CSE 5345 – Fundamentals of Wireless Networks

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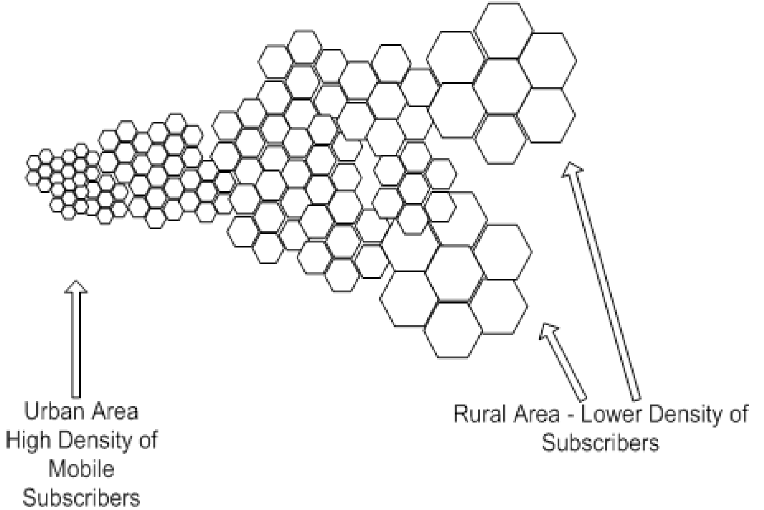
Part I: Basic Knowledge

- Introduction of wireless networks
- Transmission fundamentals
  - Chapters: 1-4
- Next: physical layer communication
  - Chapters: 5-8 (antenna, propagation, coding, etc.)

Overview

- A cell is a physical, geographic area where a particular set of frequencies (channels) serves users, with all adjacent cells using different means to avoid interference
- Cell base stations are capable of handling many simultaneous conversations and serve as the initial access point to the cellular network
- There are many low-power radio transmitter/receivers (called transceivers) located within each base station to support customer's transmissions — whether they be conversations, accessing the Internet, or sending a picture to a friend or relative
- Cells are classified based on morphology: urban, dense urban, suburban and rural
- Cell size can range from a few 100 feet to several miles based on the morphology and/or capacity needs



Cell Site Locations

- Raw land sites
- Rooftop sites
- Water tank sites
- Colocated sites
- Stealth sites
- DAS sites

Cell Site Locations (II)

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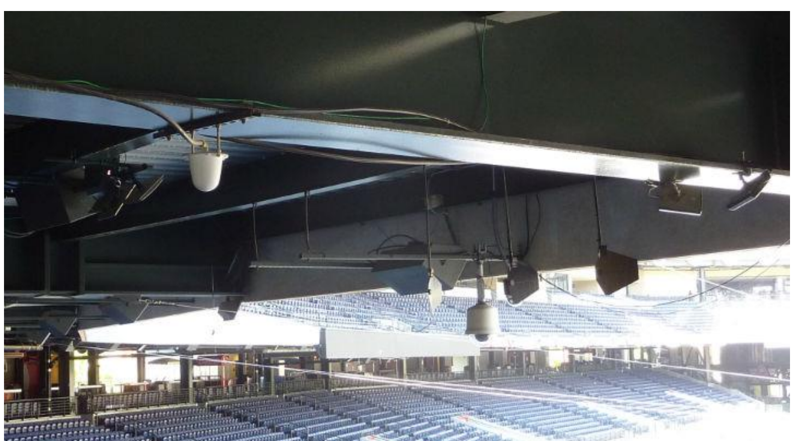
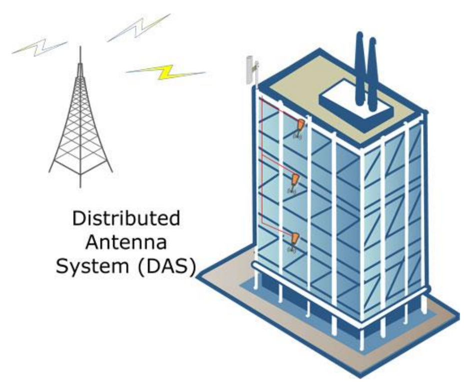


