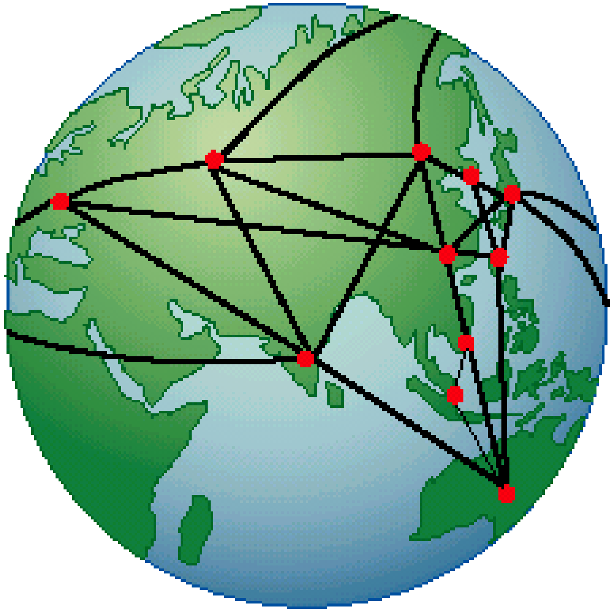
Computer Networks



Computer Networks

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Roadmap

Introduction

Physical Layer

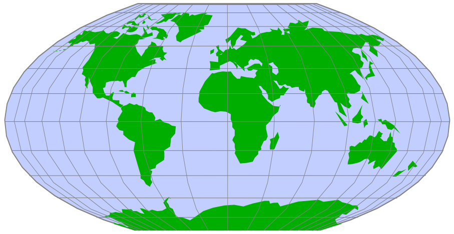
Data Link Layer

Medium Access Sublayer

Network Layer

Transport Layer

Application Layer



Chapter 2

The Physical Layer

What You Will Learn

1. **Theoretical Basis For Data Transmission**

   How much data can be put on a wire? What are the limits imposed by a medium?

2. **Guided transmission media**
3. **Wireless Transmission. (terrestrial radio)**
4. **Communication Satellites.**
5. **Digital modulation and Multiplexing**
6. **Examples of communication systems**

   the (fixed) telephone system/ xDSL

   the mobile phone system

   the cable television system. / CableModem

2.1 Theoretical Basis for Data Communication

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

Fourier Analysis

- Information can be transmitted on wires by varying some **physical property** such as voltage or current.
- By representing the value of this voltage or current as a **single-valued function of time**, **f(t),** we can model the behavior of the signal and analyze it mathematically.

Fourier Series

- **Fourier Series -** Any reasonably behaved periodic function, **g(t)** with period **T**, can be constructed as the sum of (possibly infinite) number of sines and cosines:

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

where $f = 1/T$ is the fundamental frequency, $\mathbf{a_n}$ and $\mathbf{b_n}$ are the sine and cosine amplitudes of the n^{th} **harmonics** (terms), and **c** is a constant.

Harmonics

- If the period T is known and the amplitudes are given, the original function of time can be found by performing the sums of **Fourier Equation**.
- Signals of any flavor are made up of harmonics. One could in theory have a pure sine wave, but that's pretty dull - it carries no real information other than its frequency (musically it's pretty dull too.)
- In practice, information-carrying-signals are made up of a number of frequencies. These typically are the **fundamental frequency**, plus other frequencies that are **multiples of the fundamental**. These higher frequency components are called **harmonics**.

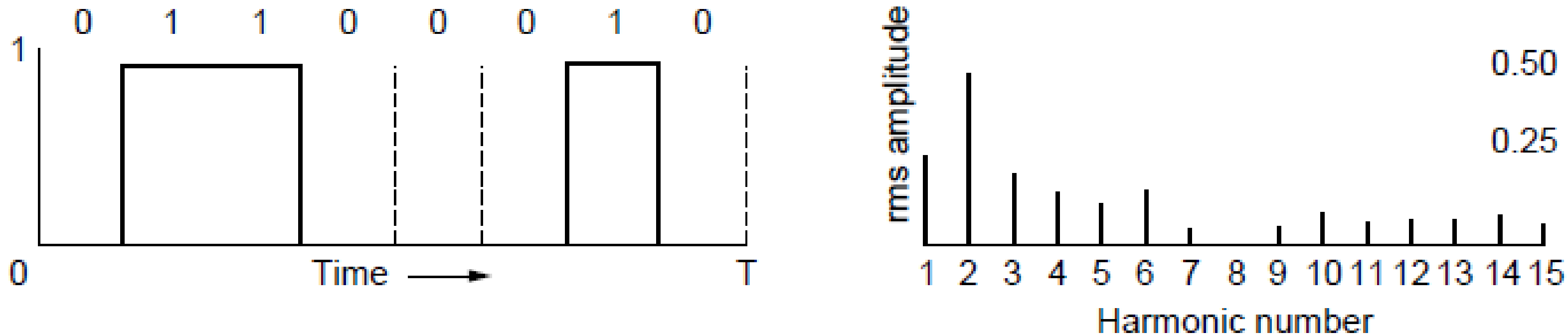
Fourier Equation

- A data signal that has a finite duration can be handled by just imagining that it repeats the entire pattern over and over forever.
- The A_n and B_n amplitudes and C can be computed for any given $g(t)$:

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

A signal in a real channel

- The relevance of Fourier Analysis to data communication is that channels affect different frequency signals differently.



(a)

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

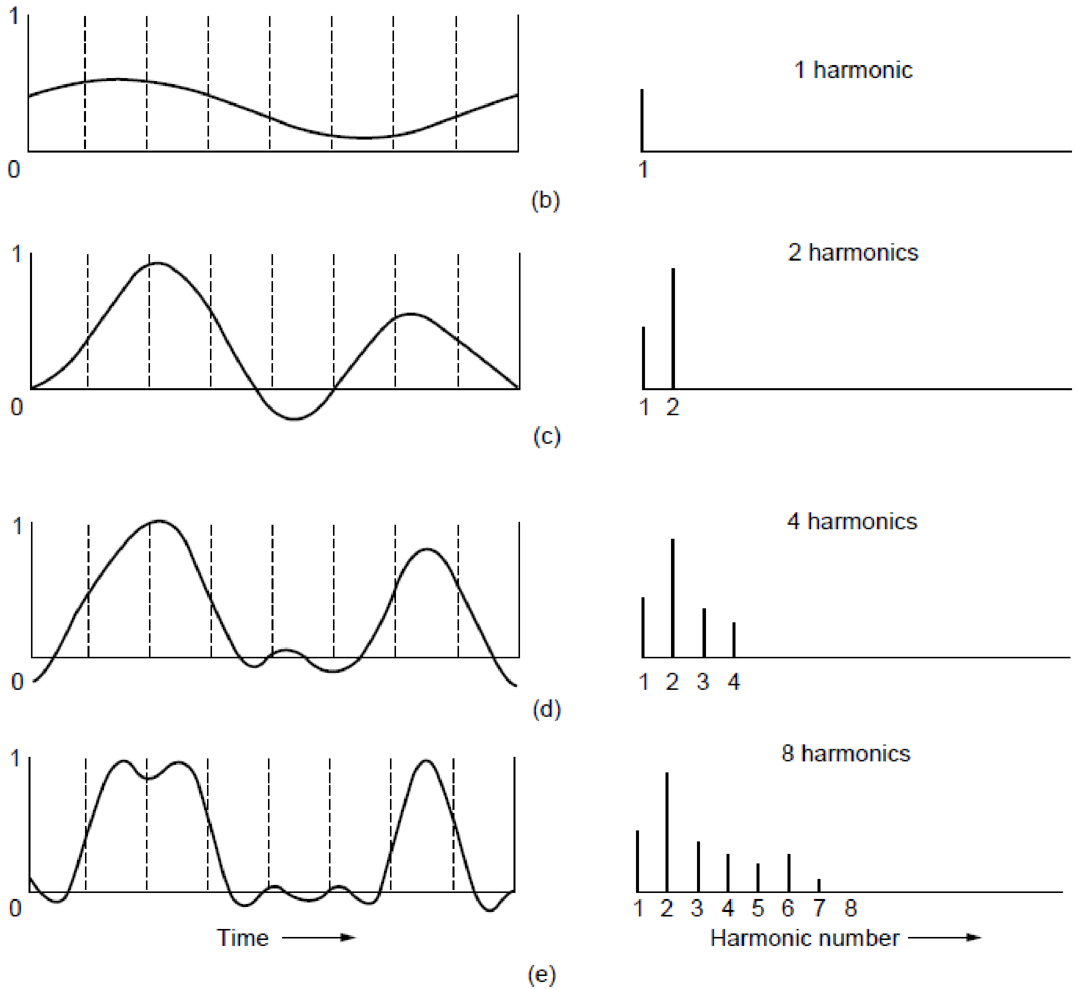
rms

- The root-mean-square amplitudes,

$$rms_n = \sqrt{a_n^2 + b_n^2} \qquad ,$$

  which are displayed on the right-hand of figure, are of interest because their squares are proportional to the energy transmitted at the corresponding frequency.

Bandwidth-Limited Signals



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

Bandwidth

- All transmission facilities diminish different Fourier components by different amounts, thus introducing **distortion**.
- Usually, for a **wire**, the amplitudes are transmitted undiminished from 0 up to some frequency f_c [measured in cycles/sec or **Hertz** (**Hz**)] with all frequencies above this cutoff frequency attenuated.
- The range of frequencies transmitted without being strongly attenuated is called the **bandwidth**.

The bandwidth property

- The bandwidth is a physical property of the transmission medium and usually depends on the construction, thickness, and length of the medium.
- **Filters** are often used to further limit the bandwidth of a signal.
  - 802.11 wireless channels are allowed to 20MHz
  - Traditional(analog) television channels occupy 6MHz each(NTSC), on a wire or over the air.

Bandwidth-limited Signals

- the information that can be carried depends only on the bandwidth and not on the starting and ending freq.
  - Signals that run from 0 up to a maximum frequency are called **baseband** signals.
  - Signals that are shifted to occupy a higher range of frequencies, as is the case for all wireless transmissions, are called **passband** signals.

Voice-grade Line

- An ordinary telephone line, often call a **voice-grade line**, may have a bandwidth of **1 MHz** for short distances, But has an artificially introduced cutoff frequency just above **3000Hz**.(telephone companies add a filter restricting each customer to about 3100 Hz).
  - ex: given bit rate *b* bit/sec,

    send *8* bits: T = *8/b* sec

  So the freq of the first harmonic of this signal is :

  f = b/8 Hz

  the number of highest harmonic passed through is:

  3000/(b/8)=24,000/b

Bandwidth limits data rate

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

f = 9600bps / 8 =1200 Hz

Data rate and harmonics

- Obviously, for **binary** signal, data rates that higher than 38.4 kbps is impossible.

Concept of Bandwidth

- To electrical engineers, (analog) **bandwidth** is a quantity measured in **Hz**.
- To Computer scientists, (digital) **bandwidth** is the maximum **data rate** of a channel, a quantity measured in **bits/sec**(bps).
- The data rate is the end result of using the analog bandwidth of a physical channel for digital transmission, and the two are related.

Maximum Data Rate of A Channel --- noiseless channel

- **Nyquist's theorem**
  - It tries to talk about the realistic amount of data that can be pushed through a channel with a given bandwidth, H. If the signal consists of V levels (for example, binary = 2), then assuming no noise (i.e., perfect signals)

maximum data rate = $2 H \log_2 V$ (in bits/sec)

Maximum Data Rate of A Channel --- noisy channel

- ***Signal to noise ratio*** - random (thermal) or interference causes a degradation of the signal. This is measured in terms of the ratio of signal power to noise power. Usually this is measured in decibels, in terms of 10 $\log_{10}$ S/N. So an S/N of 100 = 20 dB.
- **Shannon's formula**

It is another way of expressing maximum data rate. It's given as

$$\text{maximum data rate} = H \log_2 (1 + S/N)$$

(in bits/sec)

Physical Media

- Guided media:
  - signals propagate in solid media: copper, fiber, coax
- Unguided media:
  - signals propagate freely, e.g., radio

2.2 Guided Transmission Media

- Magnetic media
- Twisted pairs
- Coaxial cable
- Power lines
- Fiber optics

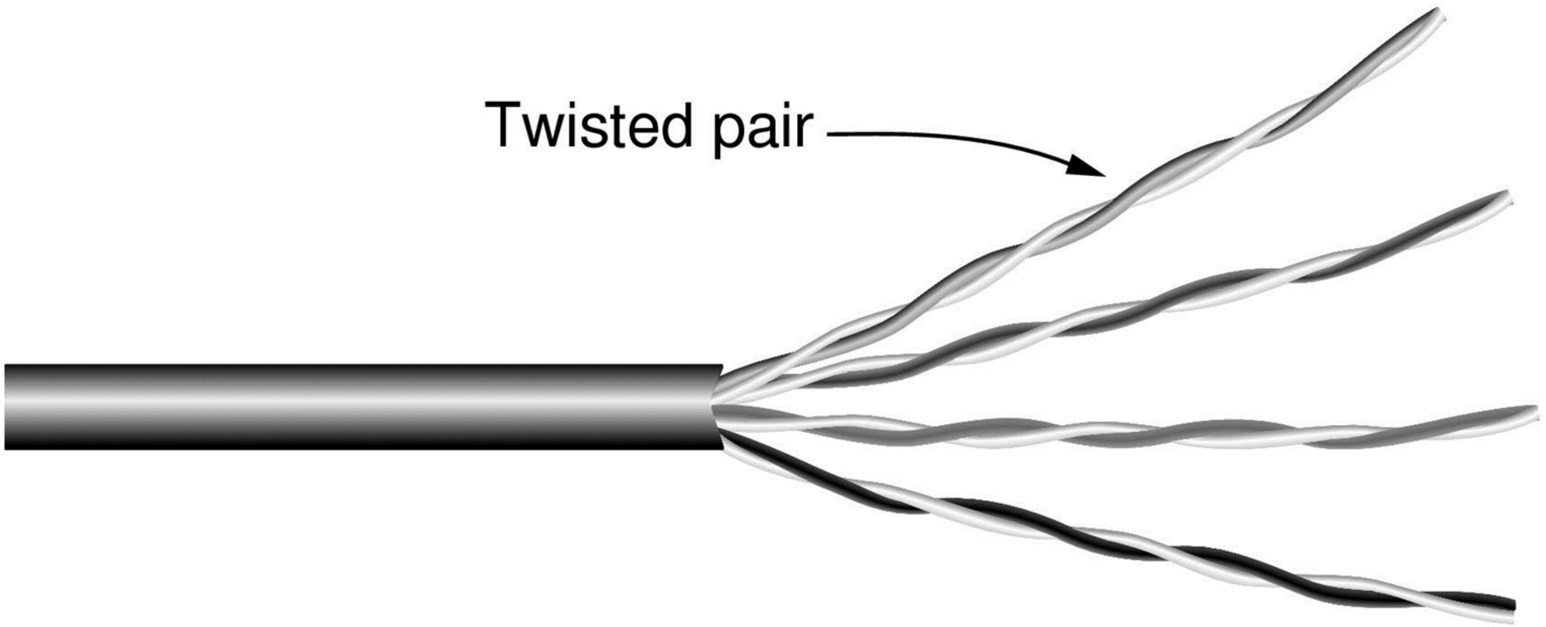
Magnetic Media

- Write data onto magnetic media
  - Disks or Tapes
- Data transmission speed
  - Ultrium tape (IBM LTO Ultrium 4)
    - Capacity : 800 Gigabytes /tape X 1(
    - Bandwidth:

      800*1000=800 terabytes/box/24hrs by FedEx

Never underestimate the bandwidth of a station wagon full of tapes hurtling down the highway

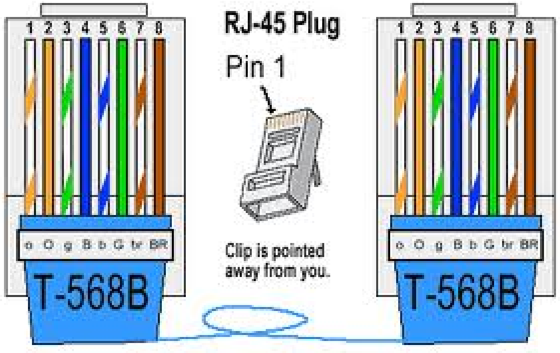
Twisted Pairs



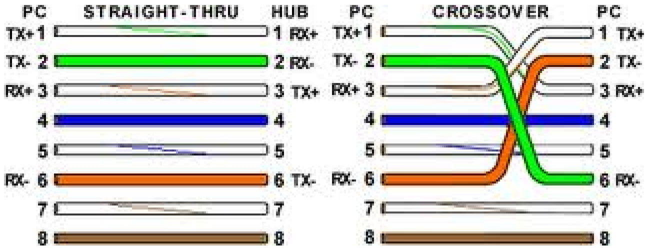
Category 5 UTP cable with four twisted pairs

Cat5. Cabling

- Bandwidth depends on the thickness of the wire and the distance traveled.
  - Cat5. >100MHz 100m
  - 100Mbps Ethernet: 2pairs
  - 1Gbps Ethernet: 4pairs



TIA/EIA 568B Standard

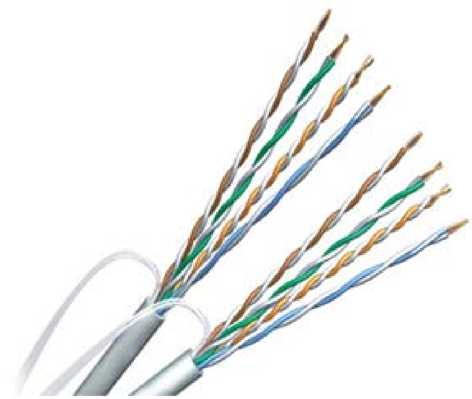


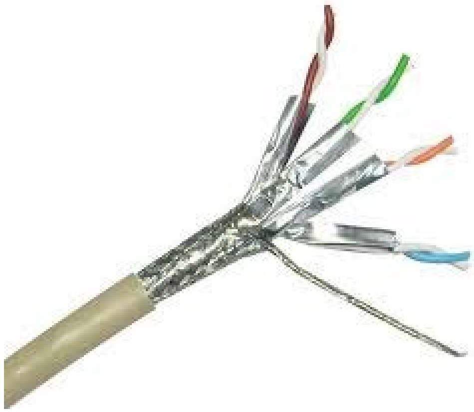
Transmission Direction over Links

- Links that can be used in both directions at the same time, like a two-lane road, are called **full-duplex**.
- Links that can be used in either direction, but only one way at a time, like a single-track railroad line, are called **half-duplex**.
- A third category consists of links that allow traffic in only one direction, like a one-way street, are called **simplex** links.

