Chapter 1

INTRODUCTION TO WIRELESS COMMUNICATION SYSTEMS

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How Wireless Technology is Used

- Wireless
  - Describes devices and technologies that are not connected by a wire
- Wireless communications
  - Transmission of user data without the use of wires
- Wireless data communications technologies include:
  - Bluetooth
  - Wireless LAN and WAN
  - Satellite
  - Cellular

A Wireless World

- Wireless devices
  - Bandwidth: 54 Mbps
  - Can also include Voice over IP (VoIP)
- Wireless network interface card (Wireless NIC)
  - Sends and receives data over radio waves
- Smartphone
  - Combination mobile phone and personal digital assistant (PDA)

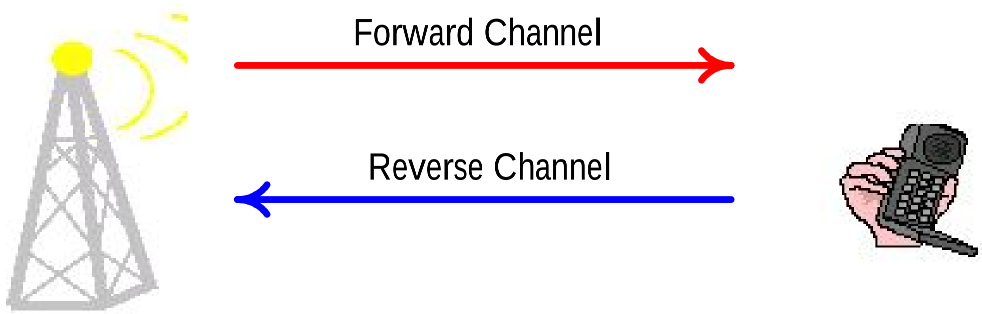
1.1 Evolution of Mobile Radio Communications

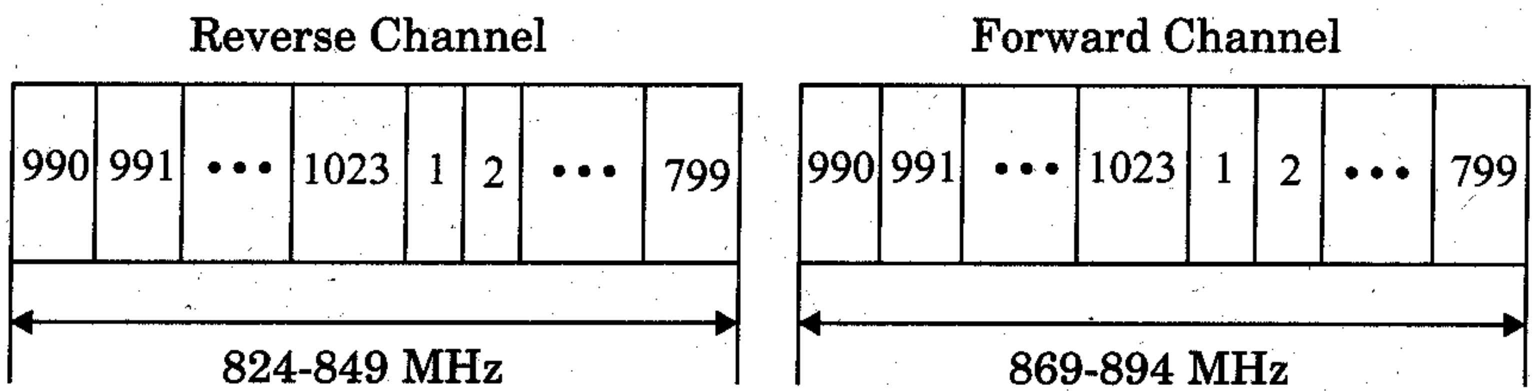
- Major Mobile Radio Systems
  - 1934 - Police Radio uses conventional AM mobile communication system.
  - 1935 - Edwin Armstrong demonstrate FM
  - 1946 - First public mobile telephone service - push-to-talk
  - 1960 - Improved Mobile Telephone Service, IMTS - full duplex
  - 1960 - Bell Lab introduce the concept of Cellular mobile system
  - 1968 - AT&T propose the concept of Cellular mobile system to FCC.
  - 1976 - Bell Mobile Phone service, poor service due to call blocking
  - 1983 - Advanced Mobile Phone System (AMPS), FDMA, FM
  - 1991 - Global System for Mobile (GSM), TDMA, GMSK
  - 1991 - U.S. Digital Cellular (USDC) IS-54, TDMA, DQPSK
  - 1993 - IS-95, CDMA, QPSK, BPSK