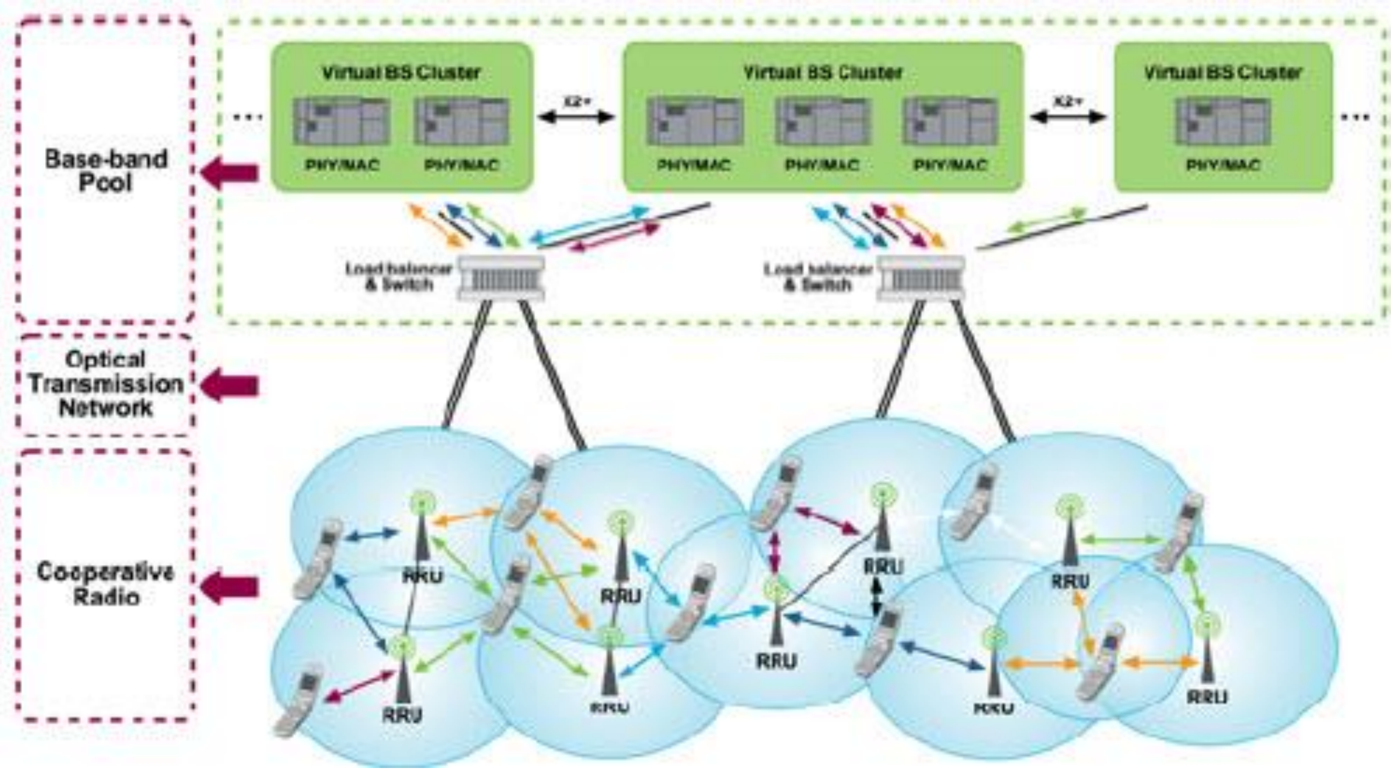


Base Station Shelters

- Shelters look like small huts/cabins and house all the base station equipment. Shelters are also sometimes known as CEV (controlled environmental vault)
- Some cell site deployments use weatherproof base stations that are completely self-contained cabinets
- Now we are testing a new concept: vRAN or virtual radio access network (see next page)

Base Station Shelters---vRAN

- vRAN or virtual radio access network (sometimes aka C-RAN – cloud radio access network)
- However, now CRAN stands for centralized RAN



Ref: http://www.telecom-cloud.net/wp-content/uploads/2011/09/CLou

Cell on Wheels (COWs)

- Fully functioning base stations; may have retractable antennas
- COWs are used to mainly provide temporary capacity relief for different situations, such as:
  - Political conventions
  - Professional sporting events
  - Major, ongoing news events
  - *Any other?*
- Back-haul via satellite/microwave

Microcells and Picocells

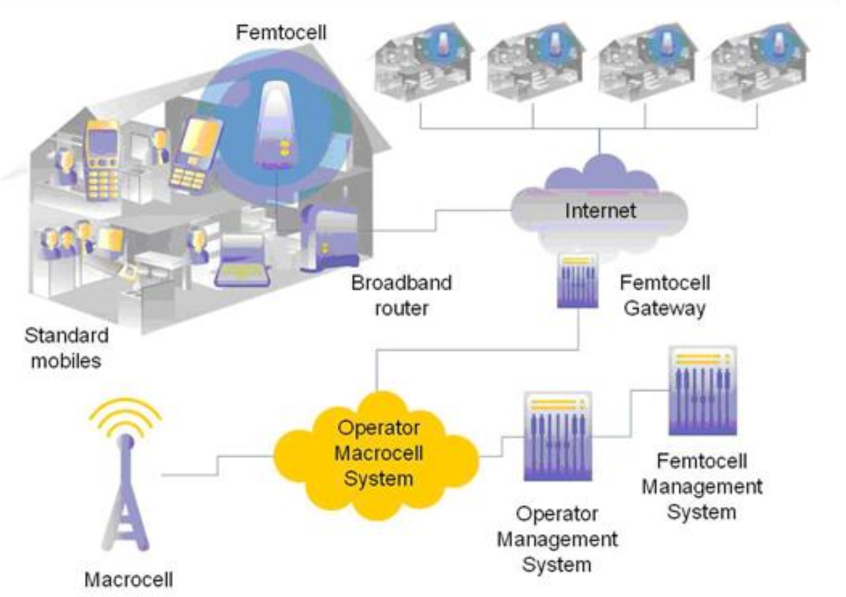
- A microcell is a low-power cell base station designed to serve a relatively small area (1.2 miles or less)
- For residential neighborhoods, office complex or campuses, airports, convention centers
- Lighter and cheaper to install
- *Leaky* coax cable may be used for microcell coverage through a tunnel

