Business Data Communications and Networking

11th Edition

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Chapter 3

Physical Layer

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Chapter 3 Outline

3.1 - Introduction

3.2 - Circuits

- **Configuration, Data Flow, Multiplexing (FDM, TDM, STDM, Inverse Mux, WDM), DSL**

3.3 - Communication Media

- **Guided and wireless media, media selection**

3.4 - Digital Transmission of Digital Data

- **Coding, Transmission Modes, Ethernet**

3.5 - Analog Transmission of Digital Data (D to A)

- **Modulation, Circuit Capacity, Modems**

3.6 - Digital Transmission of Analog Data (A to D)

- **Translating, Voice Data Transmission, Instant Messenger Transmitting Voice Data, VOIP**

3.7 – Implications for Management

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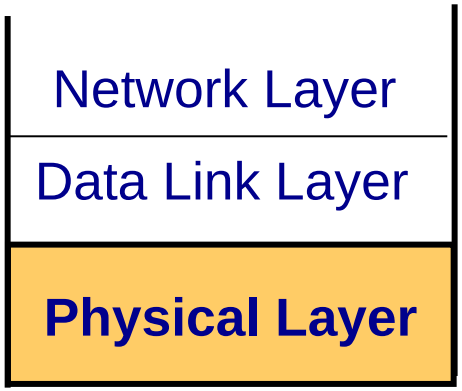
3.1 Introduction

- **Includes network hardware and circuits**
- **Network circuits:**
  - **physical media (e.g., cables) and**
  - **special purposes devices (e.g., routers and hubs).**
- **Types of Circuits**
  - **Physical circuits connect devices & include actual wires such as twisted pair wires**
  - **Logical circuits refer to the transmission characteristics of the circuit, such as a T-1 connection refers to 1.544 Mbps**
  - **Physical and logical circuits may be the same or different. For example, in multiplexing, one physical wire may carry several logical circuits.**



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Types of Connections

- **A T1 connection refers to a phone company cable which can carry a whole lot more data than the ordinary telephone wire. It was first developed by AT&T for Japan and North America in the late 1950s. It was meant to be a solution for digital transmission of voice data.**
- **A T1 speeds data through at a bruising 1.544 Mbps, which is 30 times faster than a 56 kbps dial up modem. T1 lines were initially all twisted copper pairs, and many still are. But the newer ones are increasingly all fiber optic cables.**
- **T-1 is a hardware specification for telecommunications trunking. A trunk is a single transmission channel between two points on the network: Each point is either a switching center or a node such as a telephone**
- **Initially, T-1 trunks were used only to connect major telephone exchanges, via the same twisted pair copper wire that the analog trunks used. If the exchanges were too far apart, a repeater boosted the signal.**

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Types of Connections

- **Before the digital T-1 system, trunks could only carry one telephone call at a time; each call was a voice-frequency analog signal.**
- **A T-1 trunk could transmit 24 telephone calls at a time, because it used a digital carrier signal called Digital Signal 1 (DS-1). ((a DS-1 is 24 DS-0s)) (((a DS-0 corresponds to 1 digital voice signal @ speed of 64kbps)))**
- **DS-1 is a communications protocol for multiplexing the bitstreams of up to 24 telephone calls,**
- **Throughout Europe and most of the rest of the world there is a comparable transmission system called E-carrier, which is not directly compatible with T-carrier.**

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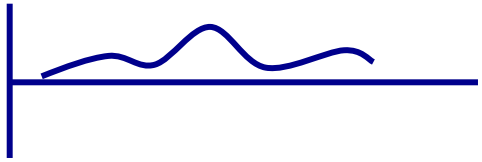
Types of Data Transmitted

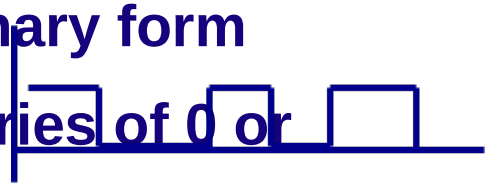
- **Analog data**



  - **Produced by telephones**
  - **Sound waves, which vary continuously over time, *analog*ous to one's voice**
  - **Analog Signals: An analog signal is a constant electrical signal sent through wires.**
  - **The signal is analogous to the original data it is copying (i.e., the sound or image), hence the name. It is a reliable technology, effective for decades and**
  - **applicable to televisions, sound systems, also to telephone lines.**

Types of Data Transmitted – cont

- **Digital data Produced by computers, in binary form**
- **Information is represented as code in a series of 0 or 1; All digital data is either on or off, 0 or 1**



- **Unlike analog signals, digital signals are not constant.**
- **Instead, they constitute a series of pulses, each the exact same amplitude and lasting the same length of time.**
- **The pulses thus create a binary code of 1s and 0s, similar to the way computers store data.**
- **They don't rise and fall the way analog signals do, and the pulses are cleaner.**

Types of Data Transmitted – cont

- **Analog transmissions**
  - **Analog data transmitted in analog form**
  - **Examples of analog data being sent using analog transmissions are broadcast TV and radio**
- **Digital transmissions**
  - **Made of discrete square waves with a clear beginning and ending**
  - **Computer networks send digital data using digital transmissions**
- **Data converted between analog and digital formats**
  - **Modem (modulator/demodulator): used when digital data is sent as an analog transmission**
  - **Codec (coder/decoder): used when analog data is sent via digital transmission**

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Types of Data Transmitted – cont

- **Short for MODulator/DEModulator, the first Modem was first released by AT&T in 1960 when it introduced its dataphone.**
- **The Modem is a hardware device that enables a computer to send and receive information over telephone lines by converting the digital data used by your computer into an analog signal used on phone lines and then converting it back once received on the other end.**



The picture is an example of an internal expansion card modem.

- **Modems are referred to as an asynchronous device, meaning that the device transmits data in an intermittent stream of small packets.**
- **Once received, the receiving system then takes the data in the packets and reassembles it into a form the computer can use.**

Below represents how an asynchronous transmission would be transmitted over a phone line. In asynchronous communication, 1 byte (8 bits) is transferred within 1 packet, which is equivalent to one character. However, for the computer to receive this information, each packet must contain a Start and a Stop bit; therefore, the complete packet would be 10 bits. The chart represents a transmission of the word HI, which is equivalent to 2 bytes (16 bits).

Stop 1 bit	Data 8 bits	Start 1 bit	Stop 1 bit	Data 8 bits	Start 1 bit
	Packet 10 bits			Packet 10 bits	

Types of Data Transmitted – cont

For visitors who did not grow up on a dial-up Modem or those of you who are nostalgic, click http://www.computerhope.com/jargon/m/modem.mp3 to hear a dial-up modem connecting to the Internet. In this audio file, you'll hear the modem dialing the phone number and then communicating with the other modem over the phone line. The squealing noise heard after the phone number, then the modem establishing a connection. Once the connection has been established the modem will go silent.

Types of Data Transmitted – cont

- **Codec (coder/decoder): used when analog data is sent via digital transmission**
- **A codec is a device or computer program capable of encoding or decoding a digital data stream or signal aka "compressor-decompressor".**
- **A codec encodes a data stream or signal for transmission, storage or encryption, or decodes it for playback or editing. Codecs are used in videoconferencing, streaming media and video editing applications.**
- **A video camera's analog-to-digital converter (ADC) converts its analog signals into digital signals, which are then passed through a video compressor for digital transmission or storage. A receiving device then runs the signal through a video decompressor, then a digital-to-analog converter (DAC) for analog display.**

Data Type vs. Transmission Type

	Analog Transmission	Digital Transmission
Analog Data	AM and FM Radio, Broadcast TV	Pulse code modulation, MP3, CDs, iPOD, cellphones, VoIP
Digital Data	Dial up modem sending email from your house	Codes such as ASCII run over Ethernet LANs

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Digital Transmission: Advantages

- **Produces fewer errors**
  - **Easier to detect and correct errors, since transmitted data is binary (1s and 0s, only two distinct values)**
  - **A weak square wave can easily be propagated again in perfect form, allowing more crisp transmission than analog**
- **Permits higher maximum transmission rates**
  - **e.g., Optical fiber designed for digital transmission**
- **More efficient**
  - **Possible to send more digital data through a given circuit**
- **More secure**
  - **Easier to encrypt digital bit stream**
- **Simpler to integrate voice, video and data**
  - **Easier mix and match V, V, D on the same circuit, since all signals made up of 0's and 1's**

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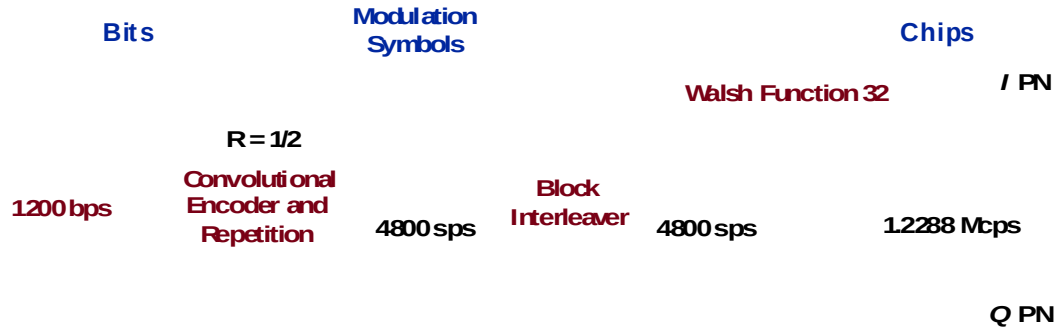
Example of error correction in digital transmission

Sync Channel Generation in IS-95



- There are 32 bits (1200 bps x 0.02666... second) in one Sync Channel frame
- The Rate 1/2 convolutional encoder doubles the bit rate, and the resulting 0s and 1s are now called “code symbols”
  - there are 64 code symbols in a Sync Channel frame
- The repetition process doubles the rate again, and each repetition of a code symbol is now called a “modulation symbol”
  - there are 128 modulation symbols in a Sync Channel frame
- Four copies of Walsh code #32 are used to spread each modulation symbol, resulting in a x256 rate increase; the resulting 0s and 1s are now called “ chips”
  - there are 32,768 chips in a Sync Channel frame (1024 chips per original bit)

Sync Channel Block Interleaver (Input Matrix)

1	9	17	25	33	41	49	57
1	9	17	25	33	41	49	57
2	10	18	26	34	42	50	58
2	10	18	26	34	42	50	58
3	11	19	27	35	43	51	59
3	11	19	27	35	43	51	59
4	12	20	28	36	44	52	60
4	12	20	28	36	44	52	60
5	13	21	29	37	45	53	61
5	13	21	29	37	45	53	61
6	14	22	30	38	46	54	62
6	14	22	30	38	46	54	62
7	15	23	31	39	47	55	63
7	15	23	31	39	47	55	63
8	16	24	32	40	48	56	64
8	16	24	32	40	48	56	64

Sync Channel Block Interleaver (Output Matrix)

assume that a burst of noise affects these symbols

1	3	2	4	1	3	2	4
33	35	34	36	33	35	34	36
17	19	18	20	17	19	18	20
49	51	50	52	49	51	50	52
9	11	10	12	9	11	10	12
41	43	42	44	41	43	42	44
25	27	26	28	25	27	26	28
57	59	58	60	57	59	58	60
5	7	6	8	5	7	6	8
37	39	38	40	37	39	38	40
21	23	22	24	21	23	22	24
53	55	54	56	53	55	54	56
13	15	14	16	13	15	14	16
45	47	46	48	45	47	46	48
29	31	30	32	29	31	30	32
61	63	62	64	61	63	62	64

Sync Channel Block Interleaver Restored

1	9	17	25	33	41	49	57
1	9	17	25	33	41	49	57
2	10	18	26	34	42	50	58
2	10	18	26	34	42	50	58
3	11	19	27	35	43	51	59
3	11	19	27	35	43	51	59
4	12	20	28	36	44	52	60
4	12	20	28	36	44	52	60
5	13	21	29	37	45	53	61
5	13	21	29	37	45	53	61
6	14	22	30	38	46	54	62
6	14	22	30	38	46	54	62
7	15	23	31	39	47	55	63
7	15	23	31	39	47	55	63
8	16	24	32	40	48	56	64
8	16	24	32	40	48	56	64

3.2 Circuits

- **Basic physical layout of the circuit**
- **Configuration types:**
  - **Point-to-Point Configuration**
    - **Goes from one point to another**
    - **Sometimes called “dedicated circuits”**
  - **Multipoint Configuration**
    - **Many computer connected on the same circuit**
    - **Sometimes called “shared circuit”**

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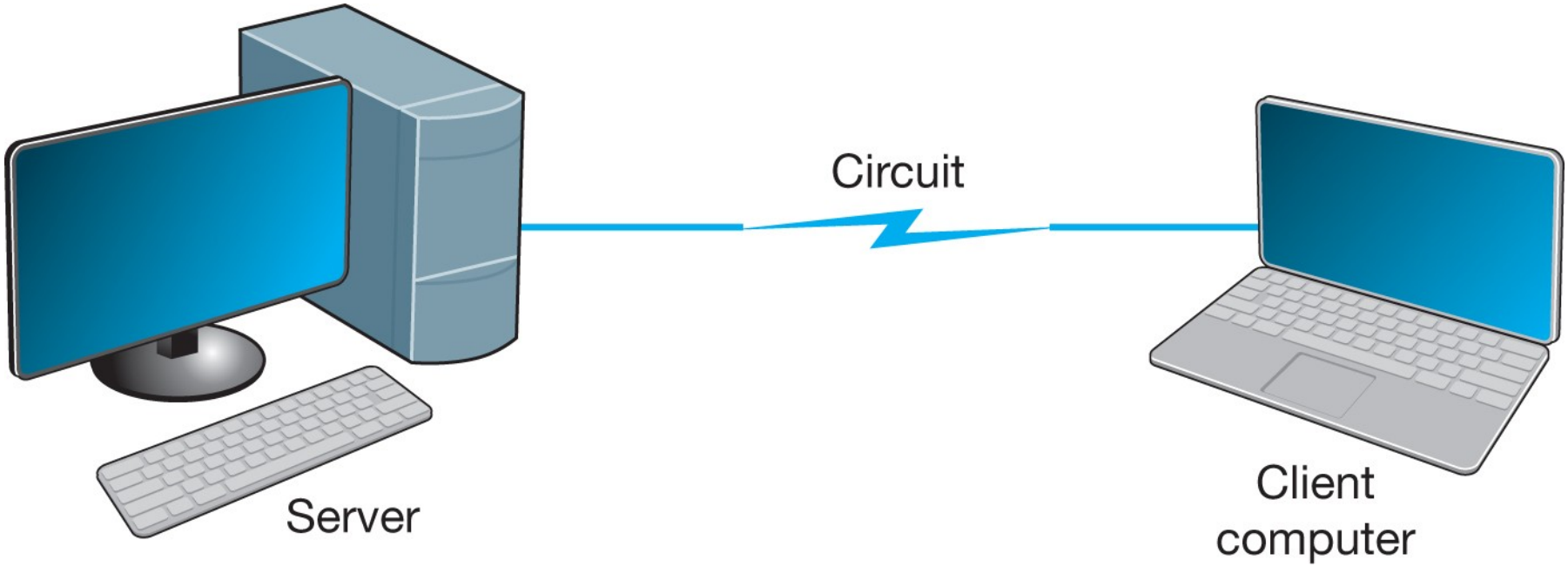
Point-to-Point Configuration



- **Used when computers generate enough data to fill the capacity of the circuit**
- **Each computer has its own circuit to reach the other computer in the network (expensive)**

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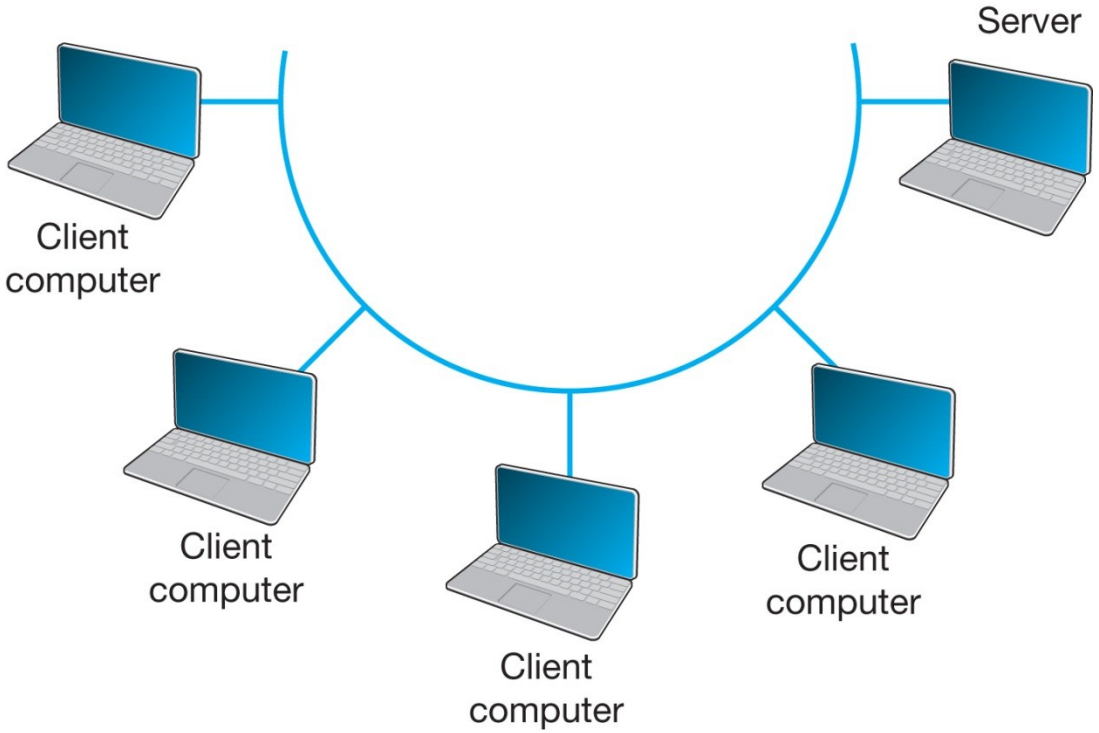
Multipoint Configuration

