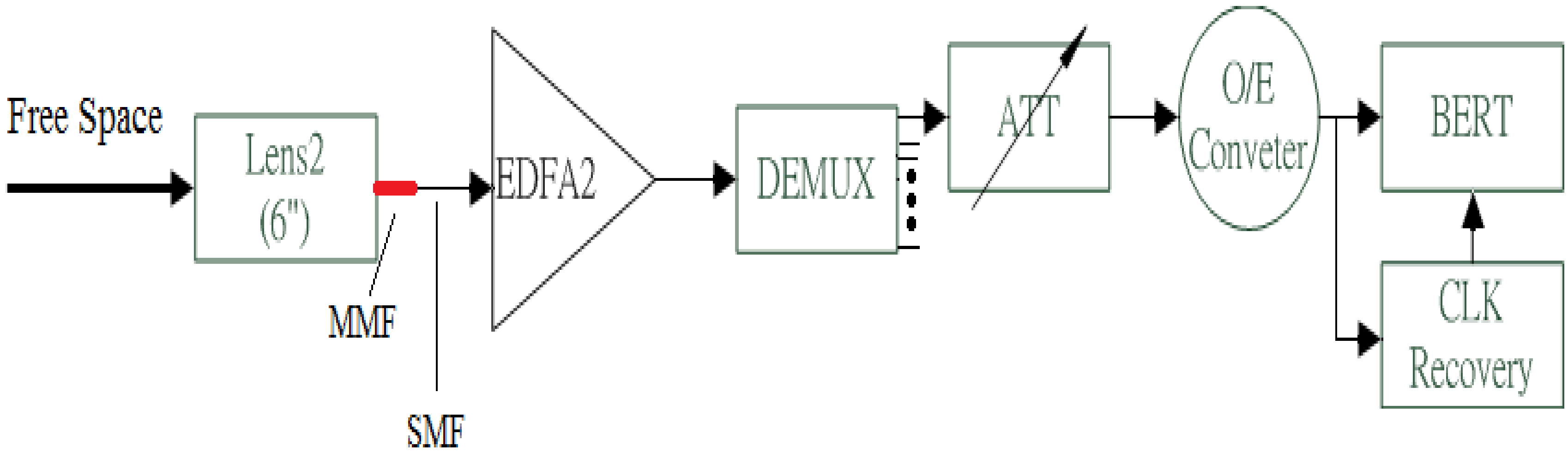
Convection currents can interfere with laser communication systems.
A bidirectional system with two lasers is pictured here.

System Description(1)



- 1.Transmitter
  - Block diagram of the transmitter

System Description(2)



a) 2.Receiver

– Block diagram of the transmitter

System Description(3)

– b. Specification of 6” lens

Diameter:6”(~15cm)

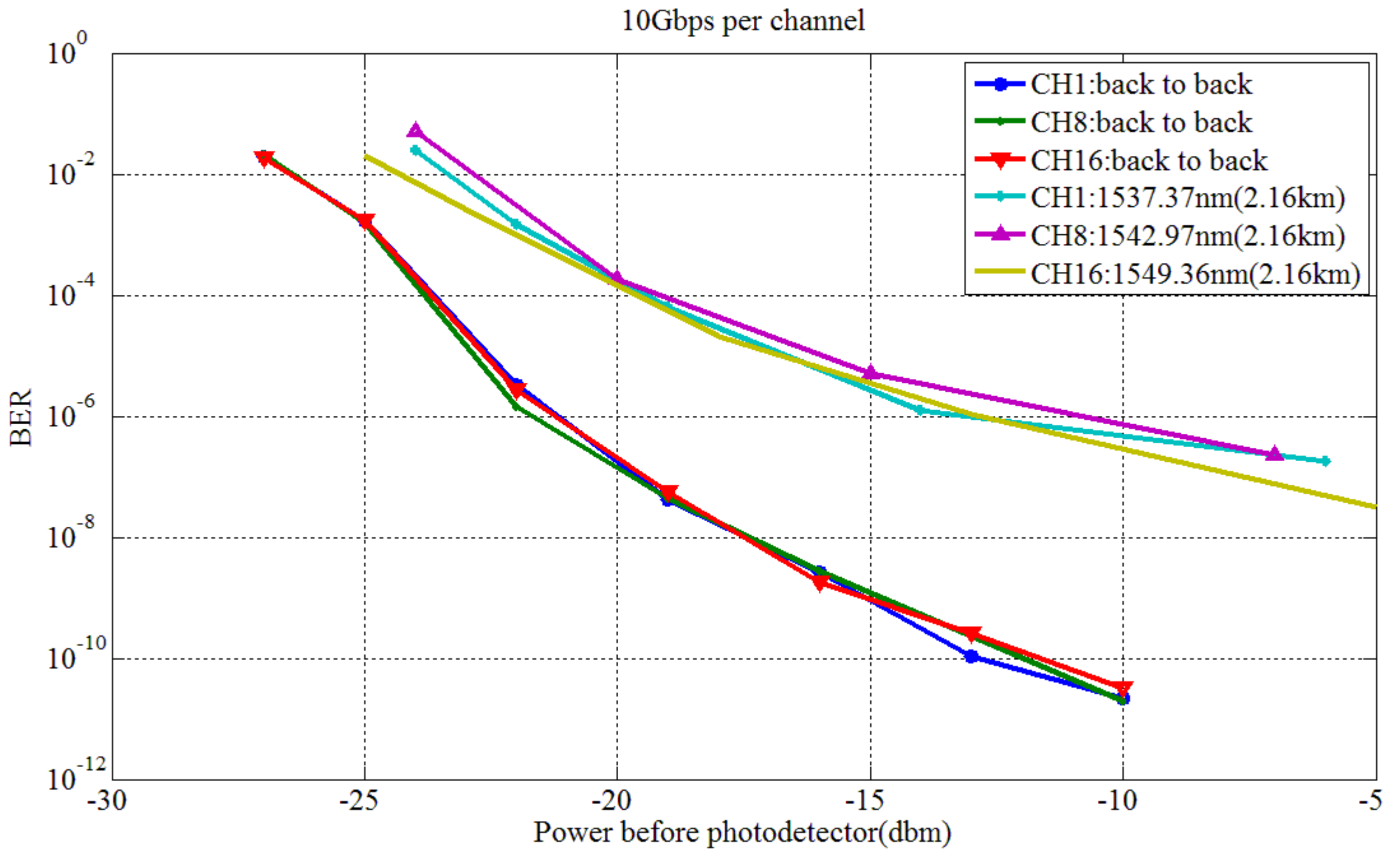
focal length:600mm

Experiment Set-up

- Tx in Lulin astronomical observatory
- Rx in Dong-Pu

Measurement Results

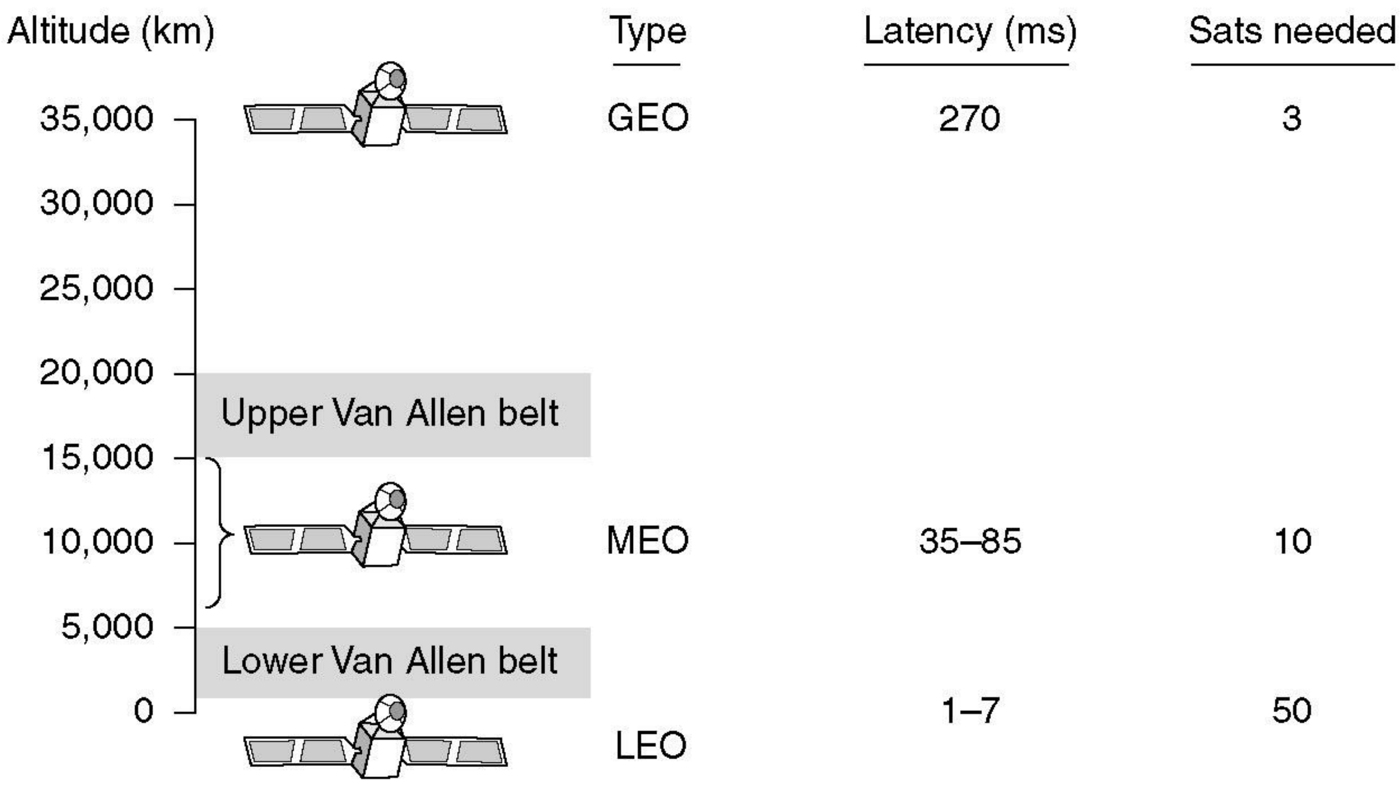
– BER versus Received Power



Communication Satellites

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

Communication Satellites



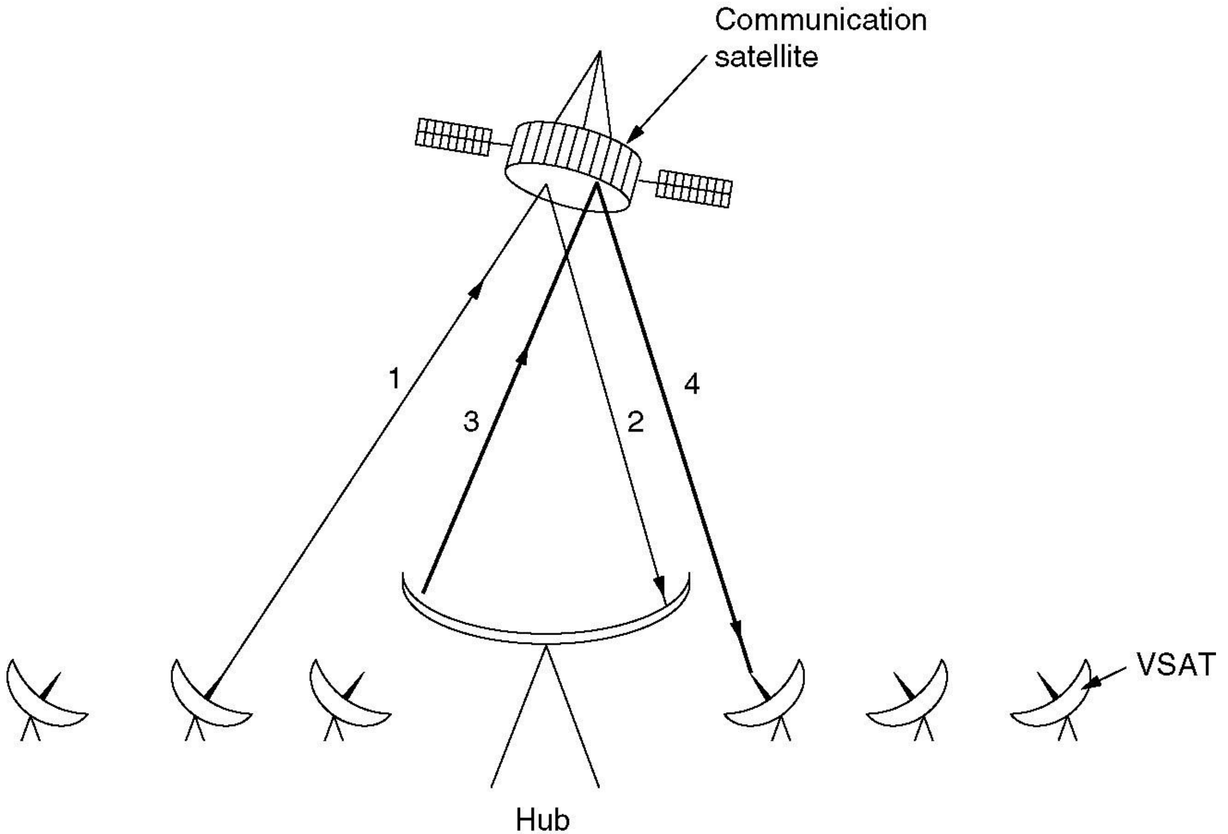
Communication satellites and some of their properties, including altitude above the earth, round-trip delay time and number of satellites needed for global coverage.

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

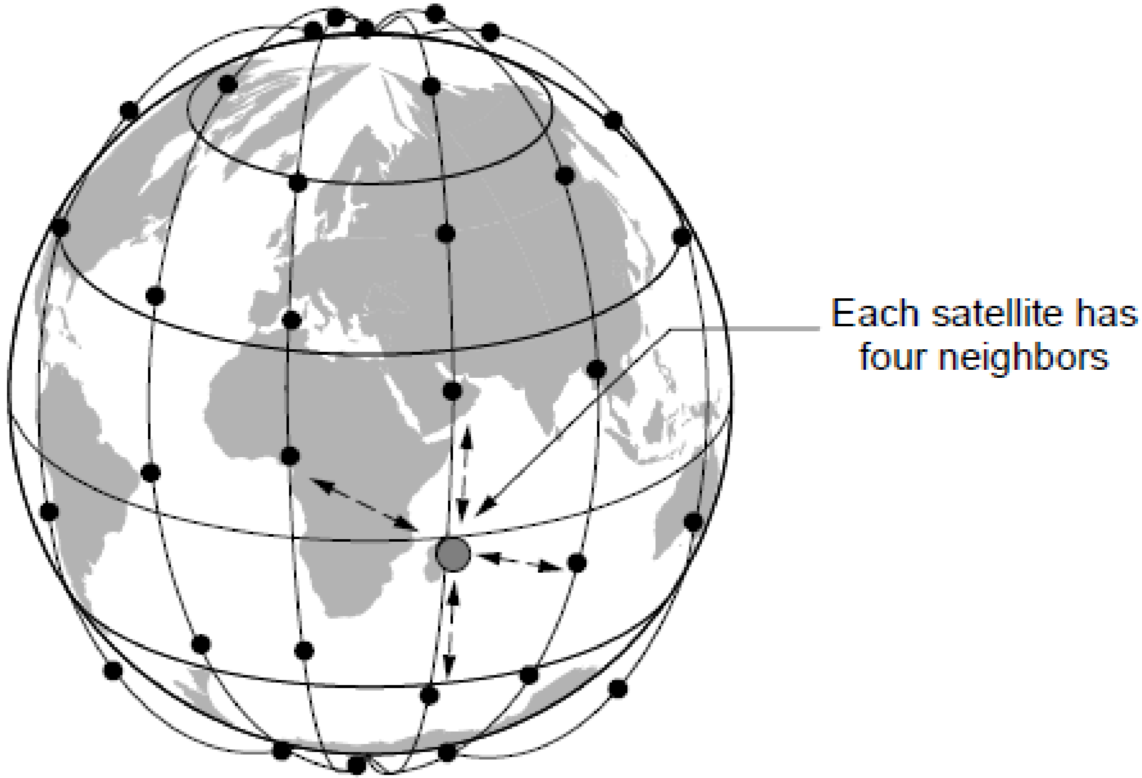
The principal satellite bands.