UTP, STP

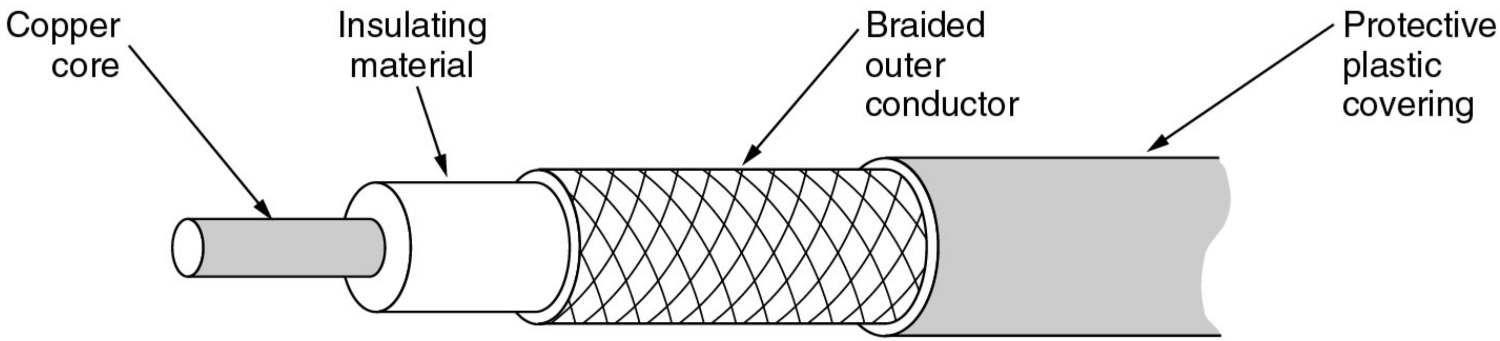
- Through Cat6. these wiring types are referred to as **UTP** (Unshielded Twisted Pair) as they consists simply of wires and insulators.
- Cat7. cables have shielding on the individual twisted pairs, as well as around the entire cable, are referred to as **STP**.





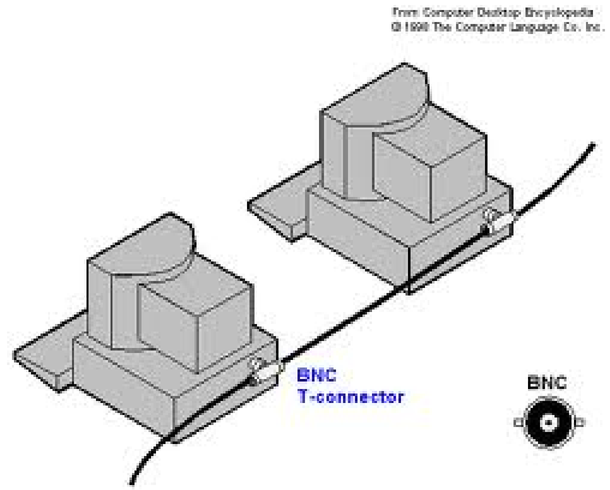
Coaxial Cable

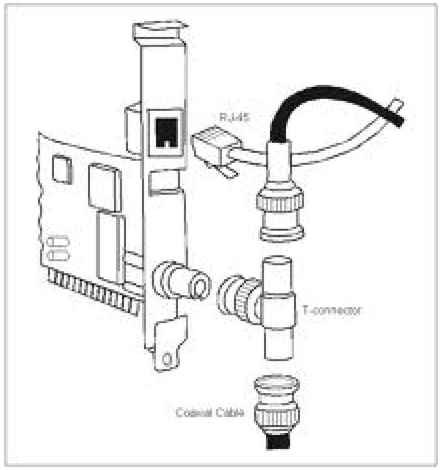
A coaxial cable.



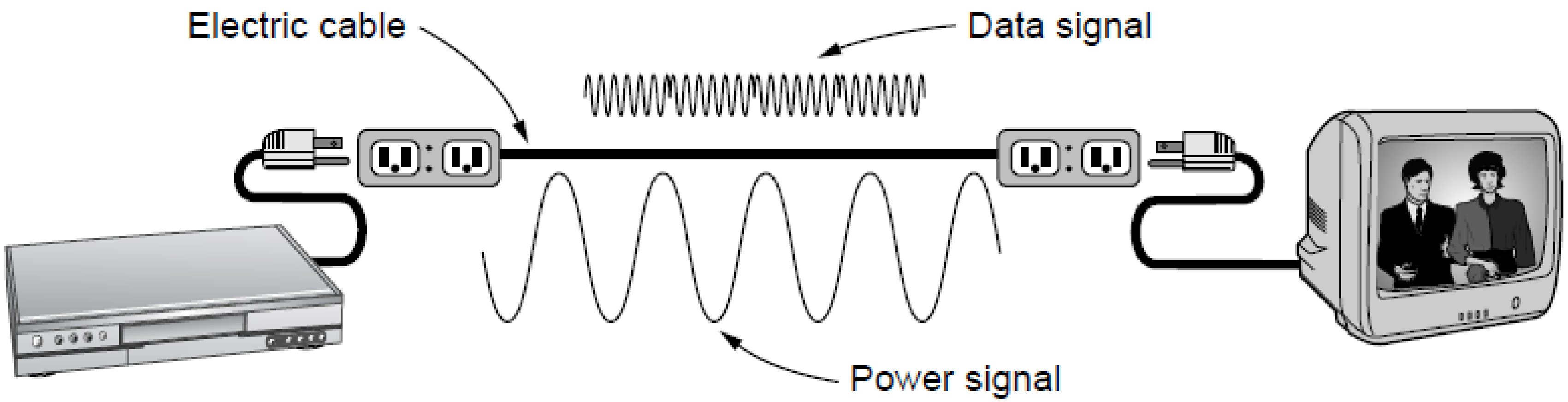
- Two type
  - 50-ohm: digital data (thin coaxial cable)
  - 75-ohm cable TV
- Bandwidth: > 1 GHz

Thin Coaxial cable





Power Lines



A network that uses household electrical wiring.

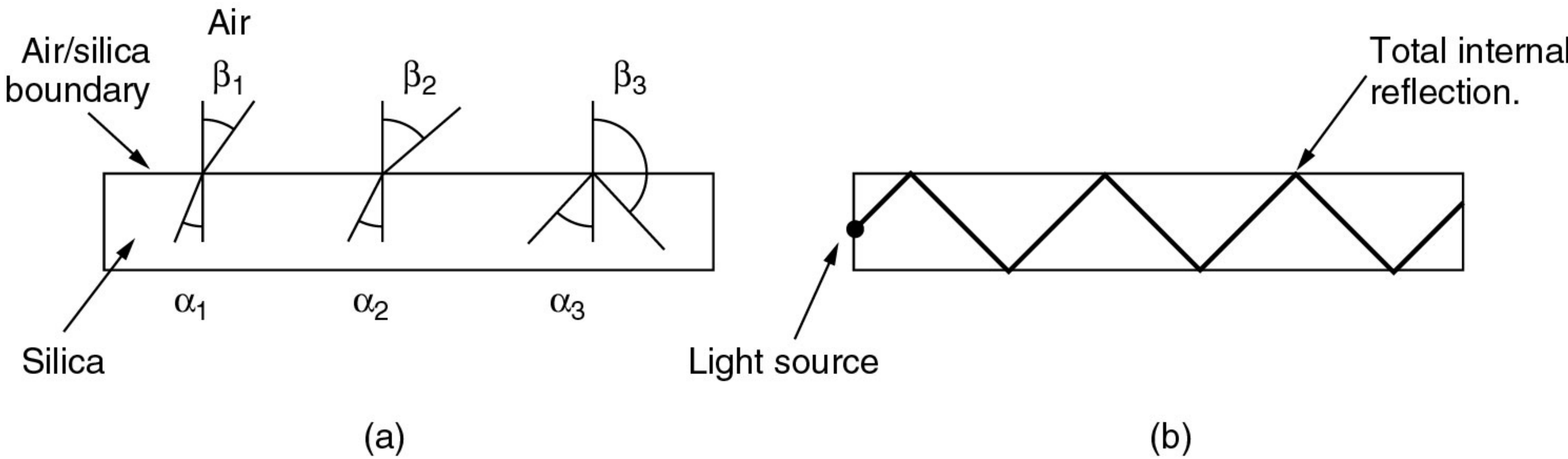
Race between computing and communication

- Single CPUs(3 GHz) are beginning to approach physical limits, which is why now the number of CPUs is increased per chip.
- The achievable bandwidth with fiber technology is in excess of 50Tbps.
- The current practical limit of around 100Gbps is due to our inability to convert between electrical and optical signals any faster.

Fiber Optics

- Fiber usages
  - Long-haul transmission in network backbones
  - High-Speed LANs
  - High-Speed Internet Access (FttH)
- Components of Optical Transmission System
  - The light source
  - The transmission medium
  - The detector

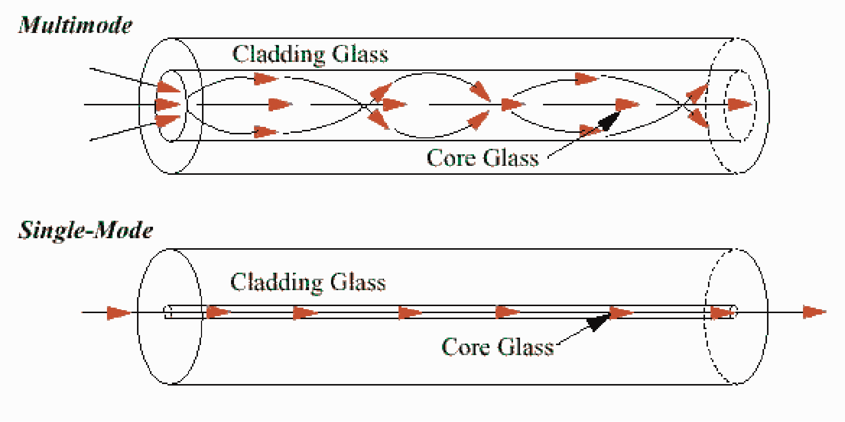
Fiber Optics

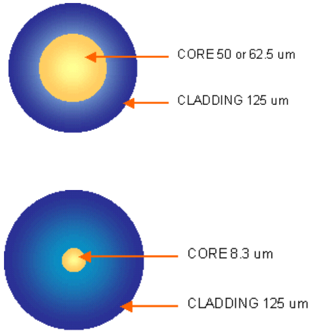


(a) Three examples of a light ray from inside a silica fiber impinging on the air/silica boundary at different angles.

(b) Light trapped by total internal reflection.

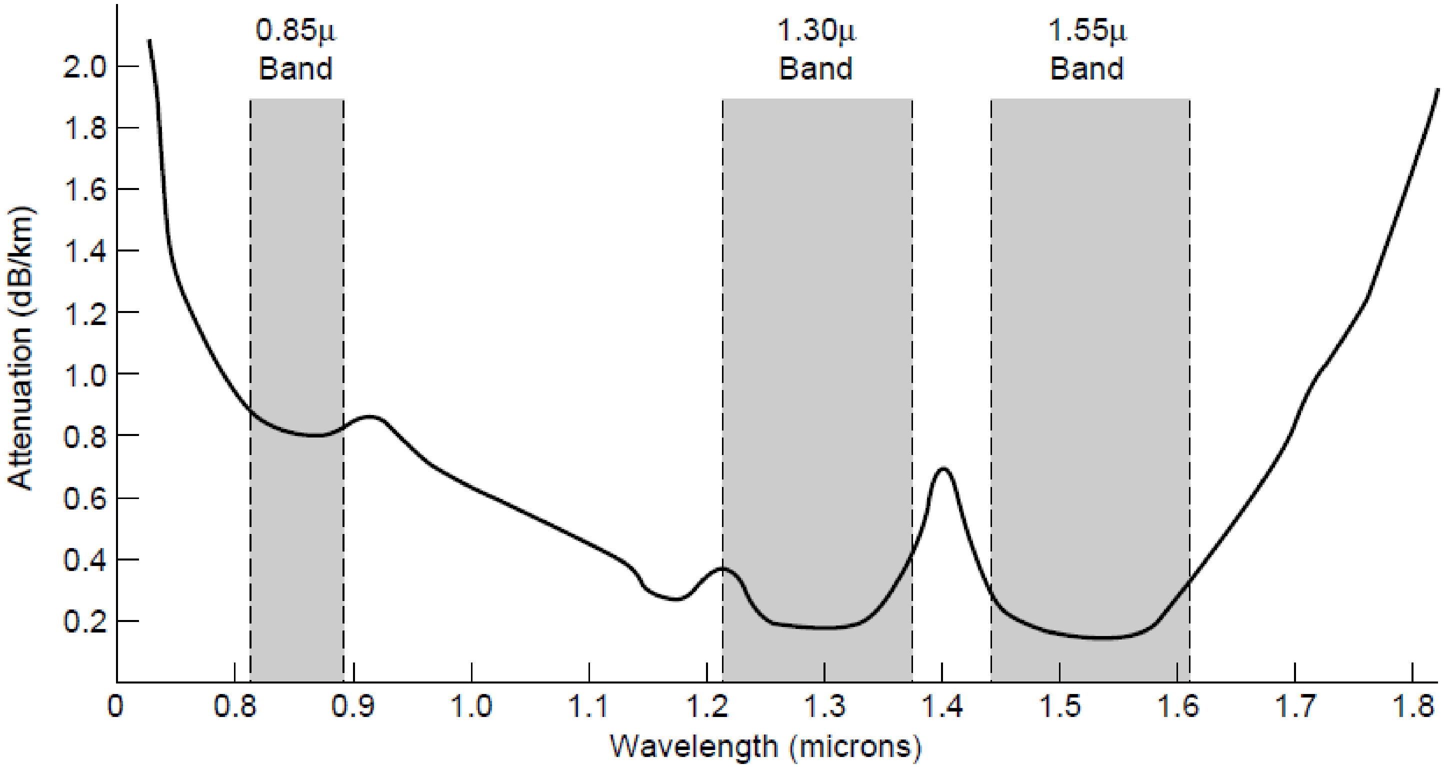
Multimode and Single-mode





- different rays will be bouncing around at different angles. Each ray is said to have a different mode, so a fiber having this property is called a multimode fiber .
- if the fiber's diameter is reduced to a few wavelengths of light, the fiber acts like a wave guide, and the light can propagate only in a straight line, without bouncing, yielding a single-mode fiber.

Transmission of Light through Fiber



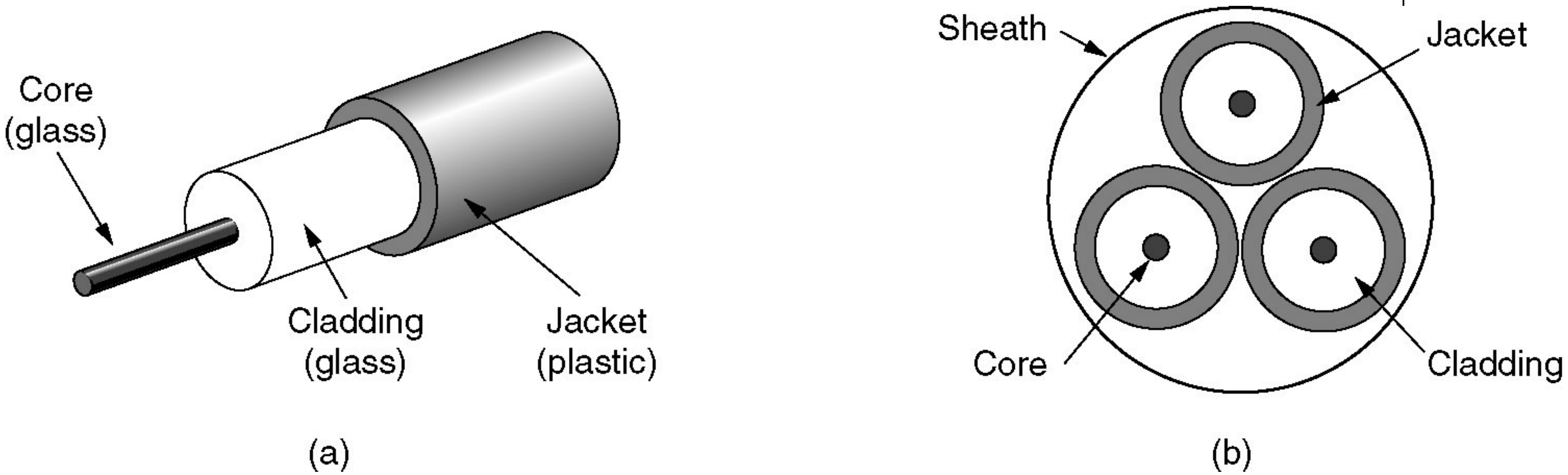
All three bands are 25,000 to 30,000 GHz wide

Attenuation of light through fiber in the infrared region.

Chromatic Dispersion

- **Chromatic dispersion** occurs because different colors of light travel through the fiber at different speeds. Since the different colors of light have different velocities, some colors arrive at the fiber end before others.
- It has been discovered that making the pulsed in a special shape related to the reciprocal of the hyperbolic cosine causes nearly all the dispersion effects cancel out. These pulses are called **solitons**.

Fiber Cables



(a) Side view of a single fiber.

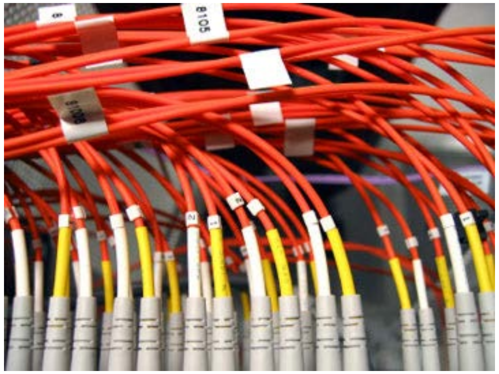
(b) End view of a sheath with three fibers.