1.2 Example of Mobile Radio Systems

- Examples
  - Cordless phone
  - Remote controller
  - Hand-held walkie-talkies
  - Pagers
  - Cellular telephone
  - Wireless LAN
- Mobile - any radio terminal that could be moves during operation
- Subscriber - mobile or portable user

- Classification of mobile radio transmission system
  - Simplex: communication in only one direction
  - Half-duplex: same radio channel for both transmission and reception (push-to-talk)
  - Full-duplex: simultaneous radio transmission and reception (FDD, TDD)
- Frequency division duplexing uses two radio channel
  - Forward channel: base station to mobile user
  - Reverse channel: mobile user to base station
- Time division duplexing shares a single radio channel in time.





	Channel Number	Center Frequency (MHz)
Reverse Channel	$1 \leq N \leq 799$	$0.030N + 825.0$
	$990 \leq N \leq 1023$	$0.030(N - 1023) + 825.0$
Forward Channel	$1 \leq N \leq 799$	$0.030N + 870.0$
	$990 \leq N \leq 1023$	$0.030(N - 1023) + 870.0$

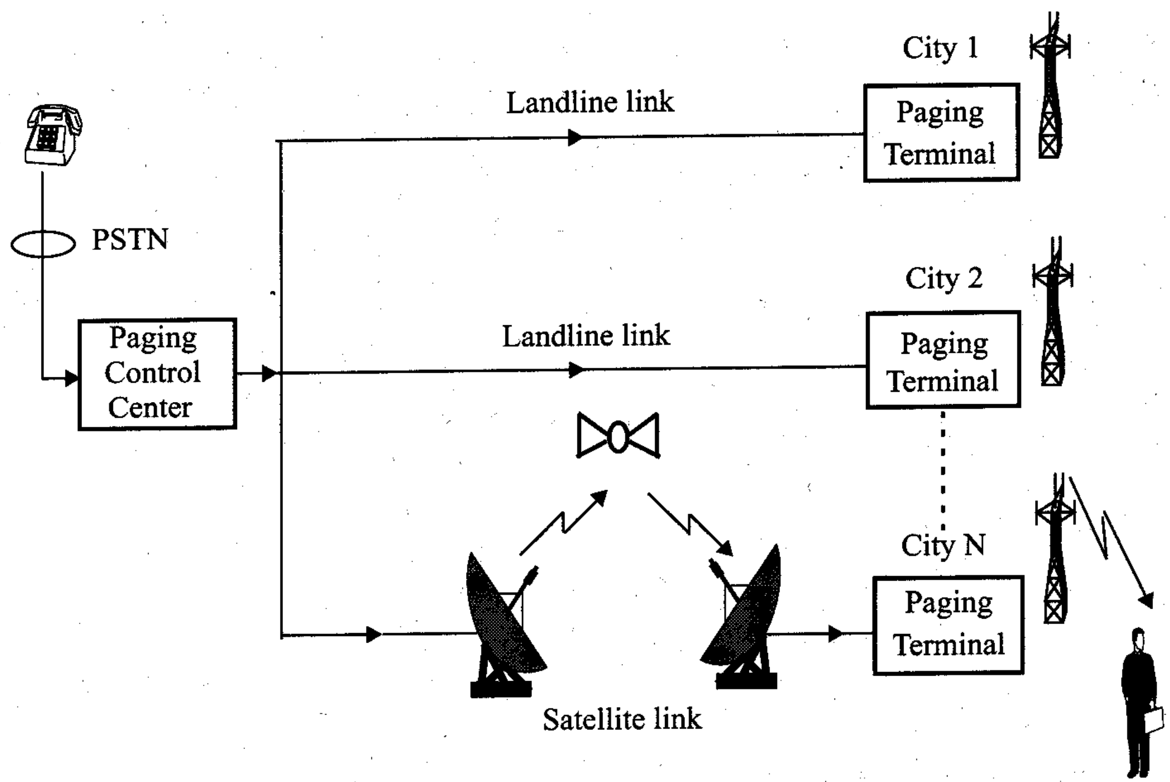
(Channels 800 - 989 are unused)