– **Used when each computer does not need to continuously use the entire capacity of the circuit**



+ Cheaper (not as many wires) and simpler to wire

- Only one computer can use the circuit at a time

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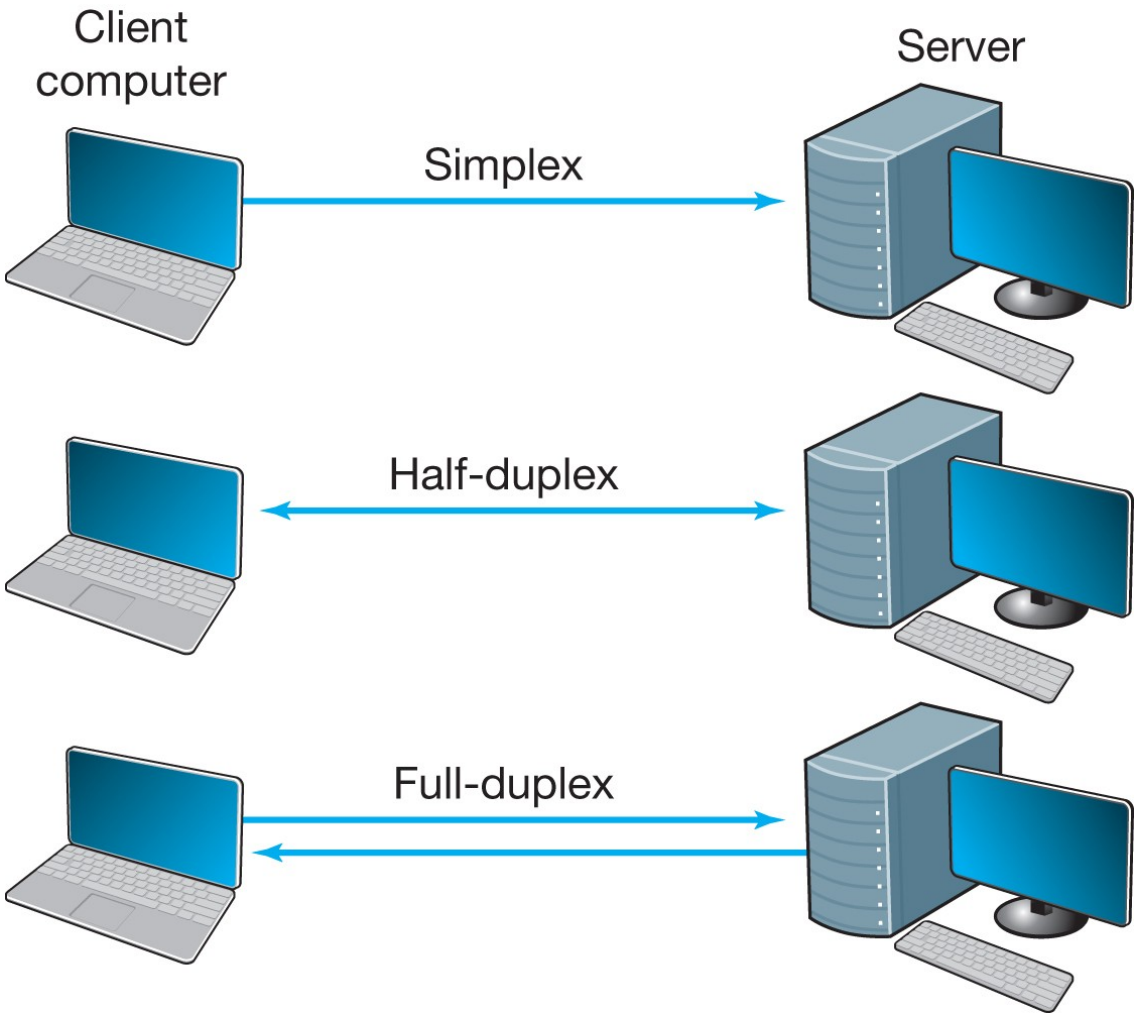
Data Flow (Transmission)



data flows in one direction only, (radio or cable television broadcasts)

data flows both ways, but only one direction at a time (e.g., CB radio, it requires control info)

data flows in both directions at the same time

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Selection of Data Flow Method

- **Main factor: Application**
  - **If data required to flow in one direction only**
    - **Simplex Method**
      - **e.g., From a remote sensor to a host computer**
  - **If data required to flow in both directions**
    - **Terminal-to-host communication (send and wait type communications)**
      - **Half-Duplex Method**
    - **Client-server; host-to-host communication (peer-to-peer communications)**
      - **Full Duplex Method**
    - **Half-duplex or Full Duplex**
- **Capacity may be a factor too**
  - **Full-duplex uses half of the capacity for each direction**

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Multiplexing

- **Breaking up a higher speed circuit into several slower (logical) circuits**
  - **Several devices can use it at the same time**
  - **Requires two multiplexer: one to combine; one to separate**
- **Main advantage: cost**
  - **Fewer network circuits needed**
- **Categories of multiplexing:**
  - **Frequency division multiplexing (FDM)**
  - **Time division multiplexing (TDM)**
  - **Statistical time division multiplexing (STDM)**
  - **Wavelength division multiplexing (WDM)**

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Note: difference between logical and physical channel:

- For example GSM uses a variety of *channels* in which the data is carried.
- In GSM, these channels are separated into *physical channels* and *logical channels*.
- The Physical channels are determined by the timeslot, whereas the logical channels are determined by the information carried within the physical channel.
- It can be further summarized by saying that several recurring timeslots on a carrier constitute a physical channel.
- These are then used by different logical channels to transfer information. These channels may either be used for user data (payload) or signaling to enable the system to operate correctly.

Physical Channels

- Associated with frequency bands, time slots, codes
- Physical channels transfer bits from one network element to another

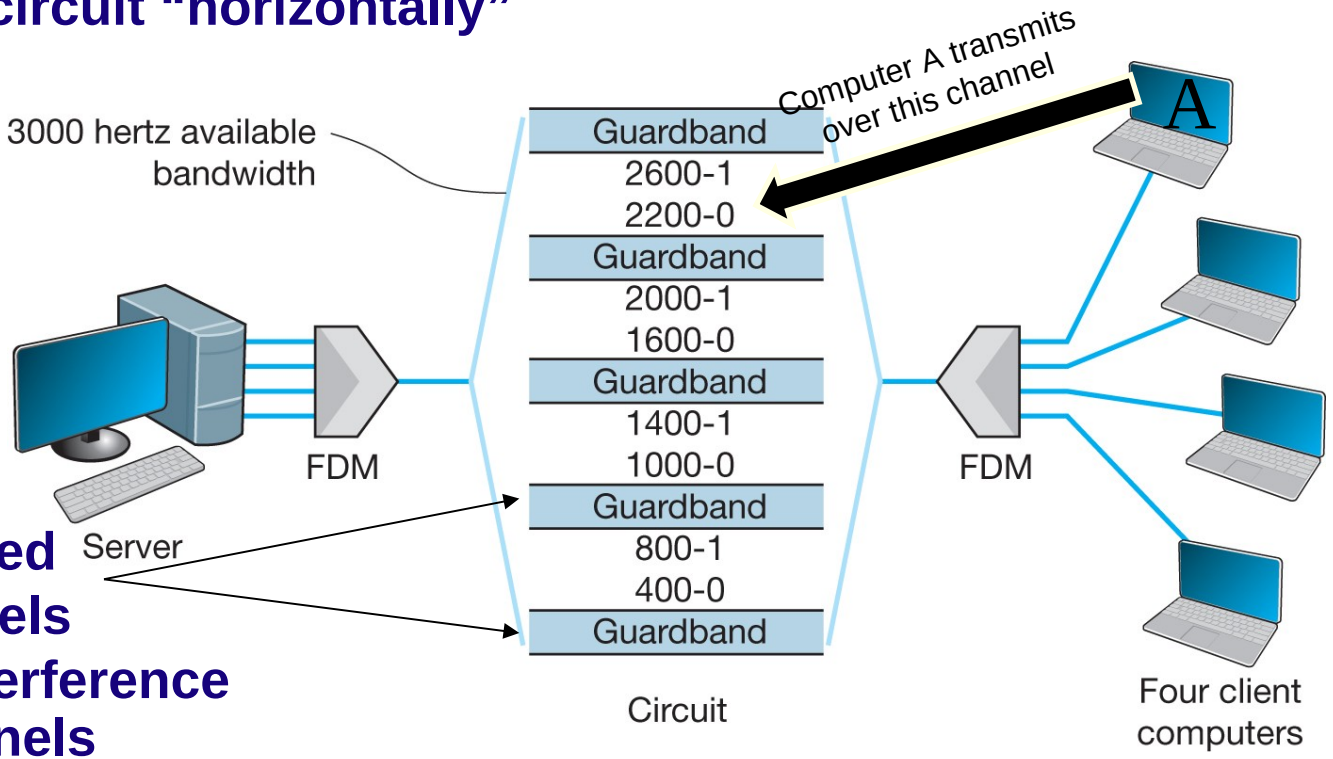
Logical Channels

Distinguished by the nature of carried information and the way to assemble bits into data units

Logical Channel Differs from that of the actual radio channel (or range of frequencies) on which the signal travels. In the case of Pay TV and other channel bundling systems they are merely a method of channel reassignment and/or rearrangement that suits whatever purpose the service operator has for their viewers. On nationally received broadcasts such as on satellite, a LCN can be used to assign the same number to multiple channels, such as when a provider wishes to have a single channel that has the same content but different regional advertising material.

Frequency Division Multiplexing

Makes a number of smaller channels from a larger frequency band by dividing the circuit "horizontally"



Guardbands needed to separate channels

- **To prevent interference between channels**
- **Unused frequency bands are wasted capacity (almost ½ in this example)**

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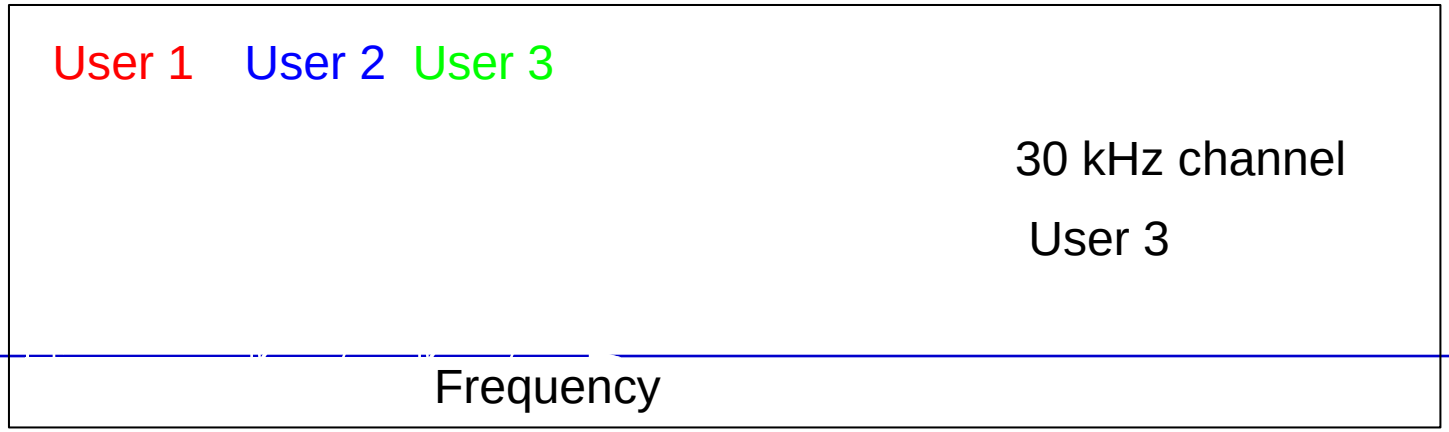
Frequency Division Multiple Access (FDMA)

Example of FDMA: AMPS access scheme, divides the frequency band into small "chunks" or channels. The width of these channels may vary from country to country, depending on their preference, but for Advanced Mobile Phone System (AMPS), a North American Standard, the channels are typically 30 kHz wide. Each FDMA user is assigned a channel on which they can make their calls.

FDMA technology is the first technology implemented for cellular applications and operated in the 800 MHz range. The AMPS standard is no longer the most widely used standard in North America. There are limitations to FDMA. Since only a limited frequency bandwidth exists for cellular use, the number of channels that can be allocated is limited. FDMA also limits the types of services offered.



Advanced Mobile Phone Service (AMPS)

Analog cellular standards: TIA/EIA-553, IS-88, IS-91

The first technology implemented for cellular (1983); Analog

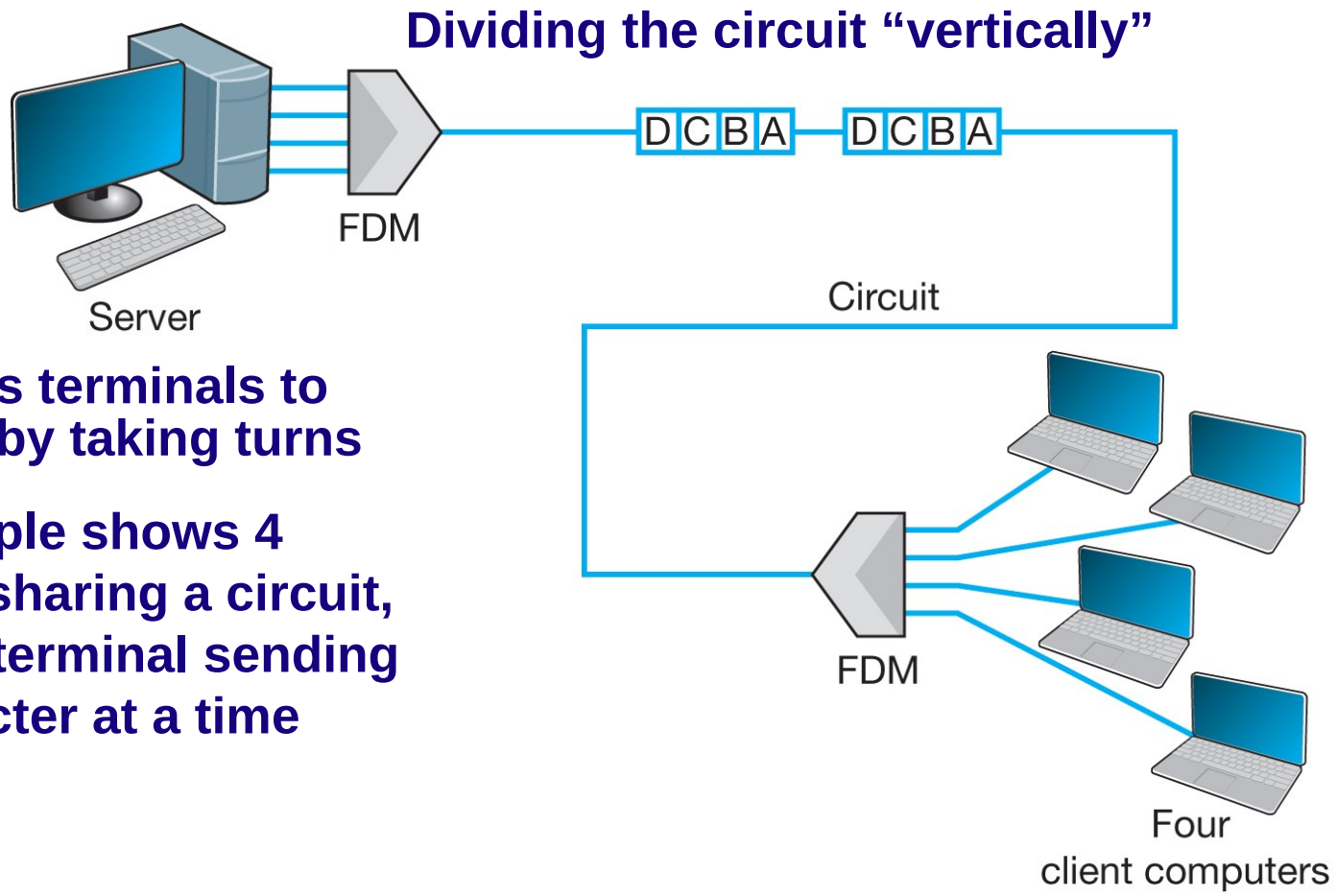
This is a narrowband technology. Therefore, each call must tune to the specific channel supporting the call...just like channels on a TV

A certain number of channels were allocated by FCC;

Only one call is carried on each channel

Capacity limitations of this standard become apparent in high traffic service areas such as Los Angeles and New York (using one call per channel, there's not enough spectrum available to serve everyone)

Time Division Multiplexing



- **TDM allows terminals to send data by taking turns**
- **This example shows 4 terminals sharing a circuit, with each terminal sending one character at a time**

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Statistical TDM (STDM)

- **Designed to make use of the idle time slots**
  - **In TDM, when terminals are not using the multiplexed circuit, timeslots for those terminals are idle**
- **Uses non-dedicated time slots**
  - **Time slots used as needed by the different terminals**
- **Complexities of STDM**
  - **Additional addressing information needed**
    - **Since source of a data sample is not identified by the time slot it occupies**
  - **Potential response time delays (when all terminals try to use the multiplexed circuit intensively)**
    - **Requires memory to store data (in case more data comes in than the outgoing circuit capacity can handle)**