Diameter:50um of Multimode

<10um of singlemode

Connecting Fibers

- Fibers can be connected in three different ways：
  - Connectors and fiber sockets
  - Mechanical splices
  - Fusion (melted) splice



Light Sources

- Two kinds of light resources are typically used to do the signaling:

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

A comparison of semiconductor diodes and LEDs as light sources.

The receiving end

- Photodiode: gives off an electrical pulse when struck by light
  - The response time of photodiodes, which convert the signal from the optical to the electrical domain, limits data rates to about 100Gbps.
  - Thermal noise is also an issue, so a pulse of light must carry enough energy to be detected, by making the pulses powerful enough, the error rate can be made arbitrarily small.

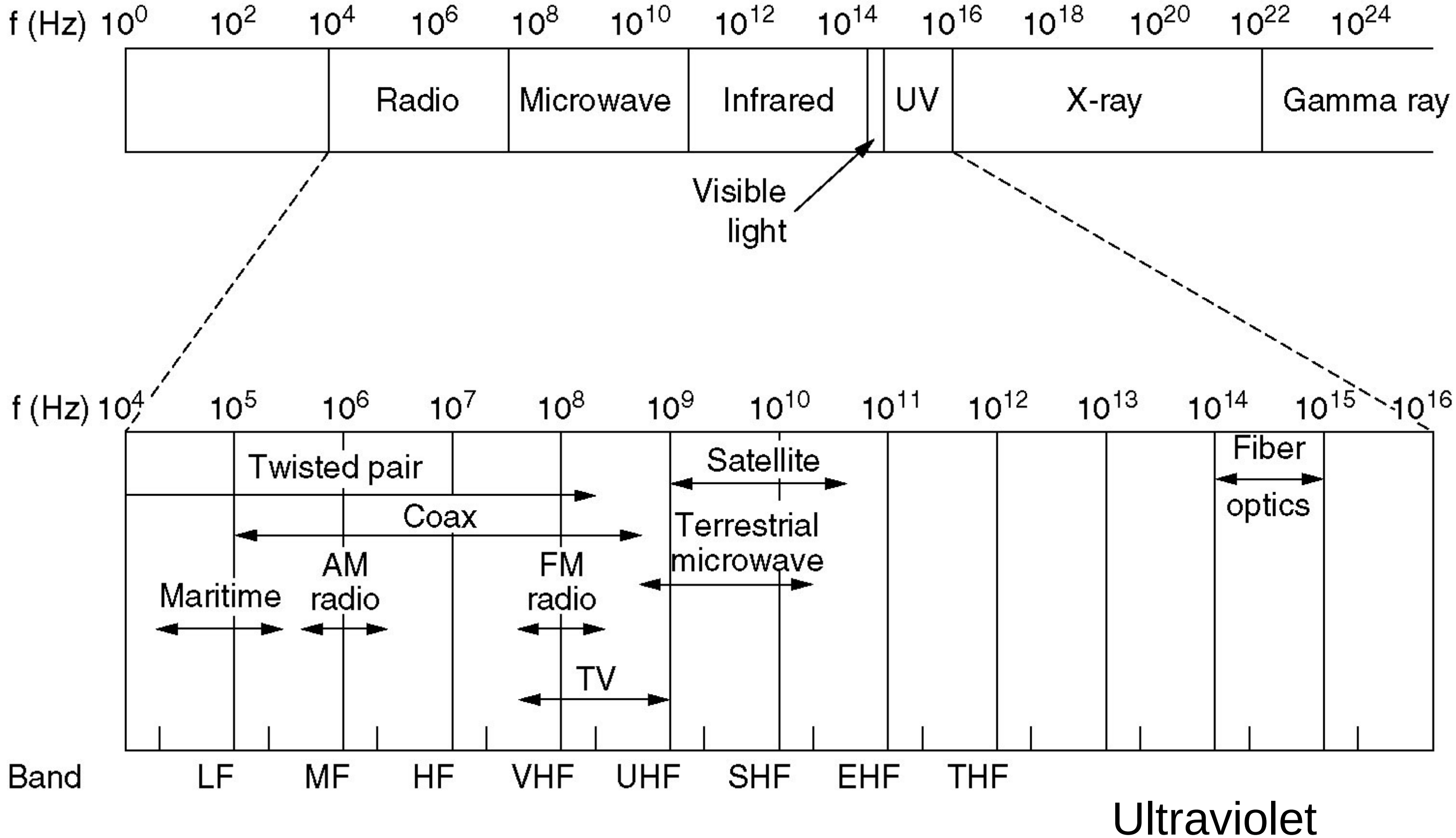
Pros and Cons of Fiber Optics

- Pros
  - High bandwidth
  - Long distance, low attenuation
  - No being affected by power surges, electromagnetic interference, or power failures
  - Thin and lightweight
  - No light leaking, difficult to tap
- Cons
  - Requiring skills to install
  - Can be damaged by being bent too much
  - Two-way communication requires either two fibers or two frequency bands on one fiber
  - Fiber interfaces cost more than electrical interfaces.

2.3 Wireless Transmission

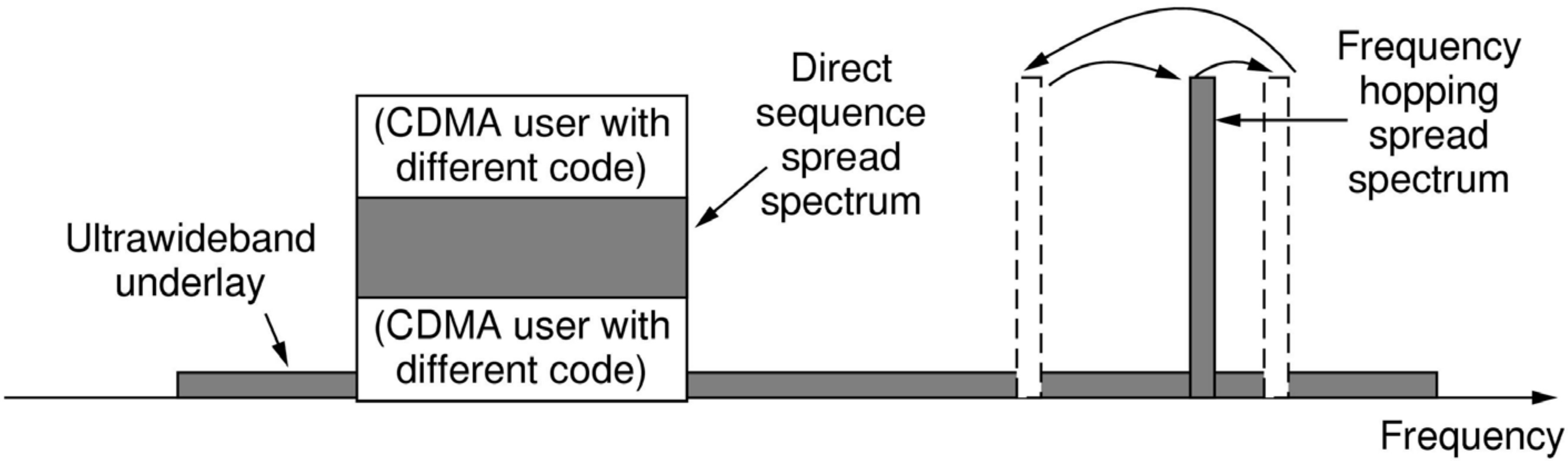
- The Electromagnetic Spectrum
- Radio Transmission
- Microwave Transmission
- Infrared Transmission
- Lightwave Transmission

The Electromagnetic Spectrum



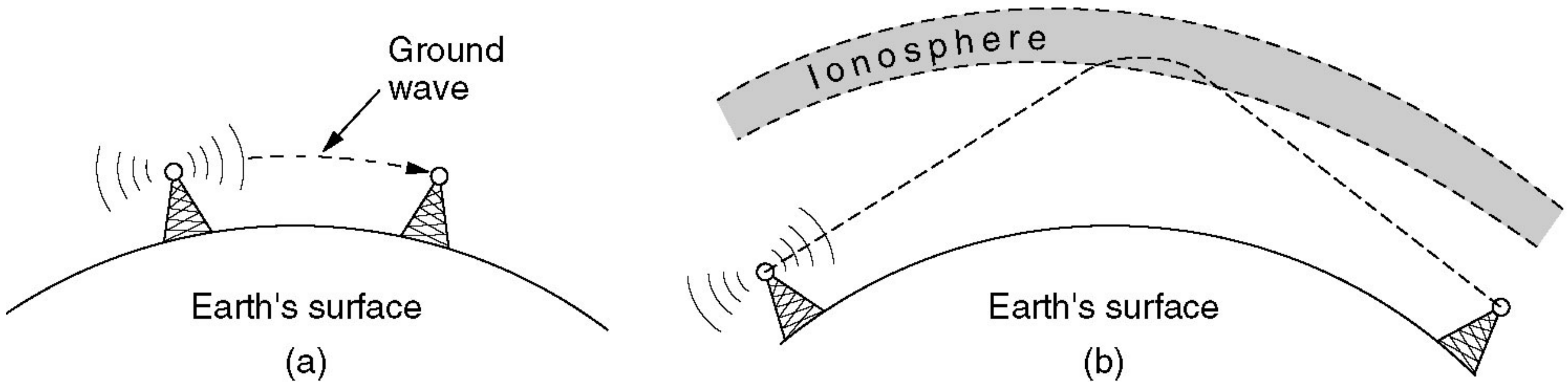
The electromagnetic spectrum and its uses for communication.

Spread spectrum & UWB



Spread spectrum and ultra-wideband (UWB) communication

Radio Transmission

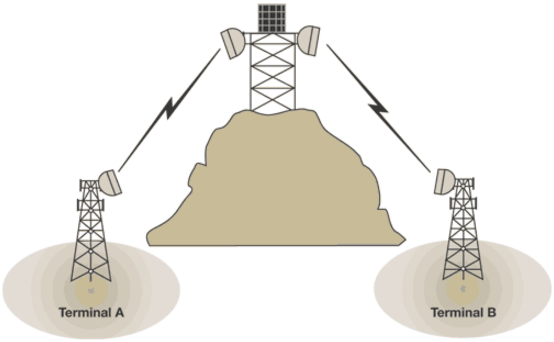


(a) In the VLF, LF, and MF bands, radio waves follow the curvature of the earth.

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

Microwave Transmission

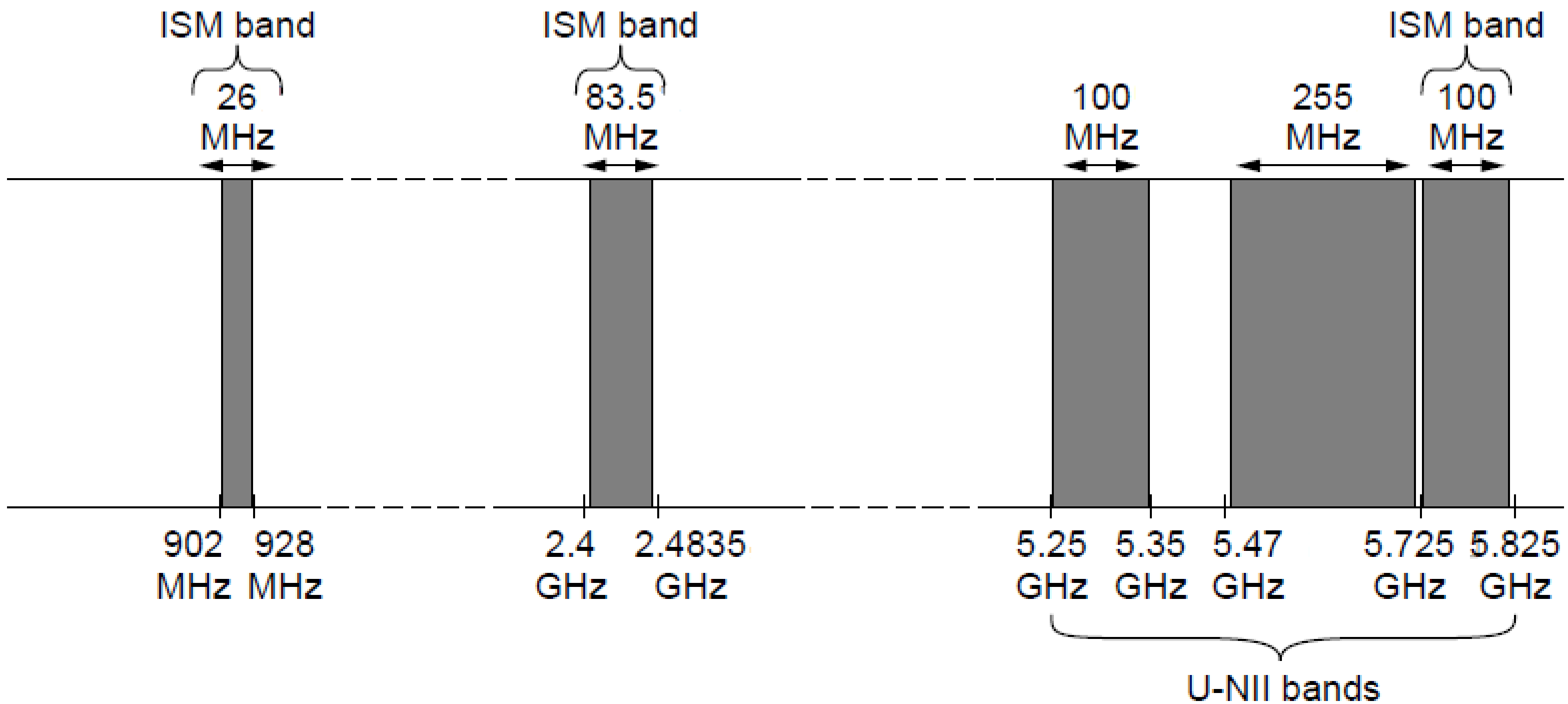
- Above 100MHz, the waves travel in nearly straight lines and can therefore be narrowly focused. Concentrating all the energy into a small beam by means of a parabolic antenna gives a much higher S/N ration, but the transmitting and receiving antennas must be accurately aligned with each other.



1. A microwave repeater link is designed to transfer signals from one terminal station to another without loss of traffic or signal performance.

2. This photograph shows a typical microwave repeater station.

Politics of the Electromagnetic Spectrum



ISM (Industrial, Scientific, Medical) and U-NII (Unlicensed National Information Infrastructure) bands used in the United States by wireless devices

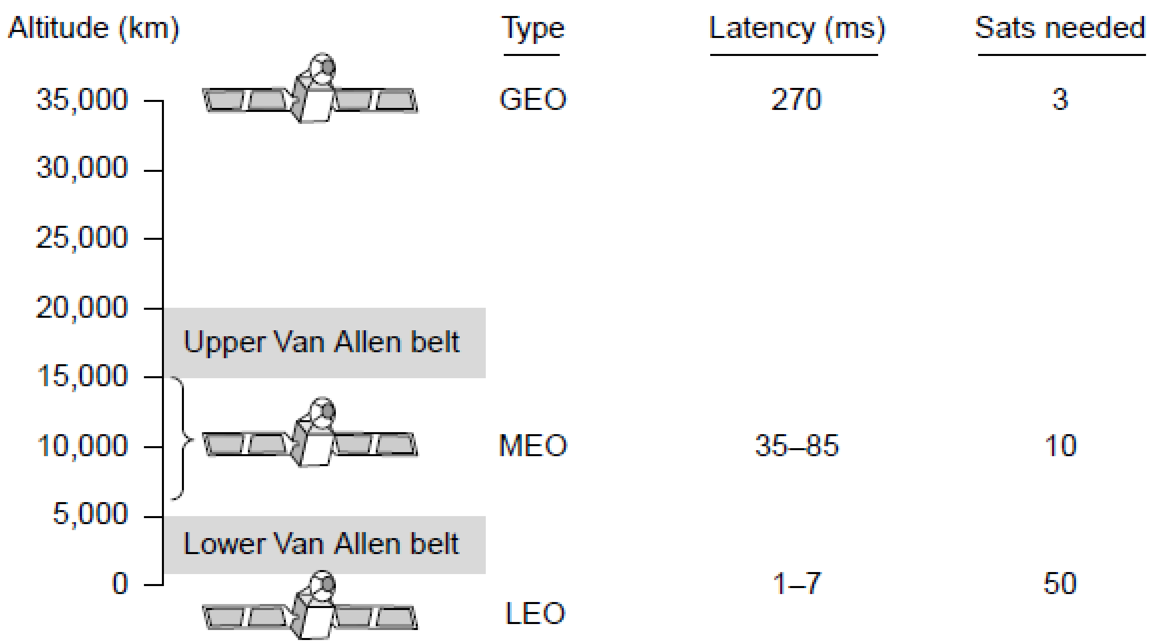
Popular Bands

- 900MHz band works best, but it is crowded and not available worldwide
- 2.4GHz band is available in most countries, but it is subject to interference from microwave ovens and radar installation.
  - Bluetooth and 802.11b/g
- 5GHz band
  - 802.11a

2.4 Communication Satellites

- Geostationary Satellites
- Medium-Erath Orbit Satellites
- Low-Earth Orbit Satellites
- Satellites Versus Fiber

Communication satellites

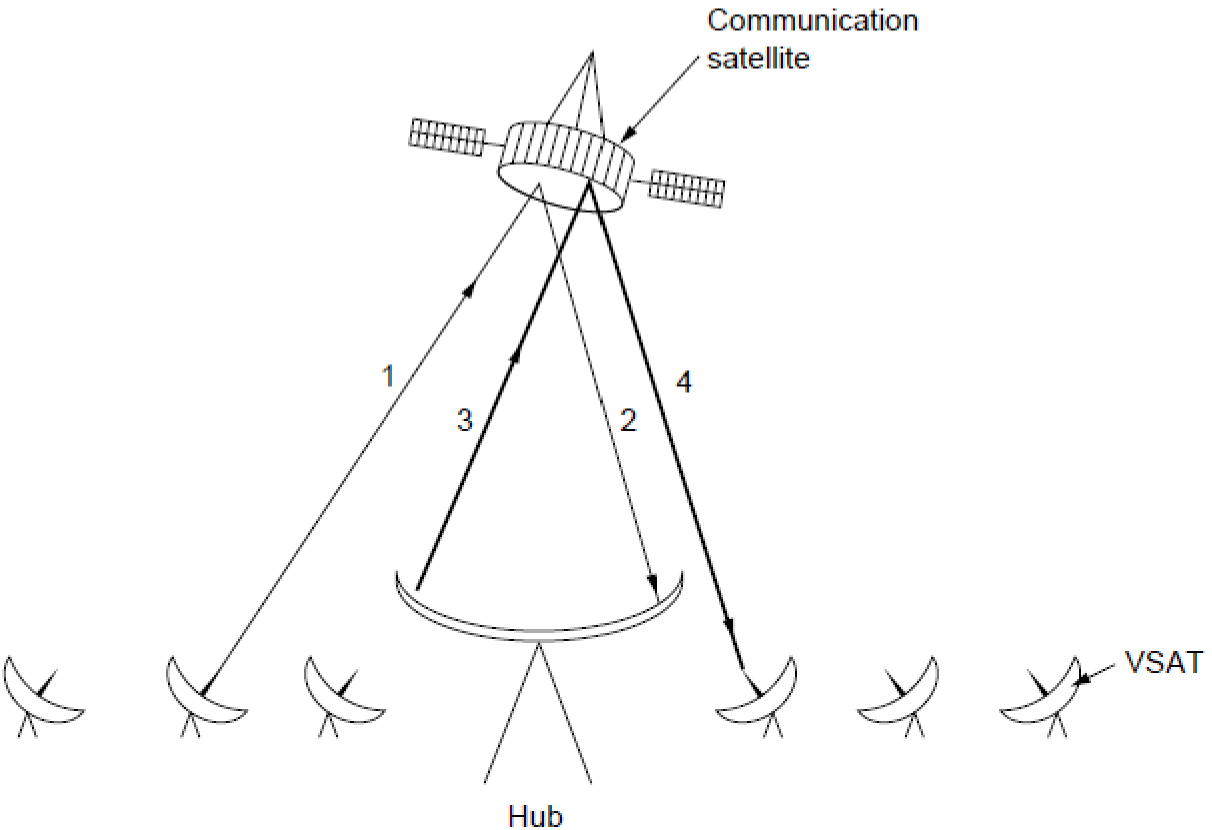


Communication satellites, some properties, including: altitude above earth, round-trip delay time, number of satellites for global coverage.