Communication Satellites (3)



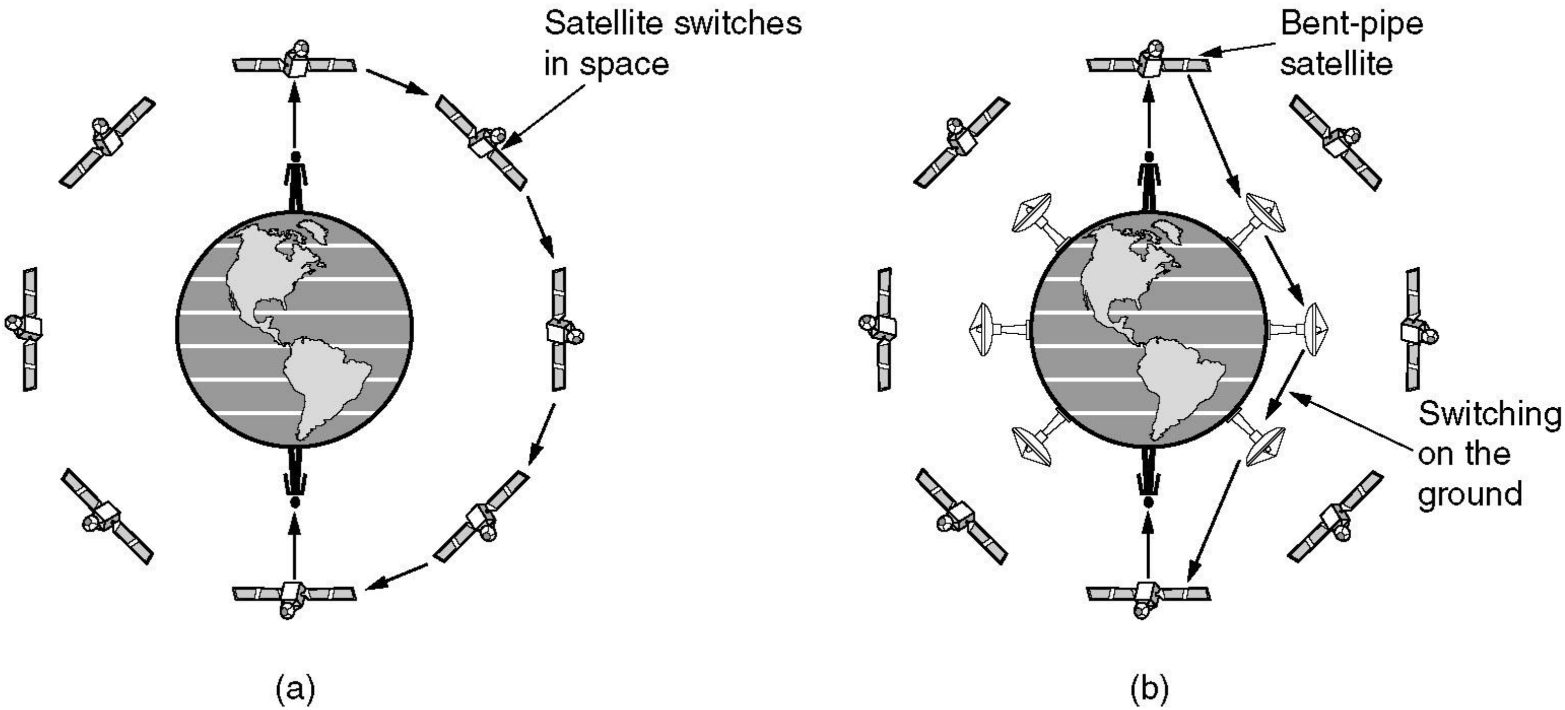
VSATs using a hub.

Low-Earth Orbit Satellites (1)



The Iridium satellites form six necklaces around the earth.

Globalstar



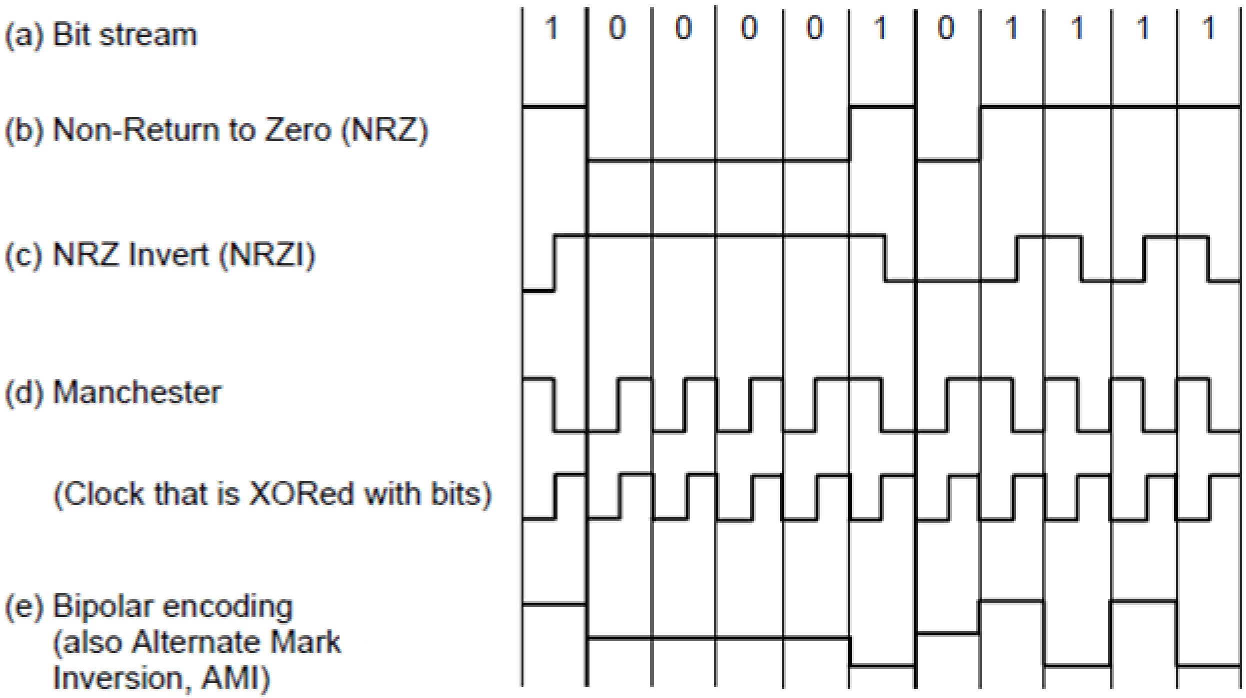
(a) Relaying in space.

(b) Relaying on the ground.

Digital Modulation and Multiplexing

- Baseband Transmission
- Passband Transmission
- Frequency Division Multiplexing
- Time Division Multiplexing
- Code Division Multiplexing

Baseband Transmission



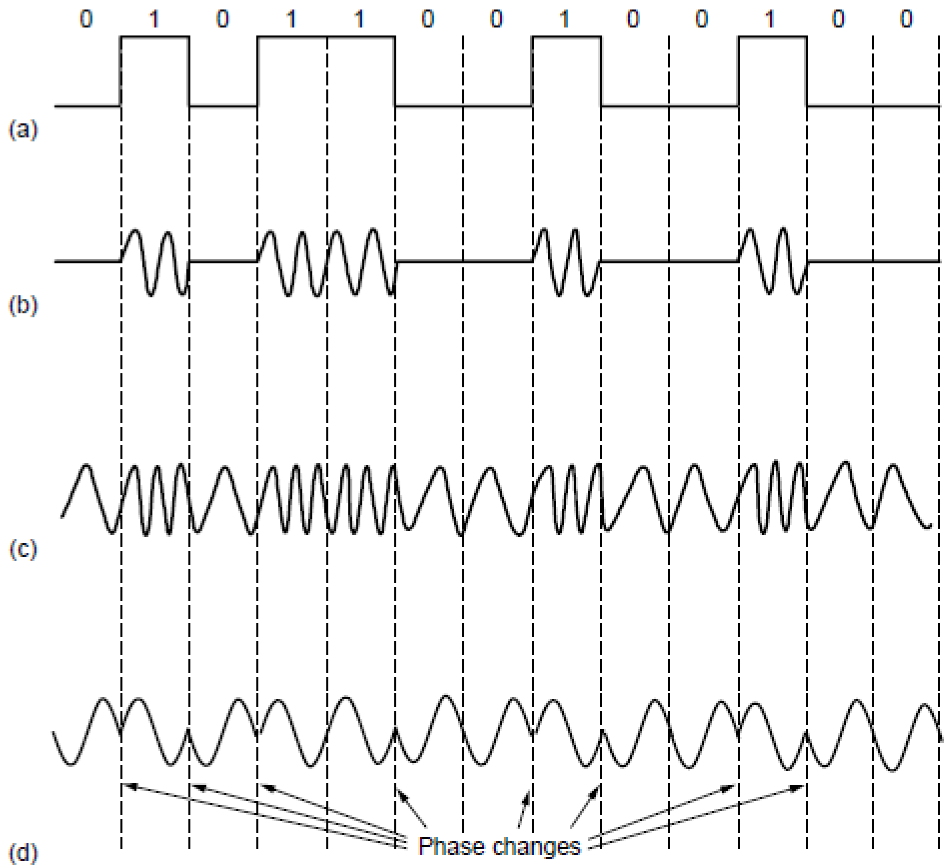
Line codes: (a) Bits, (b) NRZ, (c) NRZI,
(d) Manchester, (e) Bipolar or AMI.

Clock Recovery

Data (4B)	Codeword (5B)	Data (4B)	Codeword (5B)
0000	11110	1000	10010
0001	01001	1001	10011
0010	10100	1010	10110
0011	10101	1011	10111
0100	01010	1100	11010
0101	01011	1101	11011
0110	01110	1110	11100
0111	01111	1111	11101

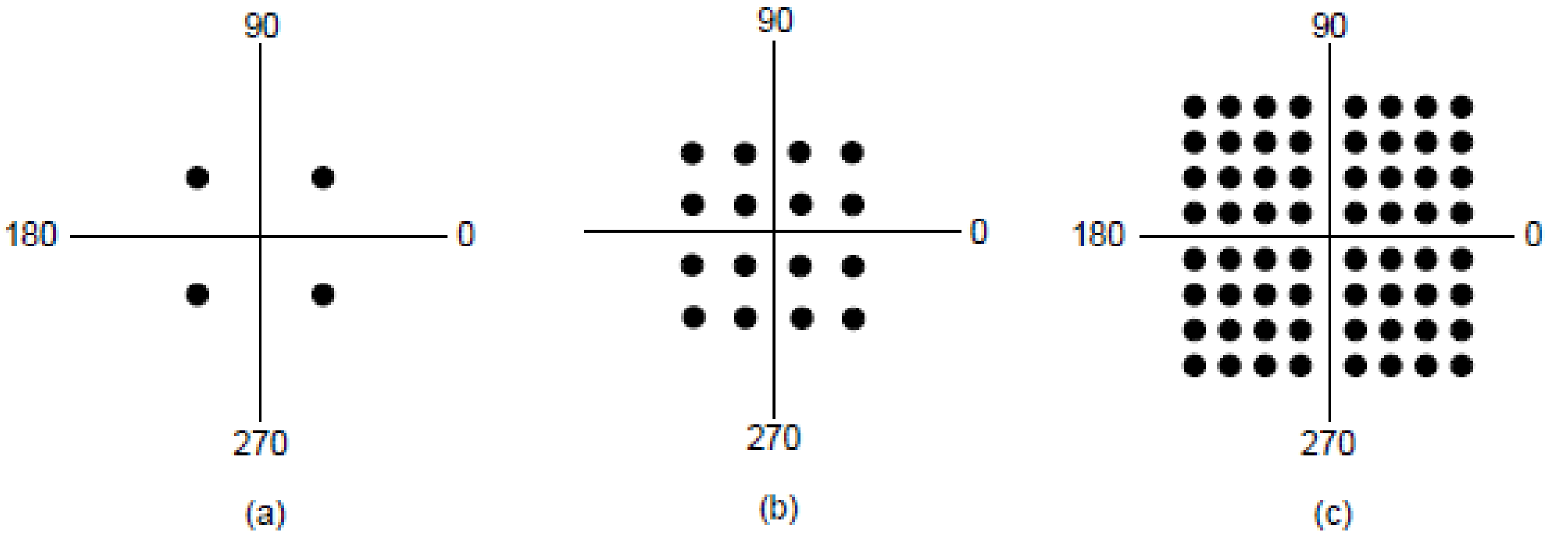
4B/5B mapping.

Passband Transmission (1)



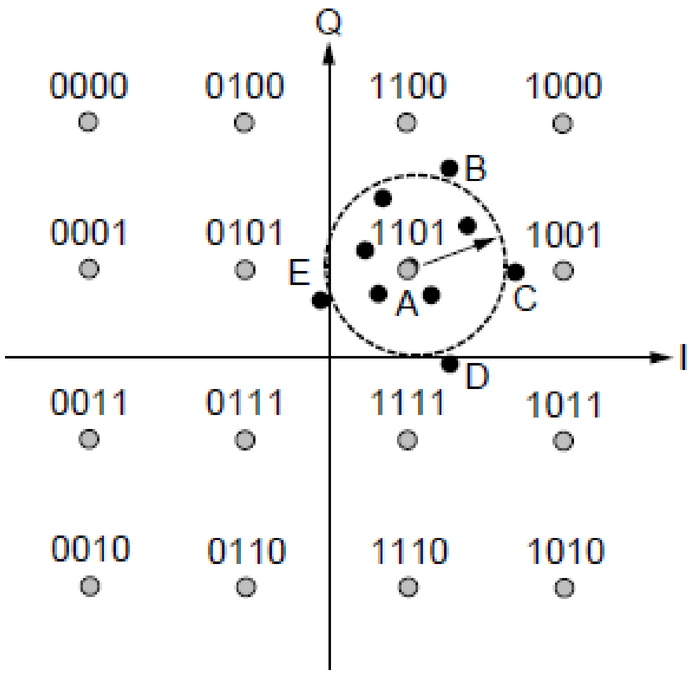
(a) A binary signal. (b) Amplitude shift keying.
(c) Frequency shift keying. (d) Phase shift keying.

Passband Transmission (2)



(a) QPSK. (b) QAM-16. (c) QAM-64.