Microcells and Picocells (II)

- A picocell is a small mobile base station that improves in-building cellular coverage (200 meters or less)
- Signal can be repeated within the building using repeaters (aka BDAs)
- Lighter and cheaper to install
- Rule of thumb:
  - *Macrocells cover greater than 1,000 meters*
  - *Microcells cover between 100 meters and 1,000 meters*
  - *Picocells cover radius less than 200 meters*

Femtocells

- Small cell base station for use in a home or at a small business (30 feet or less)
- Require broad band connection
- Easy to install (plug-n-play)
- Home version support up to 4 UEs. Enterprise version, 8 to 16 UEs
- Pros
  - *Improved coverage at home (or business)*
  - *Reduced strain on the wireless carrier's*
- Cons
  - *May interfere with macrocell coverage*



Wireless Comes of Age

- Guglielmo Marconi invented the wireless telegraph in 1896
  - Communication by encoding alphanumeric characters in analog signal
  - Sent telegraphic signals across the Atlantic Ocean
- Communications satellites launched in 1960s
- These days, they are ubiquitous
  - Cell phone, notebook, cordless phone, bluetooth, walkie-talkie, etc.

Guglielmo Marconi (1874 – 1937)

Probably the Most Important Application

- Voice support through cellphone
- Martin Cooper (Motorola):
  the first handheld mobile phone (1973)

Cell Phone Spending Surpasses Land Lines
By DIBYA SARKAR – Dec 17, 2007

WASHINGTON (AP) — With Americans cutting the cord to their land lines, 2007 is likely to be the first calendar year in which U.S. households spend more on cell phone services, industry and government officials say…

Broadband Wireless Technology

- Higher data rates can be obtained
  - Graphics, video, audio
  - Tens of kbps to Tens of Mbps
- Shares same advantages of all wireless services: convenience and reduced cost
  - Service can be deployed faster than fixed service
  - No cost of cable plant
  - Service is mobile, deployed almost anywhere

Limitations and Difficulties

- Political difficulty
  - Frequency allocation
  - Standardization
- Technical difficulties
  - Bandwidth/Coverage
  - Device limitations
    - Form factor: e.g., small LCD on a mobile telephone can only displaying limited content
    - Battery: limited time of activities
  - Security
  - …

Chapter 2: Transmission Fundamentals

- Basic overview of transmission topics
- Data communications concepts
  - Includes techniques of analog and digital data transmission
- **Channel capacity**
- Transmission media
- **Multiplexing**

Chapter 3: Communication Networks

- Comparison of basic communication network technologies
  - Circuit switching
  - Packet switching
  - Frame relay
  - ATM

SKIP

Chapter 4: Protocols and the TCP/IP Protocol Suite

- Protocol architecture
- Overview of TCP/IP
- Open systems interconnection (OSI) reference model
- Internetworking

SKIP

Chapter 2: Transmission Fundamentals

Electromagnetic Signal

- Function of time
- Can also be expressed as a function of frequency
  - Signal consists of components of different frequencies

Time-Domain Concepts

- Analog signal
  - Signal intensity varies in a smooth fashion over time
  - No breaks or discontinuities in the signal
- Digital signal
  - signal intensity maintains a constant level for some period of time and then changes to another constant level
- Periodic signal - analog or digital signal pattern that repeats over time
  - $s(t + T) = s(t) \quad -\infty < t < +\infty$
    - where T is the period of the signal

Time-Domain Concepts

- Aperiodic signal
  - Analog or digital signal pattern that doesn't repeat over time
- Random signal
  - Analog or digital signal that is randomly generated and no deterministic algorithm can model it accurately
- Peak amplitude (*A*)
  - Maximum value or strength of the signal over time; typically measured in volts
- Frequency (*f*)
  - Rate, in cycles per second, or Hertz (Hz) at which the signal repeats