The principal satellite bands

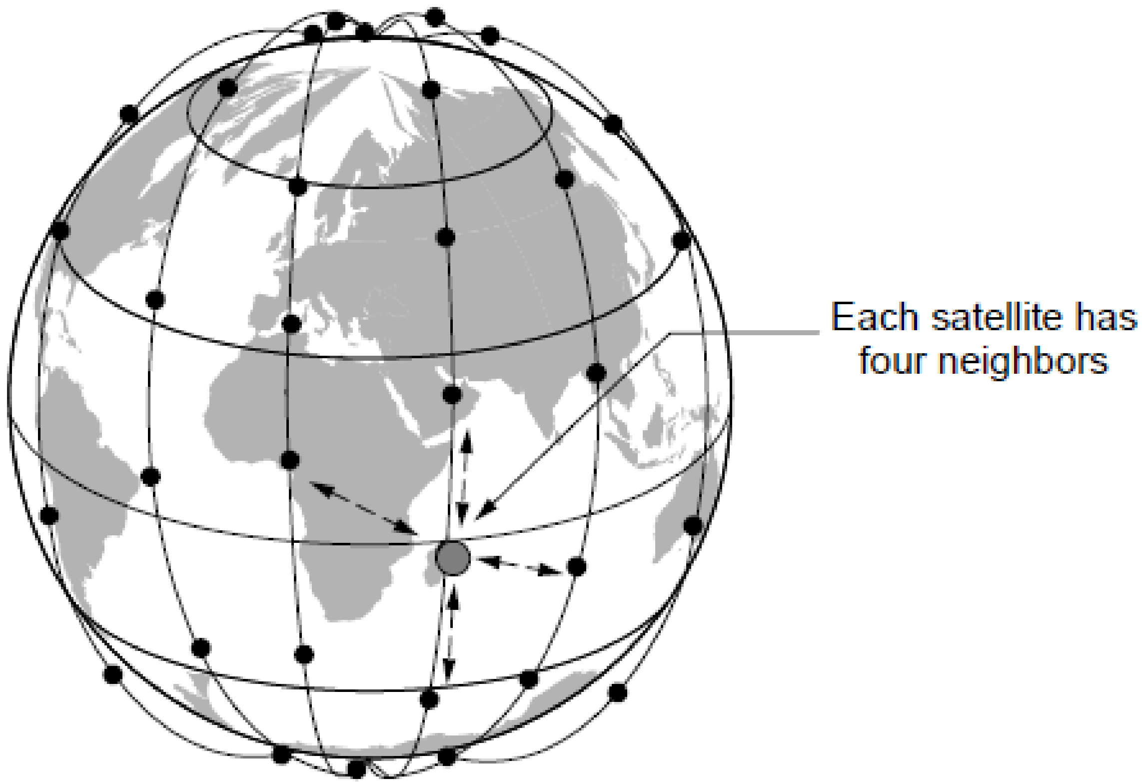
Band	Downlink	Uplink	Bandwidth	Problems
L	1.5 GHz	1.6 GHz	15 MHz	Low bandwidth; crowded
S	1.9 GHz	2.2 GHz	70 MHz	Low bandwidth; crowded
C	4.0 GHz	6.0 GHz	500 MHz	Terrestrial interference
Ku	11 GHz	14 GHz	500 MHz	Rain
Ka	20 GHz	30 GHz	3500 MHz	Rain, equipment cost

Geostationary Satellites



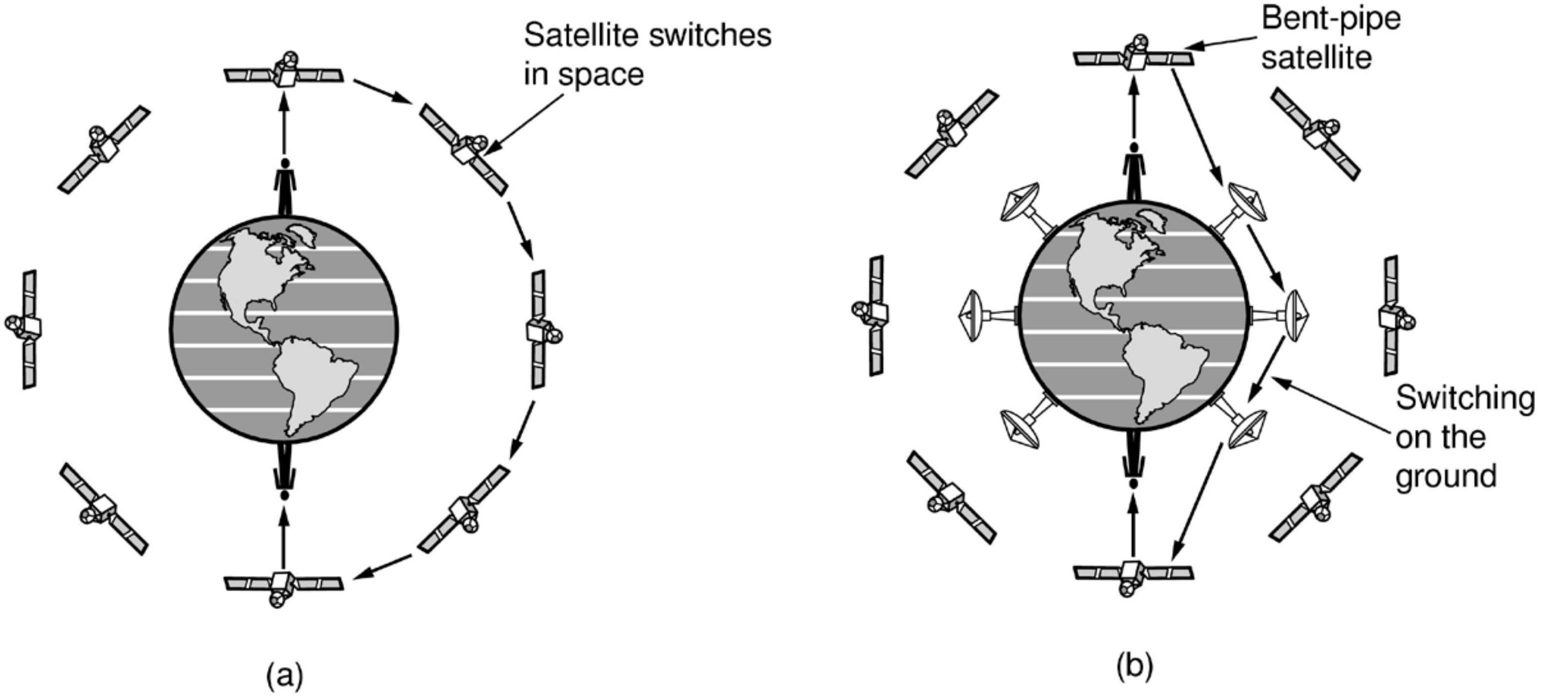
VSATs using a hub.

Low-Earth Orbit Satellites



The Iridium satellites form six necklaces around the earth.

Relaying



(a) Relaying in space. (b) Relaying on the ground

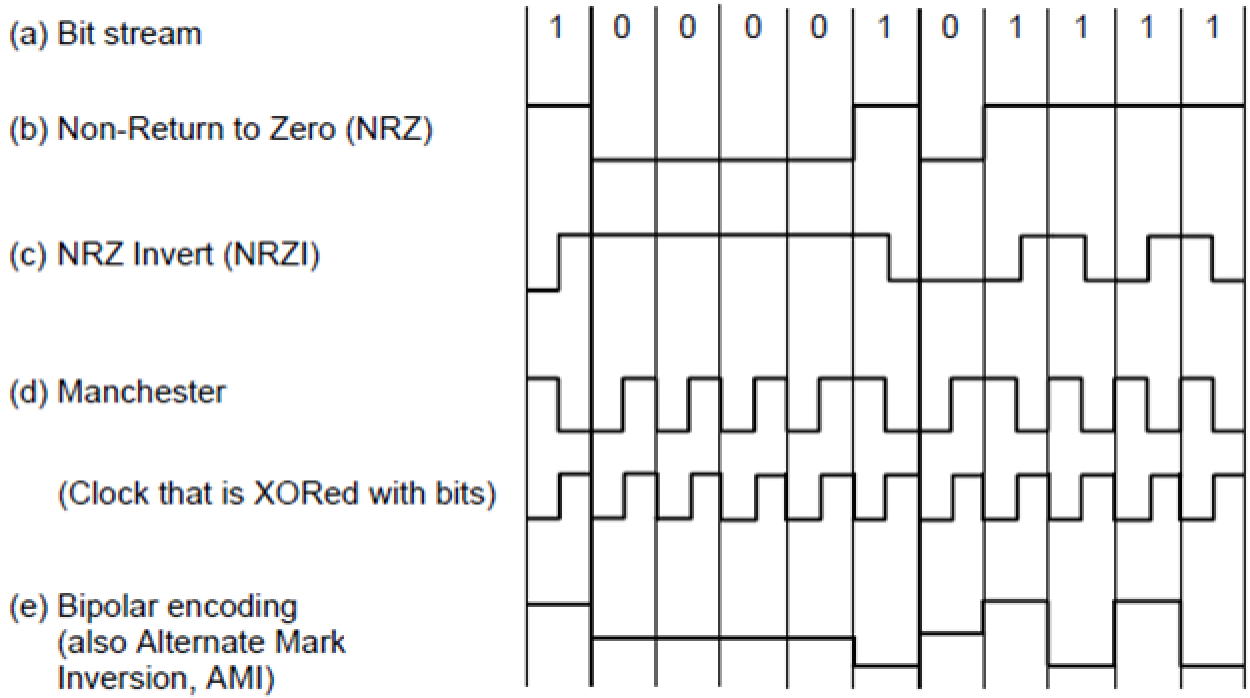
2.5 Digital modulation and multiplexing

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

Terms

- The process of converting between bits and signals that represent them is called **digital modulation**.
- Schemes that directly convert bits into a signal result in **baseband transmission.** It is common for wires.
- Schemes that regulate/modulate the amplitude, phase, or frequency of a carrier signal to convey bits result in **passband transmission**. It is common for wireless and optical channels for which the signals must reside in a given frequency band.
- Channels are often shared by multiple signals. It is called **multiplexing**.

Baseband Transmission



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

Bandwidth efficiency

- One strategy for using limited bandwidth more efficiently is to use more than two signaling levels.
- By using four voltages, for instance, we can send 2 bits at once as a single **symbol**.
- The rate at which the signal changes is then half the bit rate. So the needed bandwidth has been reduced.

Bit rate and symbol rate

- We call the rate at which the signal changes the **symbol rate** to distinguish it from the **bit rate**.
- The bit rate(an older name is **baud rate**) is the symbol rate multiplied by the number of bits per symbol.
- If the signal is BINARY (only two voltage levels), then the bit rate is equal to the symbol rate.

Clock Recovery

- For all schemes that encode bits into symbols, the receiver must know when one symbol ends and the next symbol begins to correctly decode the bits.
  - Manchester encoding: mix the clock signal with the data signal by XORing them together so that no extra line is needed. But the downside is that it requires twice as much bandwidth as NRZ because of the clock.

Code pattern to break consecutive 0s

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.

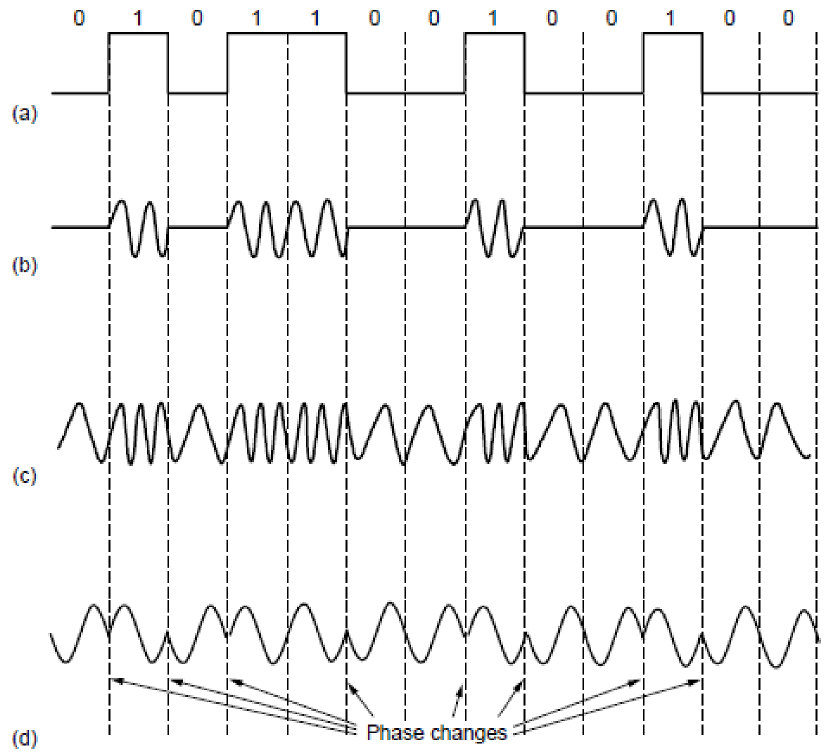
Balanced Signals

- Signals that have as much positive voltage as negative voltage even over short periods of time are called **balanced signals**.
- Balancing helps to provide transitions for clock recovery and provides a simple way to calibrate receivers.
- A straightforward way to construct a balanced code is to use two voltage levels represent a logical 1, (say +1v or -1v) with 0v representing a logical zero. To send a 1, the transmitter alternates between the +1v and -1v levels to that they always average out. The scheme is called **bipolar encoding** (**AMI, Alternate Mark Inversion**).

Passband Transmission

- We can take a **baseband** signal that occupies 0 to B Hz and shift it up to occupy a passband of S to S+B Hz without changing the amount of information that it can carry, even though the signal will look different.
- To process a signal at the receiver, we can shift it back down to baseband, where it is more convenient to detect symbols.