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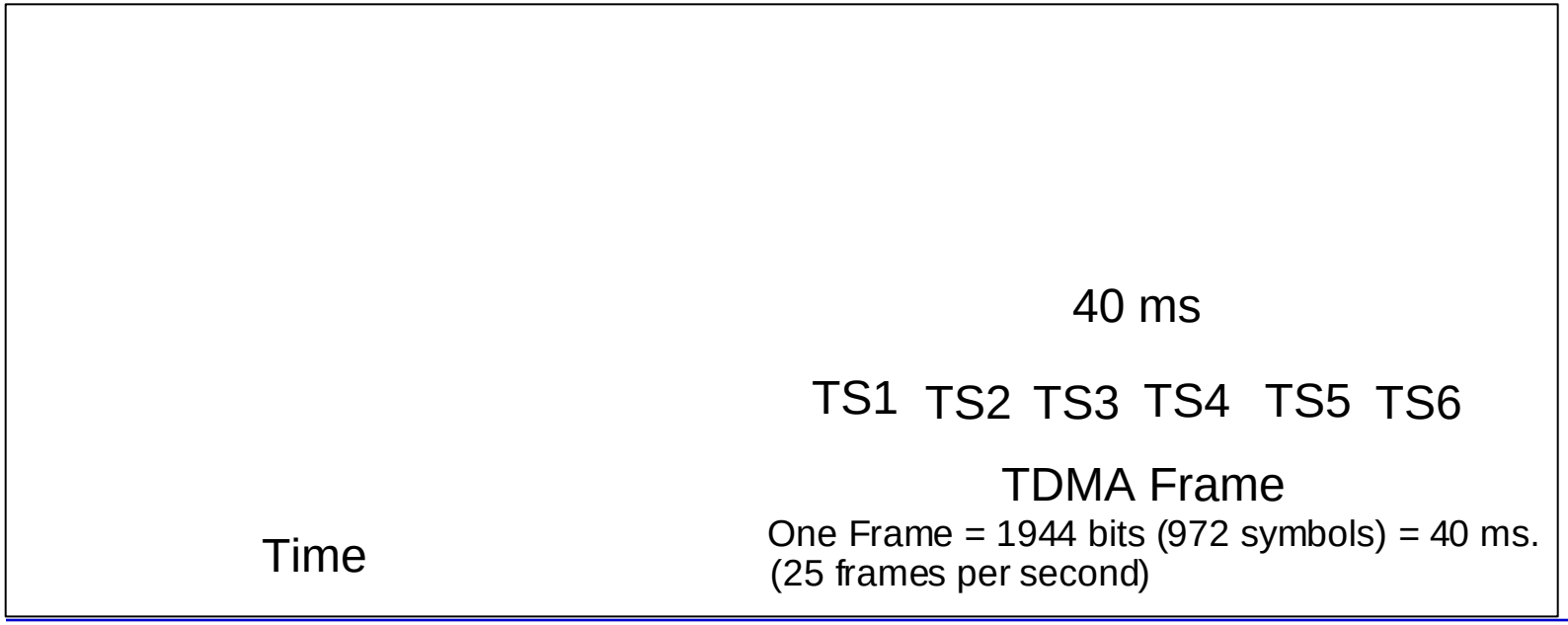
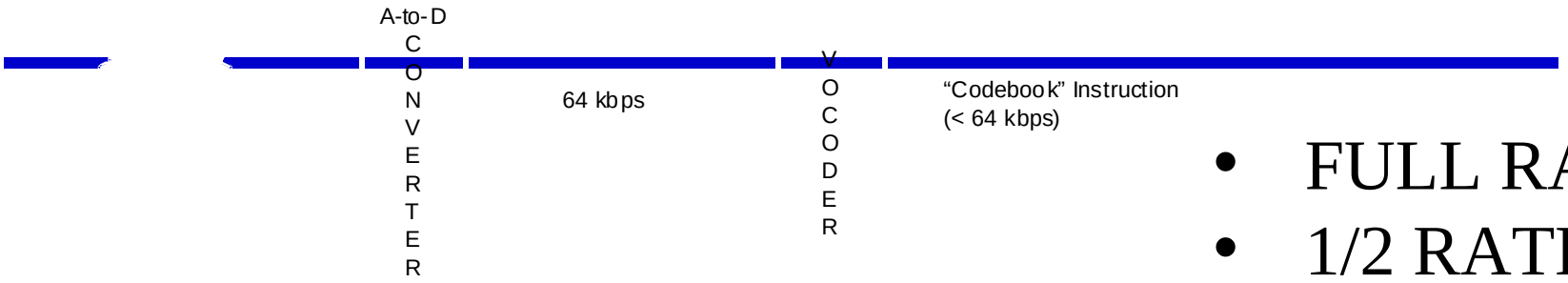
Time Division Multiple Access (TDMA)

TDMA is a digital technology that was first used in wireline telephone applications and has been modified for use in wireless networks. TDMA allows multiple users to time-share one RF channel. This is accomplished by reducing the bandwidth requirements of the digitized voice signal using digital voice coding (Vocoder). Combined with FDMA, the access method allows up to 3 users to timeshare each of the FDMA channels (full-rate TDMA). Each call uses the whole channel 1/3 of the time. TDMA divides each channel into timeslots and assigns each user two timeslots. The number of timeslots in each channel depends on the specific TDMA standard (GSM or IS-54, IS-136).



Variable Rate Vocoder



- FULL RATE
- 1/2 RATE
- ¼ RATE
- 1/8 RATE

- Speech coding algorithms (digital compression) are necessary to increase cellular system capacity
- Coding must also ensure reasonable fidelity, i.e., a minimum level of quality as perceived by the user
- Coding can be performed in a variety of ways (ex. waveform, time or frequency domain)
- Vocoders transmit parameters which control "reproduction" of voice instead of the explicit, point-by-point waveform description

Speech coding takes advantage of the fact that most typical voice conversations consist of better than 50% dead (or idle) time. Thus, it makes sense to compress voice traffic and send only intelligence, thereby increasing capacity. As shown later, CDMA also takes advantage of this to decrease the overall required user power.

The average "duty cycle" for each speaker in a conversation is estimated at about 35% to 40% of the time.

EXAMPLE: Me 20%, my sister 90%

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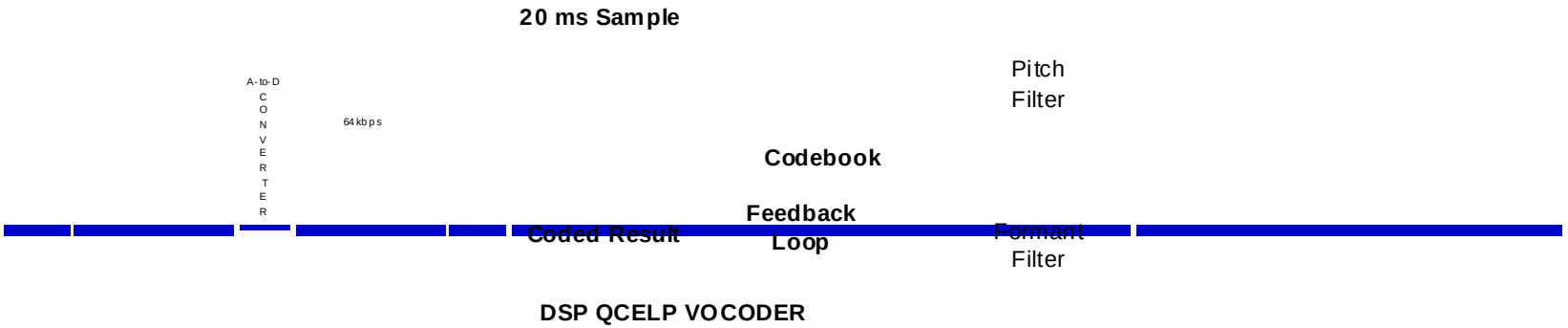

DSP QCELP VOCODER

- Performed by Digital Speech Processors (DSPs)
- TDMA uses VSELP encoding - fixed at 8 kbps rate
- CDMA uses QCELP - encoding a variable rate (adaptive threshold)
  - Ranges from 13 kbps to 1 kbps (averaging 4 kbps)
  - Takes advantages of natural pauses in speech
- Both VSELP & QCELP are *Hybrid* Coders which combine waveform matching & speech signal parameters

Simplified Vocoder Functions:

Codebook: stores a collection of arbitrary waveform segments (a sort of digitized vocal clip art collection) in digital form. Within the 20ms sample time, the vocoder -- through approximation based upon previous samples -- approximates as closely as possible a code representation of the sample signal.

Pitch Filter: can be thought of as modelling the periodic pulse train coming from the vocal cords during voiced speech.

Formant Filter: models the characteristics of the vocal tract. It has resonant frequencies near the resonant frequencies of the original speech caused by the vocal tract filtering.

Digital Signal Processors (DSPs): Special purpose microprocessors designed specifically for high-speed signal processing applications such as speech coding, signaling tone-generation and detection, and speech synthesis.

VSELP: Vector Sum Excited Linear Predictive encoding.

QCELP: Qualcomm Code Excited Linear Predictive encoding.

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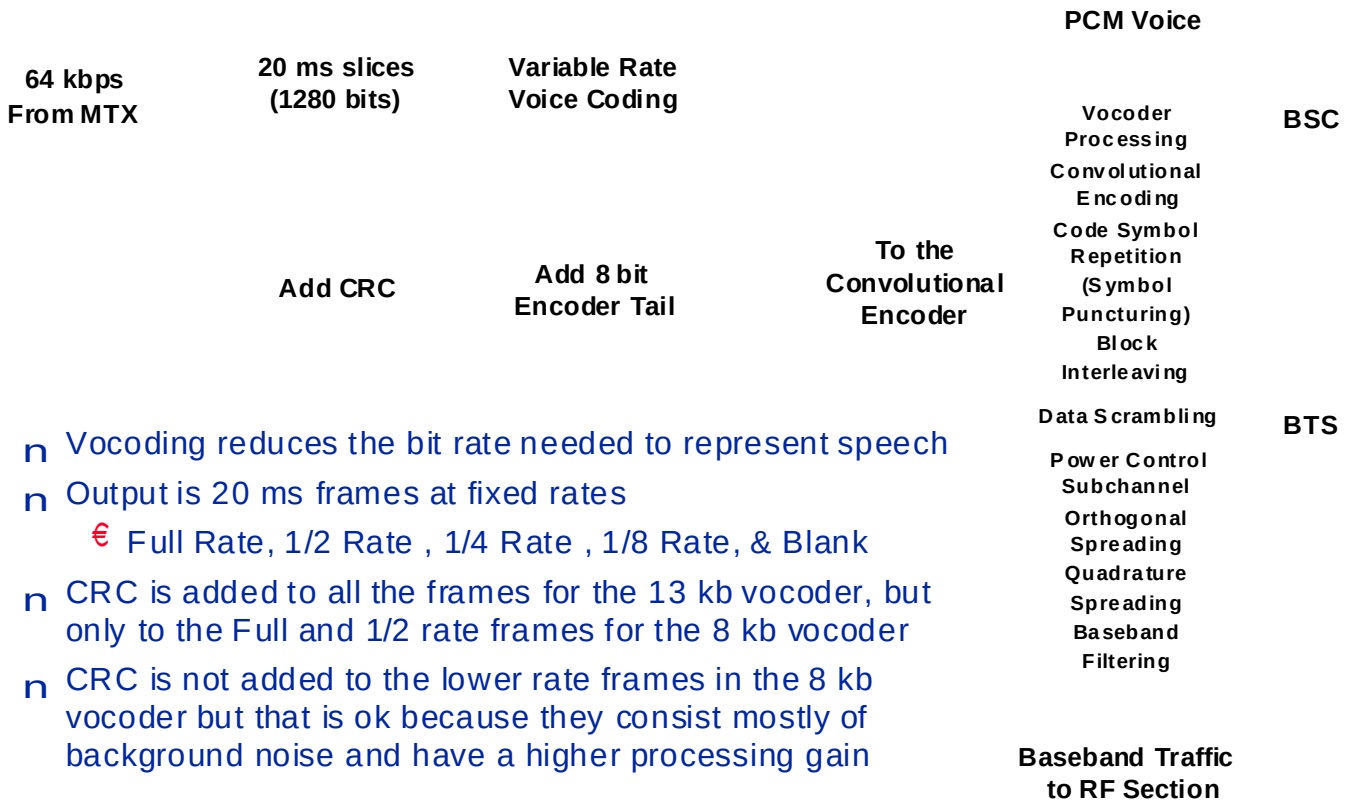
Example (where Vocoder situated)



- Vocoding reduces the bit rate needed to represent speech
- Output is 20 ms frames at fixed rates
  - Full Rate, 1/2 Rate , 1/4 Rate , 1/8 Rate, & Blank
- CRC is added to all the frames for the 13 kb vocoder, but only to the Full and 1/2 rate frames for the 8 kb vocoder
- CRC is not added to the lower rate frames in the 8 kb vocoder but that is ok because they consist mostly of background noise and have a higher processing gain

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TDMA Standards Compared

Various TDMA standards have been developed for different countries:

GSM - Global System for Mobile Communications. Europe/world.

PDC - Japanese Personal Digital Cellular.

IS-54, IS-136 - North America.

TDMA Standard	Channel Width (kHz)	Time slots
North American Digital Cellular (IS-54, IS-136)	**30**	**3**
Japanese Digital Cellular (PDC)	**25**	**3**
Global System for Mobile Communications (GSM)	**200**	**8**

TDMA is a narrowband technology. Therefore, as with AMPS, each call must tune to the specific channel supporting the call. However, since the channel is also multiplexed (in time) with other calls, the mobile must also “tune” to the specific time slot associated with the call.

Wavelength Division Multiplexing

- In fiber-optic communications, WDM is a technology that multiplexes a number of optical carrier signals onto a single optical fiber by using different wavelengths (i.e. colours) of laser light.
- This technique enables bidirectional communications over one strand of fiber, as well as multiplication of capacity.
- The term wavelength-division multiplexing is commonly applied to an optical carrier (which is typically described by its wavelength),
- A WDM system uses a multiplexer at the transmitter to join the signals together, and a demultiplexer at the receiver to split them apart.

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Wavelength Division Multiplexing

- **Transmitting data at many different frequencies**
  - **Lasers or LEDs used to transmit on optical fibers**
  - **Previously single frequency on single fiber (typical transmission rate being around 622 Mbps)**
  - **Now multi frequencies on single fiber → n x 622+ Mbps**



Nortel's WDM System

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Wavelength Division Multiplexing

- **Dense WDM (DWDM)**
  - **Over a hundred channels per fiber**
  - **Each transmitting at a rate of 10 Gbps**
  - **Aggregate data rates in the low terabit range (Tbps)**

Note: A tera per second (Tbit/s, or Tb/s) is a unit of data transfer rate equal to 1,000 gigabits per second .

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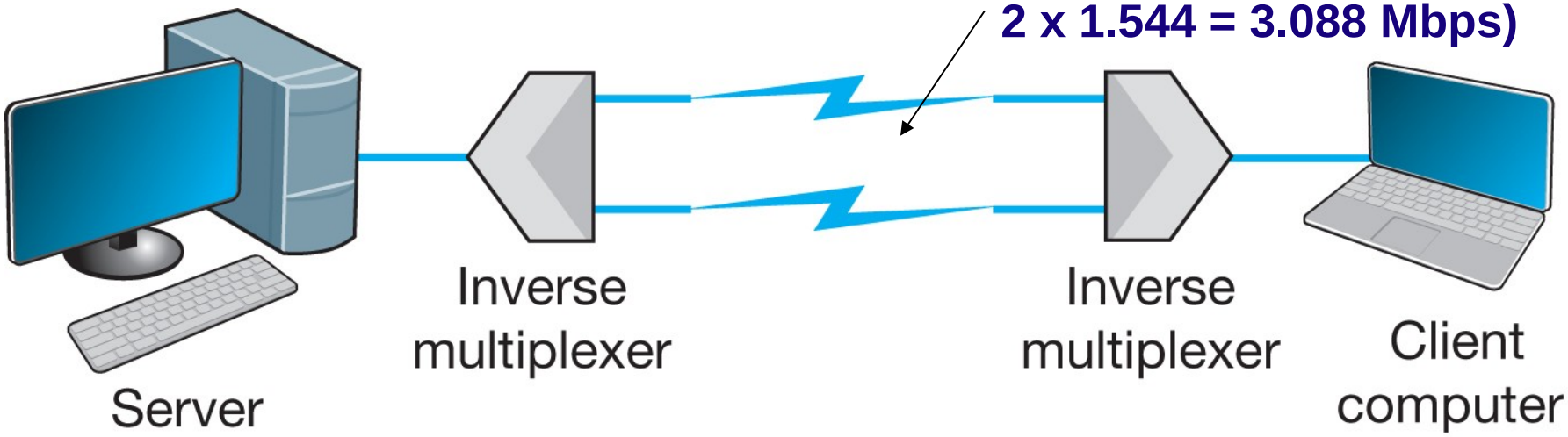
Inverse Multiplexing (IMUX)

Shares the load by sending data over two or more lines

e.g., two T-1 lines used (creating a combined multiplexed capacity of 2 x 1.544 = 3.088 Mbps)



- **"Bandwidth ON Demand Network Interoperability Group" (BONDING) standard**
- **Commonly used for videoconferencing applications**
- **Six 64 kbps lines can be combined to create an aggregate line of 384 kbps for transmitting video**

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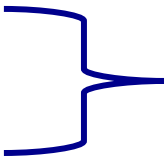
Digital Subscriber Line (DSL)