Frequency Division Multiplexing (1)

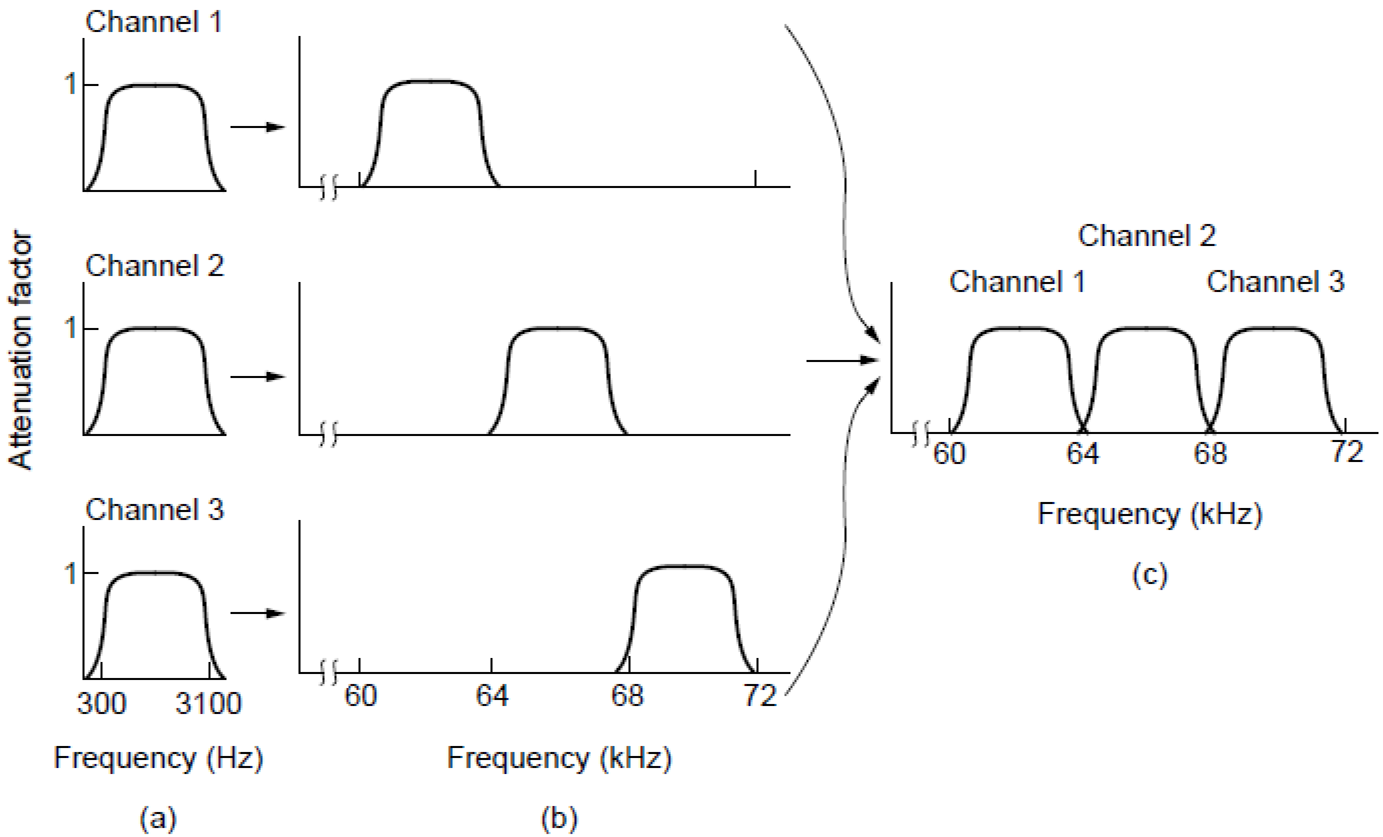


When 1101 is sent:

Point	Decodes as	Bit errors
A	1101	0
B	110<u>0</u>	1
C	1<u>0</u>01	1
D	11<u>1</u>1	1
E	<u>0</u>101	1

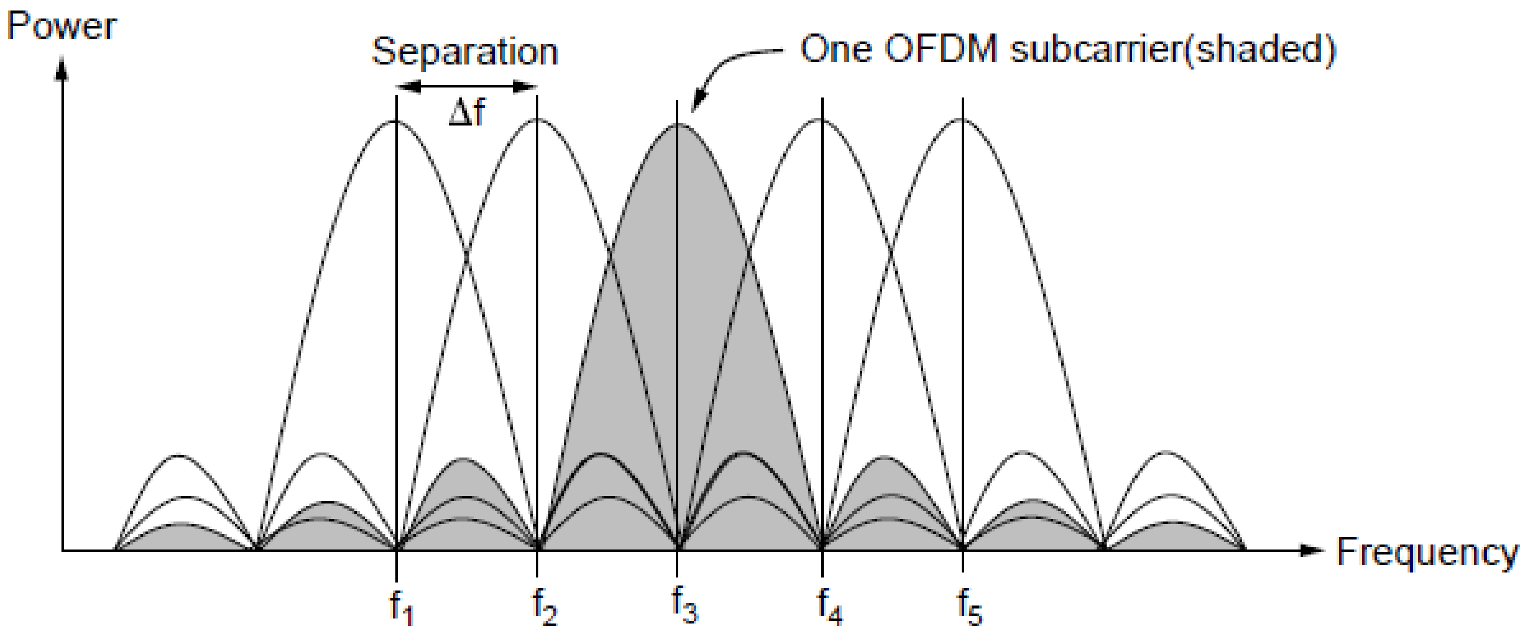
Gray-coded QAM-16.

Frequency Division Multiplexing (2)



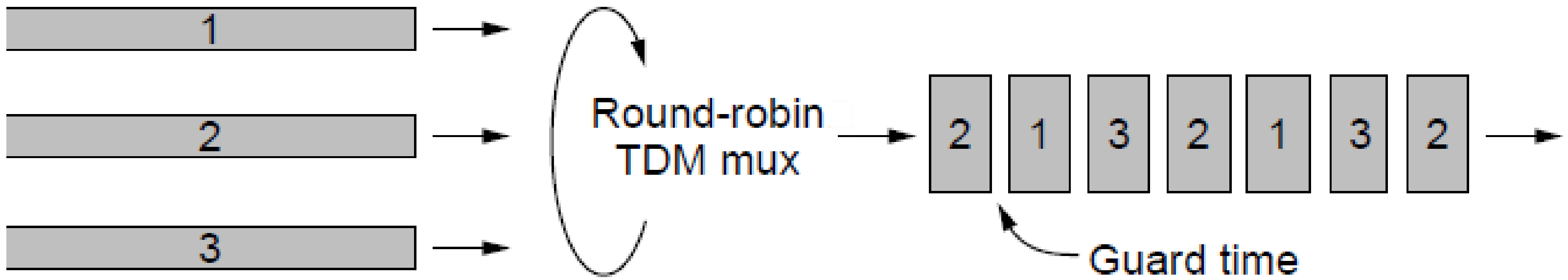
Frequency division multiplexing. (a) The original bandwidths. (b) The bandwidths raised in frequency. (c) The multiplexed channel.

Frequency Division Multiplexing (3)



Orthogonal frequency division multiplexing (OFDM).

Time Division Multiplexing



Time Division Multiplexing (TDM).

Code Division Multiplexing (1)

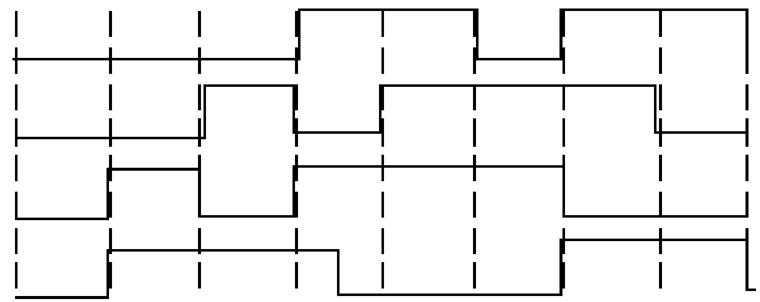
A = (−1 −1 −1 +1 +1 −1 +1 +1)

B = (−1 −1 +1 −1 +1 +1 +1 −1)

C = (−1 +1 −1 +1 +1 +1 −1 −1)

D = (−1 +1 −1 −1 −1 −1 +1 −1)

(a)



(b)

(a) Chip sequences for four stations.

(b) Signals the sequences represent

Code Division Multiplexing (2)

$$
\begin{array}{ll}
S_1 = C & = (-1\ +1\ -1\ +1\ +1\ +1\ -1\ -1) \\
S_2 = B+C & = (-2\ \ 0\ \ 0\ \ 0\ +2\ +2\ \ 0\ -2) \\
S_3 = A+\overline{B} & = (\ \ 0\ \ 0\ -2\ +2\ \ 0\ -2\ \ 0\ +2) \\
S_4 = A+\overline{B}+C & = (-1\ +1\ -3\ +3\ +1\ -1\ -1\ +1) \\
S_5 = A+B+C+D & = (-4\ \ 0\ -2\ \ 0\ +2\ \ 0\ +2\ -2) \\
S_6 = A+B+\overline{C}+D & = (-2\ -2\ \ 0\ -2\ \ 0\ -2\ +4\ \ 0)
\end{array}
$$

(c)

$$
\begin{array}{l}
S_1 \bullet C = [1+1-1+1+1+1-1-1]/8 = 1 \\
S_2 \bullet C = [2+0+0+0+2+2+0+2]/8 = 1 \\
S_3 \bullet C = [0+0+2+2+0-2+0-2]/8 = 0 \\
S_4 \bullet C = [1+1+3+3+1-1+1-1]/8 = 1 \\
S_5 \bullet C = [4+0+2+0+2+0-2+2]/8 = 1 \\
S_6 \bullet C = [2-2+0-2+0-2-4+0]/8 = -1
\end{array}
$$

(d)

(a) Six examples of transmissions.

(b) Recovery of station C's

Public Switched Telephone System

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

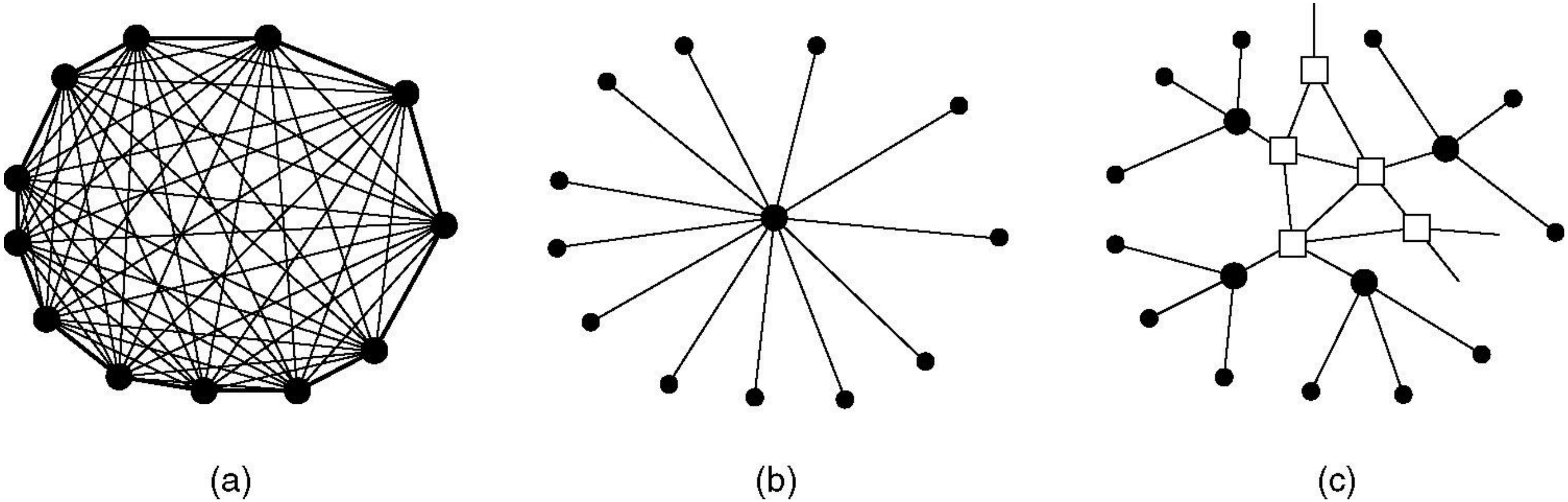
Telephone System

- **Telephone system is tightly intertwined with WAN**
  - cable between two computers
    - transfer at memory speeds: 10^8 bps
    - error rate: 10^{-12} bits (one per day)
  - dial up line
    - data rate: 10^4 bps
    - error rate: 10^{-5} bits
    - 11 orders of magnitude worse than cable

Structure of Telephone System

- **Hierarchy of telephone system: 5 levels**
- **Terms**
  - end office (local central office): area code + first 3 digits
  - local loop: two copper wires/telephone, < 10 km
  - toll office
    - tandem office: within the same local area
  - switching centers: primary, sectional, and regional exchanges
  - See Fig. 2-21
- **Advantages of digital signaling (-5 & +5 volts)**
  - lower error rate: less loss for long distance with regenerators
  - voice, data, music, and images can be interspersed
  - much higher data rates with existing lines
  - much cheaper (to distinguish 0 & 1 is easier)
  - maintenance is easier: tracking problems

Structure of the Telephone System (2)

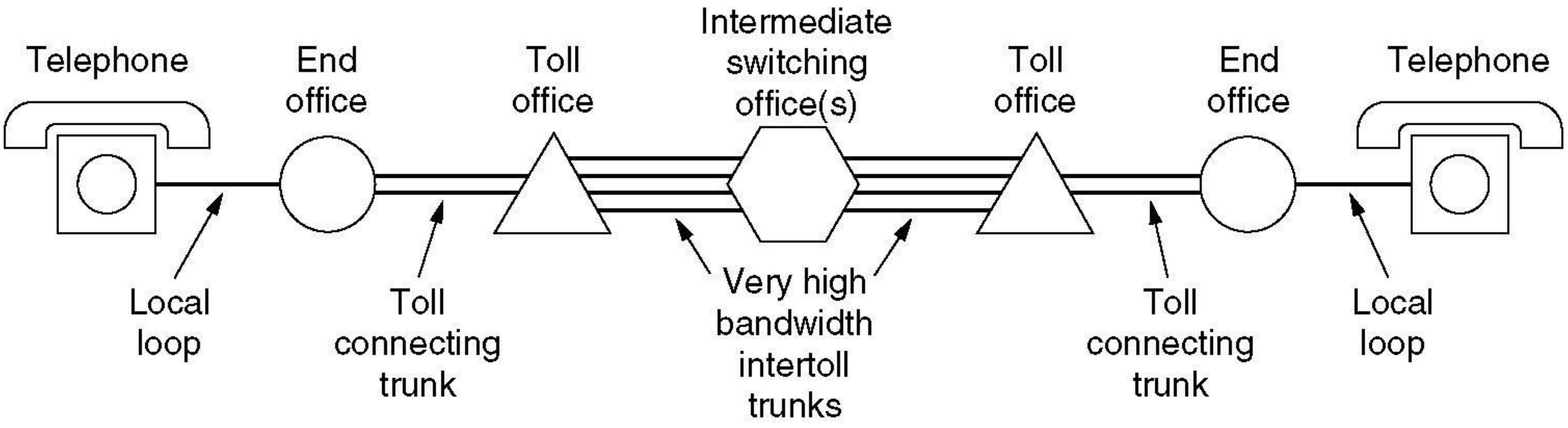


(a) Fully-interconnected network.

(b) Centralized switch.

(c) Two-level hierarchy.