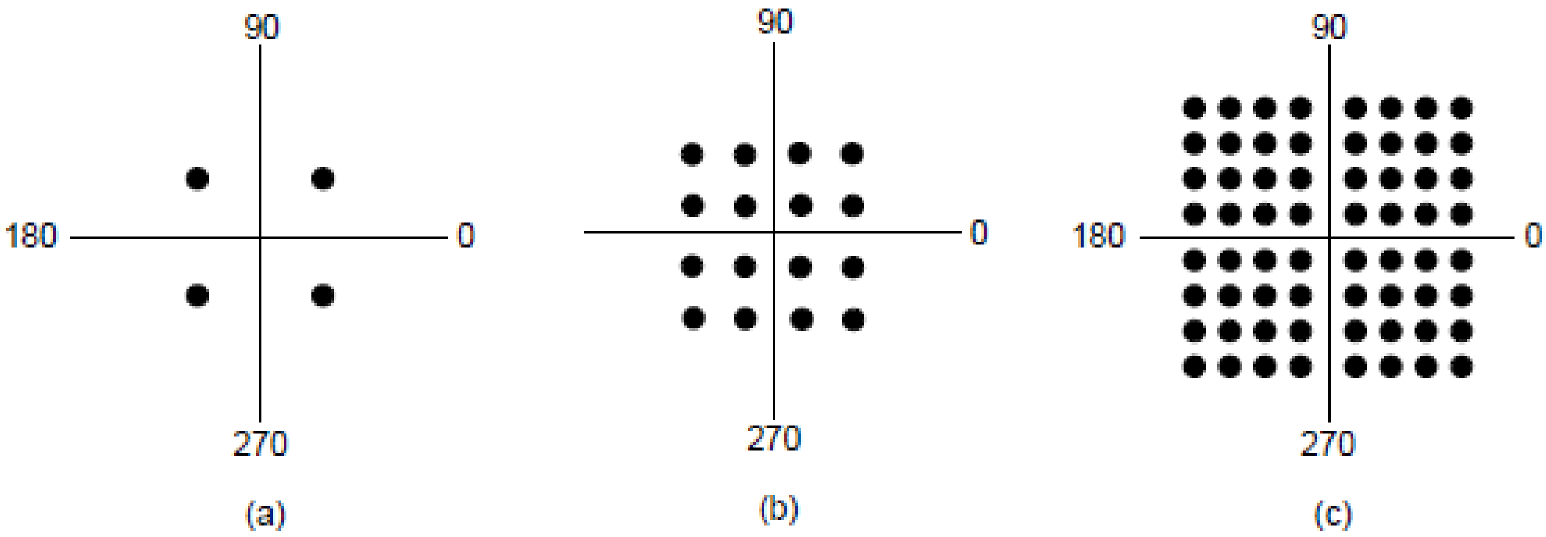
Digital modulation



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

More bits per symbol

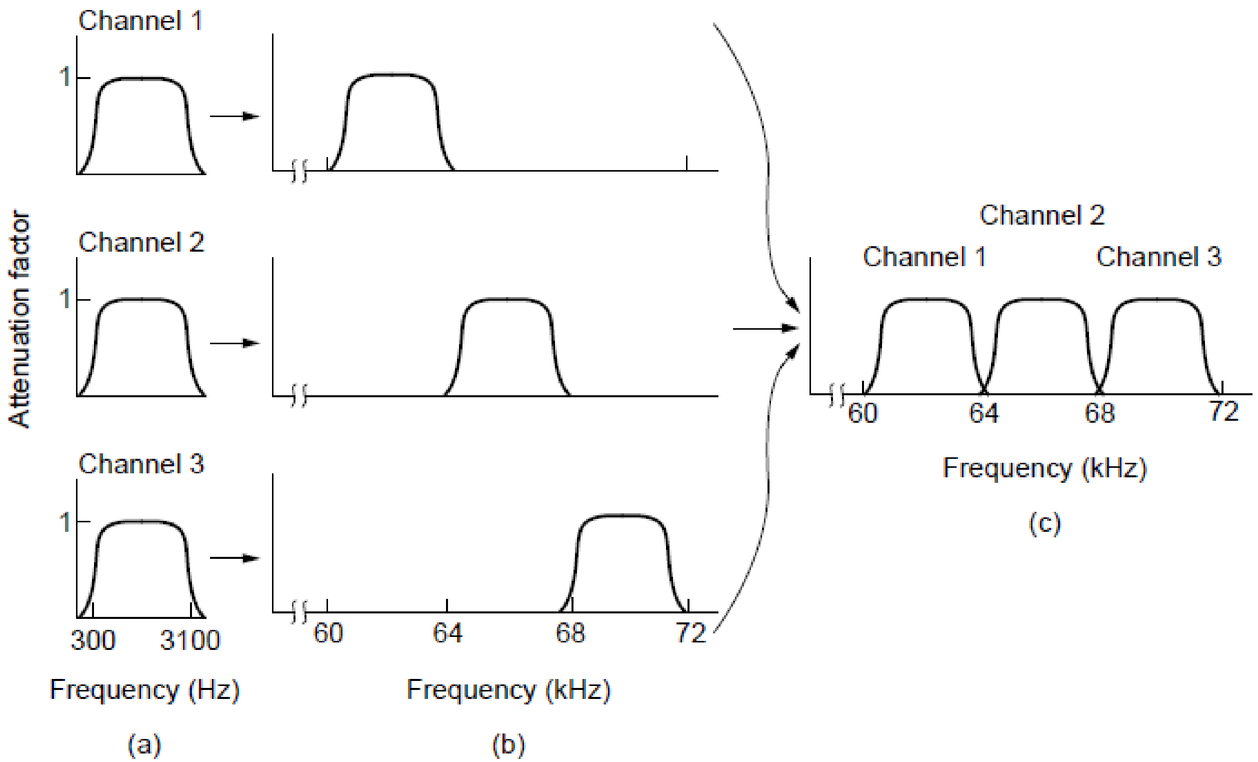
- Amplitude and phase are modulated in combination.



Constellation diagram

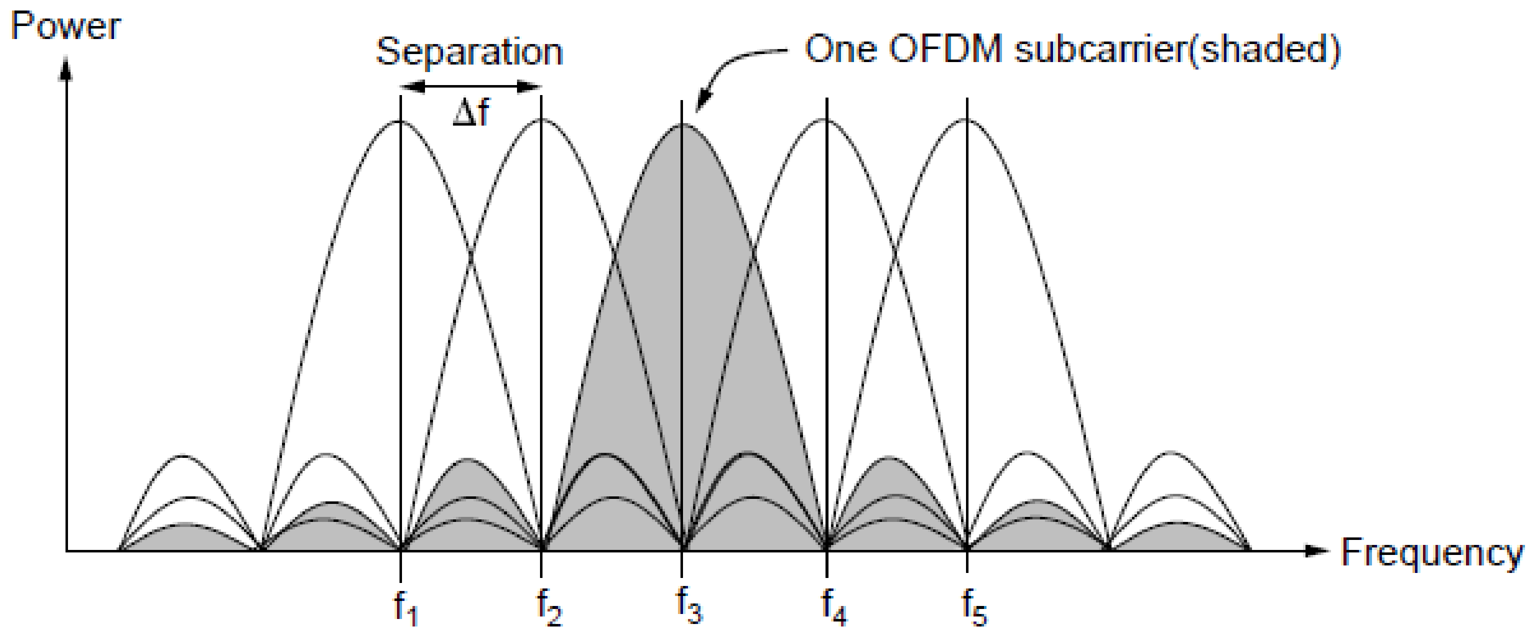
(a) QPSK. (b) QAM-16. (c) QAM-64.

Frequency Division Multiplexing



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

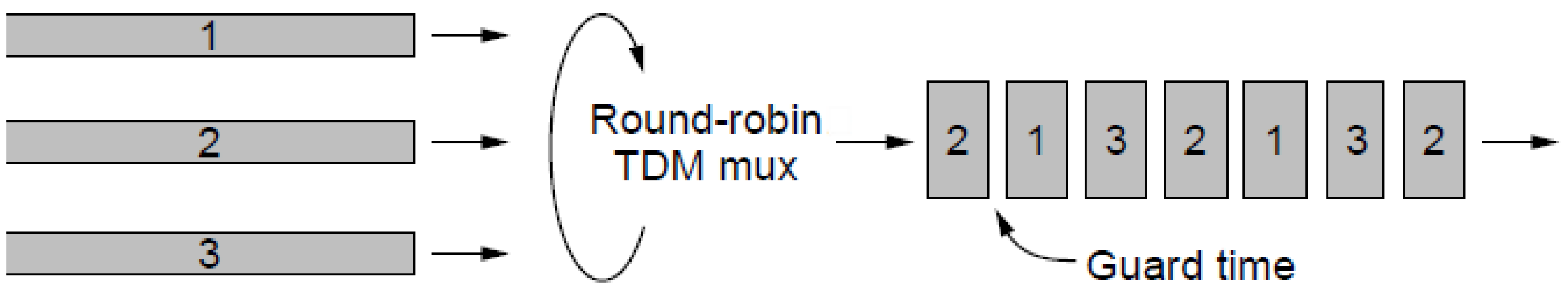
Digital data transmission



Orthogonal frequency division multiplexing (OFDM).

Time Division Multiplexing

- Here, the users take turns (in a round-robin fashion), each one periodically getting the entire bandwidth for a little burst of time.
- the streams must be synchronized in time.



Time Division Multiplexing (TDM).

Code Division Multiplexing

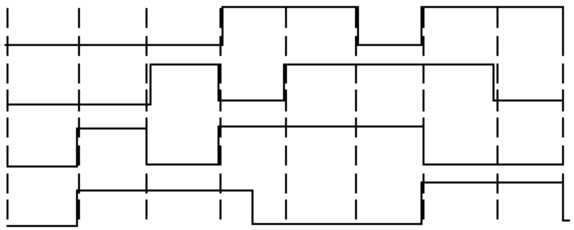
A = (−1 −1 −1 +1 +1 −1 +1 +1)

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)

$S_1 = C \quad = (-1\ +1\ -1\ +1\ +1\ +1\ -1\ -1)$

$S_2 = B + C \quad = (-2\ \ 0\ \ 0\ \ 0\ +2\ +2\ \ 0\ -2)$

$S_3 = A + \overline{B} \quad = (\ 0\ \ 0\ -2\ +2\ \ 0\ -2\ \ 0\ +2)$

$S_4 = A + \overline{B} + C \quad = (-1\ +1\ -3\ +3\ +1\ -1\ -1\ +1)$

$S_5 = A + B + C + D = (-4\ \ 0\ -2\ \ 0\ +2\ \ 0\ +2\ -2)$

$S_6 = A + B + \overline{C} + D = (-2\ -2\ \ 0\ -2\ \ 0\ -2\ +4\ \ 0)$

(c)

$S_1 \bullet C = [1+1-1+1+1+1-1-1]/8 = 1$

$S_2 \bullet C = [2+0+0+0+2+2+0+2]/8 = 1$

$S_3 \bullet C = [0+0+2+2+0-2+0-2]/8 = 0$

$S_4 \bullet C = [1+1+3+3+1-1+1-1]/8 = 1$

$S_5 \bullet C = [4+0+2+0+2+0-2+2]/8 = 1$

$S_6 \bullet C = [2-2+0-2+0-2-4+0]/8 = -1$

(d)

(a) Chip sequences for four stations.

(b) Signals the sequences represent

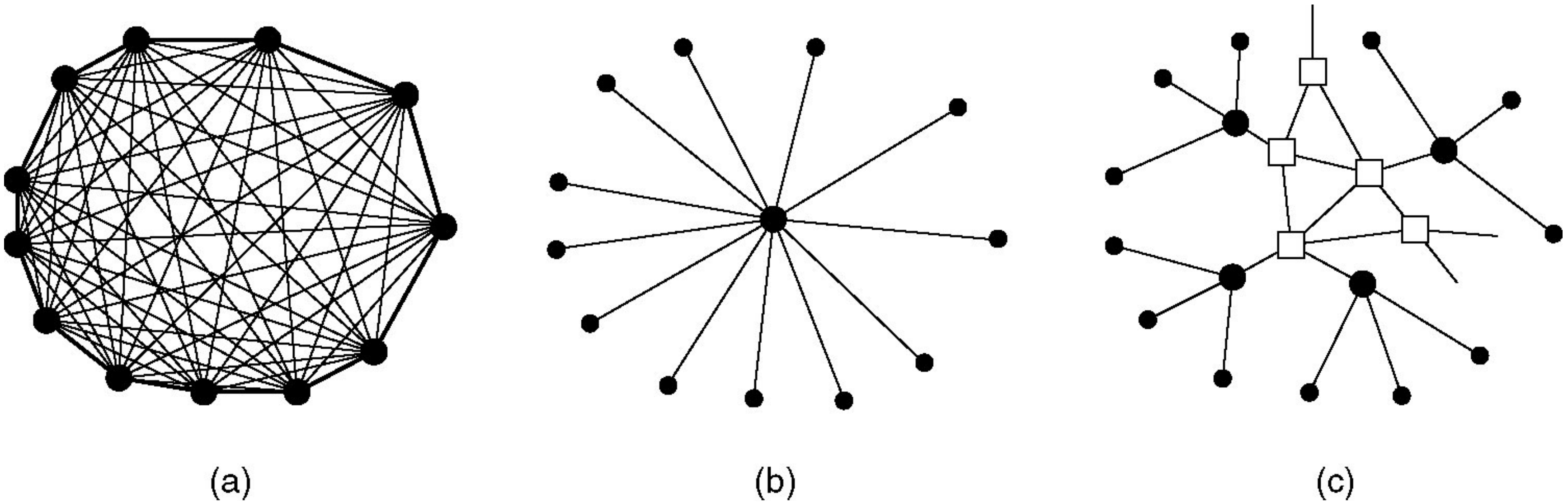
c) Six examples of transmissions.

d) Recovery of station C’s

2.6 Public Switched Telephone System

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

Mode of Connecting

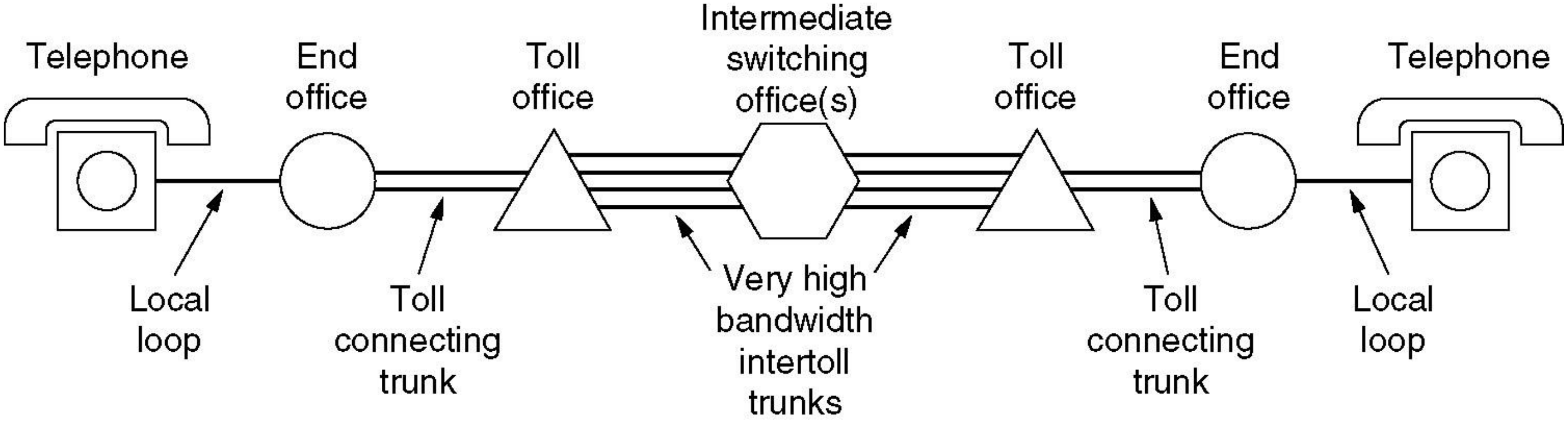


(a) Fully-interconnected network.

(b) Centralized switch.

(c) Two-level hierarchy.

Structure of the Telephone System



A typical circuit route for a medium-distance call.

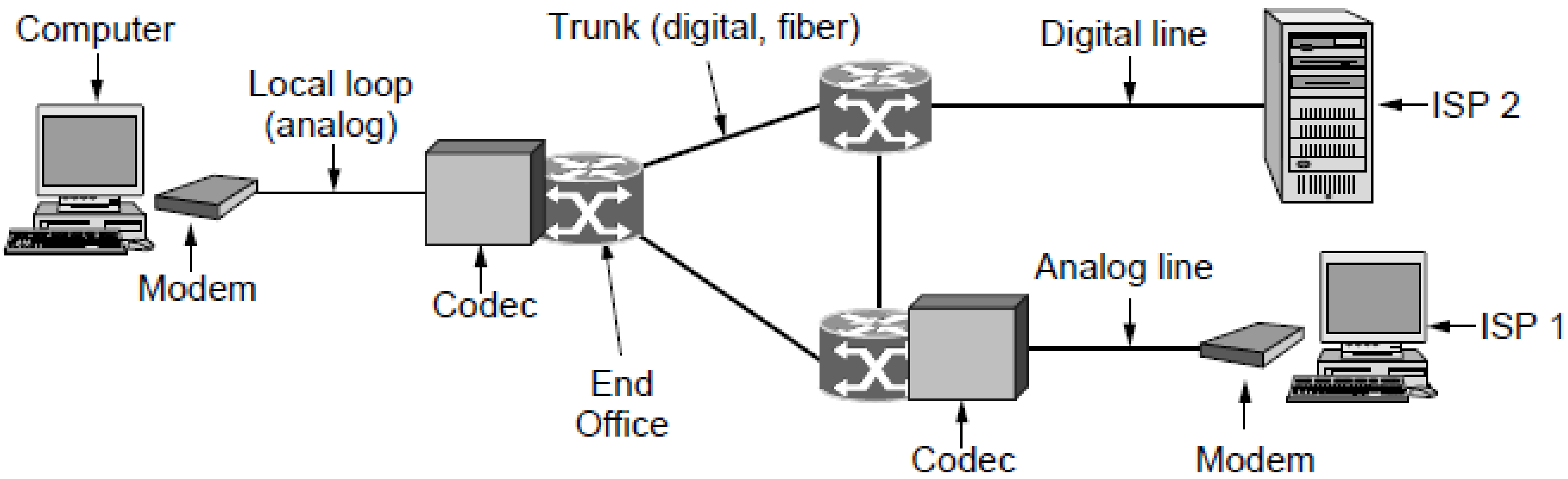
Major Components of the Telephone System