Time-Domain Concepts

- Period (T)
  - Amount of time it takes for one repetition of the signal
  - $T = 1/f$
- Phase (ϕ)
  - Measure of the relative position in time within a single period of a signal
- Wavelength (λ)
  - Distance occupied by a single cycle of the signal
  - Or, the distance between two points of corresponding phase of two consecutive cycles

Sine Wave Parameters

- General sine wave
  - $s(t) = A \sin(2\pi f t + \phi)$
- Figure 2.3 shows the effect of varying each of the three parameters
  - (a) $A = 1$, $f = 1$ Hz, $\phi = 0$; thus $T = 1$s
  - (b) Reduced peak amplitude; $A=0.5$
  - (c) Increased frequency; $f = 2$, thus $T = ½$
  - (d) Phase shift; $\phi = \pi/4$ radians (45 degrees)
- note: 2π radians = 360° = 1 period

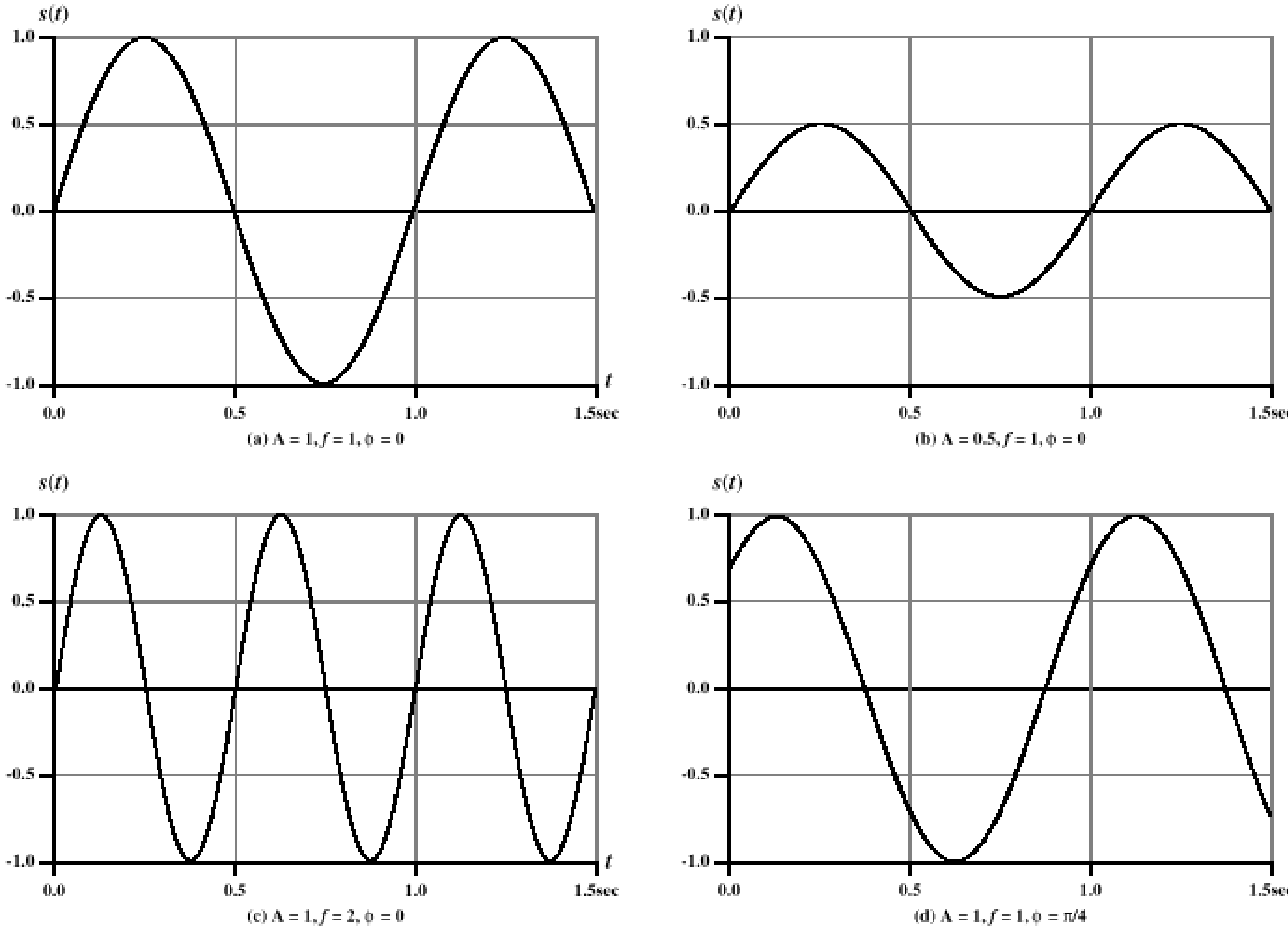


Figure 2.3 $s(t) = A \sin (2\ \ ft + \phi)$

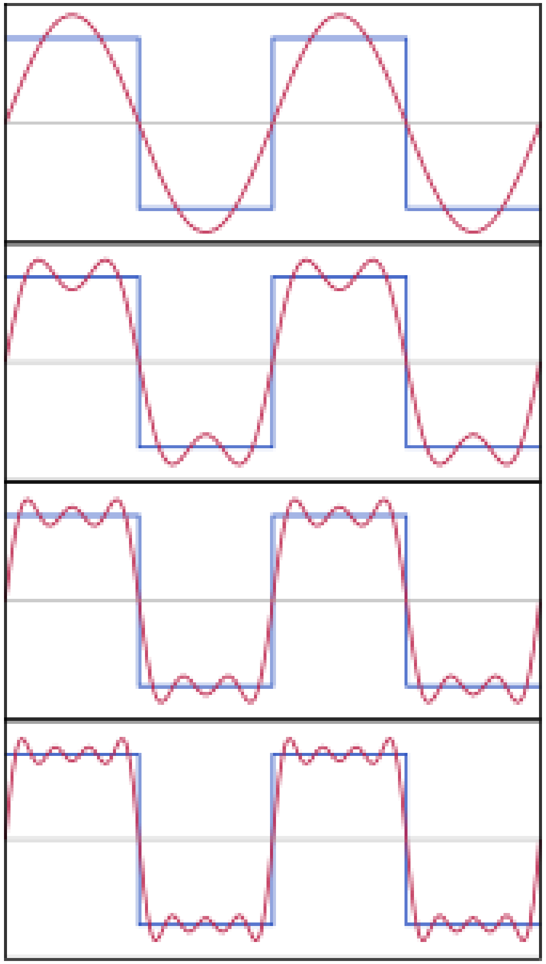
Time vs. Distance

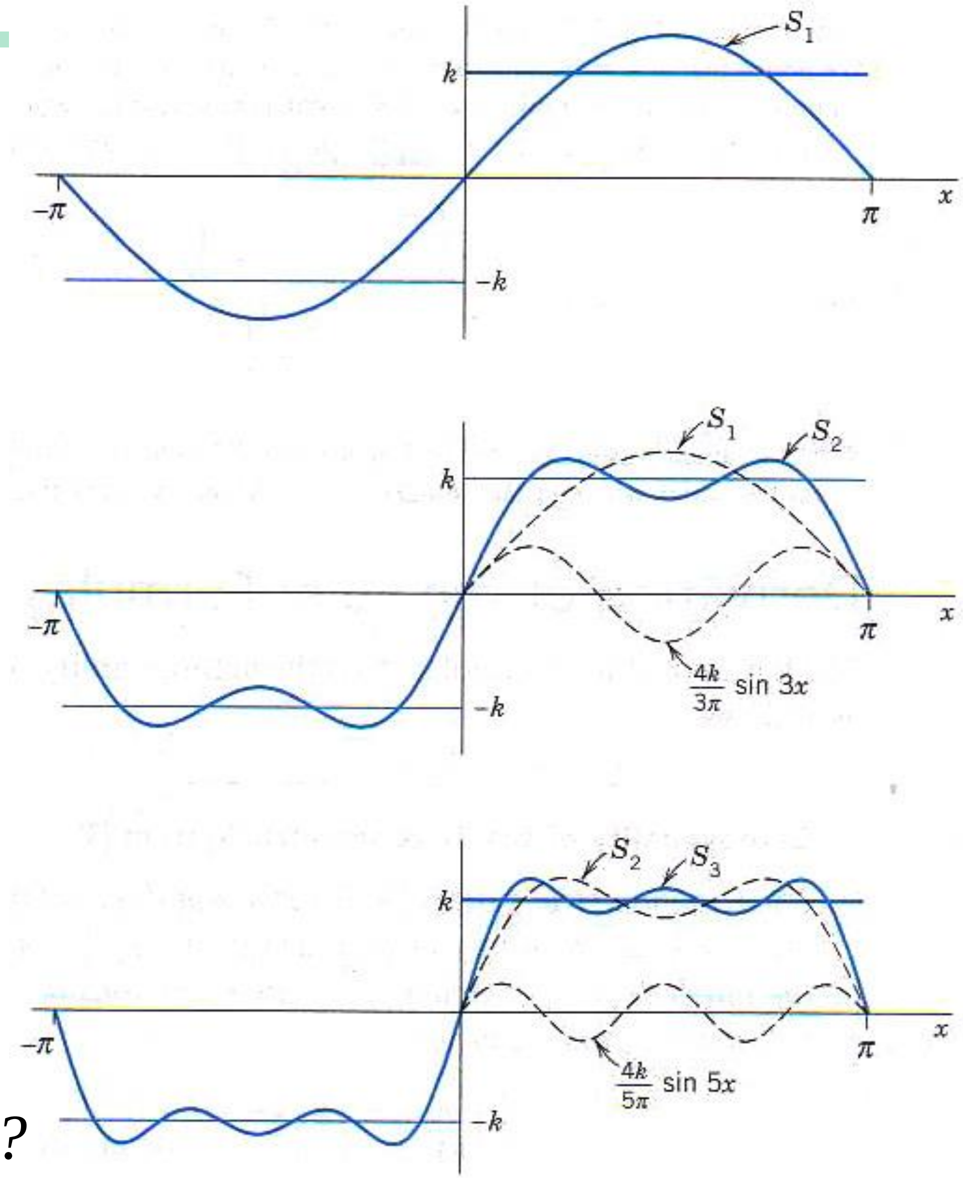
- When the horizontal axis is *time*, as in Figure 2.3, graphs display the value of a signal at a given point in *space* as a function of *time*
- With the horizontal axis in *space*, graphs display the value of a signal at a given point in *time* as a function of *distance*
  - At a particular instant of time, the intensity of the signal varies as a function of distance from the source