- **Became popular as a way to increase data rates in the local loop.**
  - **Uses full physical capacity of twisted pair (copper) phone lines (up to 1 MHz)**
- **Requires a pair of DSL modems One at the customer's site; one at the CO site**
- **1 MHz capacity split into (FDM):**
  - **a 4 KHz voice channel**
  - **an upstream channel**
  - **a downstream channel**



May be divided further (via TDM) to have one or more logical channels

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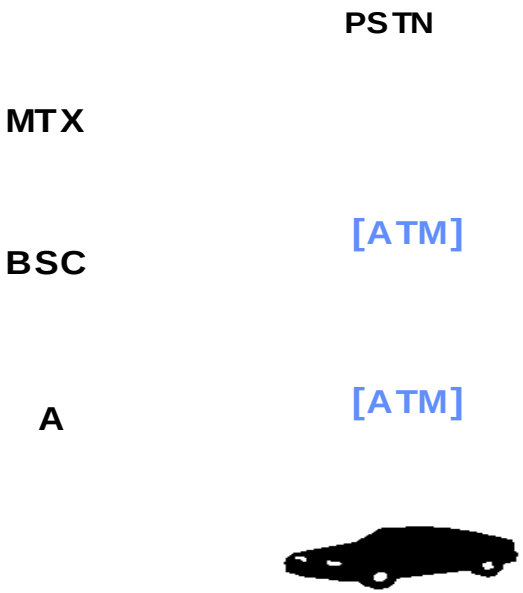
xDSL

- **Several versions of DSL**
  - **Depends on how the bandwidth is allocated between the upstream and downstream channels (A, H, etc)**
    - **(A) Asynchronous**
      - **Many DSL technologies implement an Asynchronous Transfer Mode (ATM) layer over the low-level bitstream layer to enable the adaptation of a number of different technologies over the same link.**
    - **(H) High speed**
      - **High-bit-rate digital subscriber line (HDSL) was the first DSL technology to use a higher frequency spectrum of copper, twisted pair cables. HDSL was developed in the US, as a better technology for high-speed, synchronous circuits typically used to interconnect local exchange carrier systems, and also to carry high-speed corporate data links and voice channels, using T1 lines.**

Example of usage of ATM in cellular network:CDMA to CDMA ie. Hard Handoff



- Between cells that could be on the same frequency and have the same frame alignment, but which are subordinated to different MTSOs
  - This type of hard handoff would become a soft handoff if the frames received at both cells could be delivered quickly to the same BSC for comparison, either by interconnecting both BSCs or both BTSs with an ATM link *(implementation would require HW & SW modifications)*

xDSL

- **G.Lite - a form of ADSL**
  - **Provides**
    - **a 4 Khz voice channel**
    - **384 kbps upstream**
    - **1.5 Mbps downstream**

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3.3 Communications Media

- **Physical matter that carries transmission**
- **Guided media:**
  - **Transmission flows along a physical guide (media guides the signal across the network)**
  - **Examples include twisted pair wiring, coaxial cable and fiber optic cable**
- **Wireless media (radiated media)**
  - **No wave guide, the transmission flows through the air or space**
  - **Examples include radio such as microwave and satellite**

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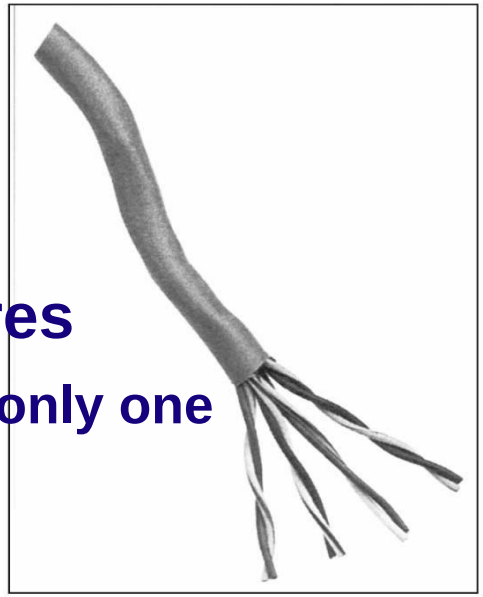
Twisted Pair (TP) Wires

- **Commonly used for telephones and LANs**
- **Reduced electromagnetic interference**
  - **Via twisting two wires together**

    (Usually several twists per inch)
- **TP cables have a number of pairs of wires**
  - **Telephone lines: two pairs (4 wires, usually only one pair is used by the telephone)**
  - **LAN cables: 4 pairs (8 wires)**
- **Also used in telephone trunk lines (up to several thousand pairs)**
- **Shielded twisted pair also exists, but is more expensive (ie. Coaxial cable)**



Courtesy South Hills Datacomm

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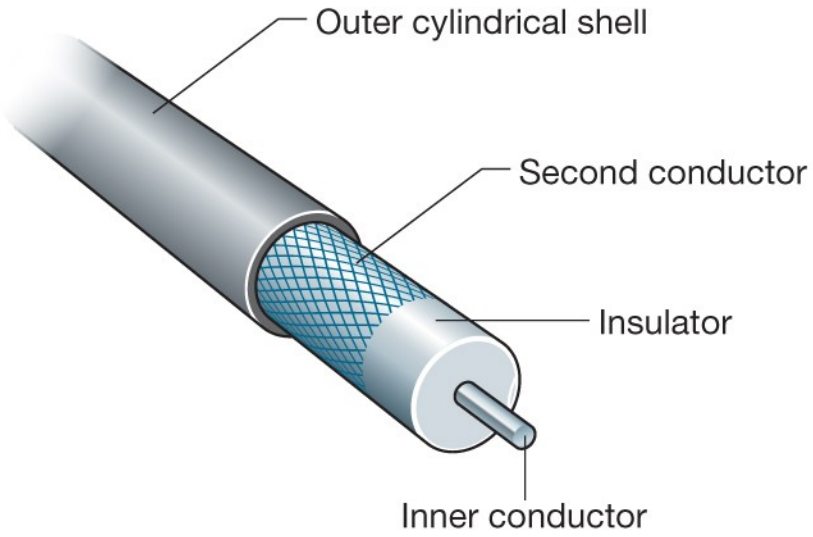
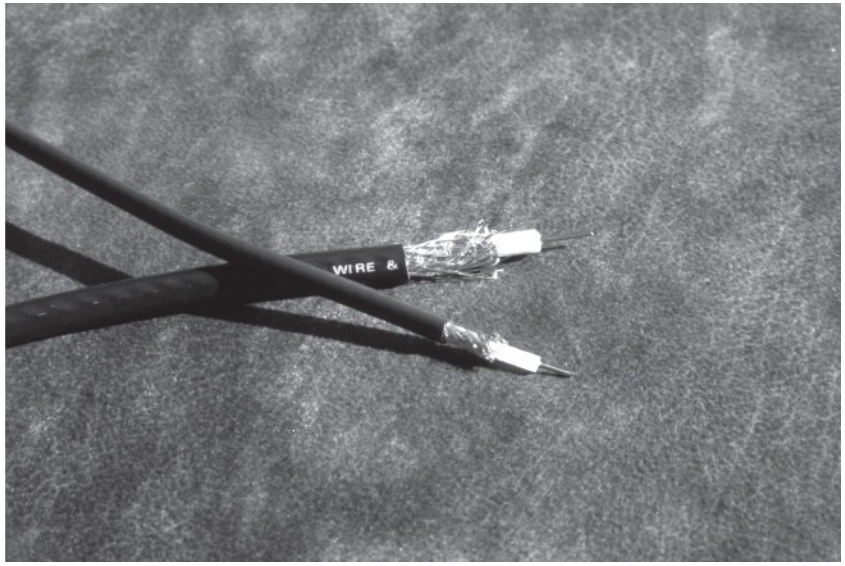
Coaxial Cable

- **Less prone to interference than TP due to shielding**
- **More expensive than TP**
- **Used mostly for cable TV**

Source: Tony Freeman/ PhotoEdit





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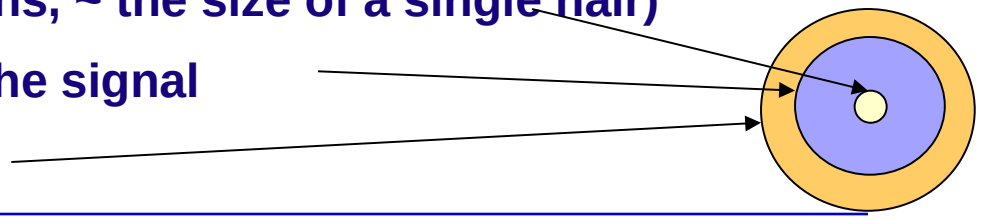
Fiber Optic Cable

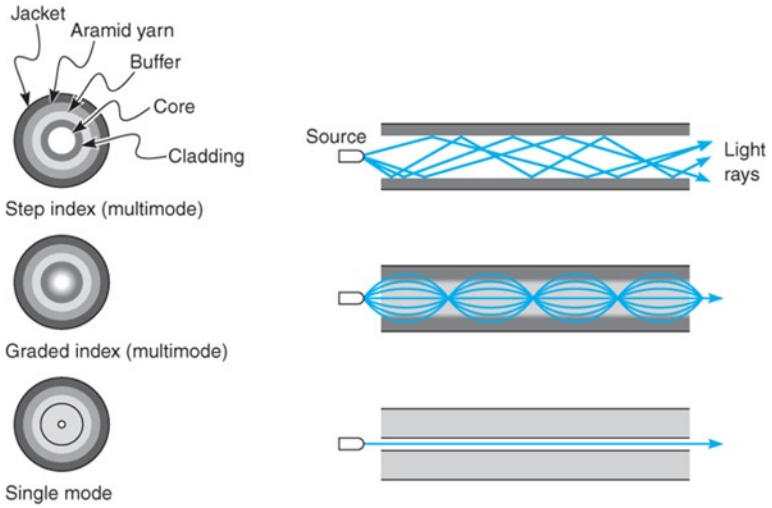
http://upload.wikimedia.org/wikipedia/commons/3/30/Fiber-engineerguy.ogv clip on FO

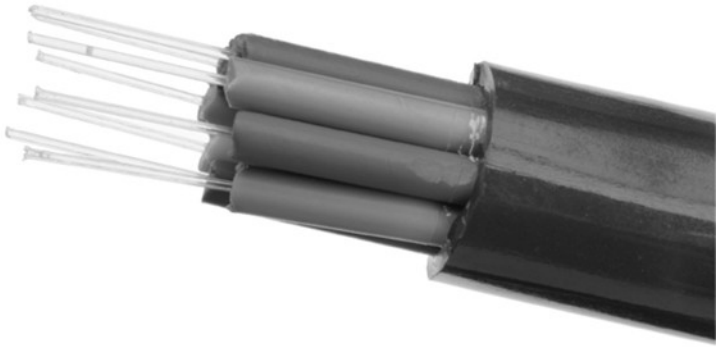
- **Light created by an LED (light-emitting diode) or laser is sent down a thin glass or plastic fiber**
- **Has extremely high capacity, ideal for broadband**
- **Works well under harsh environments**
  - **Not fragile, nor brittle; Not heavy nor bulky**
  - **More resistant to corrosion, fire, water**
  - **Highly secure, know when is tapped**
- **Fiber optic cable structure (from center):**
  - **Core (v. small, 5-50 microns, ~ the size of a single hair)**
  - **Cladding, which reflects the signal**
  - **Protective outer jacket**



Types of Optical Fiber

- **Single mode (about 5 micron core)**
  - **Transmits a single direct beam through the cable**
  - **Signal can be sent over many miles without spreading**
  - **Expensive (requires lasers; difficult to manufacture)**





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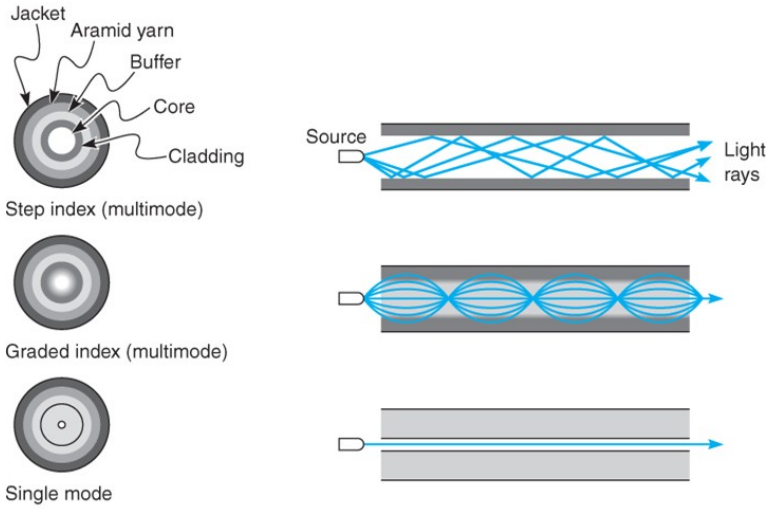
Types of Optical Fiber

- **Multimode (about 50 micron core)**
  - **Earliest fiber-optic systems**
  - **Signal spreads out over short distances (up to ~500m)**
  - **Inexpensive**
- **Graded index (multimode)**
  - **Reduces the spreading problem by changing the refractive properties of the fiber to refocus the signal *(Refraction** is the bending of light or sound waves that happens when a wave moves from one medium to another)*
  - **Can be used over distances of up to about 1000 meters**





Fiber with large core diameter (greater than 10 micrometers) may be analyzed by geometrical optics. Such fiber is called multi-mode fiber,

Types of Optical Fiber

The structure of a typical single-mode fiber

1. **Core: 8 μm (8 micrometer) diameter**

(Light is kept in the core by total internal reflection)

2. **Cladding :125 μm diameter**

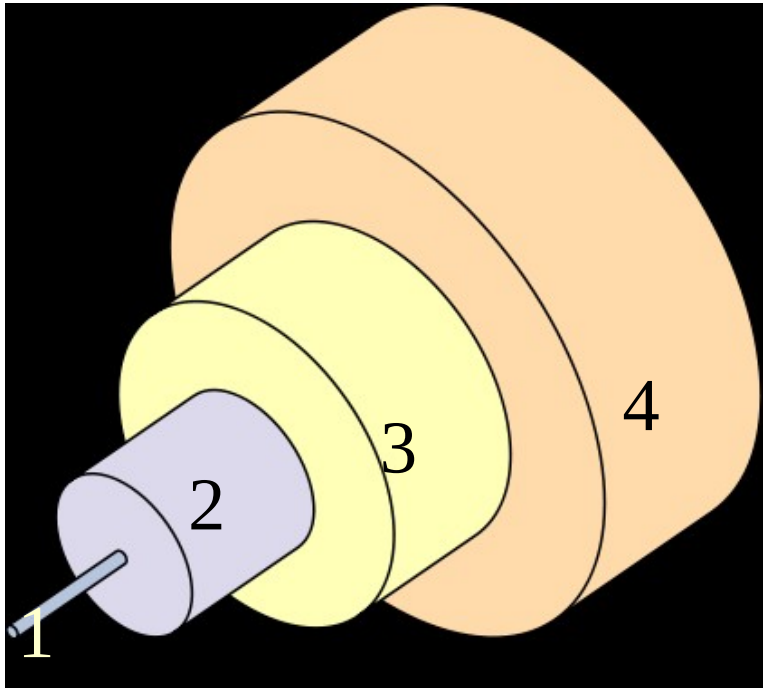
(Made of material of higher refractive index than Core; The cladding causes light to be confined to the core of the fiber)

3. **Buffer: (adds strength)**

   250 μm diameter

4. **Jacket (adds strength)**

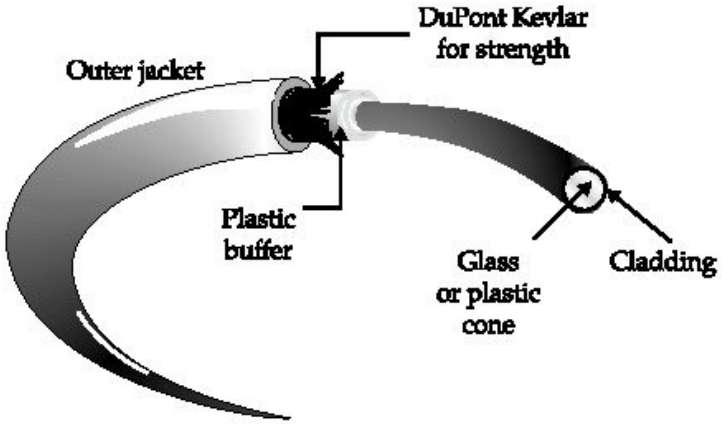
   400 μm diameter



Cladding is usually coated with a tough resin buffer layer, which may be further surrounded by a jacket layer, usually glass. These layers add strength to the fiber but do not contribute to its optical wave guide properties.

Types of Optical Fiber

- **The core is the transparent silica (or plastic) through which the light travels.**
- **The cladding is a glass sheath that surrounds the core, and acts like a mirror, reflecting light back into the core.**
- **The cladding itself is covered with a plastic coating and strength material when appropriate.**



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Types of Optical Fiber

- **An optical fiber (or optical fiber) is a flexible, transparent fiber made of glass (silica) or plastic, slightly thicker than a human hair.**
- **It can function as a waveguide, or “light pipe” to transmit light between the two ends of the fiber**
- **The field of applied science and engineering concerned with the design and application of optical fibers is known as fiber optics.**
- **Optical fibers are widely used in fiber-optic communications, which permits transmission over longer distances and at higher bandwidths (data rates) than other forms of communication.**
- **Fibers are used instead of metal wires because signals travel along them with less loss and are also immune to electromagnetic interference.**

Types of Optical Fiber

- **Optical fibers typically include a transparent core surrounded by a transparent cladding material with a lower index of refraction.**
- **Light is kept in the core by total internal reflection. This causes the fiber to act as a waveguide.**
- **Fibers that support many propagation paths or transverse modes are called multi-mode fibers (MMF),**
- **while those that only support a single mode are called single-mode fibers (SMF).**
- **Multi-mode fibers generally have a wider core diameter, and are used for short-distance communication links and for applications where high power must be transmitted.**
- **Single-mode fibers are used for most communication links longer than 1,050 meters (3,440 ft).**



An optical fiber junction box.
The yellow cables are single mode fibers;
the orange and blue cables are multi-mode fibers: 50/125 µm (micrometer) OM2 (Optical Mode2) and 50/125 µm OM3 fibers respectively.