Figure

Frequency spectrum allocation for the U.S. cellular radio service. Identically labeled channels in the two bands form a forward and reverse channel pair used for duplex communication between the base station and mobile. Note that the forward and reverse channels in each pair are separated by 45 MHz.

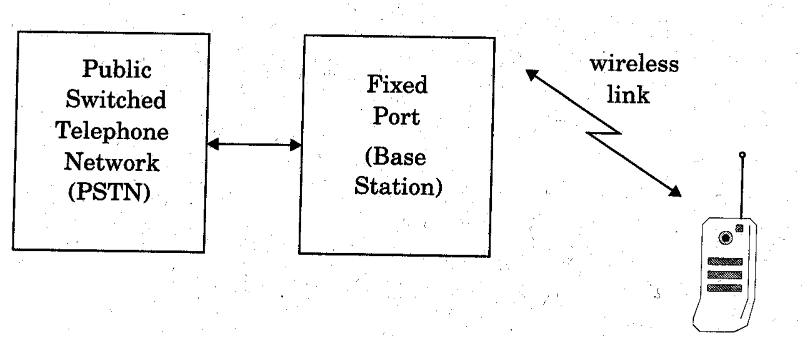
1.2.2 Paging Systems

- Conventional paging system send brief messages to a subscriber
- Modern paging system: news headline, stock quotations, faxes, etc.
- Simultaneously broadcast paging message from each base station (simulcasting)
- Large transmission power to cover wide area.



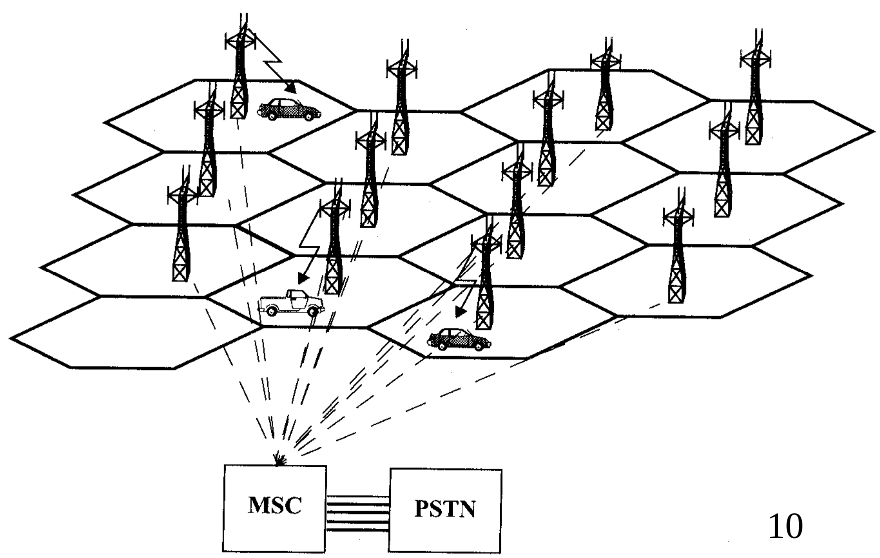
1.2.3 Cordless Telephone System

- Cordless telephone systems are full duplex communication systems.
- First generation cordless phone
  - in-home use
  - communication to dedicated base unit
  - few tens of meters
- Second generation cordless phone
  - outdoor
  - combine with paging system
  - few hundred meters per station