Frequency-Domain Concepts

- ***Any*** electromagnetic signal can be shown to consist of a collection of periodic analog signals (sine waves) at different amplitudes, frequencies, and phases
- The period of the total signal is equal to the period of the fundamental frequency

Frequency-Domain Concepts





What is the bandwidth of the signal?

Frequency-Domain Concepts

- Fundamental frequency
  - when all frequency components of a signal are integer multiples of one frequency, it's referred to as the fundamental frequency
- Spectrum
  - Range of frequencies that a signal contains
- Absolute bandwidth
  - Width of the spectrum of a signal
- Effective bandwidth (or just bandwidth)
  - Narrow band of frequencies that most of the signal's energy is contained in

Relationship between Data Rate and Bandwidth

- The greater the bandwidth of a medium (channel), the higher the information-carrying capacity
- Conclusions
  - Any digital waveform will have infinite bandwidth
  - BUT the transmission system will limit the bandwidth that can be transmitted
  - AND, for any given medium, the greater the bandwidth transmitted, the greater the cost
  - HOWEVER, limiting the bandwidth creates distortions

Data Communication Terms

- Data - entities that convey meaning, or information
- Signals - electric or electromagnetic representations of data
- Transmission - communication of data by the propagation and processing of signals

Examples of Analog and Digital Data

- Analog
  - Video
  - Audio
- Digital
  - Text
  - Integers

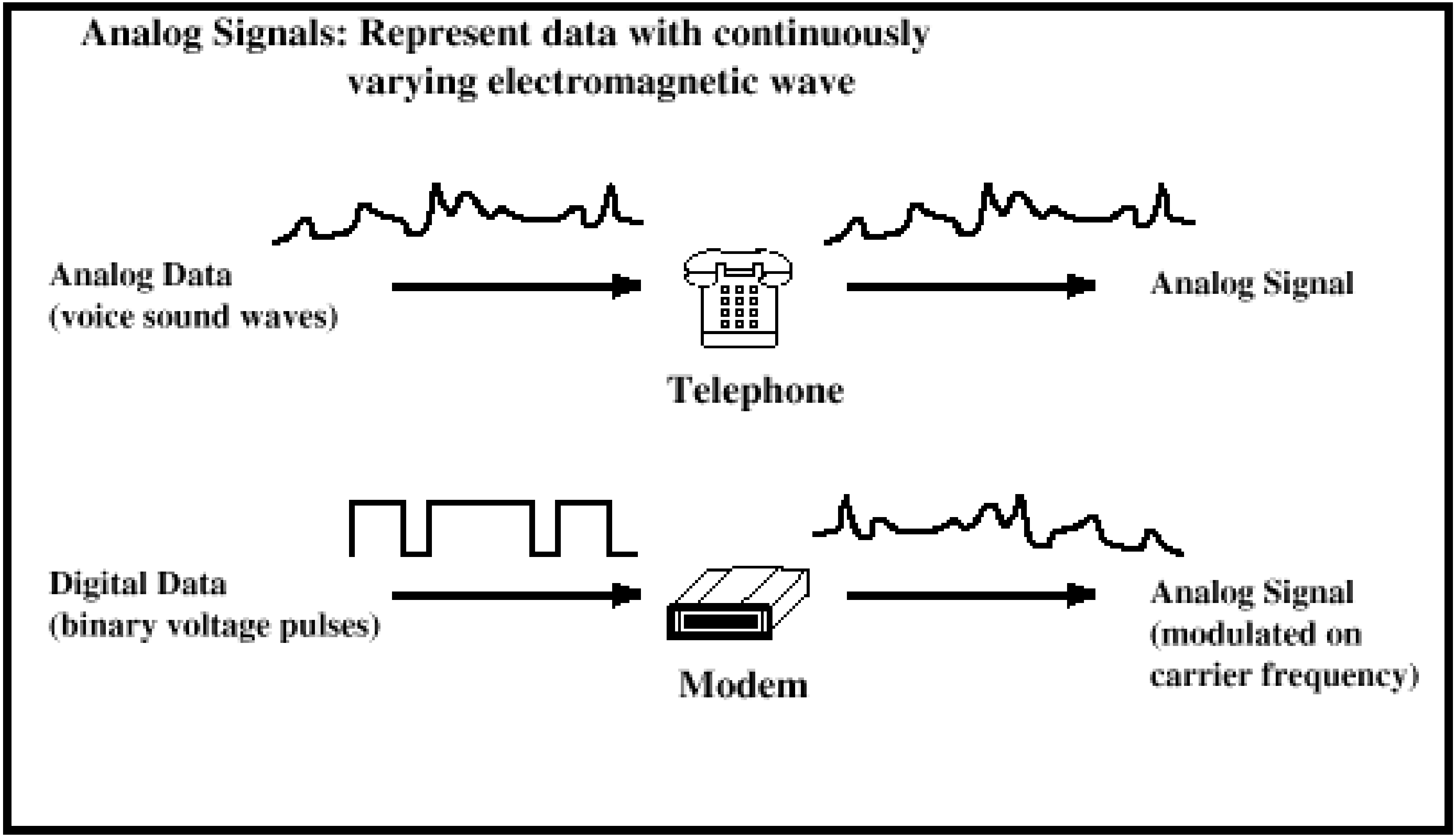
Analog Signals

- A continuously varying electromagnetic wave that may be propagated over a variety of media, depending on frequency
- Examples of media:
  - Copper wire media (twisted pair and coaxial cable)
  - Fiber optic cable
  - Atmosphere or space propagation
- Analog signals can propagate analog and digital data