Types of Optical Fiber

Multimode fibers are identified by the OM ("optical mode") designation as outlined in the ISO/IEC 11801 standard.

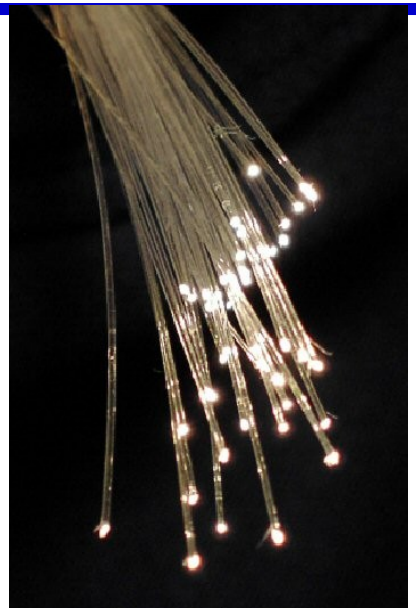
- OM1, for fiber with 200/500 MHz*km
- OM2, for fiber with 500/500 MHz*km
- OM3, for laser-optimized 50um micrometer, fiber having 2000 MHz*km, designed for 10 Gb/s transmission.
- OM4, for laser-optimized 50um fiber having 4700 MHz*km; designed for 10 Gb/s, 40 Gb/s, and 100 Gb/s transmission.

Multimode Fiber		
OM Designation	TIA Fiber Standard	Fiber Type (um)
OM1	492-AAAA	62.5/125
OM2	492-AAAB	50/125
OM3	492-AAAC	50/125
OM4	492-AAAD	50/125

Note on MHz*km:
Modal Bandwidth, in the discipline of telecommunications, refers to the signaling rate per distance unit. The signaling rate can typically be measured in MHz, and the modal bandwidth is expressed as MHz·km (multiplied).

Types of Optical Fiber

Fibers are also used for illumination, and are wrapped in bundles so that they may be used to carry images



- **Joining lengths of optical fiber is more complex than joining electrical wire or cable.**
- **The ends of the fibers must be carefully cleaved, and then spliced together, either mechanically or by fusing them with heat.**

Types of Optical Fiber

- **The index of refraction is a way of measuring the speed of light in a material.**
- **Light travels fastest in a vacuum, such as outer space.**
- **The speed of light in a vacuum is about 300,000 kilometers (186,000 miles) per second.**
- **Index of refraction is calculated by dividing the speed of light in a vacuum by the speed of light in some other medium.**
- **The index of refraction of a vacuum is therefore 1, by definition. The typical value for the cladding of an optical fiber is 1.52.**
- **The core value is typically 1.62.**
- **The larger the index of refraction, the slower light travels in that medium. From this information, a good rule of thumb is that signal using optical fiber for communication will travel at around 200,000 kilometers per second**

Types of Optical Fiber

- **Total internal reflection is referred to a situation where light traveling in an optically dense medium hits a boundary at a steep angle (larger than the critical angle for the boundary), the light is completely reflected.**
- **This is called total internal reflection.**
- **This effect is used in optical fibers to confine light in the core. Light travels through the fiber core, bouncing back and forth off the boundary between the core and cladding.**
- **Because the light must strike the boundary with an angle greater than the critical angle, only light that enters the fiber within a certain range of angles can travel down the fiber without leaking out.**
- **This range of angles is called the acceptance cone of the fiber. The size of this acceptance cone is a function of the refractive index difference between the fiber's core and cladding.**

Radio Waves

- Wireless transmission of electrical waves through air
- Each device has a radio transceiver with a specific frequency
  - Low power transmitters (few miles range)
  - Often attached to portables (Laptops, PDAs, cell phones)
- Includes
  - AM and FM radios, Cellular phones
  - Wireless LANs (IEEE 802.11) and Bluetooth
  - Microwaves and Satellites, Low Earth Orbiting Satellites

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Microwave Radio

- **High frequency form of radio communications**
  - **Extremely short (*micro*) wavelength (1 cm to 1 m)**
  - **Requires line-of-sight**
- **Performs same functions as cables**
  - **Often used for long distance, terrestrial transmissions (over 50 miles without repeaters)**
  - **No wiring and digging required**
  - **Requires large antennas (about 10 ft) and high towers**
- **Possesses similar properties as light**
  - **Reflection, refraction, and focusing**
  - **Can be focused into narrow powerful beams for long distance**



Source: Matej, Pribelsky listock photo

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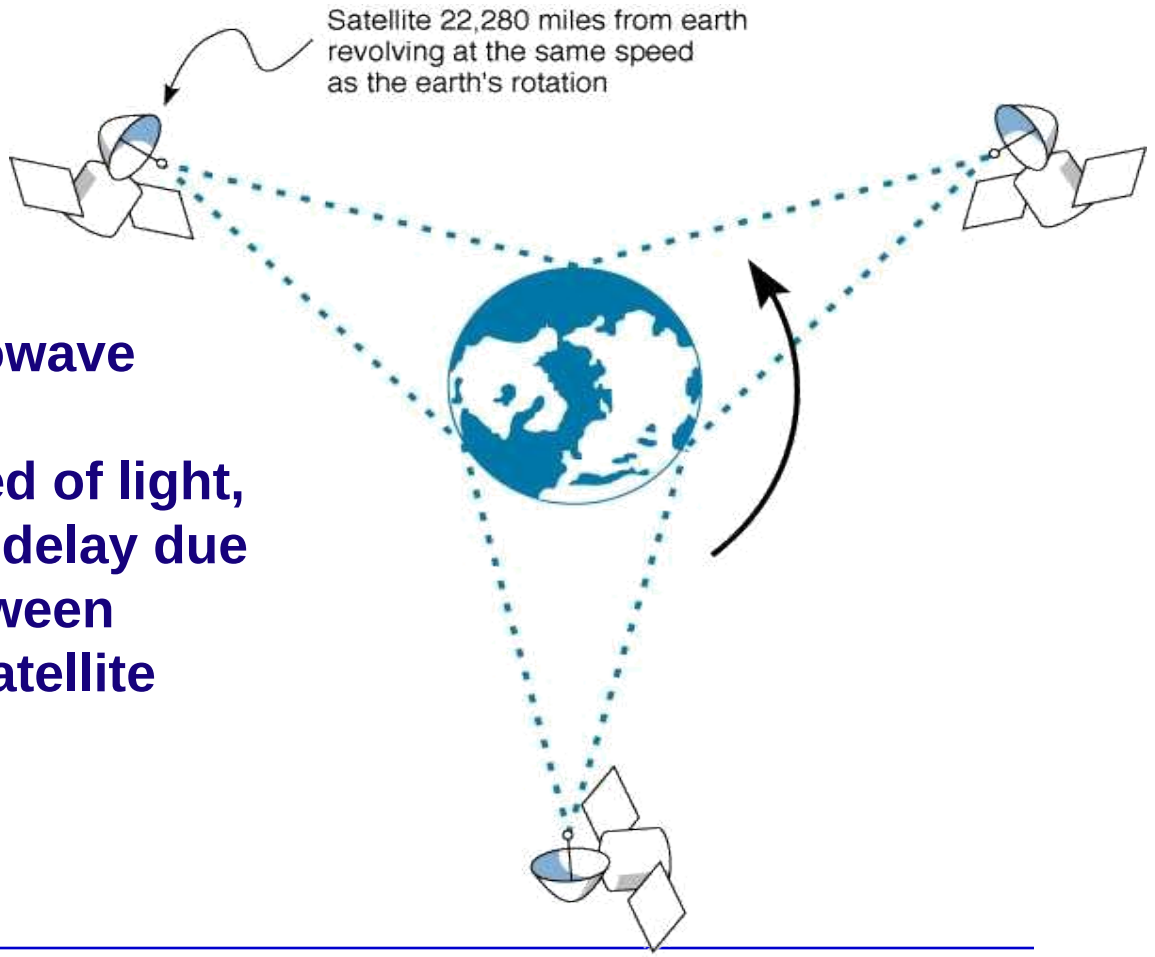
Satellite Communications



- **Special form of microwave communications**
- **Signals travel at speed of light, yet long propagation delay due to great distance between ground station and satellite**

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Factors Used in Media Selection

- **Type of network**
  - **LAN, WAN, or Backbone**
- **Cost**
  - **Always changing; depends on the distance**
- **Transmission distance**
  - **Short: up to 300 m; medium: up to 500 m**
- **Security**
  - **Wireless media is less secure**
- **Error rates**
  - **Wireless media has the highest error rate (interference)**
- **Transmission speeds**
  - **Constantly improving; Fiber has the highest**

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Media Summary

Guided Media						
Media	**Network Type**	**Cost**	**Transmission Distance**	**Security**	**Error Rates**	**Speed**
Twisted Pair	LAN	Low	Short	Good	Low	Low-high
Coaxial Cable	LAN	Moderate	Short	Good	Low	Low-high
Fiber Optics	Any	High	Moderate-long	Very good	Very low	High-very high
Radiated Media						
Media	**Network Type**	**Cost**	**Transmission Distance**	**Security**	**Error Rates**	**Speed**
Radio	LAN	Low	Short	Poor	Moderate	Moderate
Microwave	WAN	Moderate	Long	Poor	Low-moderate	Moderate
Satellite	WAN	Moderate	Long	Poor	Low-moderate	Moderate

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3.4 Digital Transmission of Digital Data

- Computers produce binary data
- Standards needed to ensure both sender and receiver understands this data
  - *Codes:* digital combinations of bits making up languages that computers use to represent letters, numbers, and symbols in a message
  - *Signals:* electrical or optical patterns that computers use to represent the coded bits (0 or 1) during transmission across media

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Coding

- Coding is the representation of a set of characters by a string of bits
  - Letters (A, B, ..), numbers (1, 2,..), special symbols (#, $, ..)
- ASCII: American Standard Code for Information Interchange
  - Originally used a 7-bit code (128 combinations), but an 8-bit version (256 combinations) is now in use
  - Found on PC computers
- EBCDIC: Extended Binary Coded Decimal Interchange Code
  - An 8-bit code developed by IBM
  - Used mostly in mainframe computer environment

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ASCII Chart

0	0011 0000	O	0100 1111	m	0110 1101
1	0011 0001	P	0101 0000	n	0110 1110
2	0011 0010	Q	0101 0001	o	0110 1111
3	0011 0011	R	0101 0010	p	0111 0000
4	0011 0100	S	0101 0011	q	0111 0001
5	0011 0101	T	0101 0100	r	0111 0010
6	0011 0110	U	0101 0101	s	0111 0011
7	0011 0111	V	0101 0110	t	0111 0100
8	0011 1000	W	0101 0111	u	0111 0101
9	0011 1001	X	0101 1000	v	0111 0110
A	0100 0001	Y	0101 1001	w	0111 0111
B	0100 0010	Z	0101 1010	x	0111 1000
C	0100 0011	a	0110 0001	y	0111 1001
D	0100 0100	b	0110 0010	z	0111 1010
E	0100 0101	c	0110 0011	.	0010 1110
F	0100 0110	d	0110 0100	,	0010 0111
G	0100 0111	e	0110 0101	:	0011 1010
H	0100 1000	f	0110 0110	;	0011 1011
I	0100 1001	g	0110 0111	?	0011 1111
J	0100 1010	h	0110 1000	!	0010 0001
K	0100 1011	I	0110 1001	'	0010 1100

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Transmission Modes

- **Bits in a message can be sent on:**
  - **a single wire one after another (Serial transmission)**
  - **multiple wires simultaneously (Parallel transmission)**
- **Serial Mode**
  - **Sends bit by bit over a single wire**
  - **Serial mode is slower than parallel mode**
- **Parallel mode**
  - **Uses several wires, each wire sending one bit at the same time as the others**
    - **A parallel printer cable sends 8 bits together**
    - **Computer's processor and motherboard also use parallel busses (8 bits, 16 bits, 32 bits) to move data around**

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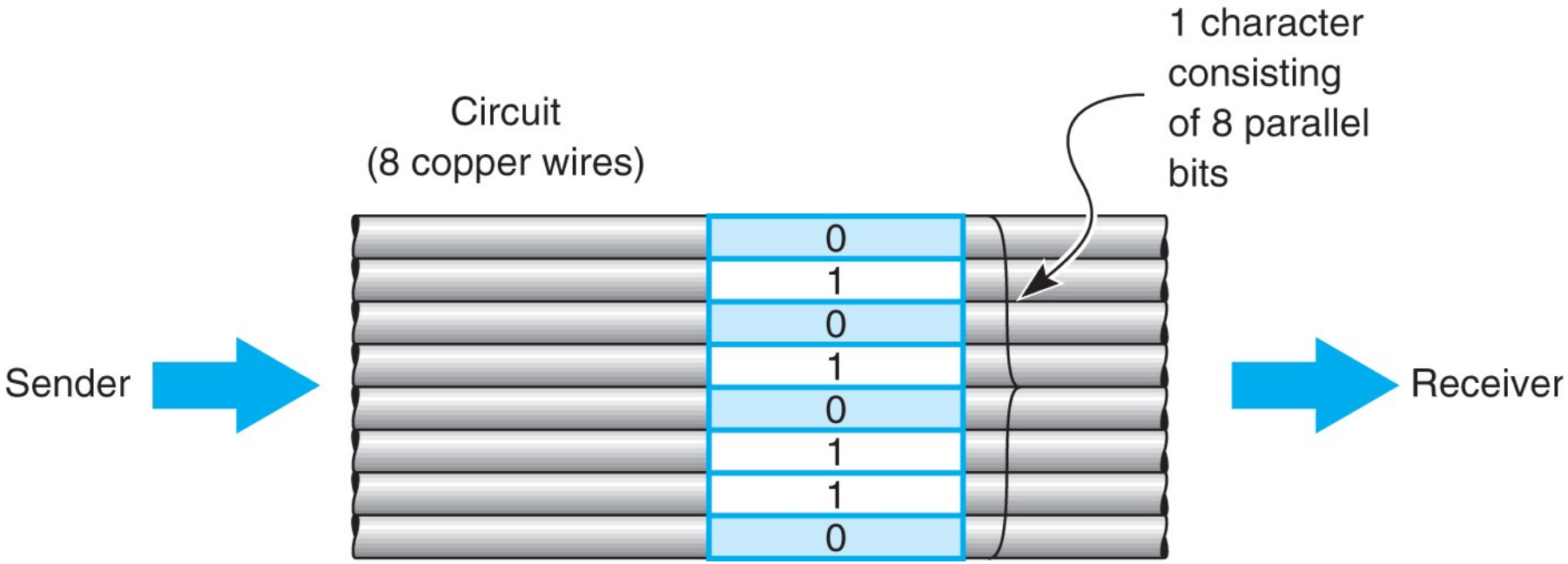
Parallel Transmission Example

Used for short distances (up to 6 meters) since bits sent in parallel mode tend to spread out over long distances



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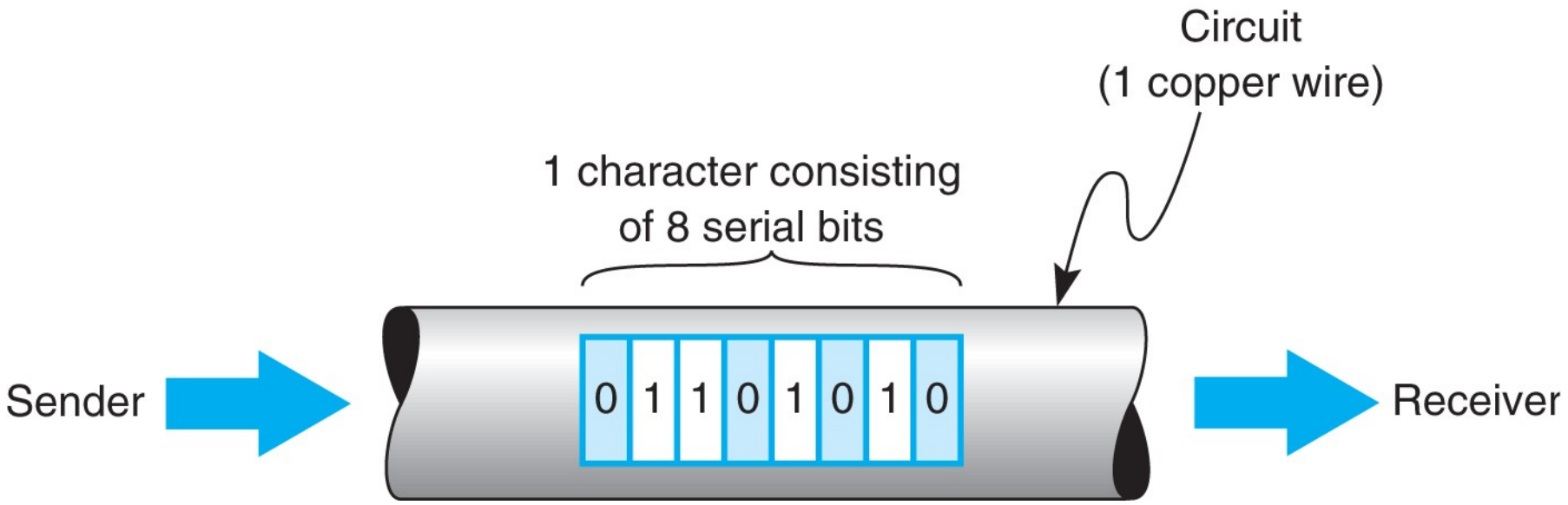
Serial Transmission Example