- 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

Modem

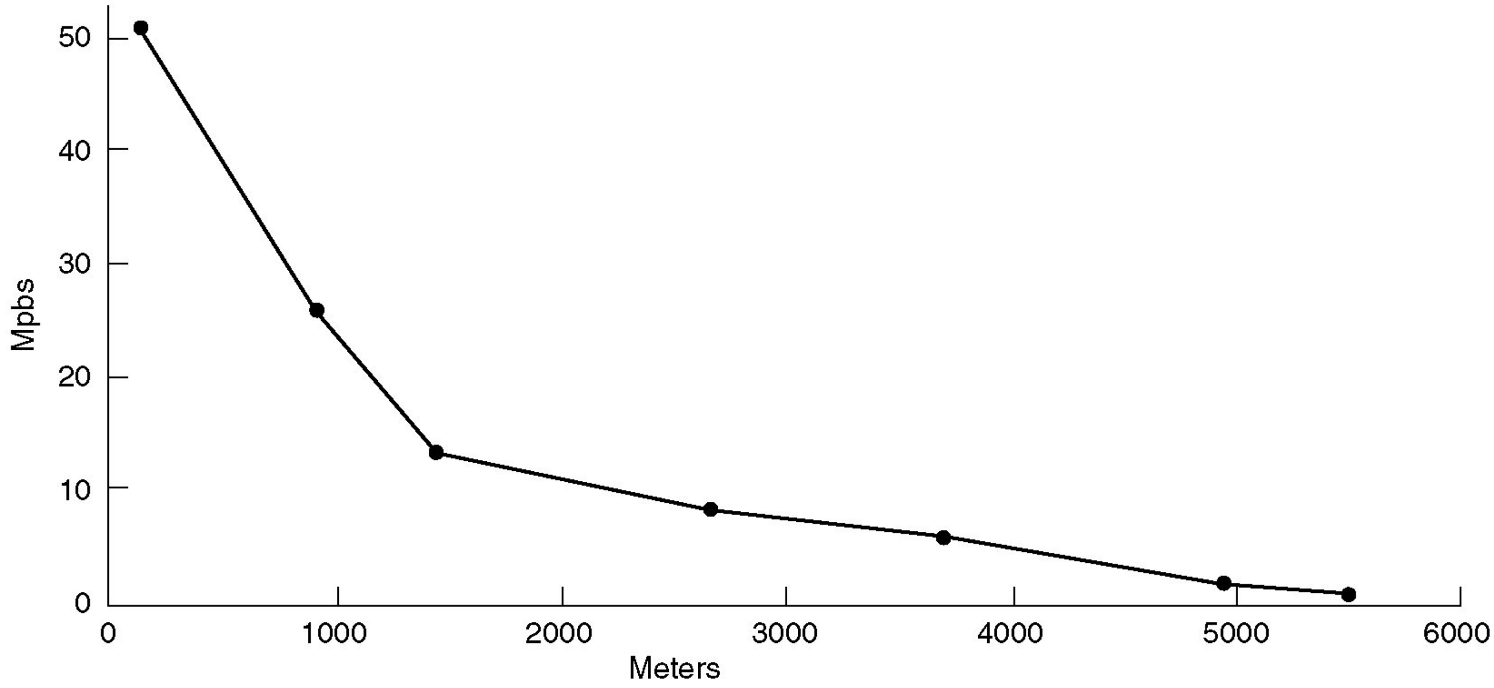
- A device that converts between a stream of digital bits and an analog signal that represents the bit is called modem.
- Modems comes in many varieties:
  - Telephone modems
  - DSL modems
  - Cable Modems
  - Wireless Modems
  - Etc.

Telephone Modems



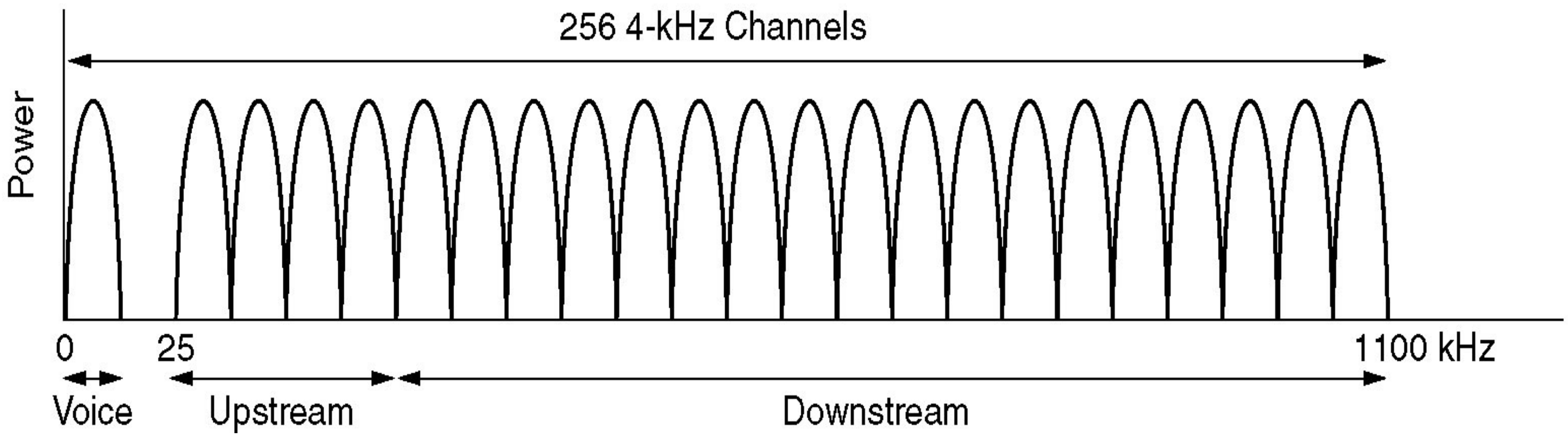
Use of both analog and digital transmission for computer -to-computer call. Conversion done by modems and codecs.

Digital Subscriber Lines



Bandwidth versus distanced over category 3 UTP for DSL.

ADSL (Asymmetric DSL)



Operation of ADSL using DMT(discrete multitone) modulation.

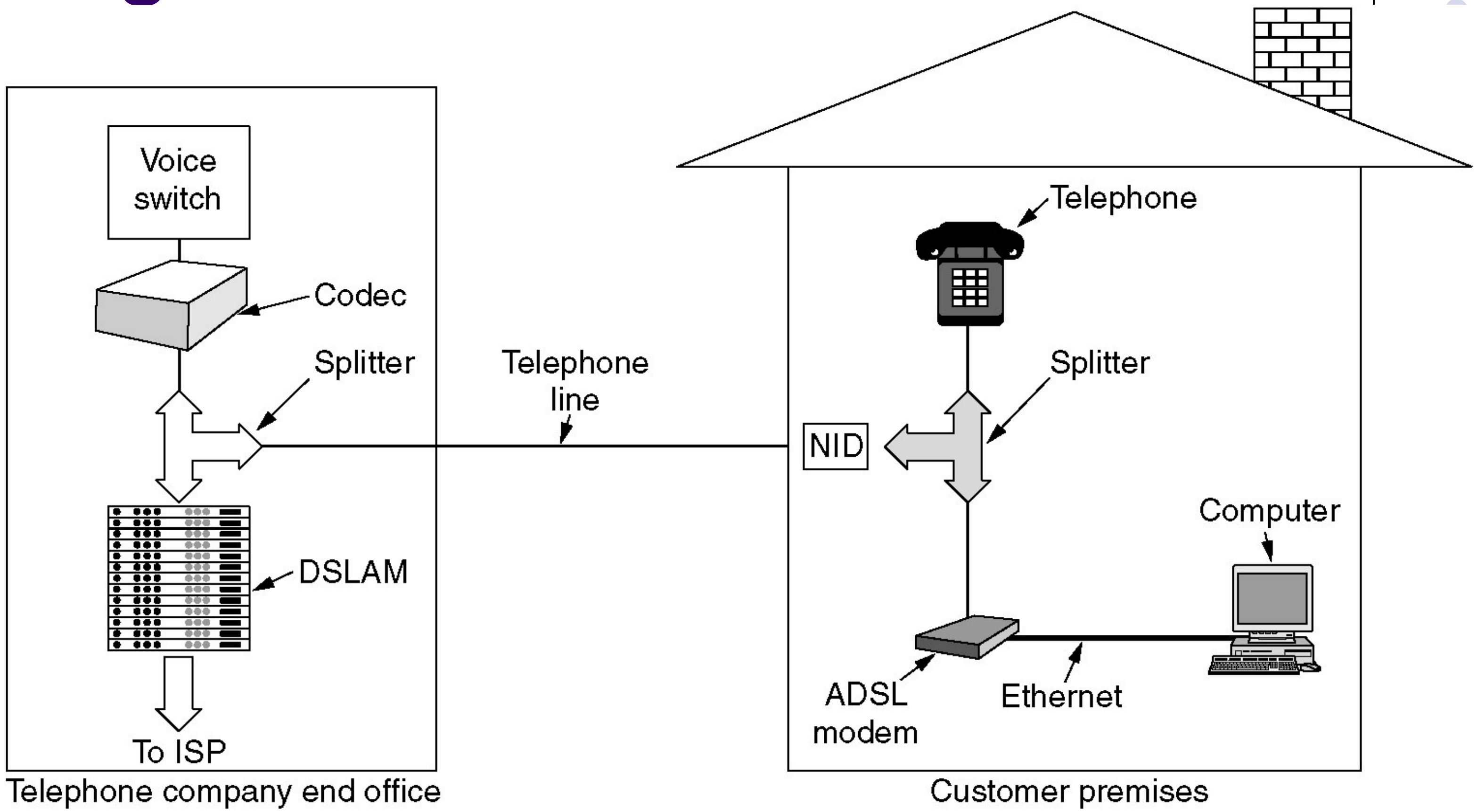
ADSL Standard

- ITU G.992.1(fullrate)

  ITU G.992.2 (G.lite)

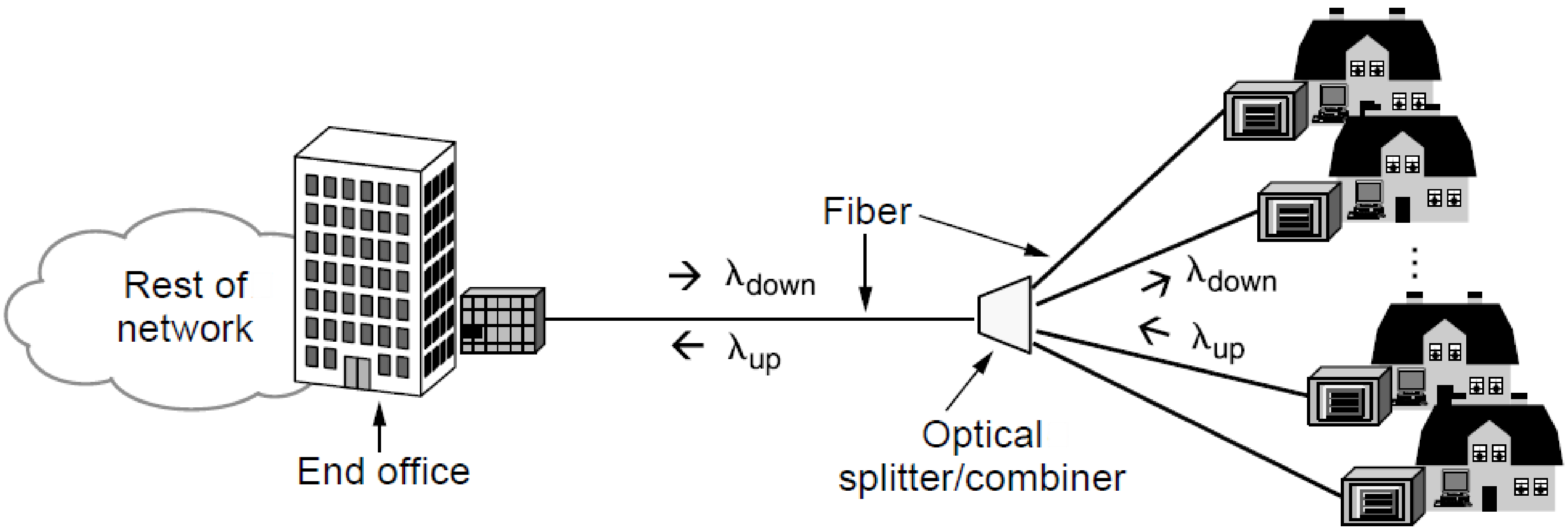
  - 8Mbps downstream, 1Mbps upstream
  - Practically, 512kbps down and 64kbps up
  - Using QAM modulation with each channel
  - Using TCM (Trellis Coded Modulation)

A typical ADSL equipment configuration.



NID (Network Interface Device)
DSLAM (Digital Subscriber Line Access Multiplexer)

FttH: Fiber to the Home

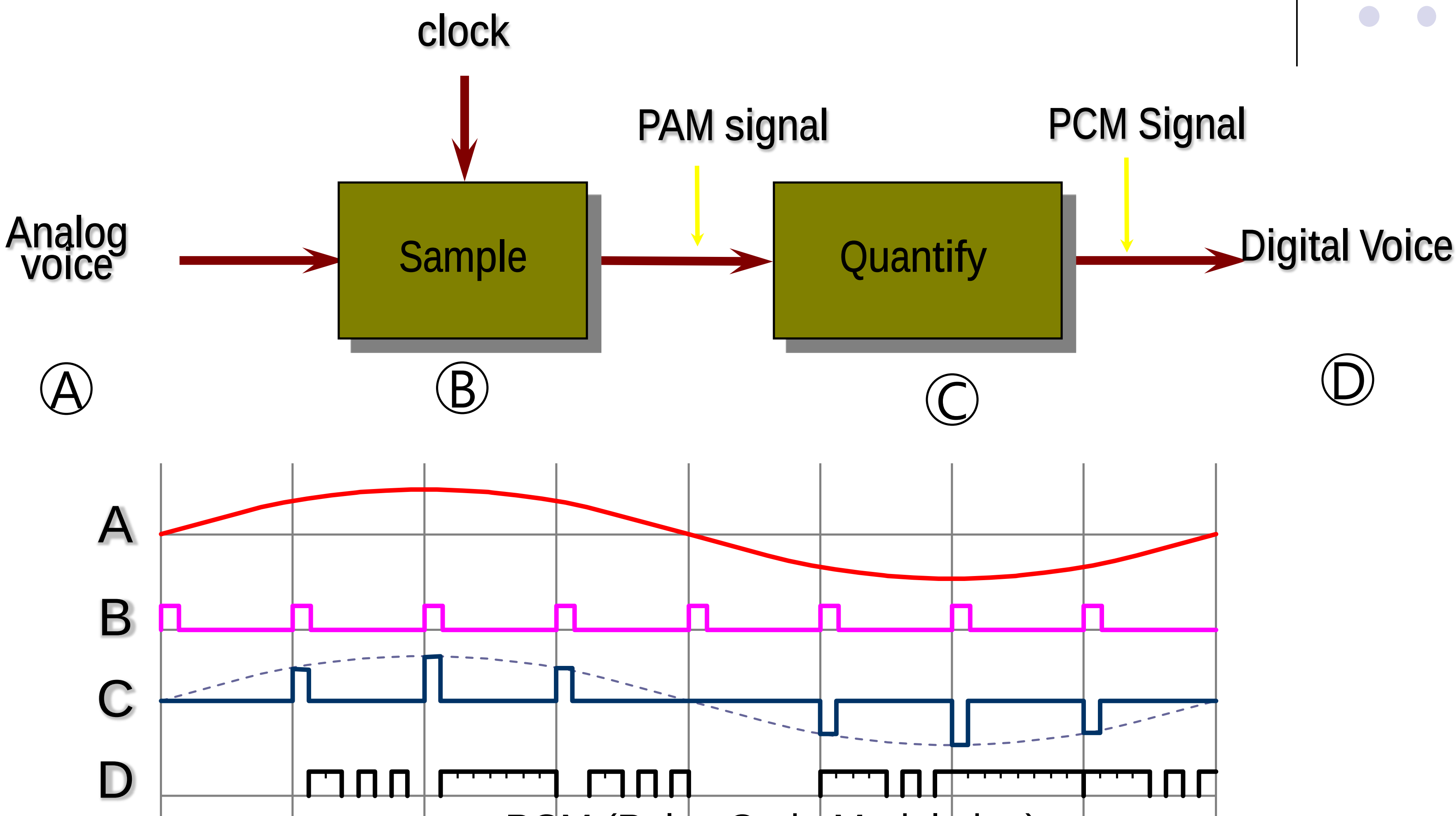


PON: Passive optical network for Fiber To The Home.

Trunks and Multiplexing

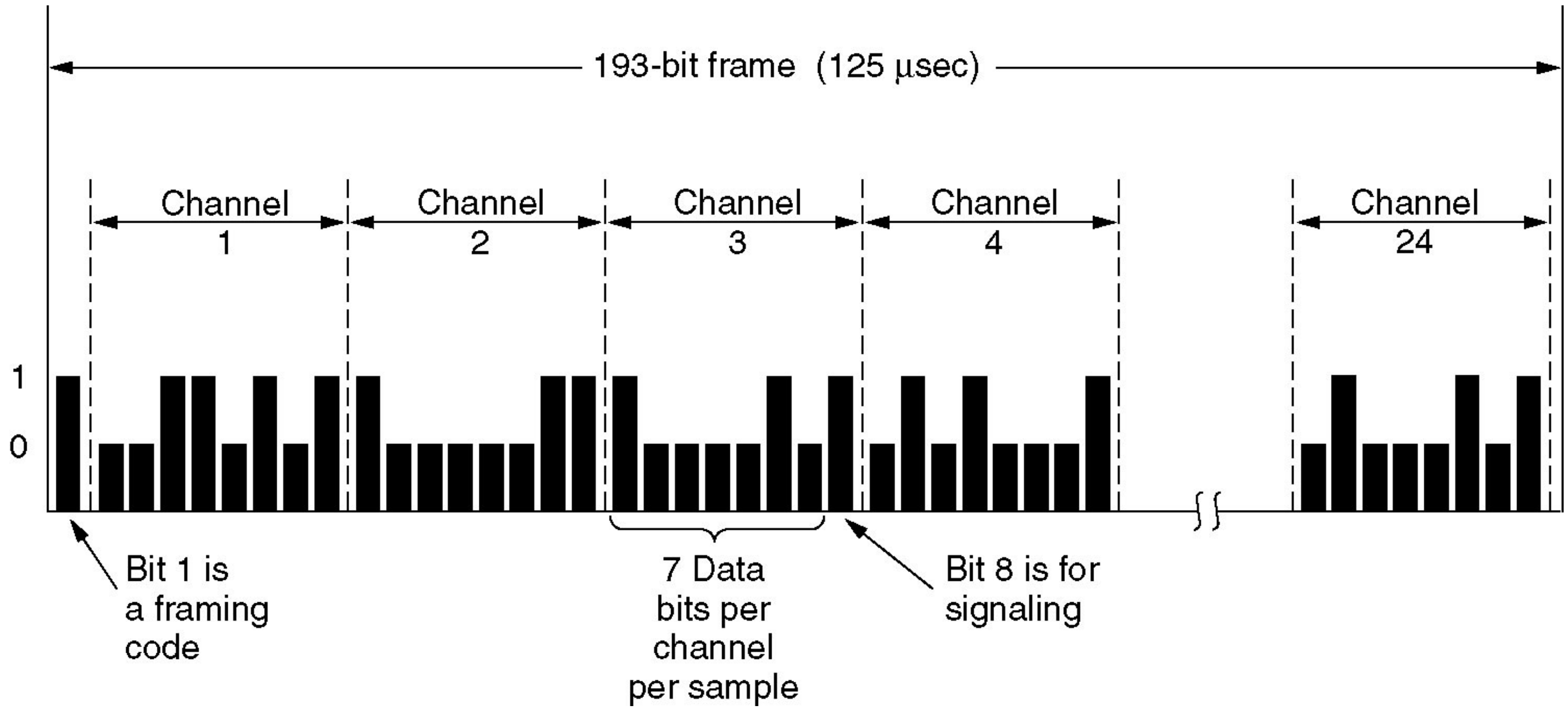
- Trunks in the core of the telephone network
  - Carries digital information, not analog voice
  - The trunks carry millions of calls simultaneously.
- This sharing trunk is important for achieving economies of scale.
- It is accomplished with versions of TDM and FDM multiplexing.