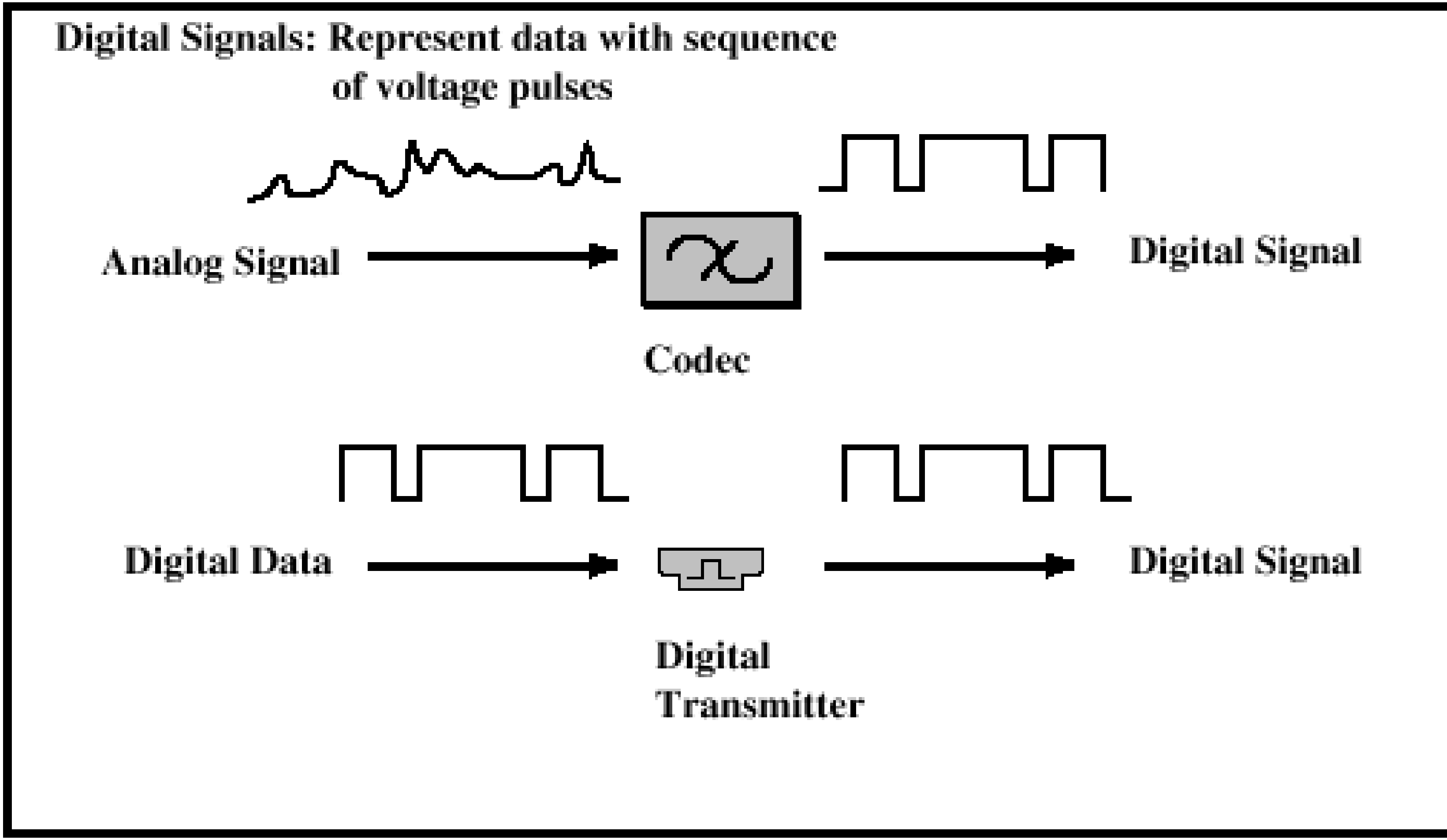
Digital Signals

- A sequence of voltage pulses that may be transmitted over a copper wire medium
- Generally cheaper than analog signaling
- Less susceptible to noise interference
- *Suffer more from attenuation and distortion*
- Digital signals can propagate analog and digital data

Analog Signaling



Digital Signaling



Reasons for Choosing Data and Signal Combinations

- Digital data, digital signal
  - Equipment for encoding is less expensive than any analog equipment
- Analog data, digital signal
  - Conversion permits use of modern digital transmission and switching technologies, like fiber optics
- Digital data, analog signal
  - Some transmission media will only propagate analog signals
  - Examples include free space/air
- Analog data, analog signal
  - Analog data easily converted to analog signal

Analog Transmission

- Transmit analog signals without regard to content
- Attenuation limits length of transmission link
- Cascaded amplifiers boost signal’s energy for longer distances but add noise and distortion
  - Analog data can tolerate distortion
  - Introduces errors in digital data

Digital Transmission

- Concerned with the content of the signal
- Attenuation endangers integrity of data
- Digital Signal
  - Repeaters achieve greater distance
  - Repeaters recover the signal and retransmit
- Analog signal carrying digital data
  - Retransmission device recovers the digital data from analog signal
  - Generates new, clean analog signal

About Channel Capacity

- Impairments, such as noise, limit data rate that can be achieved
- For digital data, to what extent do impairments limit data rate?

- Channel Capacity
  - the ***maximum*** rate at which data can be transmitted over a given communication path, or channel, under given conditions

Concepts Related to Channel Capacity

- Data rate