Can be used over longer distances since bits stay in the order they were sent



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Signaling of Bits

- **Digital Transmission**
  - **Signals sent as a series of “square waves” of either positive or negative voltage**
  - **Voltages vary between +3/-3 and +24/-24 depending on the circuit**
- **Signaling (encoding)**
  - **Defines how the voltage levels will correspond to the bit values of 0 or 1**
  - **Examples:**
    - **Bipolar**
      - **RTZ (Return To Zero),**
      - **NRZ (Non Return to Zero)**
      - **Manchester**
    - **Unipolar**
  - **Data rate: describes how often the sender can transmit data**
    - **64 Kbps → once every 1/64000 of a second**

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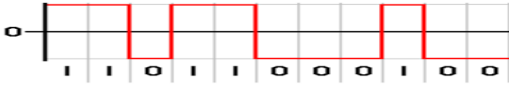
Signaling (Encoding) Techniques

- **Unipolar signaling**
  - **Use voltages either vary between 0 and a positive value or between 0 and some negative value**
- **Bipolar signaling**
  - **Use both positive and negative voltages**
  - **Experiences fewer errors than unipolar signaling**
    - **Signals are more distinct (more difficult for interference to change polarity of a current)**
  - **Return to zero (RZ)**



    - **Signal returns to 0 voltage level after sending a bit**
  - **Non return to zero (NRZ)**



    - **Signals maintains its voltage at the end of a bit**
  - **Manchester encoding (used by Ethernet)**

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Manchester Encoding

- **Used by Ethernet, most popular LAN technology**
- **Defines a bit value by a mid-bit transition**
  - **A high to low voltage transition is a 0 and a low to high mid-bit transition defines a 1**
- **Data rates: 10 Mb/s, 100 Mb/s, 1 Gb/s**
  - **10- Mb/s → one signal for every 1/10,000,000 of a second (10 million signals or bits every second)**
- **Less susceptible to having errors go undetected**
  - **If there is no mid-bit voltage transition, then an error took place**

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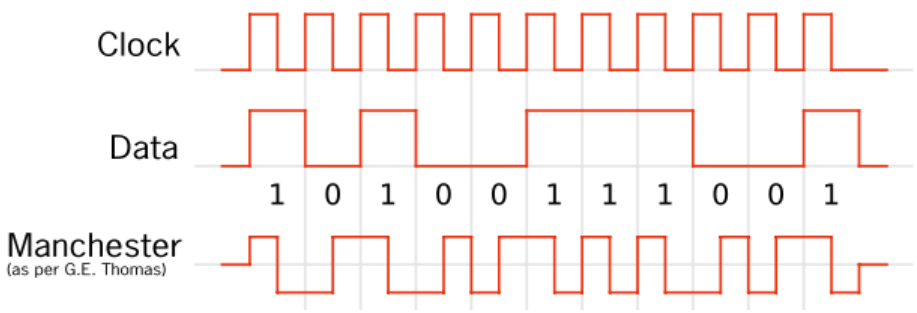
Manchester Encoding

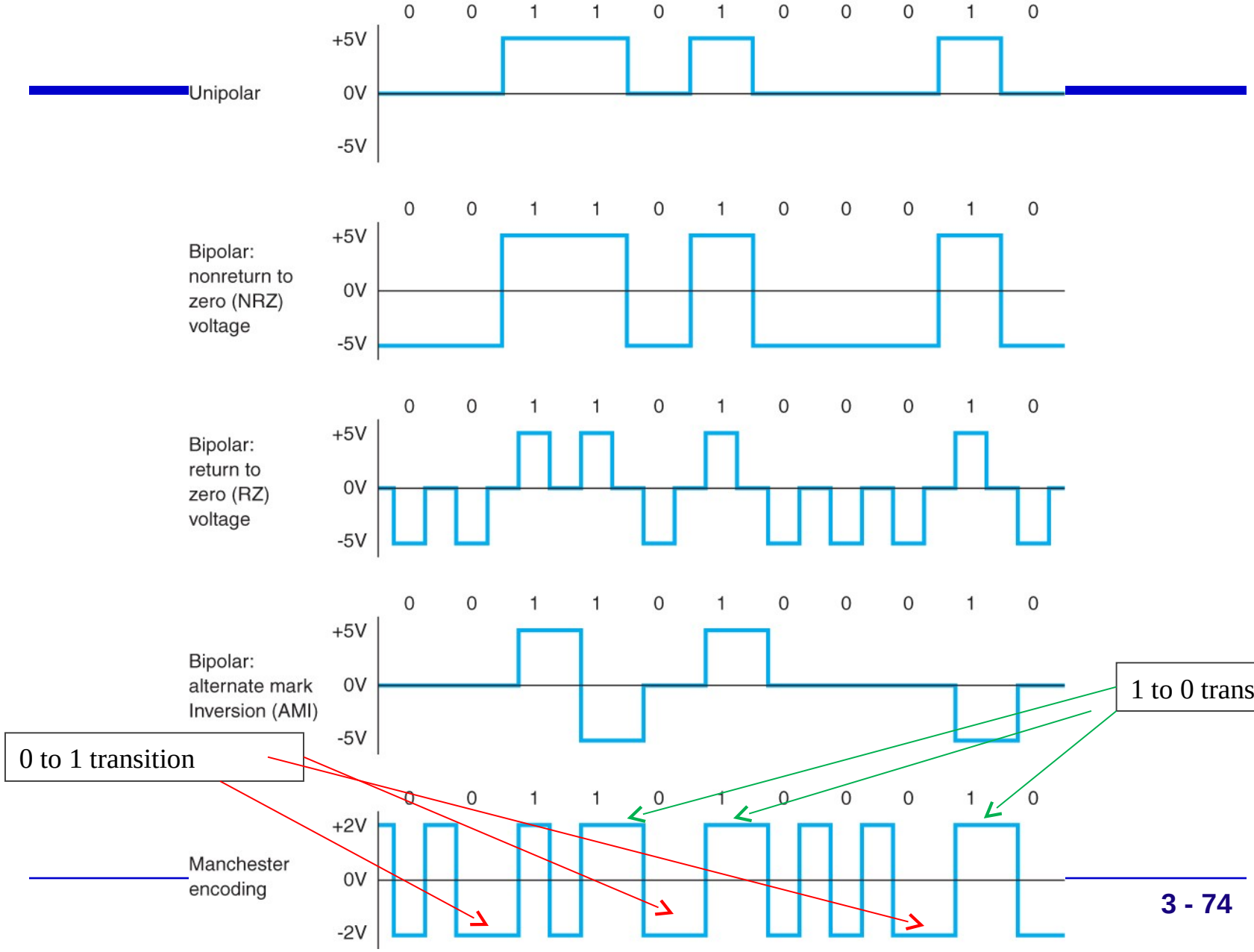
- Developed at the University of Manchester; Manchester coding (also known as Phase Encoding, or PE) is a line code in which the encoding of each data bit has at least one transition (sometimes more than one transition), and occupies the same time. It therefore has no DC component, and is self-clocking.



- Manchester code ensures frequent line voltage transitions, directly proportional to the clock rate.

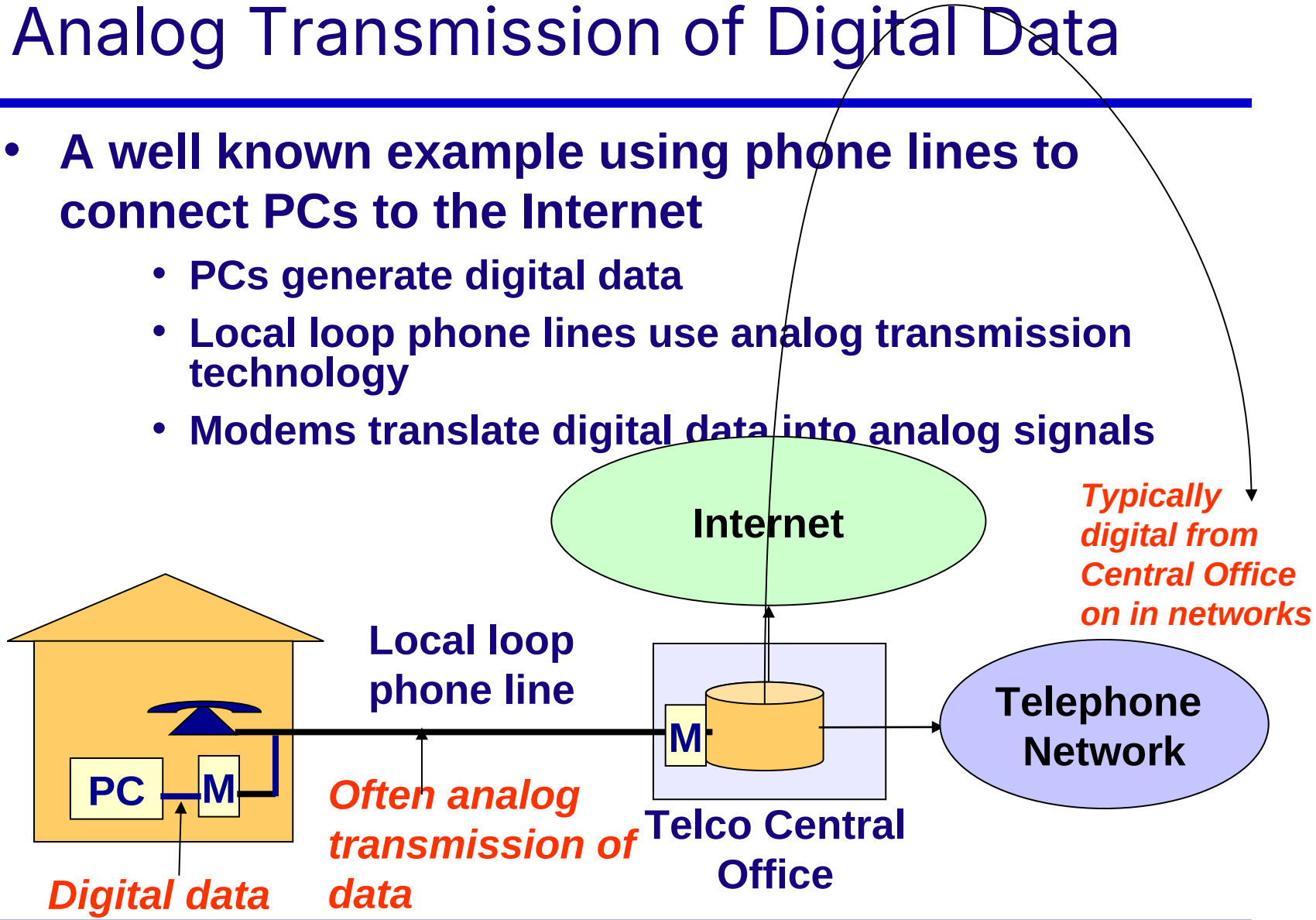
- The DC component of the encoded signal is not dependent on the data and therefore carries no information, allowing the signal to be conveyed conveniently by media (e.g., Ethernet) which usually do not convey a DC component.

Digital Transmission Types



3.5 Analog Transmission of Digital Data

- **A well known example using phone lines to connect PCs to the Internet**
  - **PCs generate digital data**
  - **Local loop phone lines use analog transmission technology**
  - **Modems translate digital data into analog signals**



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Telephone Network

- **Originally designed for human speech (analog communications) only**
- **POTS (Plain Old Telephone Service)**
  - **Enables voice communications between two telephones**
  - **Human voice (sound waves) converted to electrical signals by the sending telephone**
  - **Signals travel through POTS and converted back to sound waves at far end**
- **Sending digital data over POTS**
  - **Use modems to convert digital data to an analog format**
    - **One modem used by sender to produce analog data**
    - **Another modem used by receiver to regenerate digital data**

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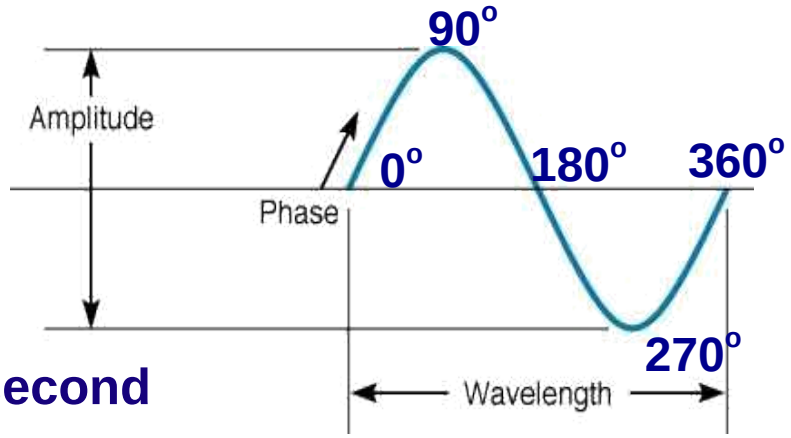
Sound Waves and Characteristics

- **Amplitude**
  - **Height (loudness) of the wave**
  - **Measured in decibels (dB)**



- **Frequency:**
  - **Number of waves that pass in a second**
  - **Measured in Hertz (cycles/second)**
  - **Wavelength, the length of the wave from crest to crest, is related to frequency**
- **Phase:**
  - **Refers to the point in each wave cycle at which the wave begins (measured in degrees)**
  - **(For example, changing a wave's cycle from crest to trough corresponds to a 180 degree phase shift).**

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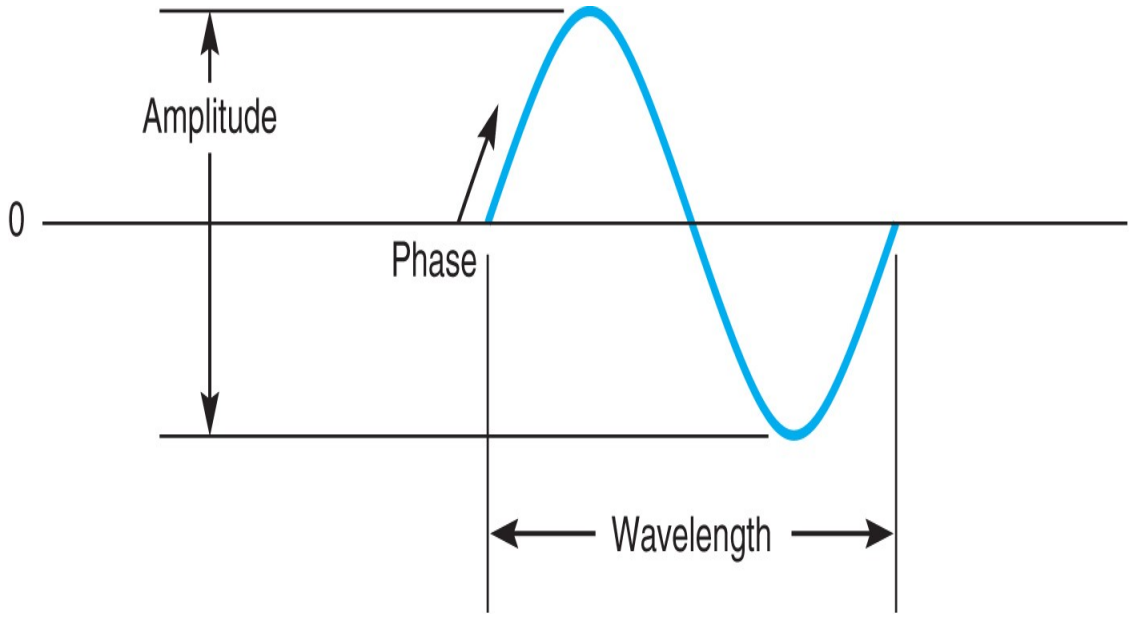
Wavelength vs. Frequency

speed = frequency * wavelength



$$v = f \lambda$$

$v = 3 \times 10^8$ m/s
= 300,000 km/s
= 186,000 miles/s

Example:
if f = 900 MHz
$\lambda = 3 \times 10^8 / 900 \times 10^3$
= 3/9 = 0.3 meters

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Modulation

- **Modifying a carrier wave's fundamental characteristics in order to encode information**
  - **Carrier wave: Basic sound wave transmitted through the circuit (provides a base which we can deviate)**
- **Basic ways to modulate a carrier wave:**
  - **Amplitude Modulation (AM)**
    - **Also known as Amplitude Shift Keying (ASK)**
  - **Frequency Modulation (FM)**
    - **Also known as Frequency Shift Keying (FSK)**
  - **Phase Modulation (PM)**
    - **Also known as Phase Shift Keying (PSK)**