Structure of the Telephone System (3)

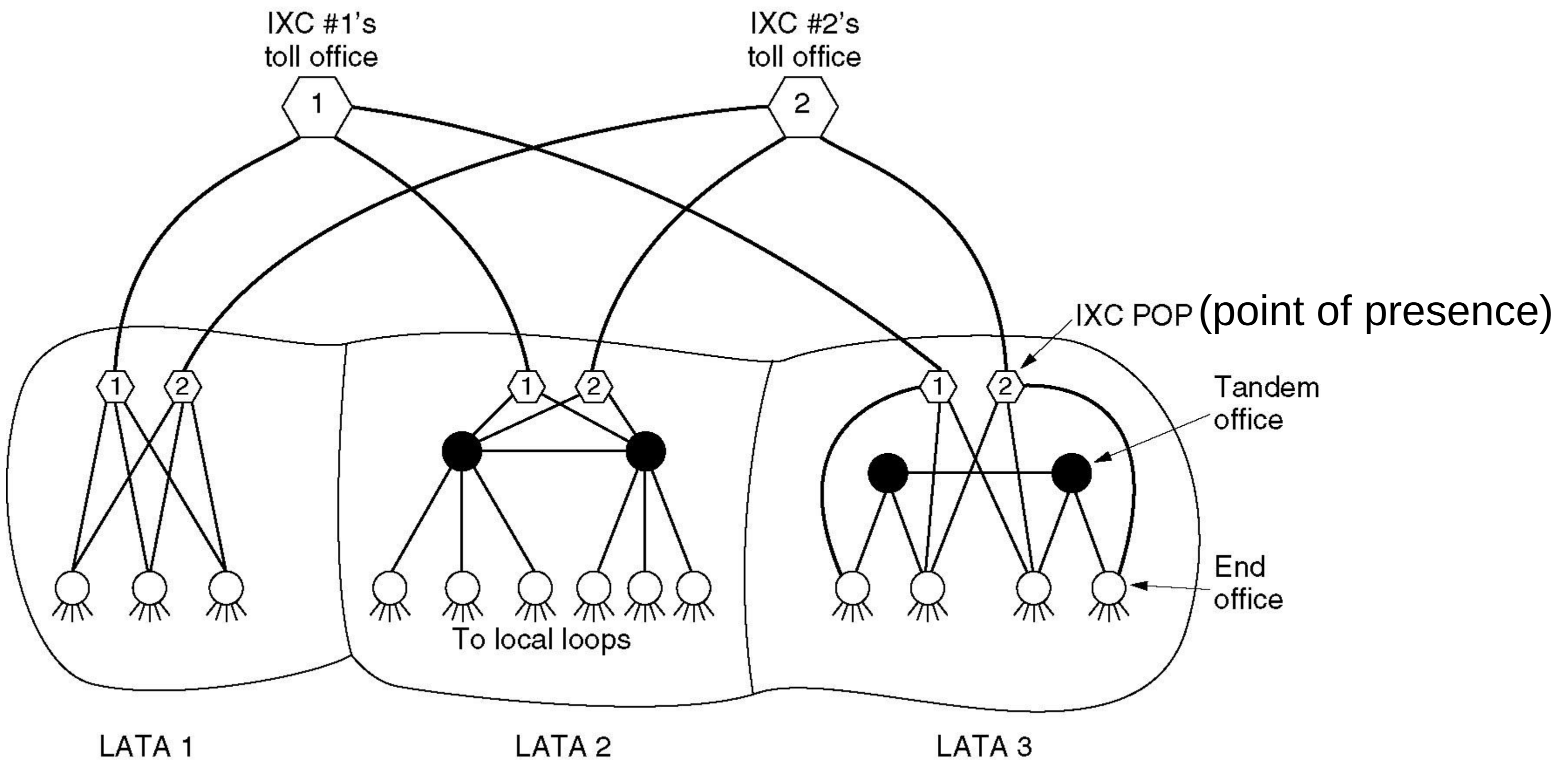


A typical circuit route for a medium-distance call.

Major Components of the Telephone System

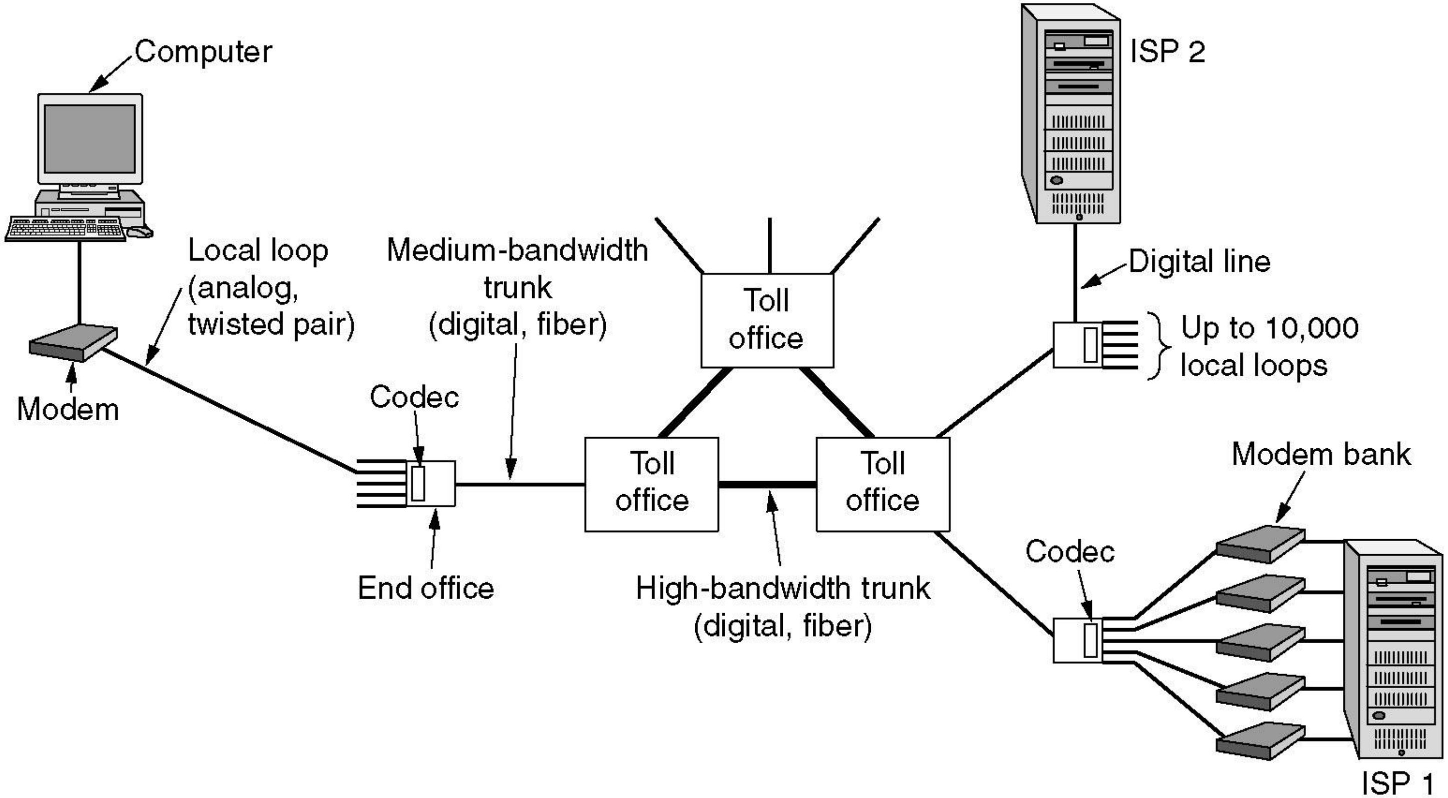
- Local loops
  - Analog twisted pairs going to houses and businesses
- Trunks
  - Digital fiber optics connecting the switching offices
- Switching offices
  - Where calls are moved from one trunk to another

The Politics of Telephones



The relationship of Local Access and Transport Areas (LATAs), Local Exchange Carriers (LECs), and IntereXchange Carriers (IXCs). All the circles are LEC switching offices. Each hexagon belongs to the IXC whose number is on it.

The Local Loop: Modems, ADSL, and Wireless



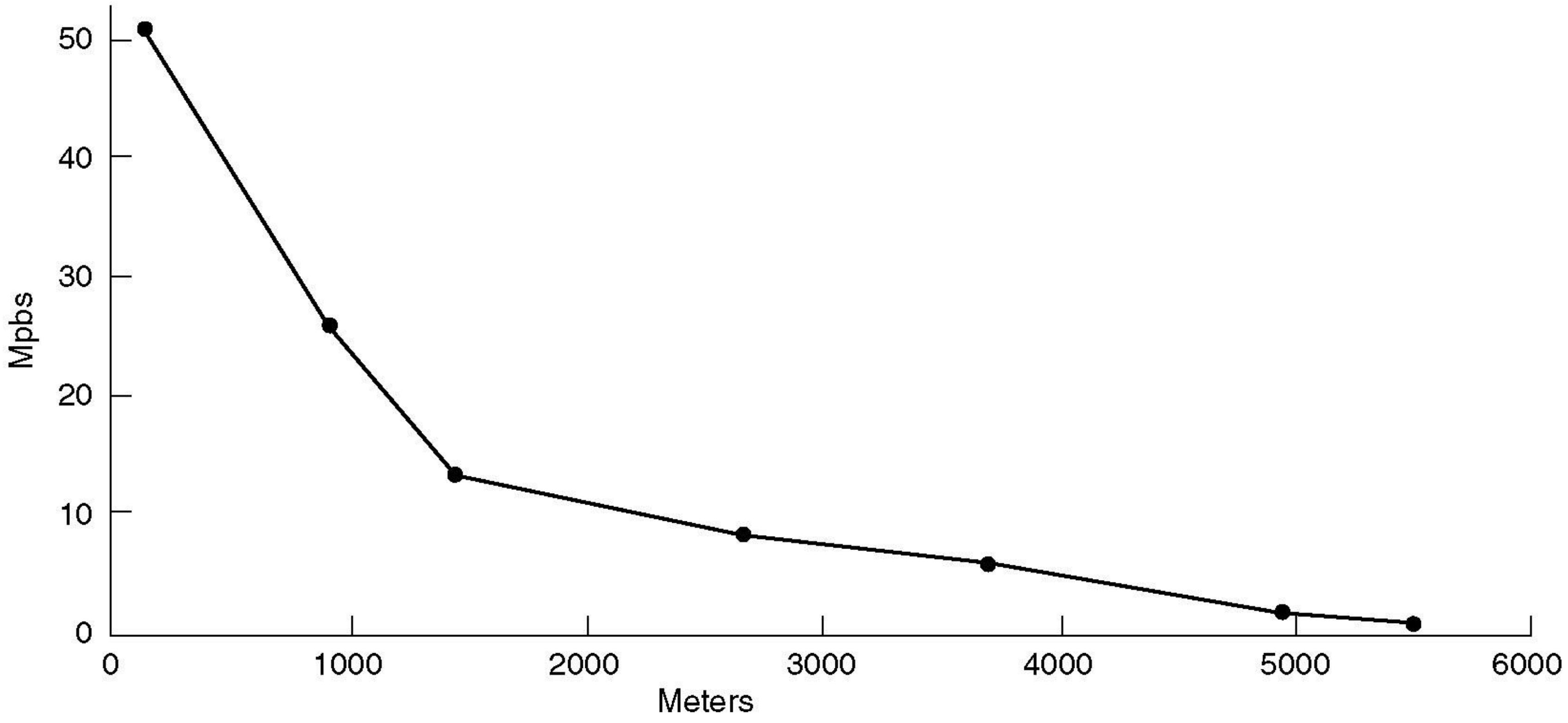
The use of both analog and digital transmissions for a computer to computer call. Conversion is done by the modems and codecs.

Modems

- **Two problems with DC (baseband signaling)**
  - attenuation: the amount of energy lost depends on the frequency
  - delay distortion: different Fourier components travel at different speeds
- **Modem**
  - Stream of bits <--> a modulated carrier
  - AC signaling
    - Sine wave carrier: a continuous tone in the 1000- to 2000-Hz
    - Amplitude, frequency, or phase can be modulated (See Fig. 2-24)
  - How to go to higher speeds
    - Baud: number of changes per second
    - Transmitting more bits per baud (See Figs. 2-25 and 2-26)
    - QAM (Quadrature Amplitude Modulation): transmitting 9600 bps using 2400 baud line

Digital Subscriber Lines (DSL)

- The DSL uses unfiltered (without coil) local loop lines
- The capacity of local loop depends on length, the thickness, and general quality



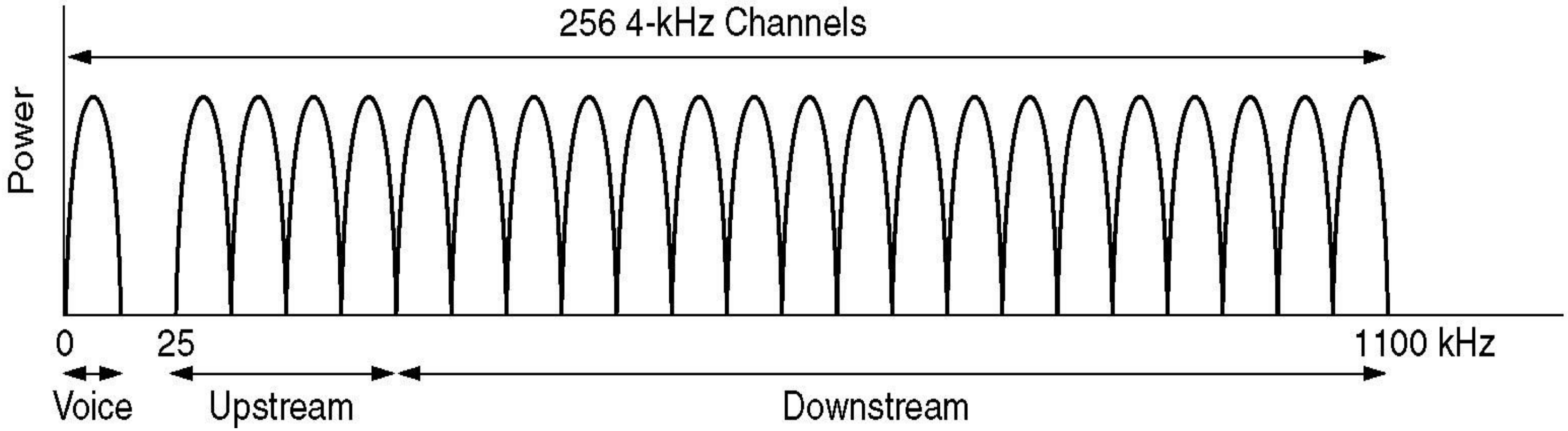
Bandwidth versus distanced over category 3 Unshielded Twisted Pair (UTP) for DSL.

When all the other factors (new wires, modest bundles, …) are optimal

Digital Subscriber Lines (2)

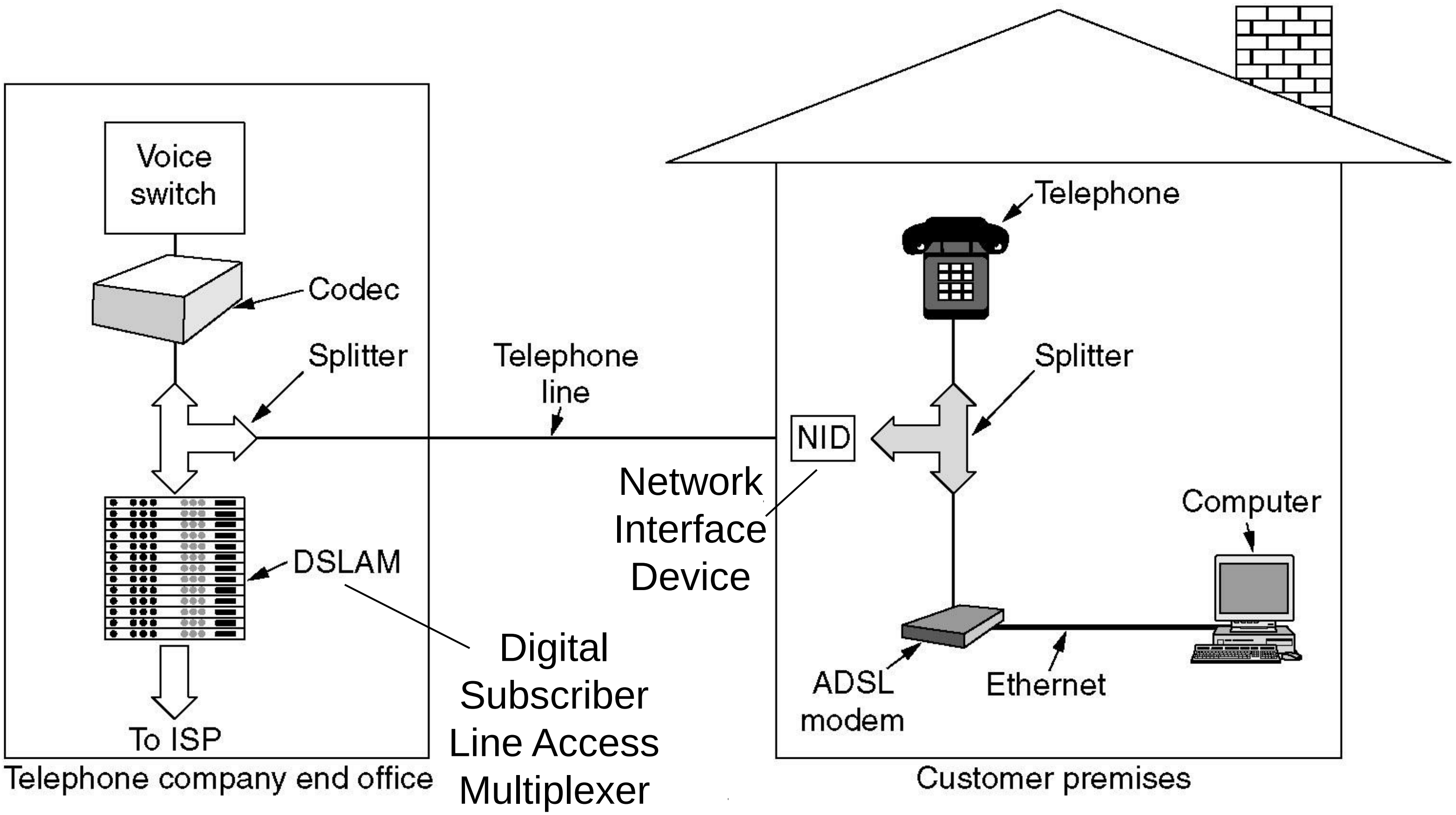
- The Discrete MultiTone (DMT) modulation divides the available 1.1 MHz spectrum on the local loop into 256 independent channels of 4312.5 Hz each
- Channel 0 is used for voice, channels 1~5 are for the guard band

Of the remaining 250 channels, one is used for upstream control, and one is used for downstream control. The others are for use data.