What is Digital Voice: PCM Signal



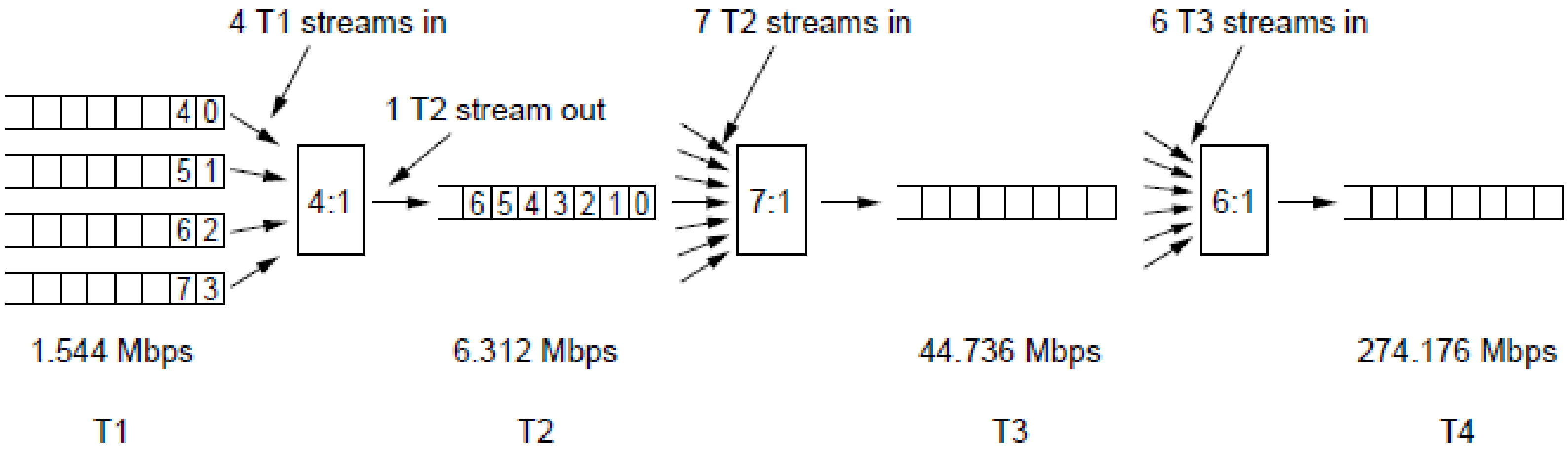
PCM (Pulse Code Modulation)

Time Division Multiplexing



The T1 carrier (1.544 Mbps).

Higher carriers



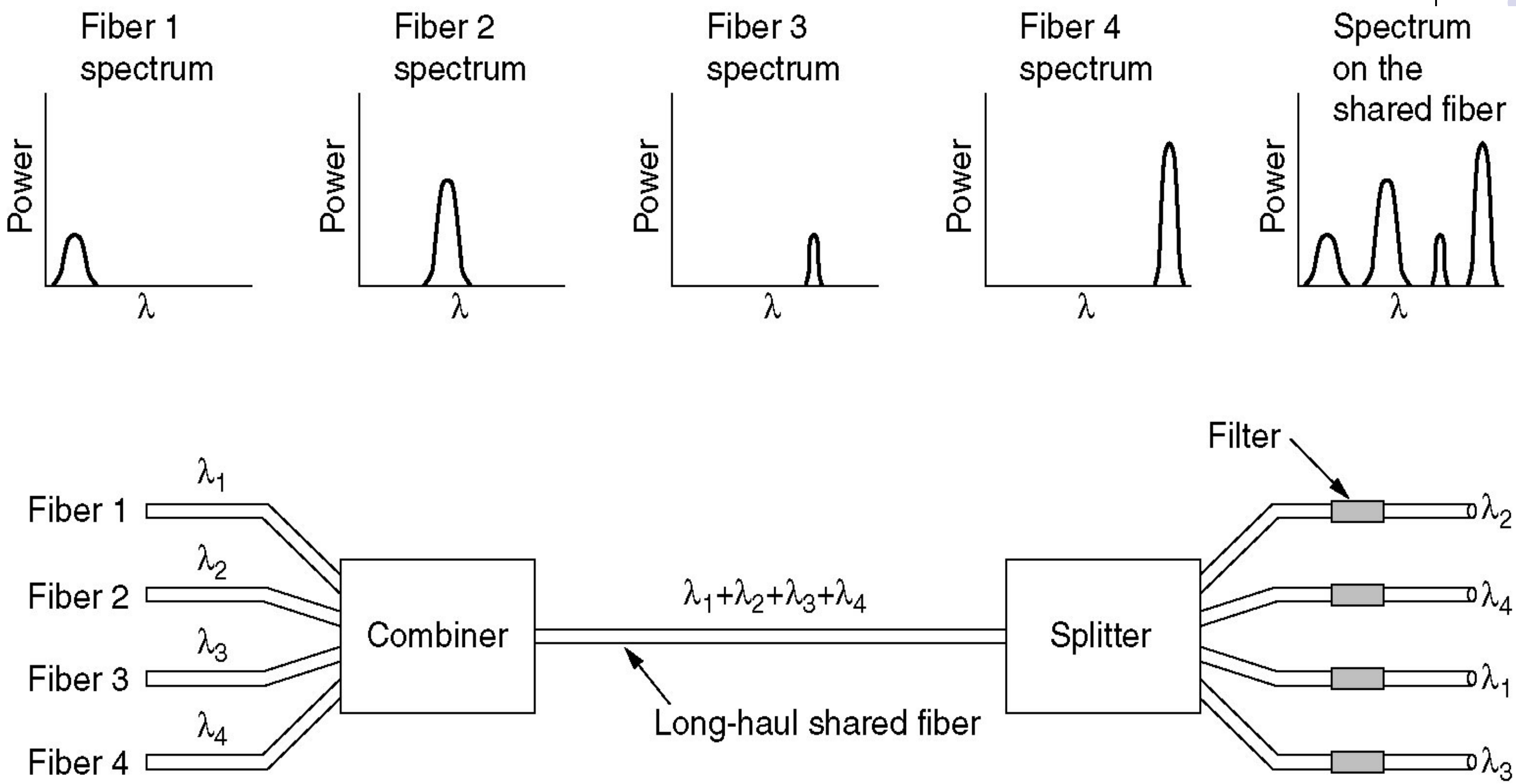
Multiplexing T1 streams into higher carriers

SONET / SDH

- **SONET (Synchronous Optical Network).**
  - Most long distance traffic in the US uses **SONET**. **SONET** is TDM - uses a highly accurate master clock. Data is transmitted **SYNCHRONOUSLY.**
- **SDH (Synchronous Digital Hierarchy)**
  - CCITT standard : G.707, G.708, G.709

A SONET frame of 810 bytes is transmitted every 125 usec. Because it's Synchronous, the frame is sent whether there's data to be carried or not. Data rate is 51.84 Mbps. This basic channel is called STS-1. Multiple channels can be multiplexed to get higher bandwidth.

Wavelength Division Multiplexing



WDM(Wavelength division multiplexing)

Switching

- The phone system is divided into
  - Outside plant: local loops and trunks
  - Inside plant: switches
- Switching techniques
  - Circuit switching
    - The traditional telephone system
  - Packet switching
    - VoIP

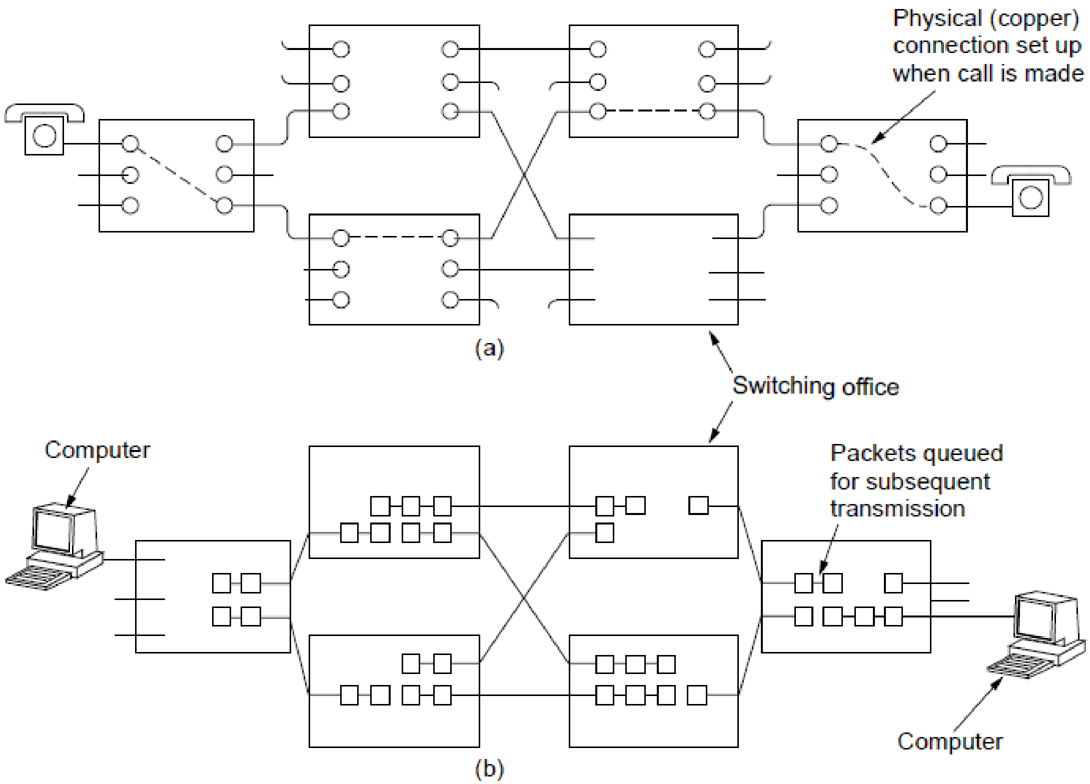
Circuit Switching

- Conceptually, when you place a phone call, the switching equipment within the telephone system seeks out a physical path all the way from your telephone to the receiver’s telephone. This technique is called **circuit switching**.
- An important property of circuit switching is the need to set up and end-to-end path ***before*** any data can be sent.

Packet Switching

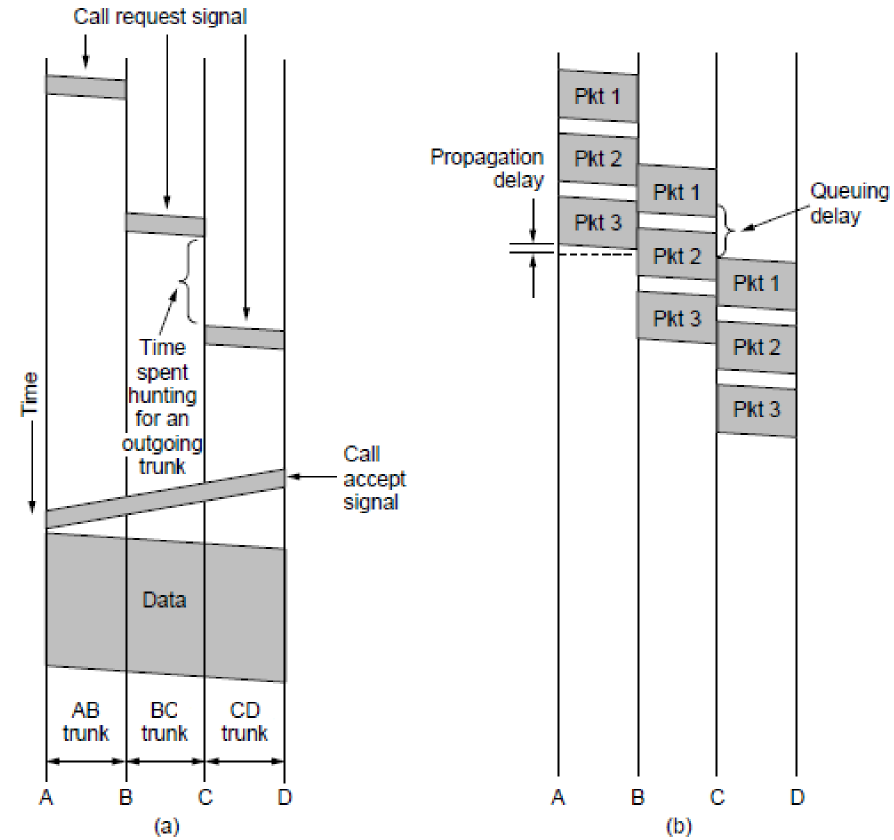
- With the packet switching technology, packets are sent as soon as they are available.
- There is no need to set up a dedicated path in advance. It is up to routers to use store-and-forward transmission to send each packet on its way to the destination on its own.

Circuit/Packet Switching



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

Timing events



Timing of events in (a) circuit switching, (b) packet switching

A comparison

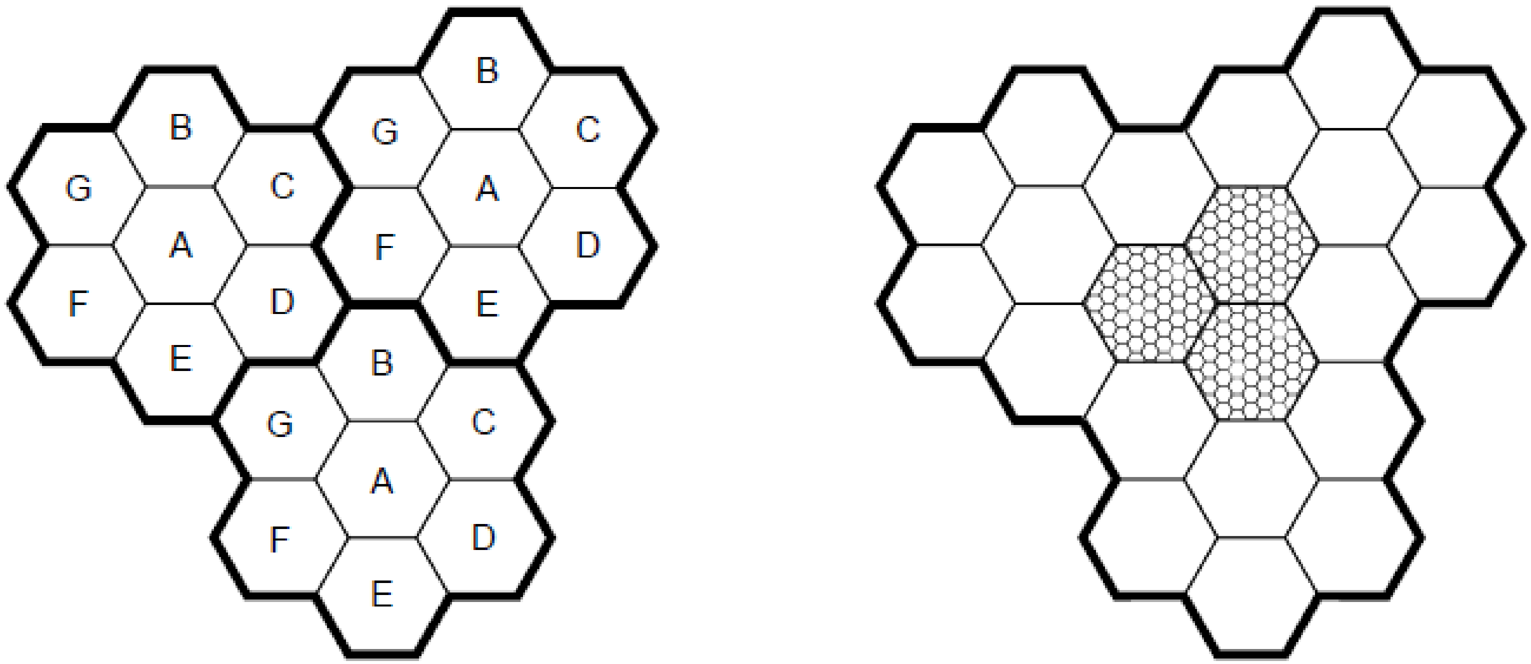
Item	Circuit switched	Packet switched
Call setup	Required	Not needed
Dedicated physical path	Yes	No
Each packet follows the same route	Yes	No
Packets arrive in order	Yes	No
Is a switch crash fatal	Yes	No
Bandwidth available	Fixed	Dynamic
Time of possible congestion	At setup time	On every packet
Potentially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

A comparison of circuit switched and packet-switched networks.