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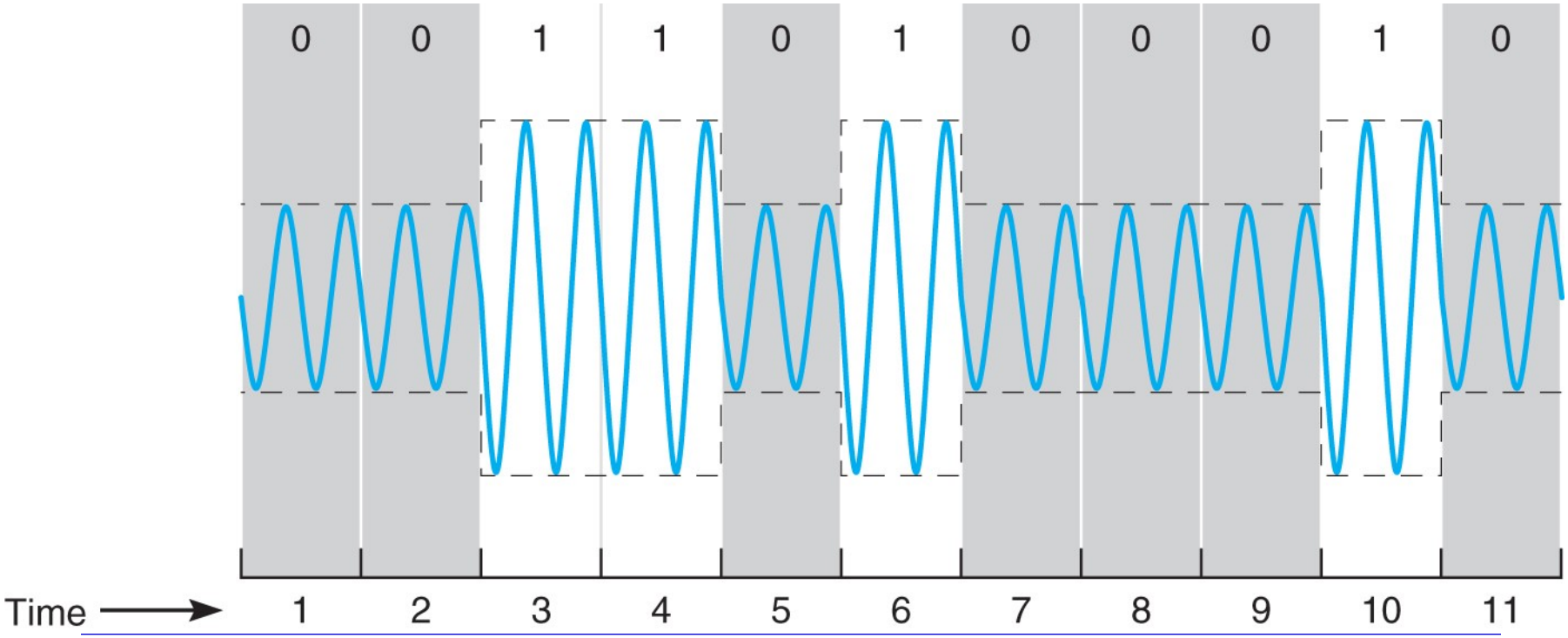
Amplitude Modulation (AM)

- **Changing the height of the wave to encode data**
- **One bit is encoded for each carrier wave change**
- **More susceptible to noise**



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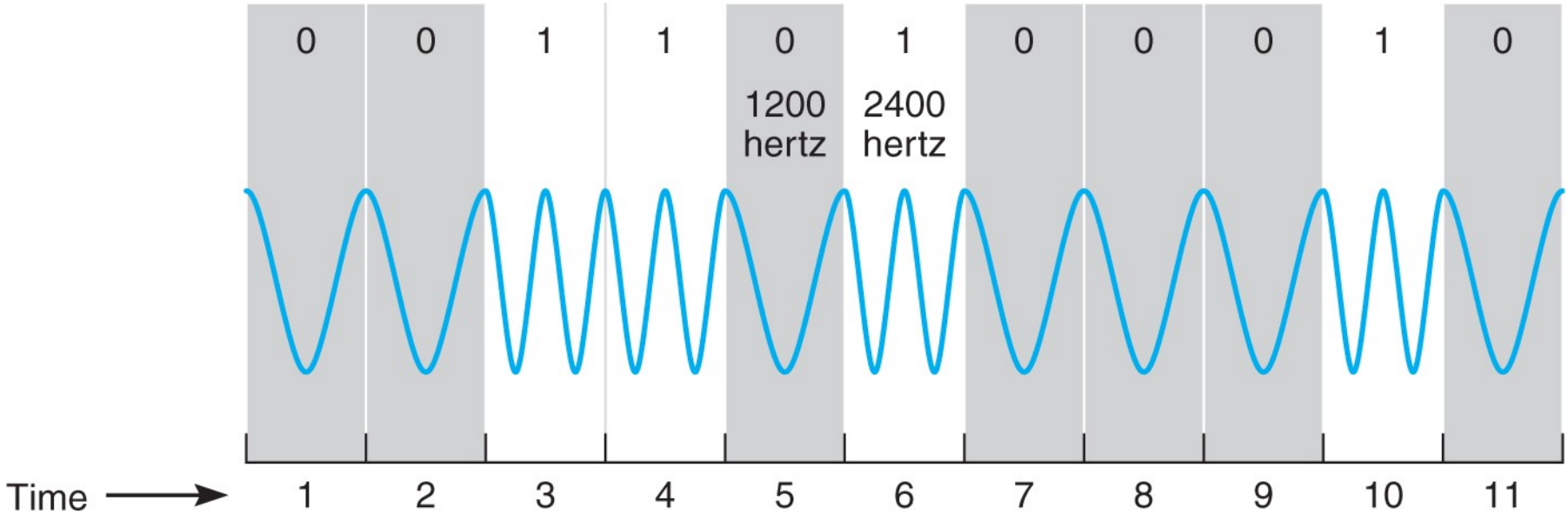
Frequency Modulation (FM)

- **Changing the frequency of carrier wave to encode data**
- **One bit is encoded for each carrier wave change**



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Phase Modulation (PM)

- **Changing the phase of the carrier wave to encode data**
- **One bit is encoded for each carrier wave change**

- **Changing carrier wave's phase by 180° corresponds to a bit value of 1**
- **No change in carrier wave's phase means a bit value of 0**

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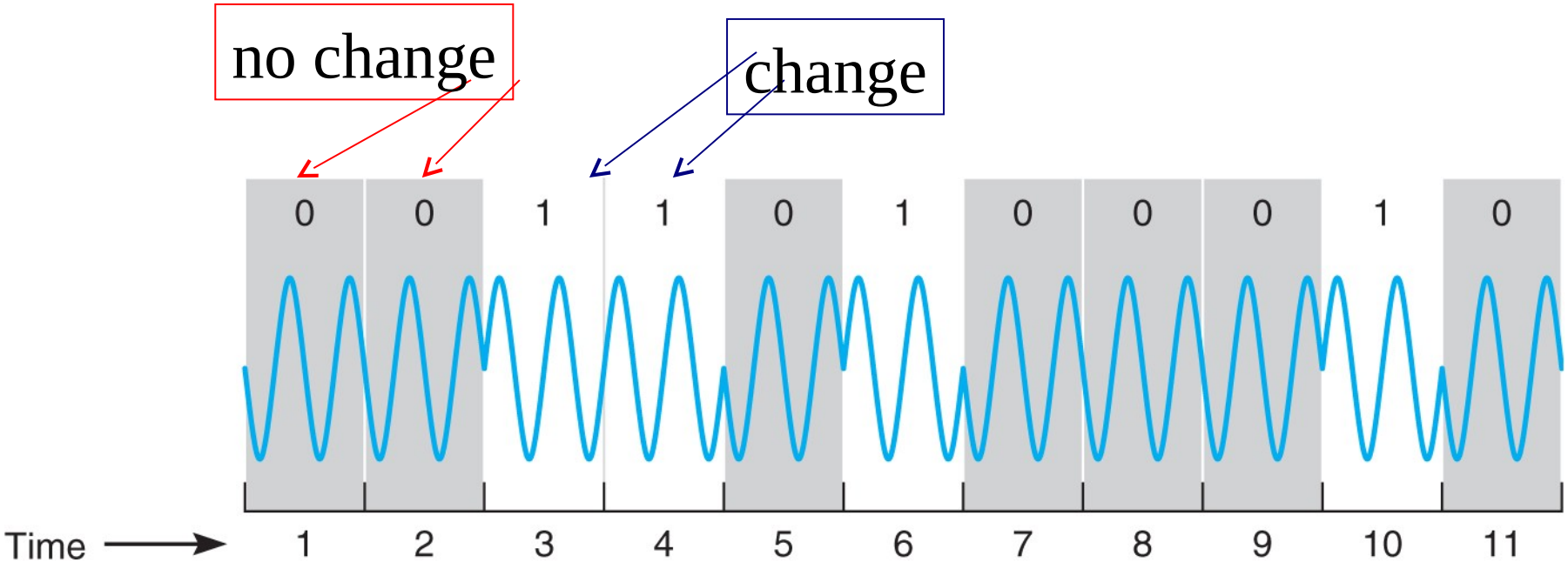
Phase Modulation (PM)



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Concept of Symbol

- **Symbol: Use each modification of the carrier wave to encode information**
- **Sending one bit of information at a time**
  - **One bit encoded for each symbol (carrier wave change) → 1 bit per symbol**
- **Sending multiple bits simultaneously**
  - **Multiple bits encoded for each symbol (carrier wave change) → n bits per symbol, n > 1**
  - **Need more complicated information coding schemes**

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Sending Multiple Bits per Symbol

- **Possible number of symbols must be increased**
  - **1 bit of information → 2 symbols**
  - **2 bits of information → 4 symbols**
  - **3 bits of information 8 → symbols**
  - **4 bits of information → 16 symbols**
  - **n bits of information → 2^n symbols**
- **Multiple bits per symbol might be encoded using amplitude, frequency, and phase modulation**
  - **e.g., PM: phase shifts of 0°, 90°, 180°, and 270°**
- **Subject to limitations: As the number of symbols increases, it becomes harder to detect**

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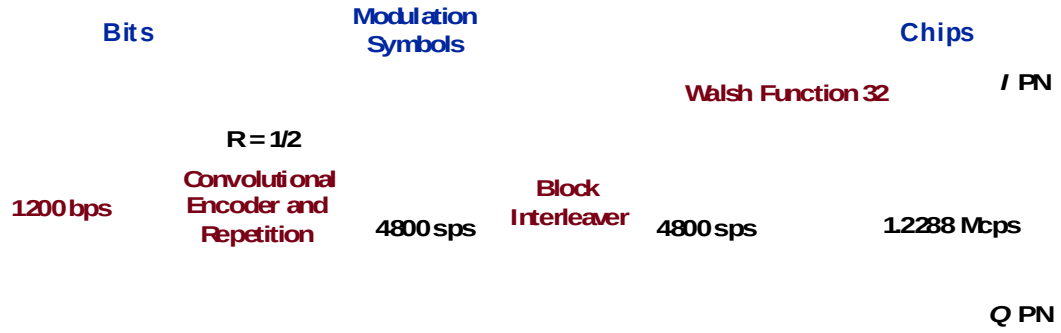
Sync Channel Generation – how bits change to become symbols



- There are 32 bits (1200 bps x 0.02666... second) in one Sync Channel frame
- The Rate 1/2 convolutional encoder doubles the bit rate, and the resulting 0s and 1s are now called "code symbols"
  - there are 64 code symbols in a Sync Channel frame
- The repetition process doubles the rate again, and each repetition of a code symbol is now called a "modulation symbol"
  - there are 128 modulation symbols in a Sync Channel frame
- Four copies of Walsh code #32 are used to spread each modulation symbol, resulting in a x256 rate increase; the resulting 0s and 1s are now called " chips"
  - there are 32,768 chips in a Sync Channel frame (1024 chips per original bit)

Bit Rate vs. Baud Rate or Symbol Rate

- **Bit: a unit of information**
- **Baud: a unit of signaling speed**
- **Bit rate (or data rate): b**
  - **Number of bits transmitted per second**
- **Baud rate or symbol rate: s**
  - **number of symbols transmitted per second**
- **General formula:**

$$b = s \times n$$

where

b = Data Rate (bits/second)
s = Symbol Rate (symbols/sec.)
n = Number of bits per symbol

Example: AM
n = 1
→ b = s

Example: 16-QAM
n = 4
→ b = 4 x s

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Bandwidth of a Voice Circuit

- **Difference between the highest and lowest frequencies in a band**
- **Human hearing frequency range: 20 Hz to 14 kHz**
  - **Bandwidth appx.14,000**
- **Voice circuit frequency range: 0 Hz to 4 kHz**
  - **Designed for most commonly used range of human voice**
- **Phone lines transmission capacity is much bigger**
  - **1 MHz for lines up to 2 miles from a telephone exchange**
  - **300 kHz for lines 2-3 miles away**

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Data Capacity of a Voice Circuit

- **Fastest rate at which you can send your data over the circuit (in bits per second)**
  - **Calculated as the bit rate: b = s x n**
    - **Depends on modulation (symbol rate)**
    - **Max. Symbol rate = bandwidth (if no noise)**

b = Data Rate (bits/second)

s = Symbol Rate (symbols/sec.)

n = Number of bits per symbol

- **Maximum voice circuit capacity:**
  - **Using QAM with 4 bits per symbol (n = 4)**
  - **Max. voice channel carrier wave frequency: 4000 Hz = max. symbol rate (under perfect conditions)**

    →Data rate = 4 * 4000 → 16,000 bps
  - **A circuit with a 10 MHz bandwidth using 64-QAM could provide up to 60 Mbps.**

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Data Compression in Modems

- **Used to increase the throughput rate of data by encoding redundant data strings**
- **Example: Lempel-Ziv encoding**
  - **Used in V.44, the ISO standard for data compression**
  - **Creates (while transmitting) a dictionary of two-, three-, and four-character combinations in a message**
  - **Anytime one of these patterns is detected, its index in dictionary is sent (instead of actual data)**
  - **Average reduction: 6:1 (depends on the text)**
    - **Provides 6 times more data sent per second**

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3.6 Digital Transmission of Analog Data

- **Analog voice data sent over digital network using digital transmission**
- **Requires a pair of special devices called Codec - Coder/decoder**
  - **A device that converts an analog voice signal into digital form**
  - **Converts it back to analog data at the receiving end**
  - **Used by the phone system**
- **Modem is reverse device than Codec, and this word stands for Modulate/Demodulate. Modems are used for analog transmission of digital data.**

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Analog to Digital Conversion

- **Analog data must be translated into a series of bits before transmission onto a digital circuit**
- **Done by a technique called Pulse Amplitude Modulation (PAM) involving 4 steps:**
  1. **Take samples of the continuously varying analog signal across time**
  2. **Measure the amplitude of each signal sample**
  3. **Encode the amplitude measurement of the signal as binary data that is representative of the sample**
  4. **Send the discrete, digital data stream of 0's and 1's that approximates the original analog signal**
- **Creates a rough (digitized) approximation of original signal**
  - **Quantizing error: difference between the original analog signal and the replicated but approximated, digital signal**
  - **The more samples taken in time, the less quantizing error**

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Pulse Code Modulation (PCM) is the most common method of encoding an analog voice signal into a digital bit stream.

Sampling

To digitize an analog signal, it must first be sampled at very precise intervals of time to measure its amplitude. The sampling period is fixed by the SHANNON's SAMPLING CRITERION, which states that the sampling rate must be at least double the highest frequency to be transmitted if the original signal is to be recovered from these samples without error.

The highest frequency component in an analog speech signal is less than 4 KHz; therefore, the sampling rate is rounded up to eight thousand times per second.

This process of sampling the amplitude of the signal is called Pulse Amplitude Modulation (PAM).

A sampled signal contains complete and unambiguous information about the source signal as long as the sampling frequency is at least twice the highest frequency fs of the source signal B. It can be shown mathematically that the spectrum of the sampled signal consists of a number of subspectra, the first of which lies in the frequency range '0' to 'B' and is identical to the spectrum of the source signal. The third subspectrum is identical to the first, but moved fs Hz in frequency (fs is the sampling frequency). The second subspectrum is a reflected image of the third starting at fs-B (that is, between the first and the third), and so on ad infinitum with a period of fs.

Since the spectrum of the sampled signal is in the fs+B band, we can conclude that the sampled signal contains all the information about the source signal, provided that fs is greater than 2B.

If this condition is not satisfied, the subspectra of the sampled signal will overlap each other, and this will result in loss of information about the original source signal. This phenomenon is called ALIASING DISTORTION.

Quantizing

Only discrete values are applicable in a digital system; therefore, each sample is allocated an integer value that represents the signal level. Eight bits are commonly allocated to represent the samples. Eight bits times 8000 samples per second results in 64,000 bits per second, the familiar rate of a DS0 bit stream.

Linear quantization produces proportionally more error on smaller amplitude signals; on the other hand, large amplitude signals are better able to mask the effects of noise. This imbalance can be improved by using a non-linear form of quantization which acts as level compression during encoding and level expansion during decoding. This technique is referred to as "companding" (from "compressing" and "expanding").

If money is to be rounded to the nearest dollar, rounding $1.49 down to $1.00 introduces a proportionally much higher error (50%) than rounding $100.49 down to $100.00 (0.5%) or $1000.49 down to $1000 (0.05%).