Operation of Asymmetric DSL (ADSL) using discrete multitone modulation.

Digital Subscriber Lines (3)

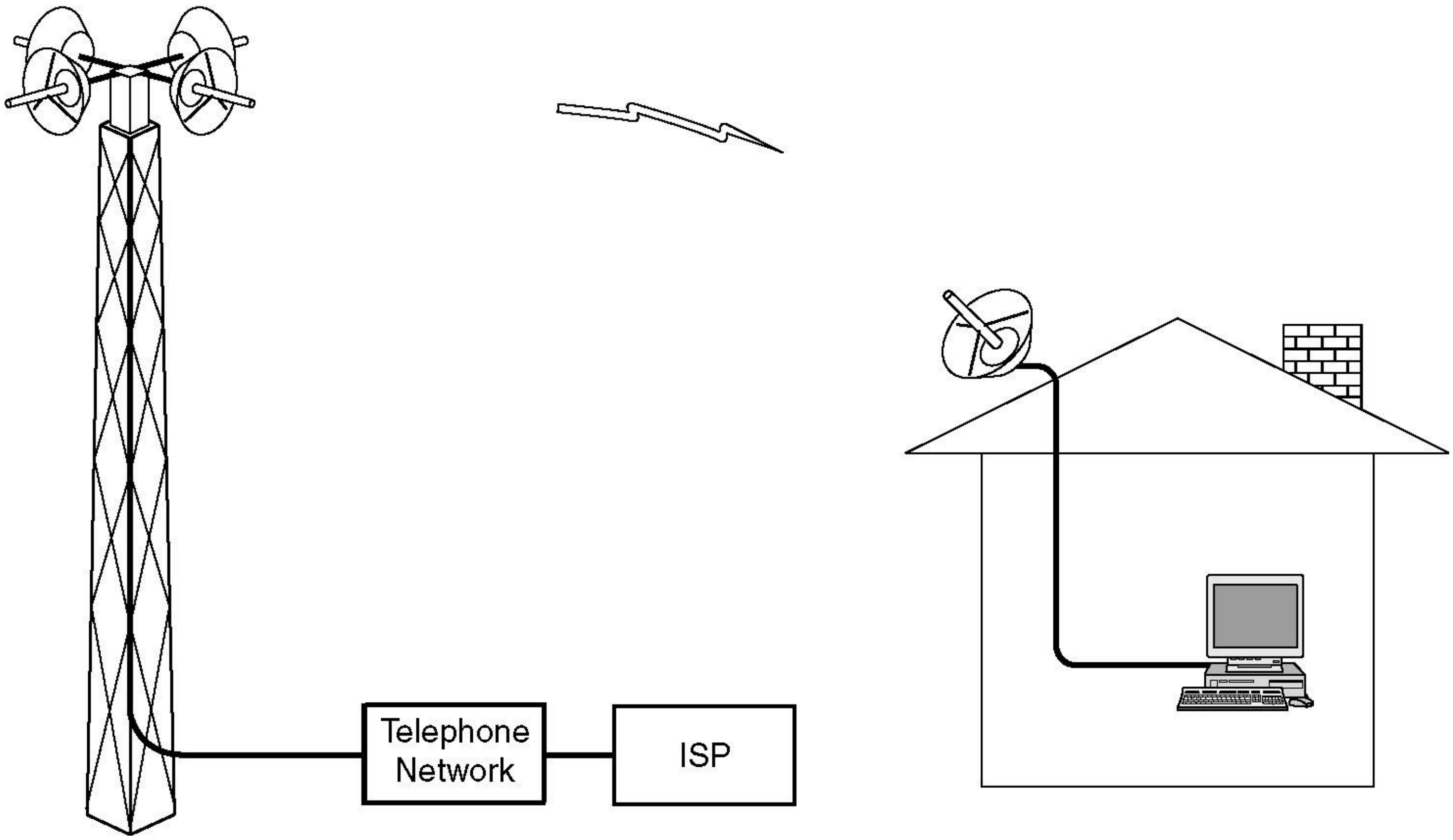


A typical ADSL equipment configuration.

Wireless Local Loops

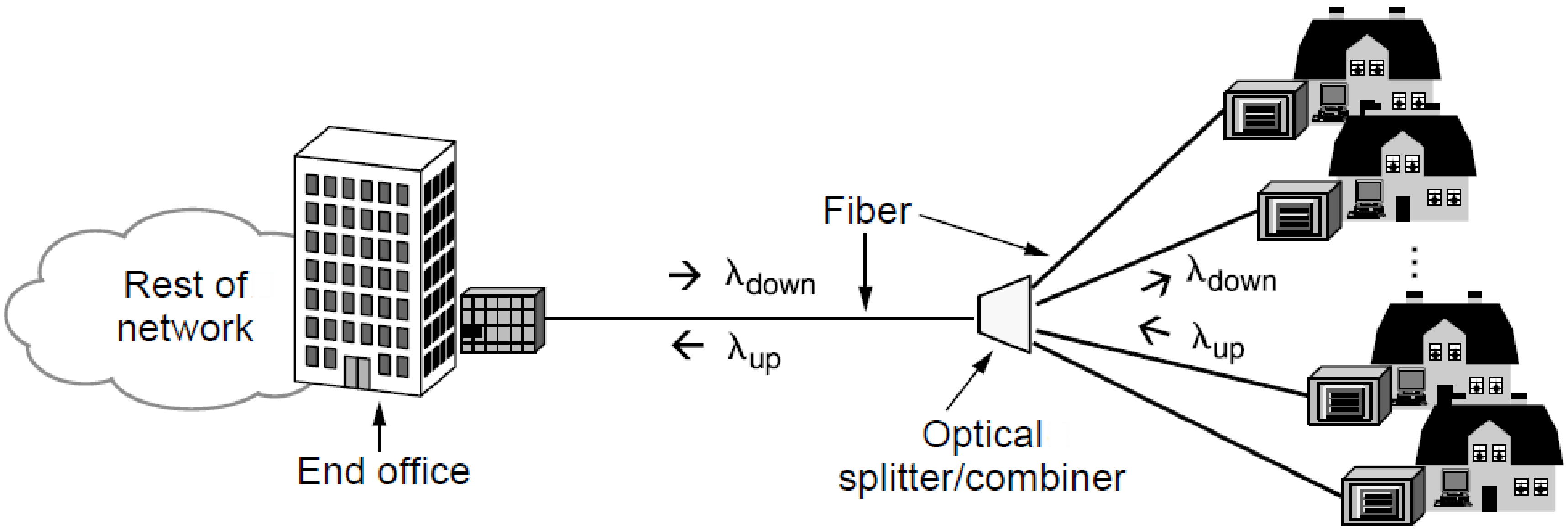
(For Competitive Local Exchange Carrier)

- LMDS uses 28 GHz, 38GHz, 58GHz…
- Problems of LMDS are high absorption (leaves, rain) and line of sight needed



Architecture of an Local Multipoint Distribution Service (LMDS) system.

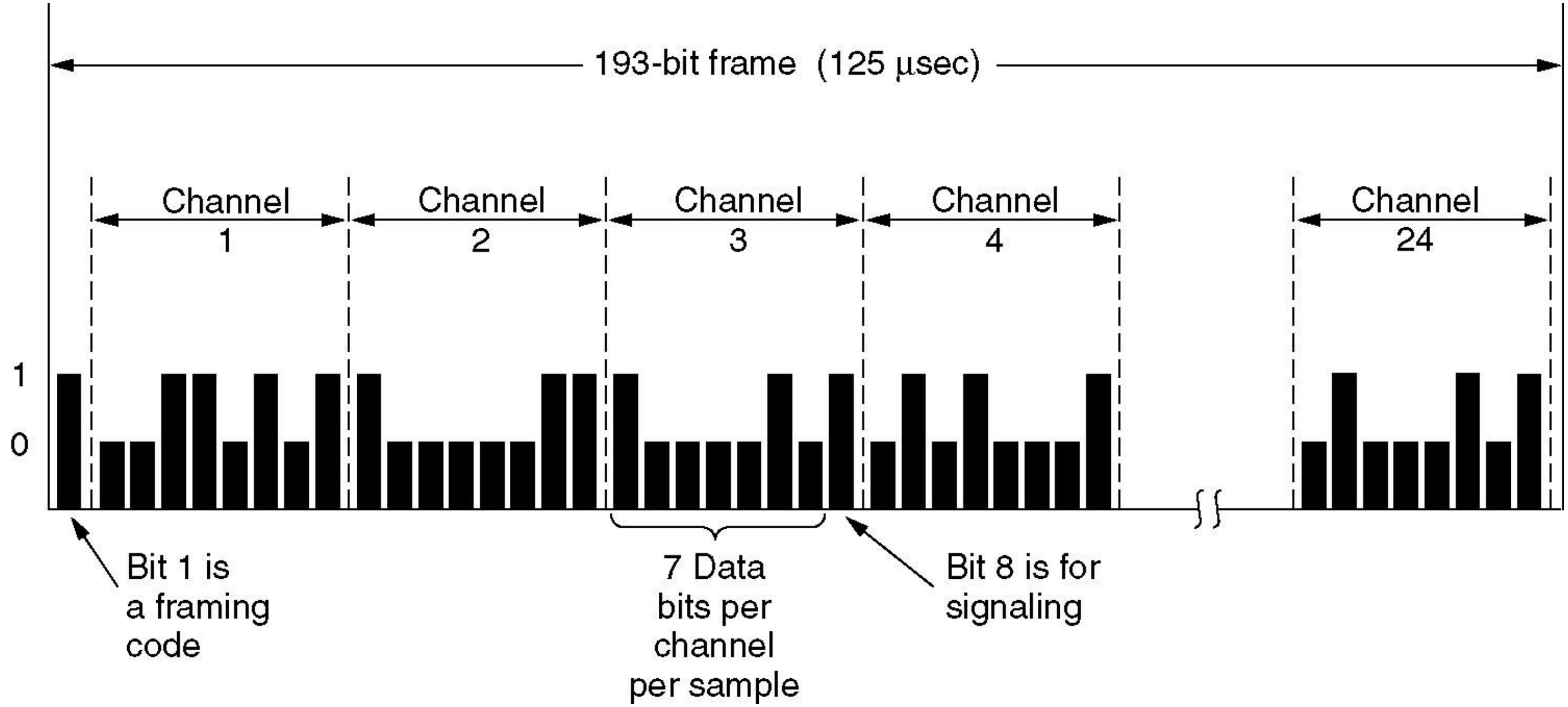
Fiber To The Home



Passive optical network for Fiber To The Home.

Time Division Multiplexing

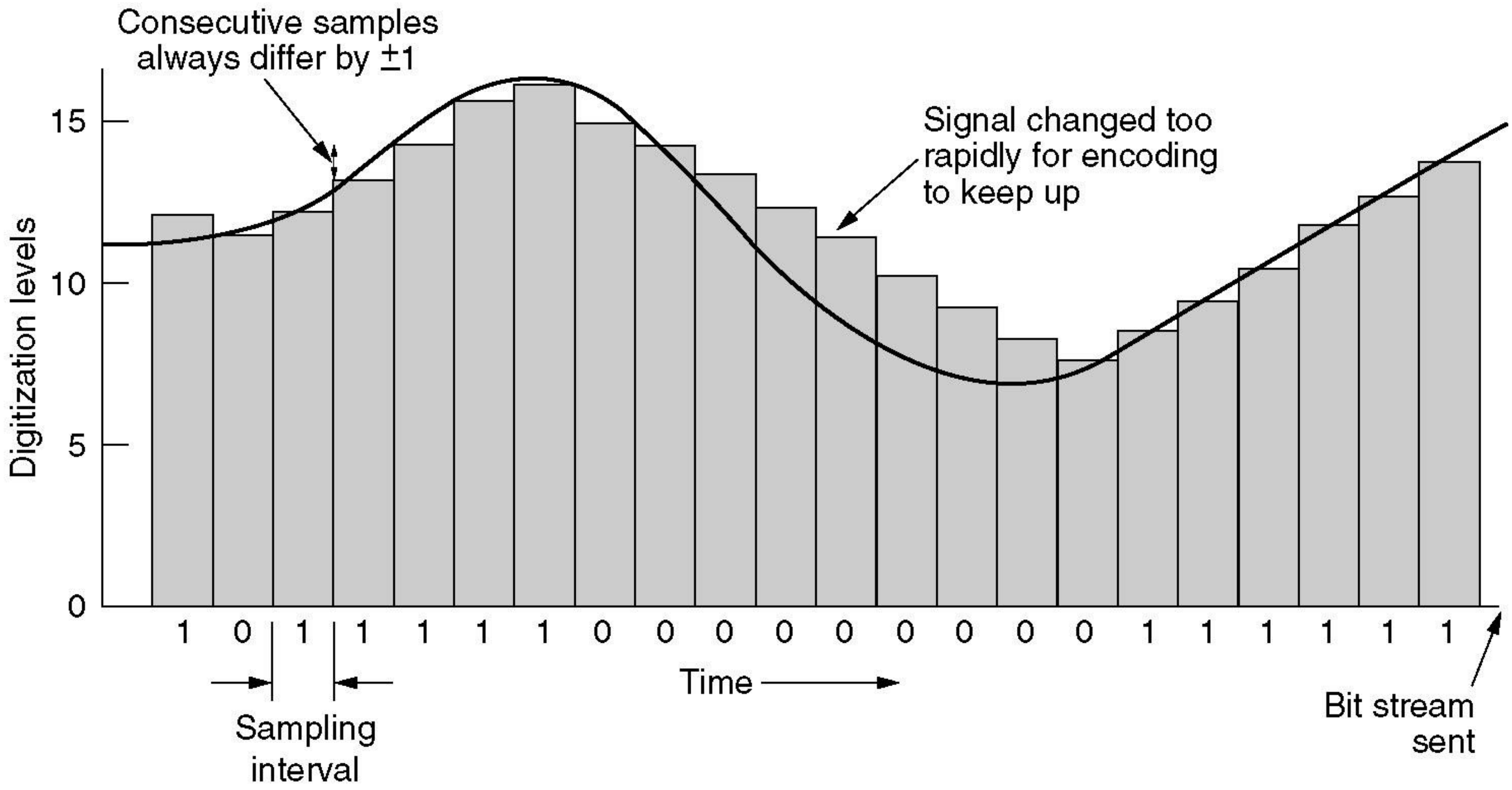
- Pulse Code Modulation (PCM) is the heart of the modern telephone system
- A analog signal is sampled, quantized and coded



Each channel has 8bits, 24 channels and one framing bit form a frame of 125 μsec

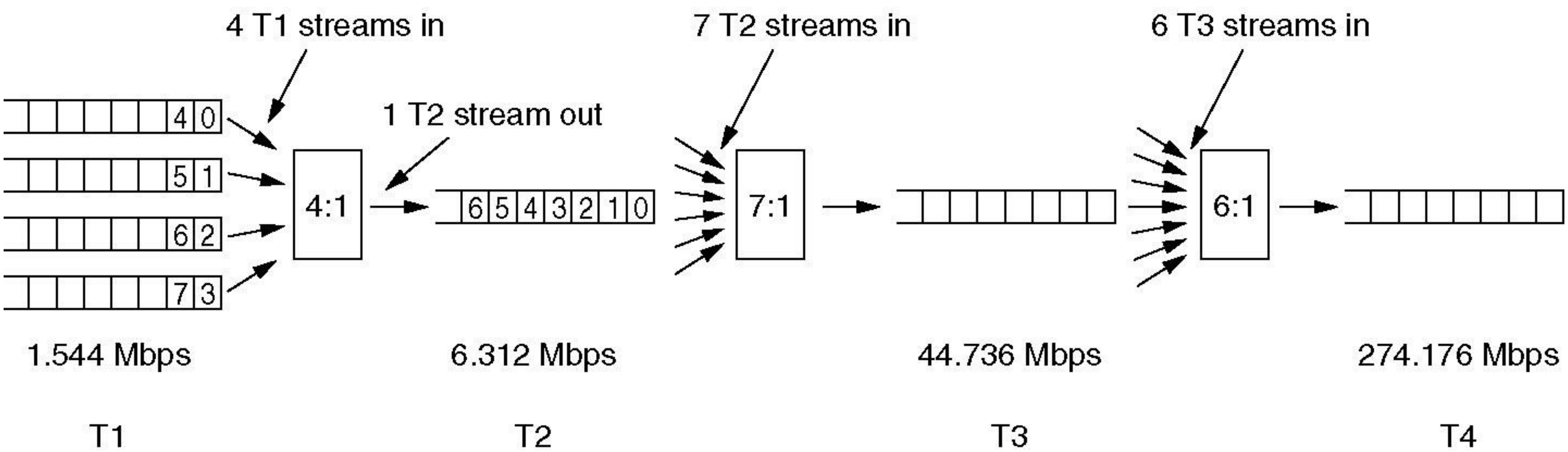
The T1 carrier (1.544 Mbps).