1.2.4 Cellular Telephone Systems

- Provide connection to the PSTN for any user location within the radio range of the system.
- Characteristic
  - Large number of users
  - Large Geographic area
  - Limited frequency spectrum
  - Reuse of the radio frequency by the concept of “cell’’.
- Basic cellular system: mobile stations, base stations(BS), and mobile switching center(MSC).



- Communication between the base station and mobiles is defined by the standard common air interface (CAI)
  - forward voice channel (FVC): voice transmission from base station to mobile
  - reverse voice channel (RVC): voice transmission from mobile to base station
  - forward control channels (FCC): initiating mobile call from base station to mobile
  - reverse control channel (RCC): initiating mobile call from mobile to base station

Satellite Networks

- Used to transmit data over very long distance
- Repeater
  - – Located in the satellite itself
  - – Simply “repeats” the same signal to another location
  - – Used to transmit data from one earth station to another
    - Transmission time is approximately 250 milliseconds

Satellite Networks (continued)

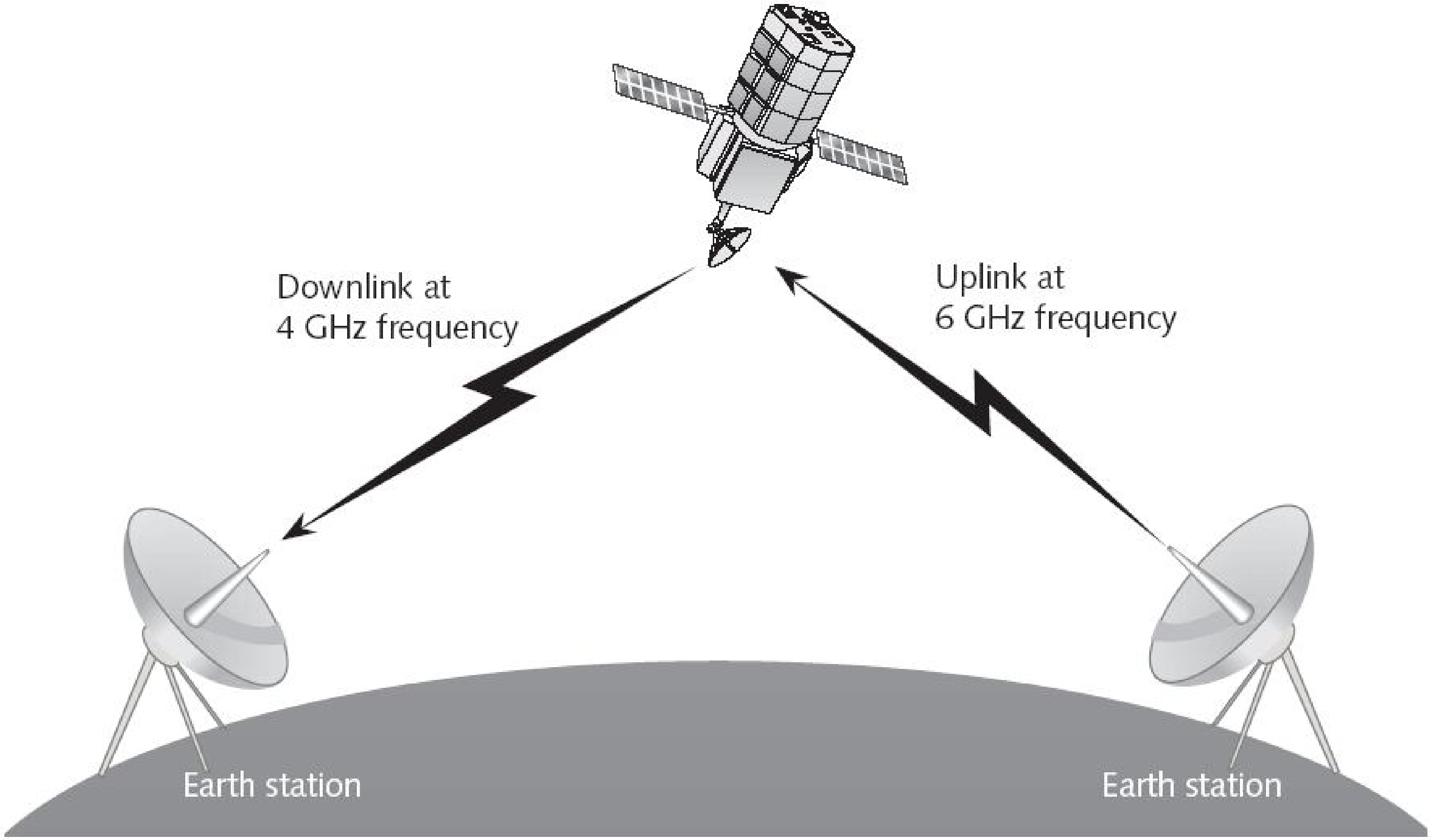


Figure 1-4 A satellite repeats a signal to another Earth station

Wireless Local Area Networks

- Wireless Local Area Network (WLAN)
  - Extension of a wired LAN
    - Connecting to it through a device called a wireless access point
- Access point (AP)
  - Relays data signals between all of the devices in the network
- Each computer on the WLAN has a wireless network interface card (NIC)
  - With an antenna built into it

Wireless Local Area Networks (continued)

- Institute of Electrical and Electronic Engineers (IEEE) standards
  - 802.11a, 802.11b, and 802.11g

Examples

Cellular Phone
- Allocated spectrum
- First generation:
  - 800, 900 MHz
  - Initially analog voice
- Second generation:
  - 1800-1900 MHz