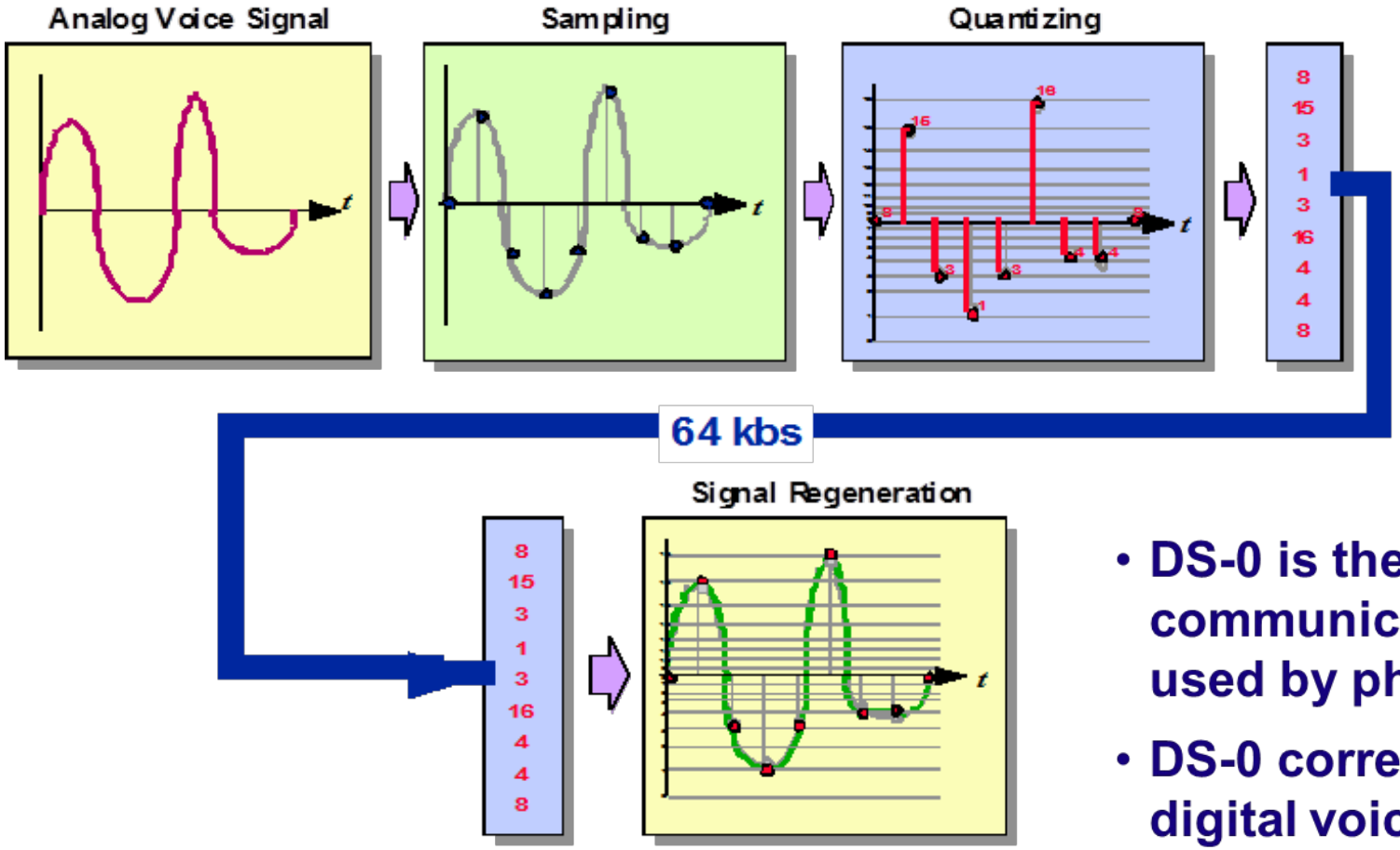
II we want to maintain the same level of error across the range, we must increase the precision of the intervals at low dollar levels at the expense of a reduction in precision at higher levels.

For example, to keep the error under 1%, we must round the dollar amounts to the nearest cent while rounding the hundreds to the nearest dollar, the thousands to the nearest multiple of $10, etc.

Signal Regeneration

In practice, any signal that is reconstructed from digitized samples will suffer from the approximations made during this quantization process. Such errors produce "quantization noise".

Digital Stream 0 (DS0)



- DS-0 is the basic digital communications unit used by phone network
- DS-0 corresponds to 1 digital voice signal

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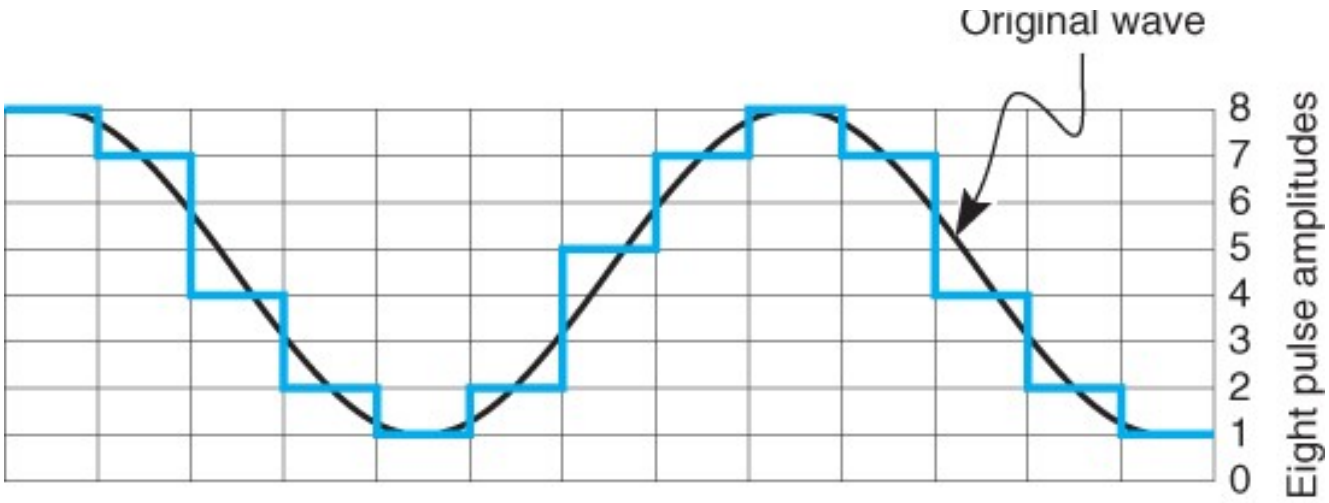
PAM – Measuring Signal



- **Sample analog waveform across time and measure amplitude of signal**
- **In this example, quantize the samples using only 8 pulse amplitudes or levels for simplicity**
- **Our 8 levels or amplitudes can be depicted digitally by using 0's and 1's in a 3-bit code, yielding 2^3 possible amplitudes**

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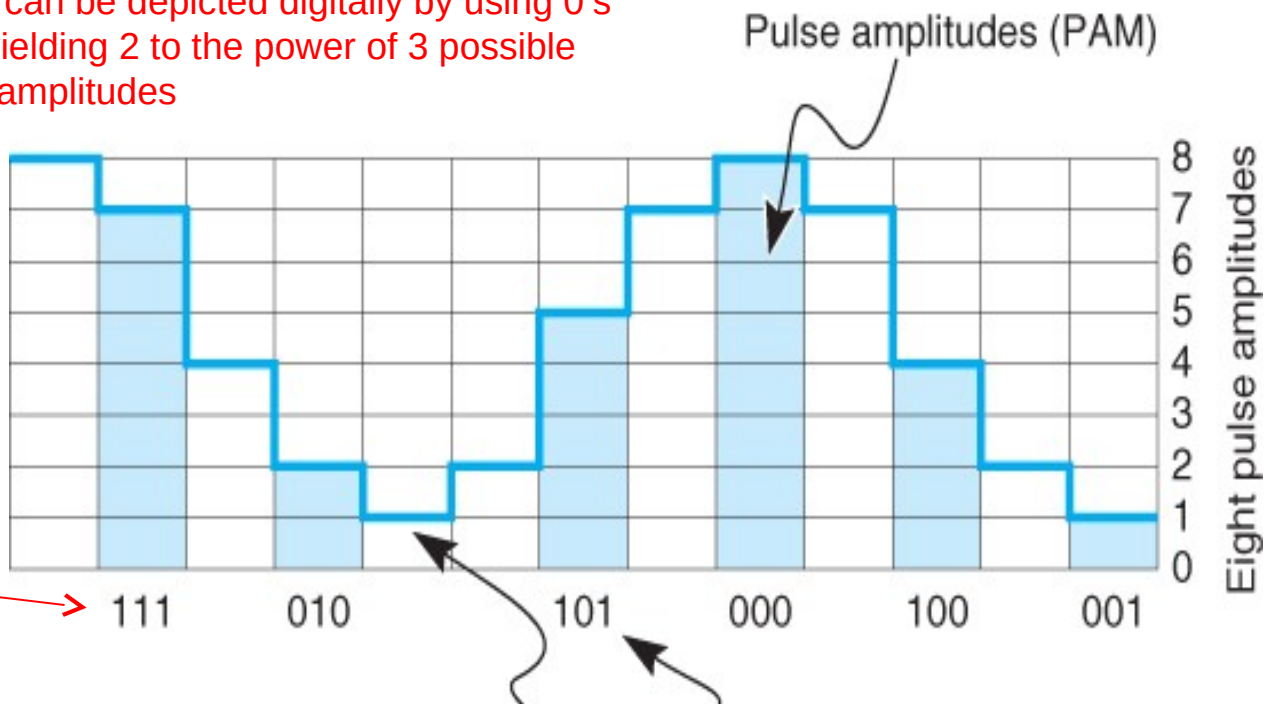
PAM – Encoding and Sampling

Our 8 levels or amplitudes can be depicted digitally by using 0's and 1's in a 3-bit code, yielding 2 to the power of 3 possible amplitudes

000 – PAM Level 1
001 – PAM Level 2
010 – PAM Level 3
011 – PAM Level 4
100 – PAM Level 5
101 – PAM Level 6
110 – PAM Level 7
111 – PAM Level 8



- **For digitizing a voice signal, it is typically 8,000 samples per second and 8 bits per sample**
- **8,000 samples x 8 bits per sample → 64,000 bps transmission rate needed**
- **8,000 samples then transmitted as a serial stream of 0s and 1s**

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Minimize Quantizing Errors

- **Increase number of amplitude levels**
  - **Difference between levels minimized → smoother signal**
  - **Requires more bits to represent levels → more data to transmit**
  - **Adequate human voice: 7 bits → 128 levels**
  - **Music: at least 16 bits → 65,536 levels**
- **Sample more frequently**
  - **Will reduce the length of each step → smoother signal**
  - **Adequate Voice signal: twice the highest possible frequency (4Khz x 2 = 8000 samples / second)**
  - **RealNetworks: 48,000 samples / second**

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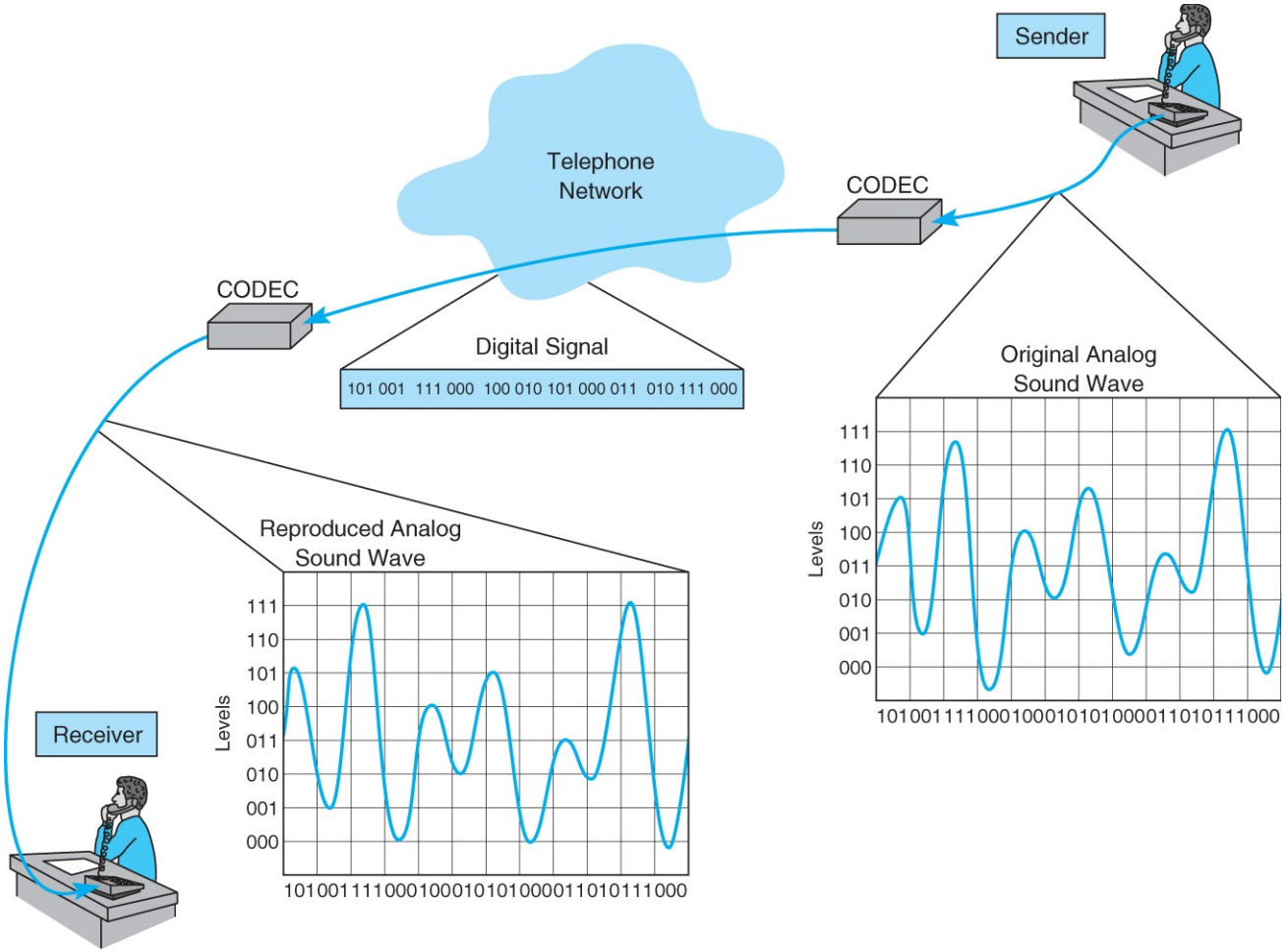
PAM for Telephones



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Combined Modulation Techniques

- **Combining AM, FM, and PM on the same circuit**
- **Examples**
  - **QAM - Quadrature Amplitude Modulation**
    - **A widely used family of encoding schemes**
      - **Combine Amplitude and Phase Modulation**
    - **A common form: 16-QAM**
      - **Uses 8 different phase shifts and 2 different amplitude levels**
        - » **16 possible symbols → 4 bits/symbol**

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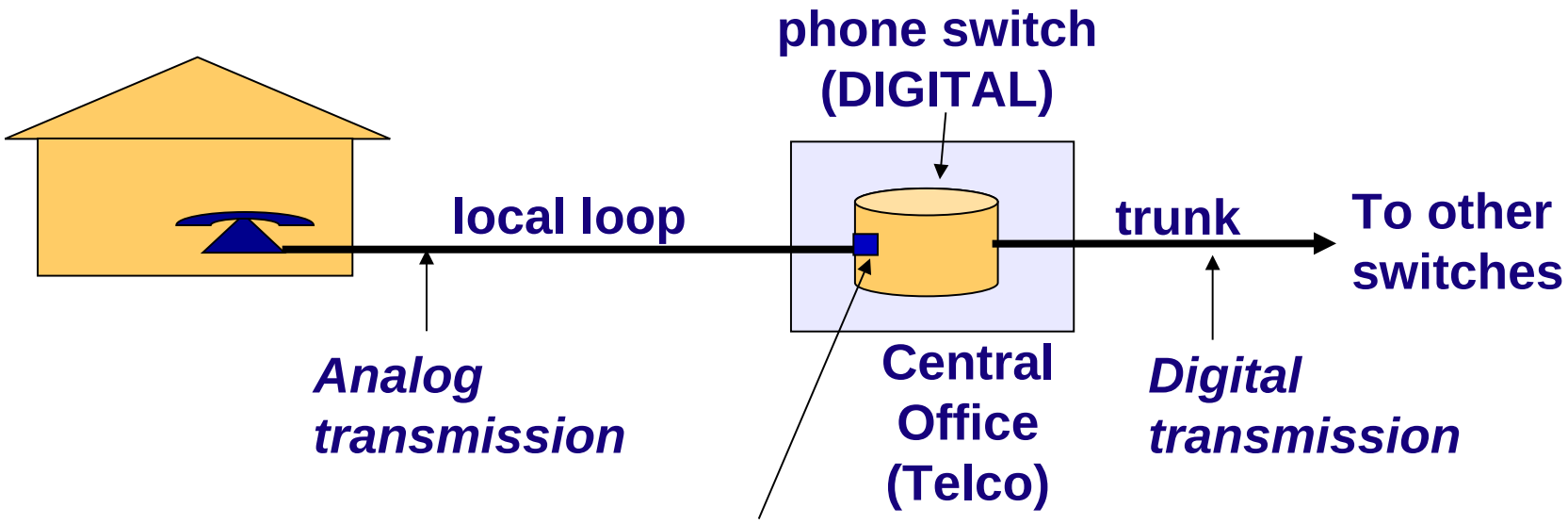
PCM - Pulse Code Modulation



- **DS-0 is the basic digital communications unit used by phone network**
- **DS-0 corresponds to 1 digital voice signal**

convert analog signals to digital data using PCM (similar to PAM)

- **8000 samples per second, and 8 bits per sample**

  → 64 Kb/s (DS-0 rate)

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3.7 Implications for Management

- **Digital is better**
  - **Easier, more manageable, faster, less error prone, and less costly to integrate voice, data, and video**
- **Organizational impact**
  - **Convergence of physical layer causing convergence of phone and data departments**
  - **emerging new technologies such as VoIP accentuate these developments**
- **Impact on telecom industry**
  - **Disappearance of the separation between manufacturers of telephone equipment and manufacturers of data equipment**

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