Time Division Multiplexing (2)



Delta modulation.

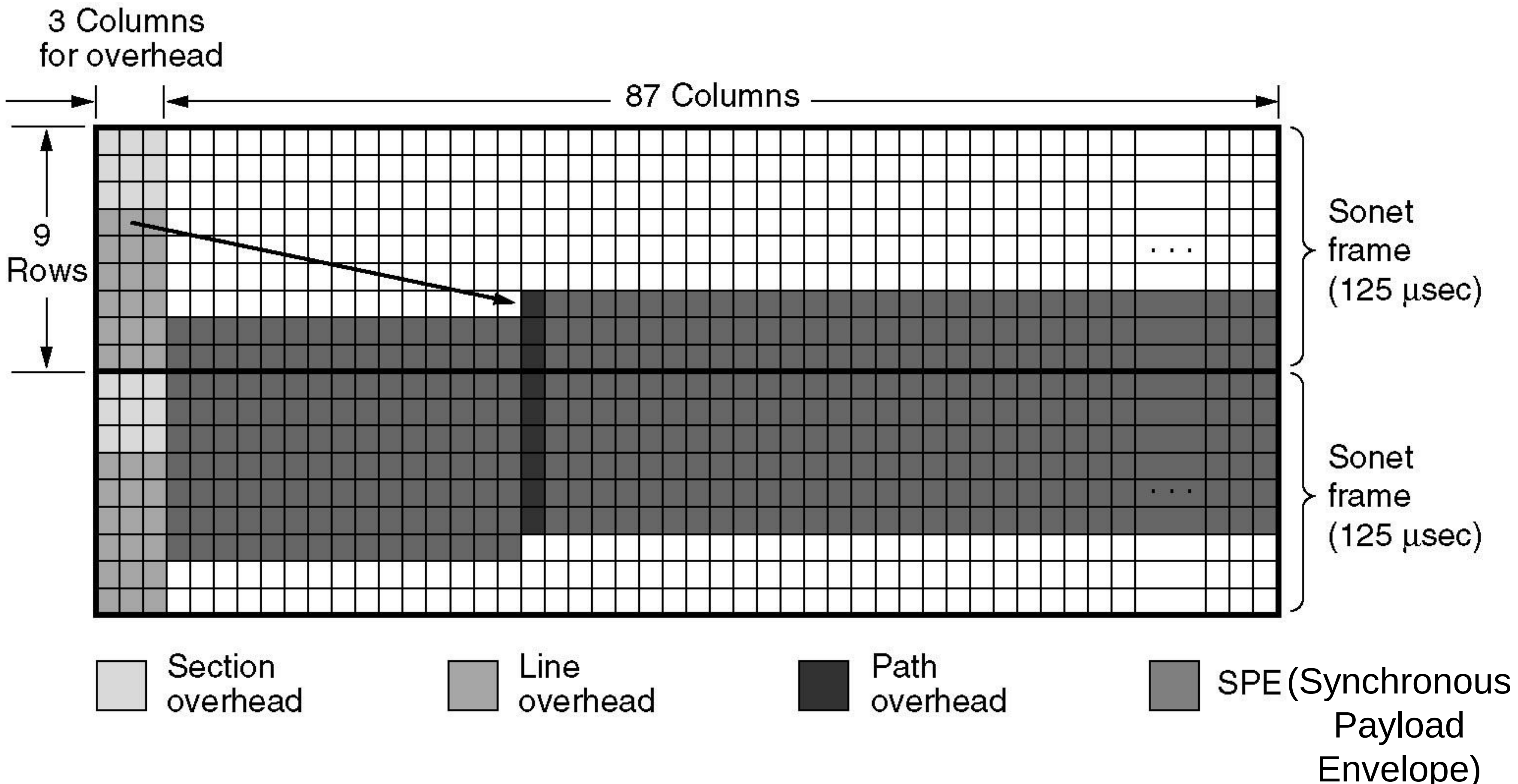
Time Division Multiplexing (3)



Multiplexing T1 streams into higher carriers.

Time Division Multiplexing (4)

A basic Synchronous Optical Network (SONET) frame is a block of 810 bytes for 125 μsec



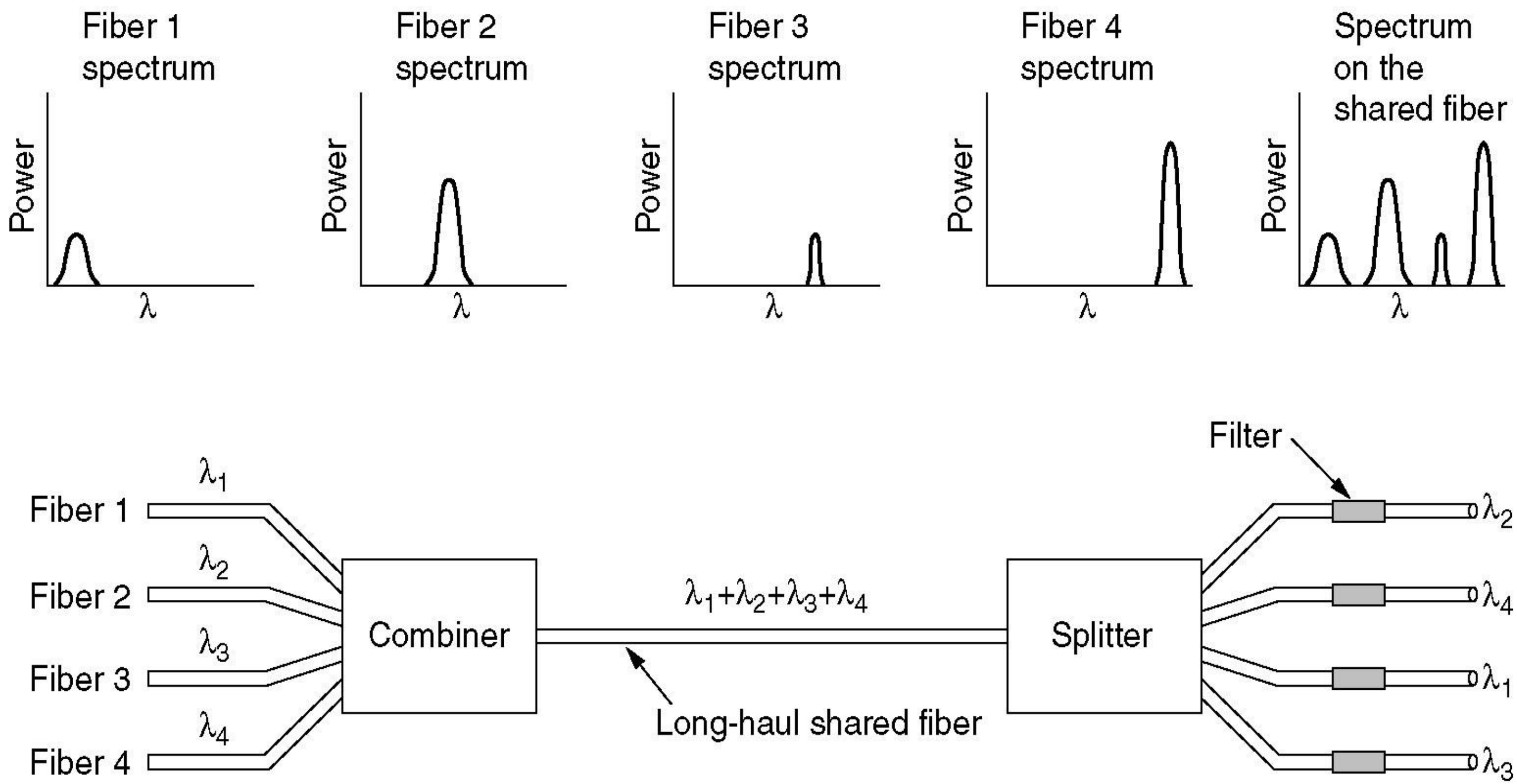
Two back-to-back SONET frames.

SONET/SDH (2)

SONET		SDH	Data rate (Mbps)		
Electrical	**Optical**	**Optical**	**Gross**	**SPE**	**User**
STS-1	OC-1		51.84	50.112	49.536
STS-3	OC-3	STM-1	155.52	150.336	148.608
STS-12	OC-12	STM-4	622.08	601.344	594.432
STS-48	OC-48	STM-16	2488.32	2405.376	2377.728
STS-192	OC-192	STM-64	9953.28	9621.504	9510.912
STS-768	OC-768	STM-256	39813.12	38486.016	38043.648

SONET and SDH multiplex rates.

Wavelength Division Multiplexing



(OR Array Waveguide, AWG)

When the wavelengths are spaced closer, e.g. 0.1 nm, the system is referred to as Dense WDM (DWDM)

Wavelength division multiplexing.

Time Division Multiplexing (5)

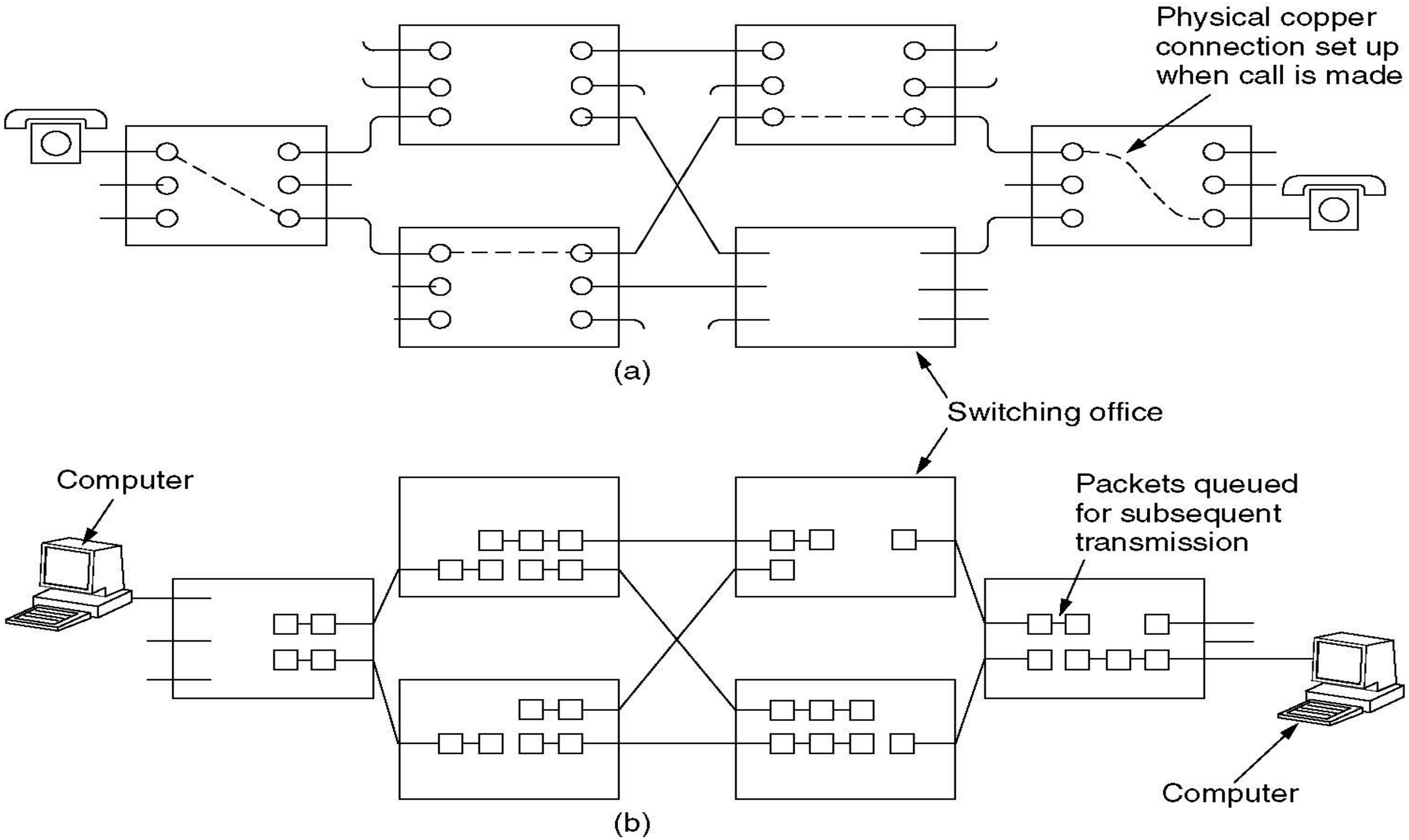
Synchronous Digital Hierarchy (SDH) differs from SONET only in minor way

SONET		SDH	Data rate (Mbps)		
Electrical	Optical	Optical	Gross	SPE	User
STS-1	OC-1		51.84	50.112	49.536
STS-3	OC-3	STM-1	155.52	150.336	148.608
STS-9	OC-9	STM-3	466.56	451.008	445.824
STS-12	OC-12	STM-4	622.08	601.344	594.432
STS-18	OC-18	STM-6	933.12	902.016	891.648
STS-24	OC-24	STM-8	1244.16	1202.688	1188.864
STS-36	OC-36	STM-12	1866.24	1804.032	1783.296
STS-48	OC-48	STM-16	2488.32	2405.376	2377.728
STS-192	OC-192	STM-64	9953.28	9621.504	9510.912

- The Synchronous Transport signal-1 (STS-1) is the basic SONET channel
- The Optical carrier (OC) corresponding to STS-n is called OC-n

SONET and SDH multiplex rates.

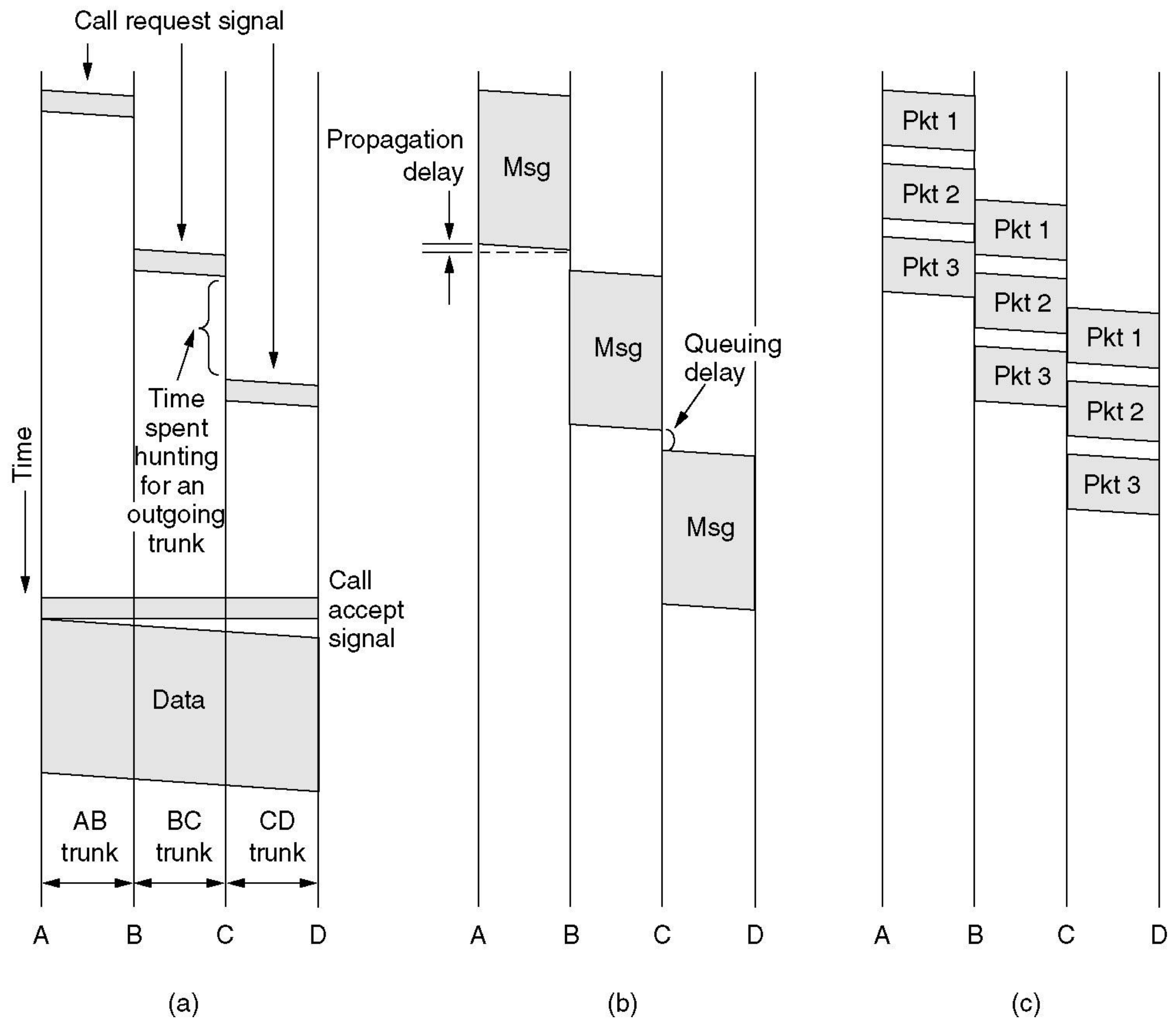
Circuit Switching



(a) Circuit switching.