  - Rate at which data can be communicated (bps)
- Bandwidth
  - Bandwidth of the transmitted signal as constrained by the nature of the transmission medium (Hertz)
- Noise
  - Average level of noise over the communications path
- Error rate
  - rate at which errors occur
  - Error = transmit 1 and receive 0 and vice versa

Nyquist Bandwidth

- For binary signals (two voltage levels)
  - $C = 2B$
- With multilevel signaling
  - $C = 2B \log_2 M$
    - M = number of discrete signal or voltage levels

Harry Nyquist (1889–1976)

This is for noise free channels

Signal-to-Noise Ratio

- Ratio of the power in a signal to the power contained in the noise that's present at a particular point in the transmission
- Typically measured at a receiver
- *Signal-to-noise ratio (SNR, or S/N)*

$$(SNR)_{\text{dB}} = 10\log_{10}\frac{\text{signal power}}{\text{noise power}}$$

- A high SNR means a high-quality signal
- SNR sets upper bound on achievable data rate

Shannon Capacity Formula

- Equation:

$$C = B\log_2\left(1+\text{SNR}\right)$$

- Represents *theoretical* maximum that can be achieved
- In practice, only much lower rates achieved
  - Formula assumes white noise (thermal noise)
  - Impulse noise is not accounted for
  - Attenuation distortion or delay distortion not accounted for

Claude E Shannon (1916 – 2001)

Example of Nyquist and Shannon Formulations

- Spectrum of a channel between 3 MHz and 4 MHz ; SNR_{dB} = 24 dB

$$B = 4\,\text{MHz} - 3\,\text{MHz} = 1\,\text{MHz}$$

$$\text{SNR}_{\text{dB}} = 24\,\text{dB} = 10\log_{10}(\text{SNR})$$

$$\text{SNR} = 251$$

- Using Shannon's formula

$$C = 10^6 \times \log_2(1 + 251) \approx 10^6 \times 8 = 8\text{Mbps}$$

Example of Nyquist and Shannon Formulations

- How many signaling levels are required?

$$C = 2B\log_2 M$$

$$8\times10^6 = 2\times\left(10^6\right)\times\log_2 M$$

$$4 = \log_2 M$$

$$M = 16$$