2.7 the mobile telephone system

- First-Generation (1G) Mobile Phones Analog Voice
- Second-Generation (2G) Mobile Phones Digital Voice
- Third-Generation (3G) Mobile Phones Digital Voice + Data

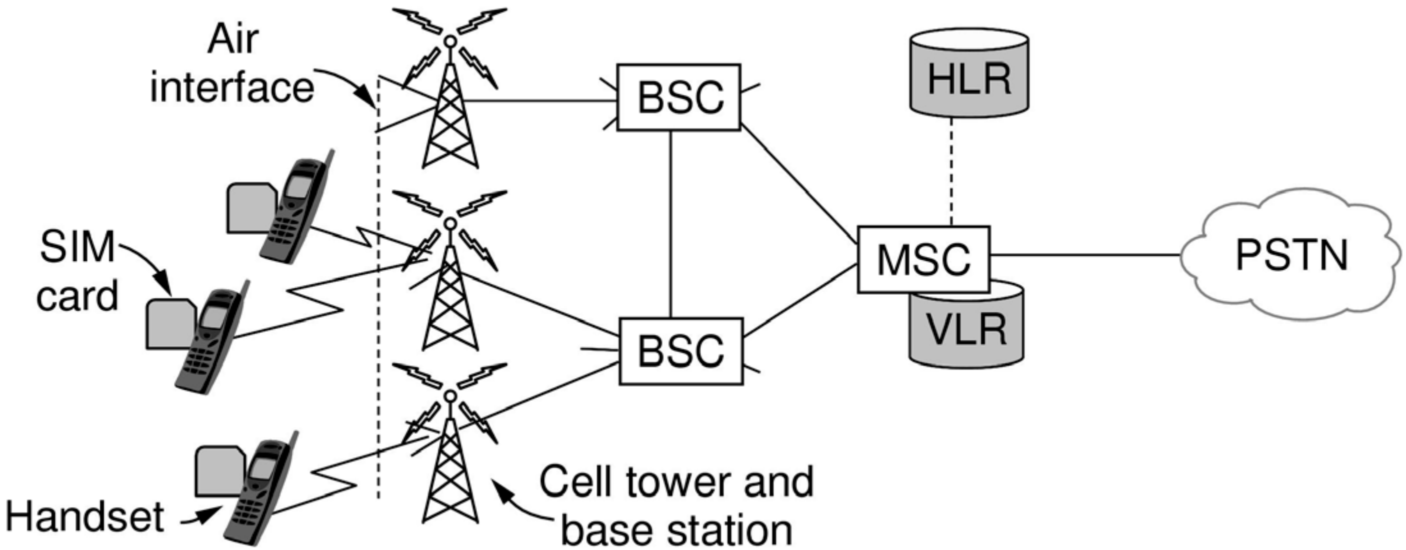
Advanced Mobile Phone System



(a) (b)

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

2G: Digital Voice



GSM mobile network architecture.

3G: Digital Voice and Data

- Basic services intend by IMT-2000 network
  - High-quality voice transmission.
  - Messaging (replacing email, fax, SMS, chat).
  - Multimedia (music, videos, films, television).
  - Internet access (Web surfing, incl. audio, video).
- IMT protocols
  - WCDMA (Wideband CDMA)
  - CDMA2000
  - TD-SCDMA (Time Division-Synchronous Code Division Multiple Access)

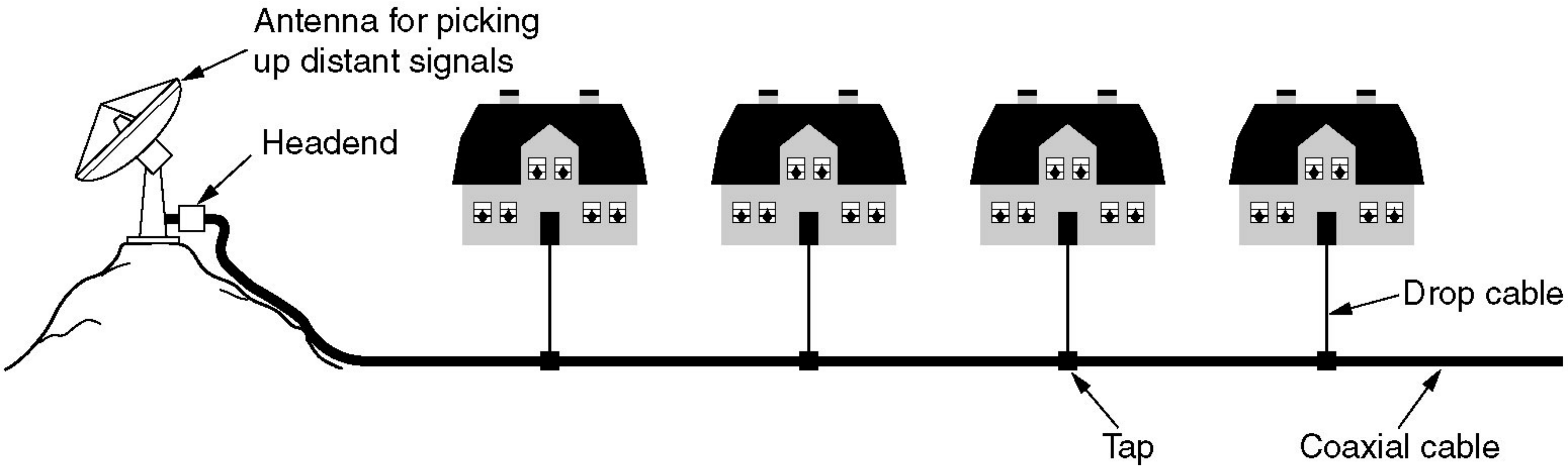
4G

- Proposed features
  - High bandwidth
  - Ubiquity (connectivity everywhere)
  - Seamless integration with other wired and wireless IP networks
  - Adaptive resource and spectrum management
  - High QoS for Multimedia
- Competitive protocols
  - LTE: Long Term Evolution
  - WiMAX: 802.16

2.8 Cable Television

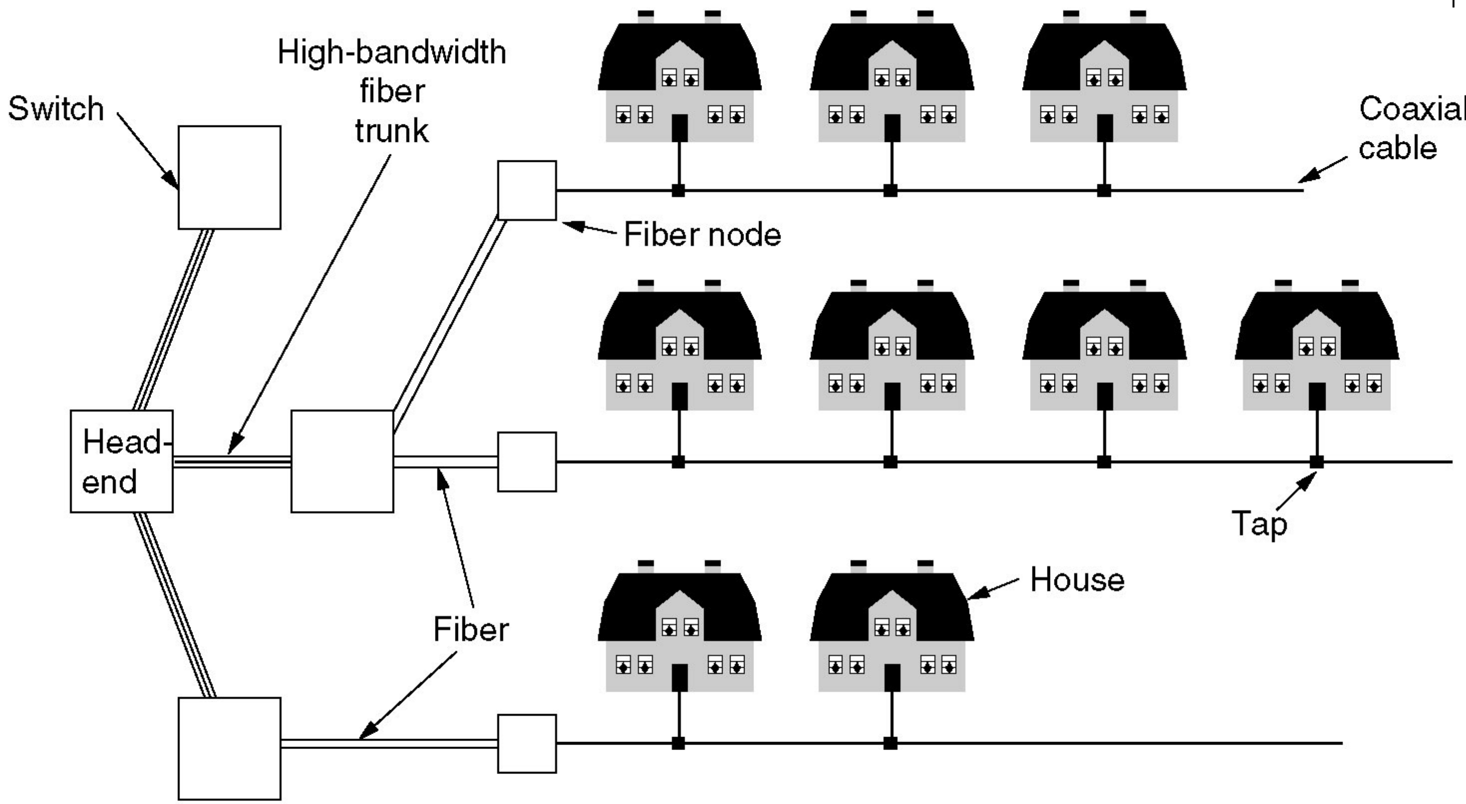
- Community Antenna Television
- Internet over Cable
- Spectrum Allocation
- Cable Modems

Community Antenna Television



An early cable television system.

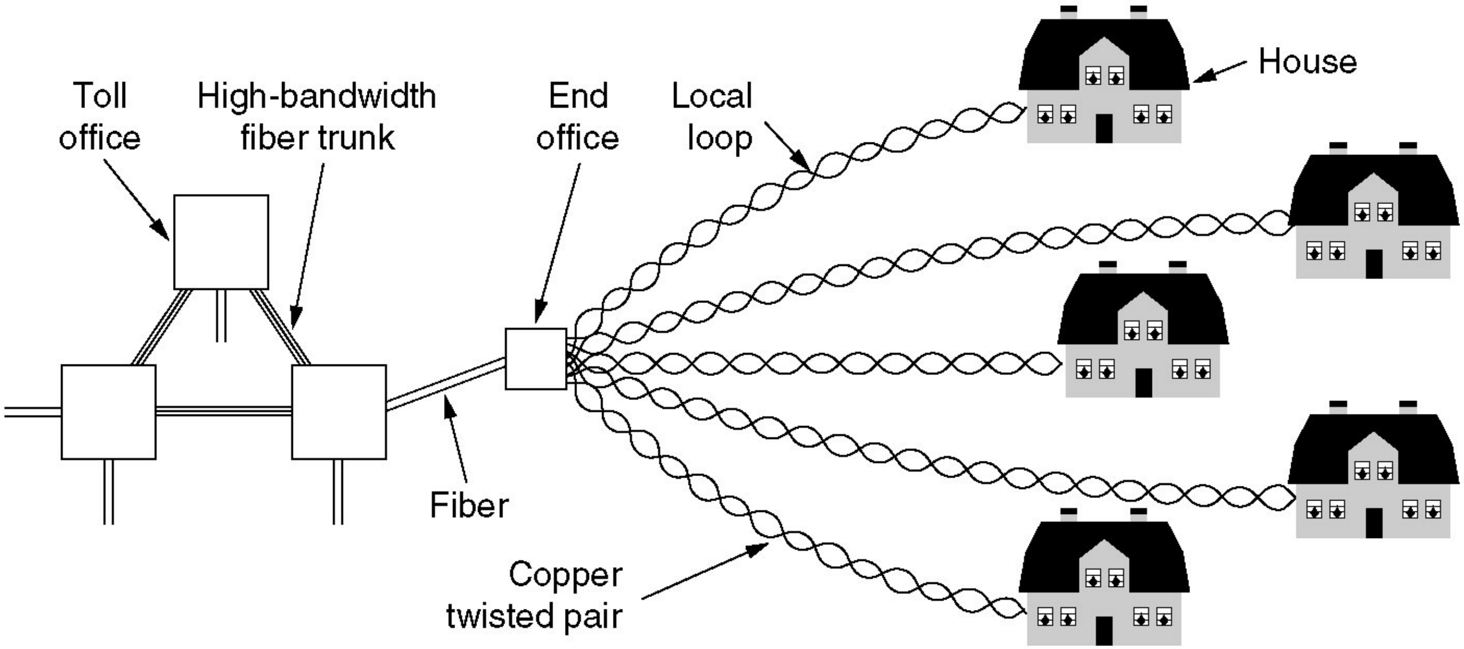
Internet over Cable



(a)

HFC (Hybrid Fiber Coax) Cable television

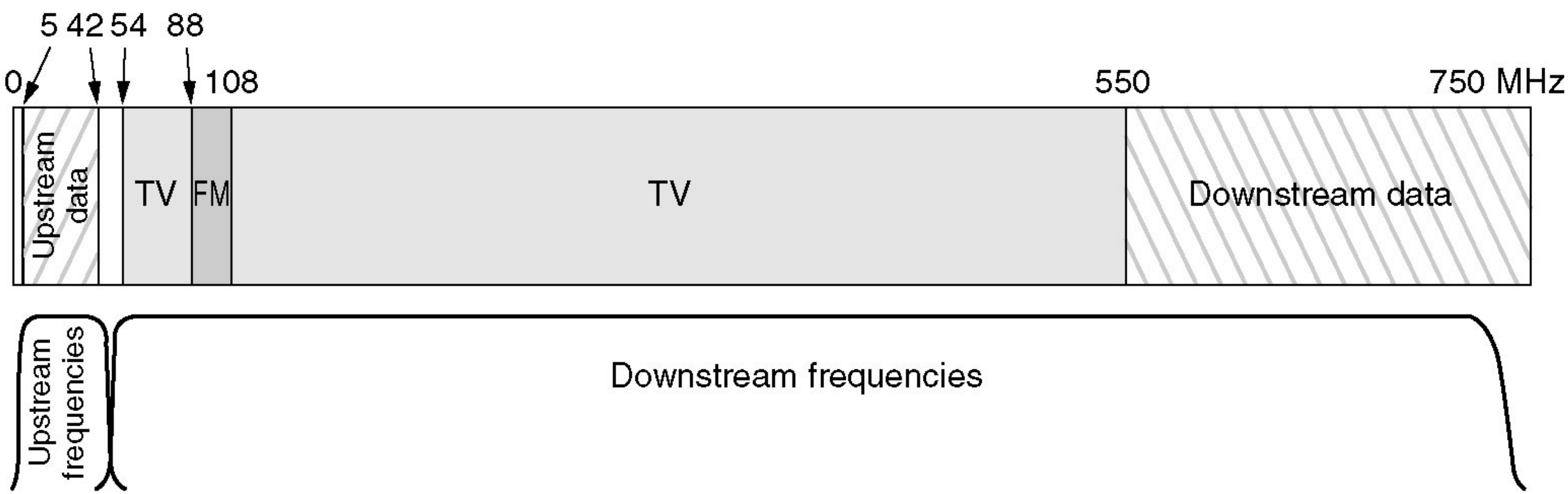
Internet over DSL



(b)

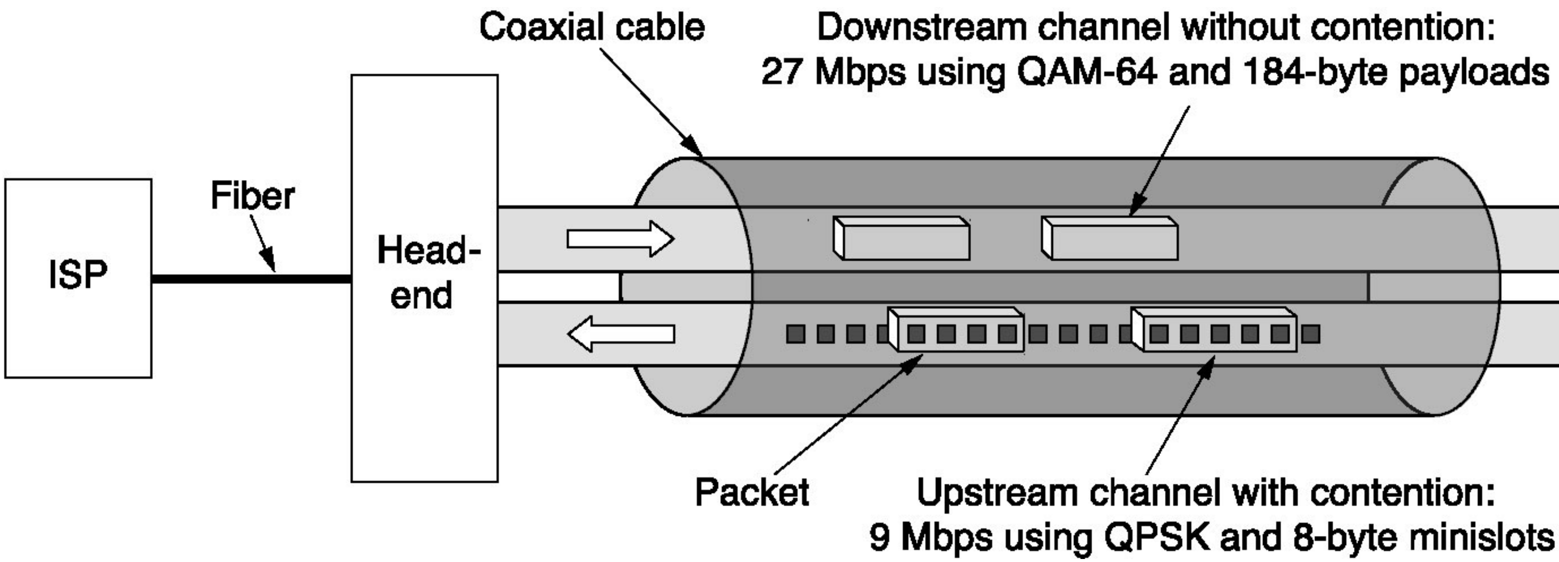
The fixed telephone system.

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.

DOCSIS (Data Over Cable Service Interface Specification)

END OF CH-2