(b) Packet switching (store-and-forward).

Message Switching



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

Circuit Switching/Packet Switching (3)

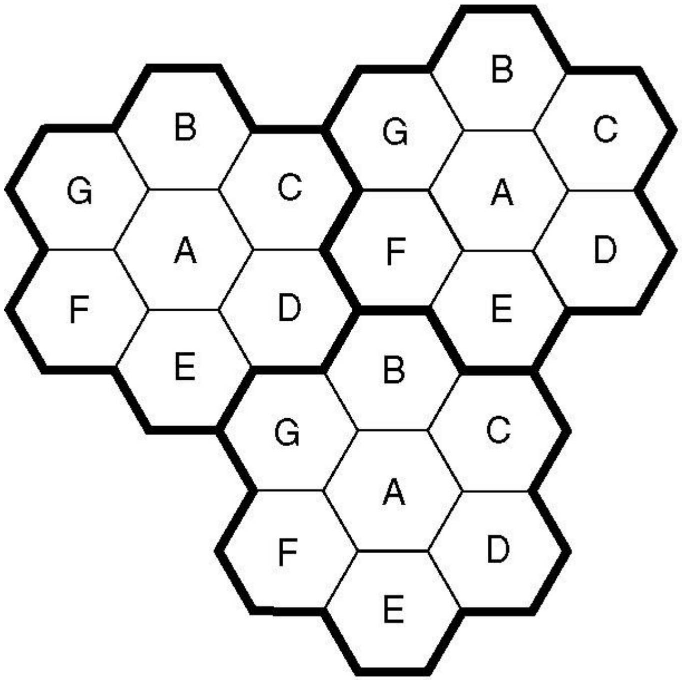
Item	Circuit switched	Packet switched
Call setup	Required	Not needed
Dedicated physical path	Yes	No
Each packet follows the same route	Yes	No
Packets arrive in order	Yes	No
Is a switch crash fatal	Yes	No
Bandwidth available	Fixed	Dynamic
Time of possible congestion	At setup time	On every packet
Potentially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

A comparison of circuit-switched and packet-switched networks.

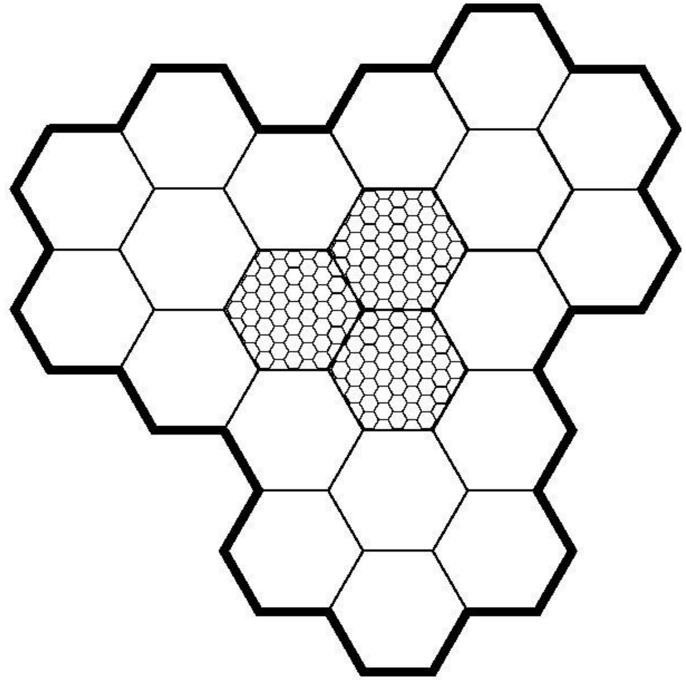
The Mobile Telephone System

- First-Generation Mobile Phones:
  Analog Voice
- Second-Generation Mobile Phones:
  Digital Voice
- Third-Generation Mobile Phones:
  Digital Voice, Data, and image
- Fourth-Generation Mobile Phones (OFDM):
  multimedia

Advanced Mobile Phone System



(a)

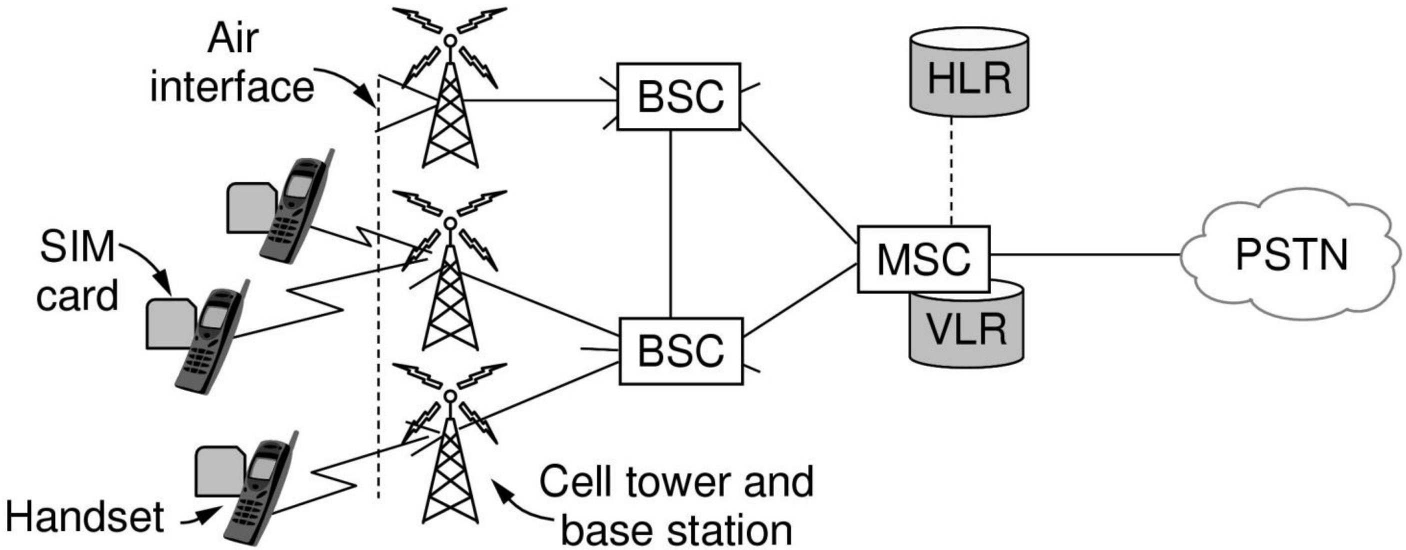


(b)

(a) Frequencies are not reused in adjacent cells.

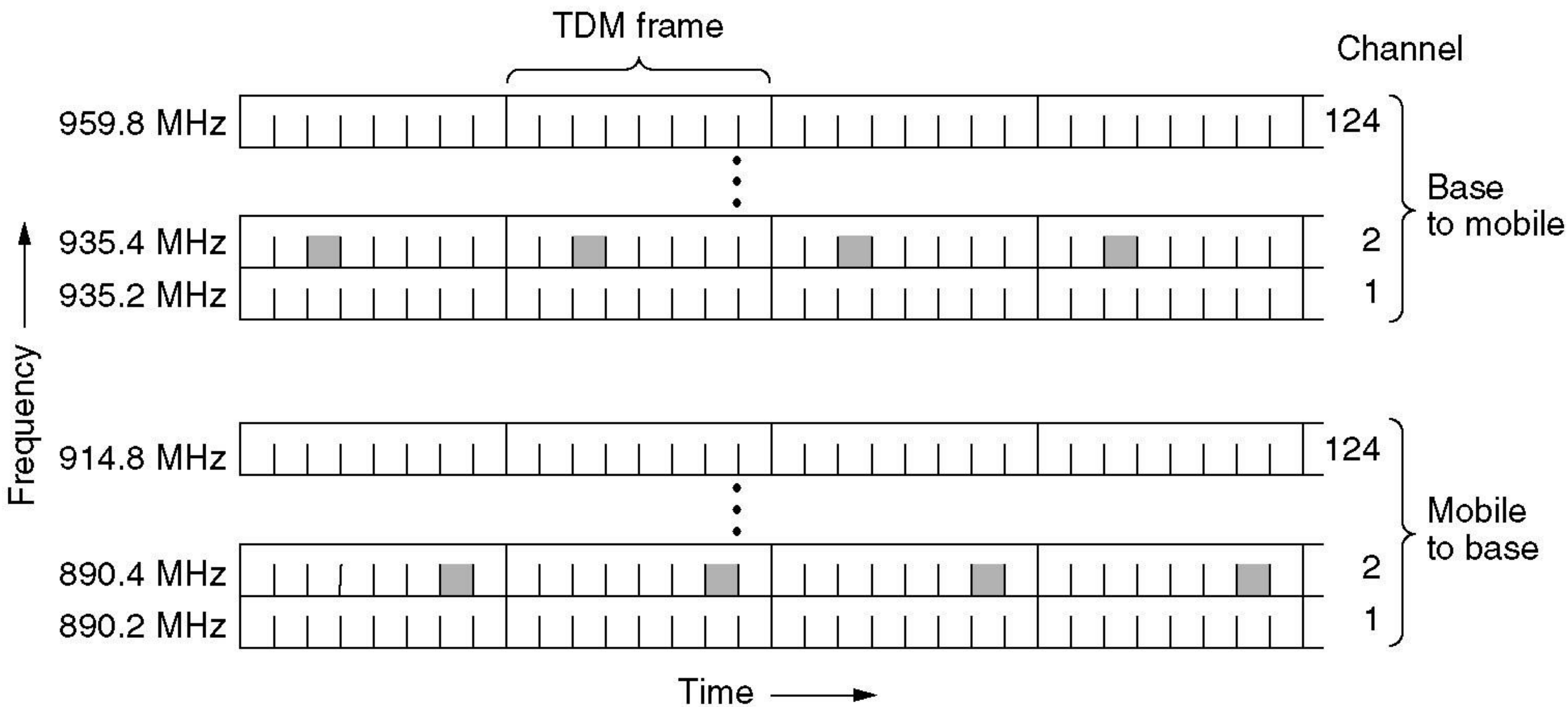
(b) To add more users, smaller cells can be used for hot spots.

GSM—The Global System for Mobile Communications (1)



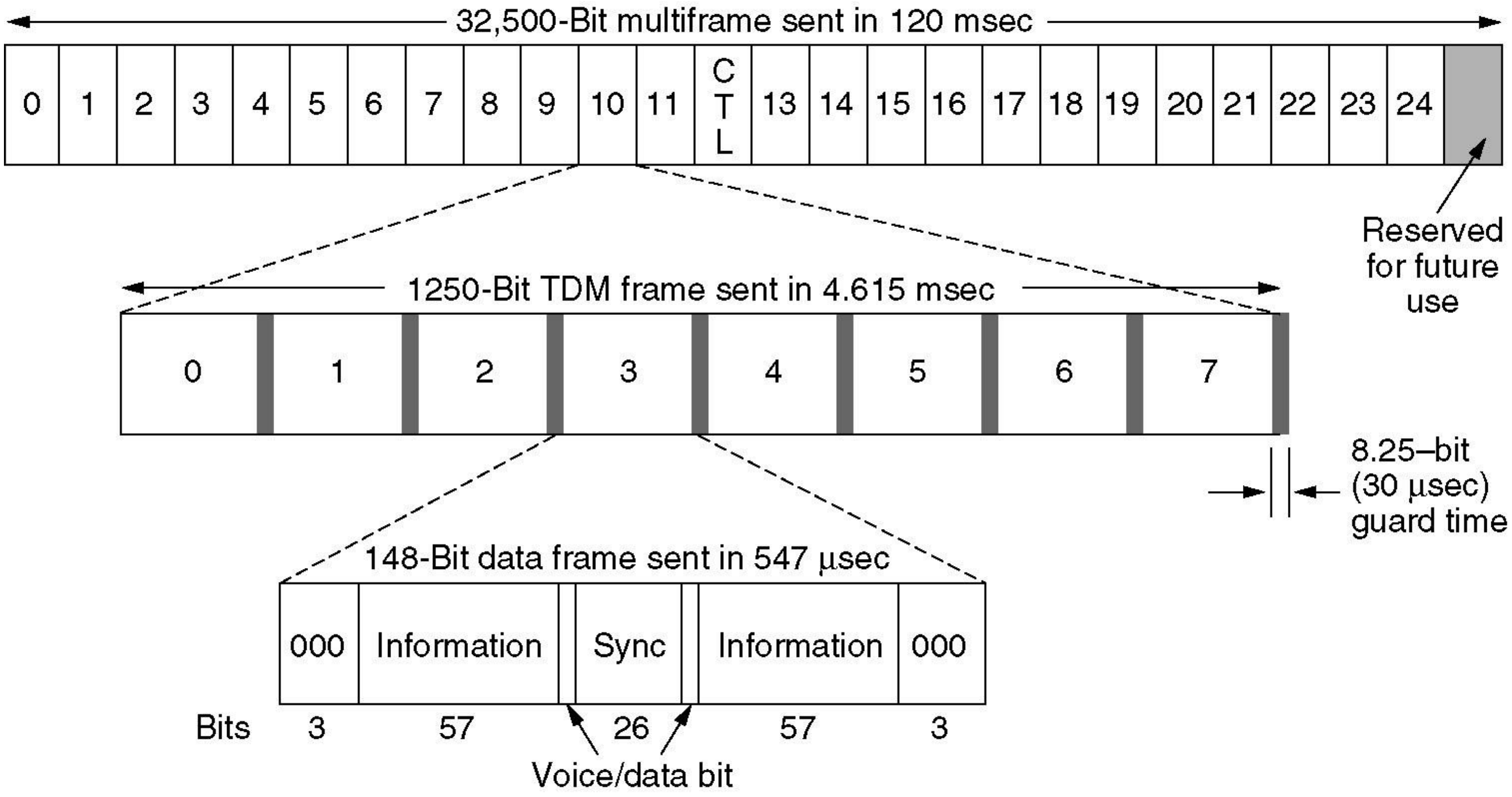
GSM mobile network architecture.

GSM
Global System for Mobile Communicationss



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

GSM (2)



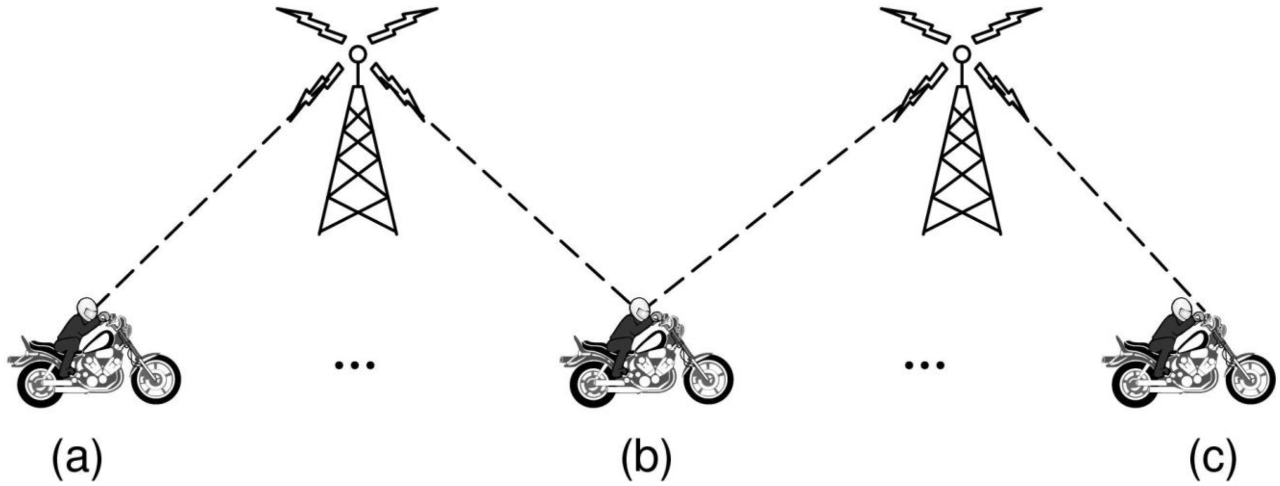
A portion of the GSM framing structure.

Digital Voice and Data (1)

Basic services intend by IMT-2000 network

a) High-quality voice transmission.
b) Messaging (replacing email, fax, SMS, chat).
c) Multimedia (music, videos, films, television).
d) Internet access (Web surfing, incl. audio, video).

Digital Voice and Data (2)

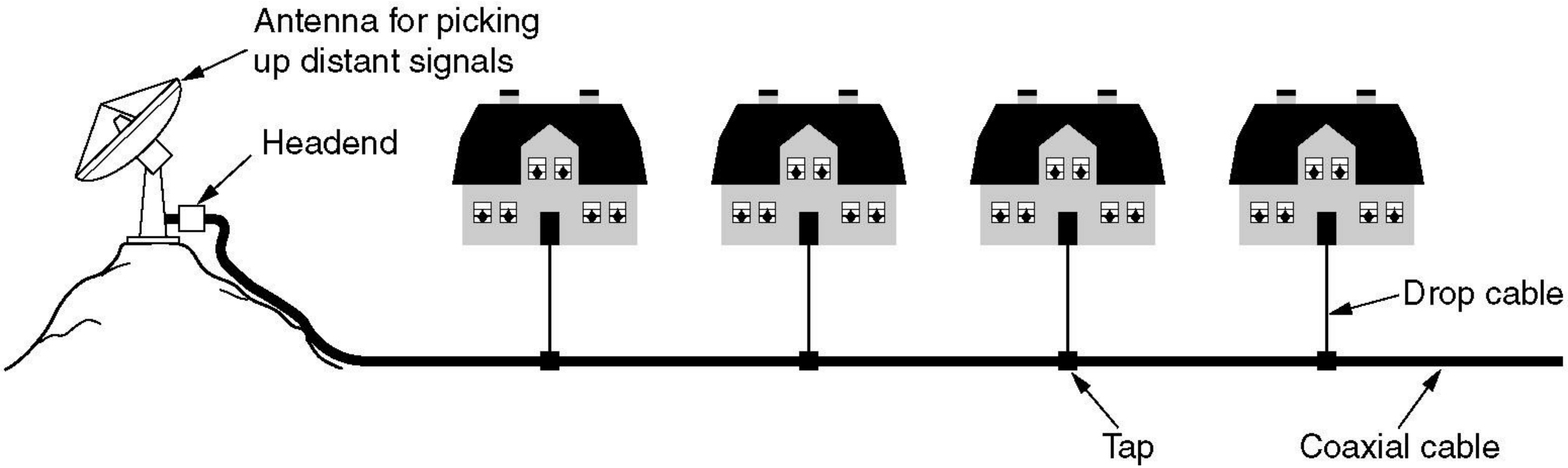


Soft handoff (a) before, (b) during, and (c) after.

Cable Television

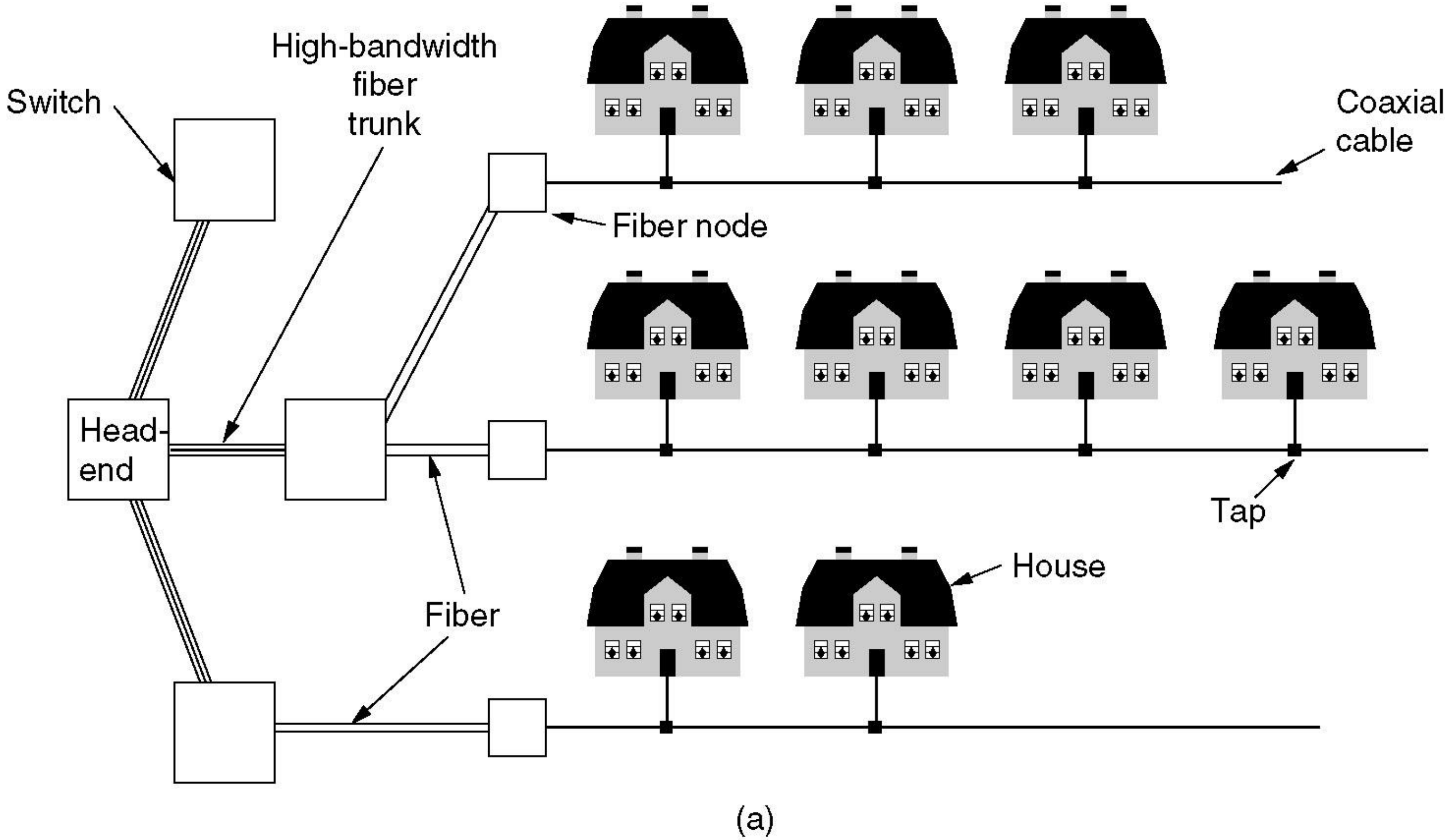
- Community Antenna Television
- Internet over Cable
- Spectrum Allocation
- Cable Modems
- ADSL versus Cable

Community Antenna Television



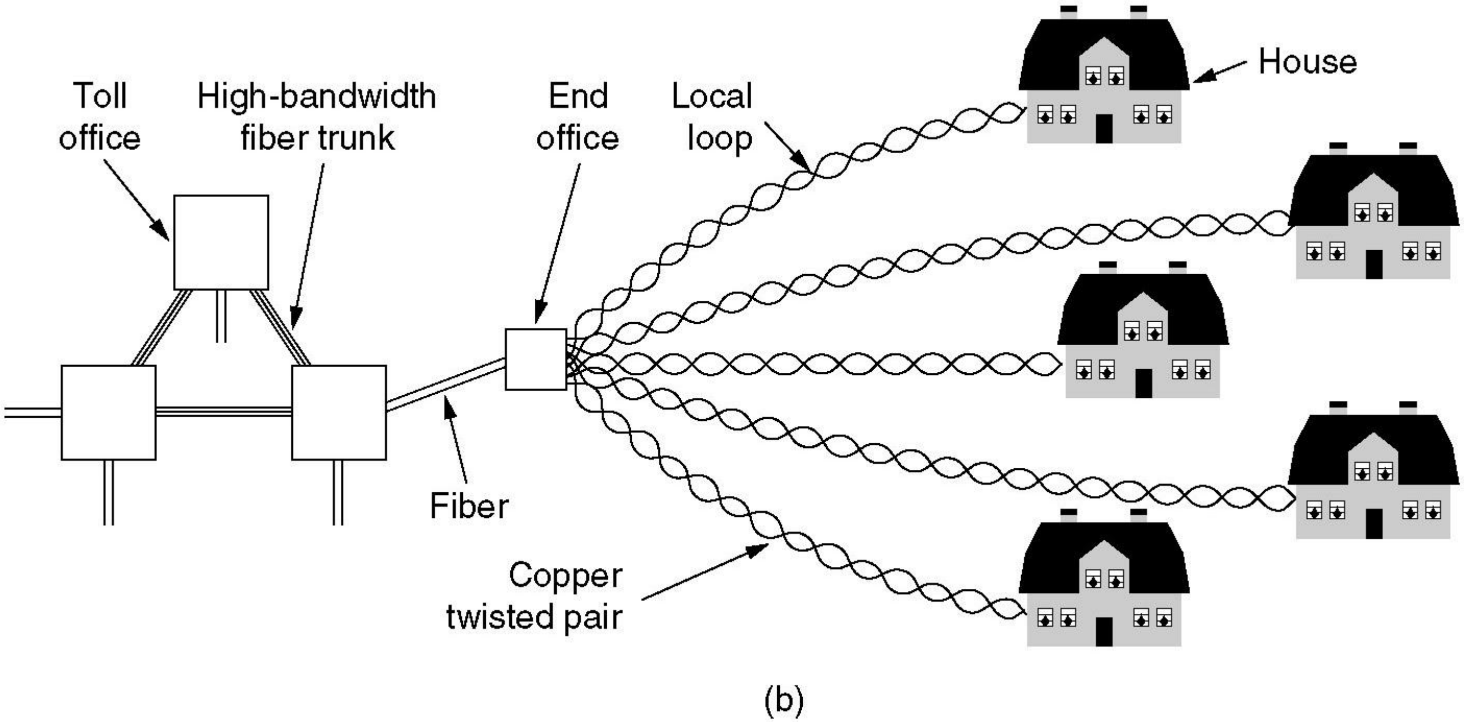
An early cable television system.

Internet over Cable



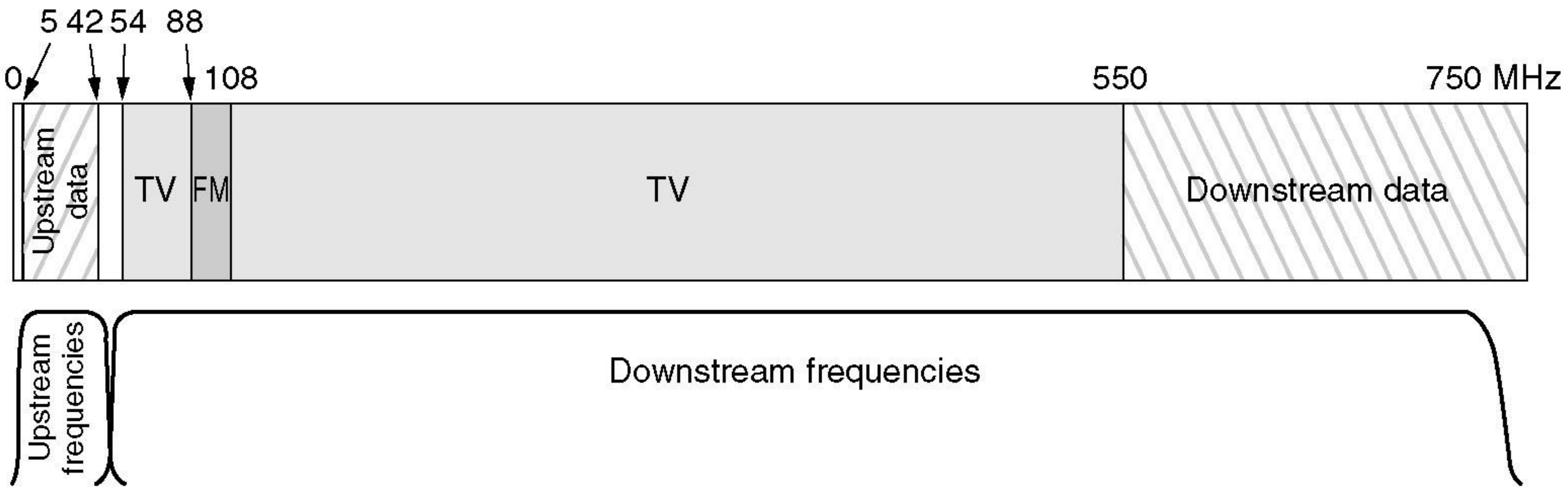
Cable Television

Internet over Cable (2)



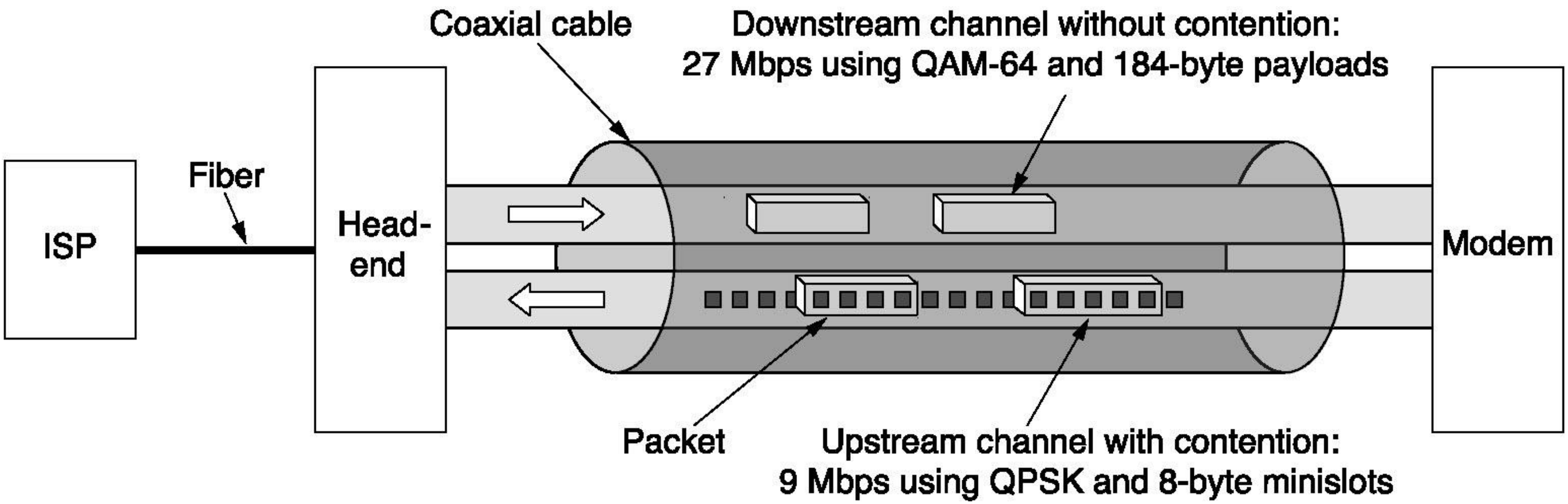
The fixed telephone system.

Spectrum Allocation



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

Cable Modems



Typical details of the upstream and downstream channels in North America.