  - Digital voice, messaging

Wireless LAN
- Unlicenced ISM spectrum
  - Industrial, Scientific, Medical
  - 902-928 MHz, 2.400-2.4835 GHz, 5.725-5.850 GHz
- IEEE 802.11 LAN standard
  - 11-54 Mbps

Point-to-Multipoint Systems
- Directional antennas at microwave frequencies
- High-speed digital communications between sites
- High-speed Internet Access Radio backbone links for rural areas

Satellite Communications
- Geostationary satellite @ 36000 km above equator
- Relays microwave signals from uplink frequency to downlink frequency
- Long distance telephone
- Satellite TV broadcast

Wireless Applications

- Main areas
  - Education
  - Home entertainment
  - Health Care
  - Government and Military
  - Office environments
  - Event management
  - Travel
  - Construction and warehouse management
  - Environmental research
  - Industrial control

Wireless Advantages and Disadvantages

- As with any new technology, wireless communications offers both advantages and disadvantages

Advantages of Wireless Networking

- Mobility
  - Freedom to move about without being tethered by wires
  - Permits many industries to shift toward an increasingly mobile workforce
  - Gives team-based workers the ability to access the network resources
- Easier and less expensive installation
  - Installing network cabling in older buildings can be a difficult, slow, and costly task

Advantages of Wireless Networking (continued)

- Increased reliability
  - Network cable failures may be the most common source of network problems
- Disaster recovery
  - In the event of a disaster, managers can quickly relocate the office

Disadvantages of Wireless Networking

- Radio signal interference
  - The potential for two types of signal interference exists
- Security

➢ -With the intent of intercepting the signals from a nearby wireless network

-Some wireless technologies can provide added levels of security

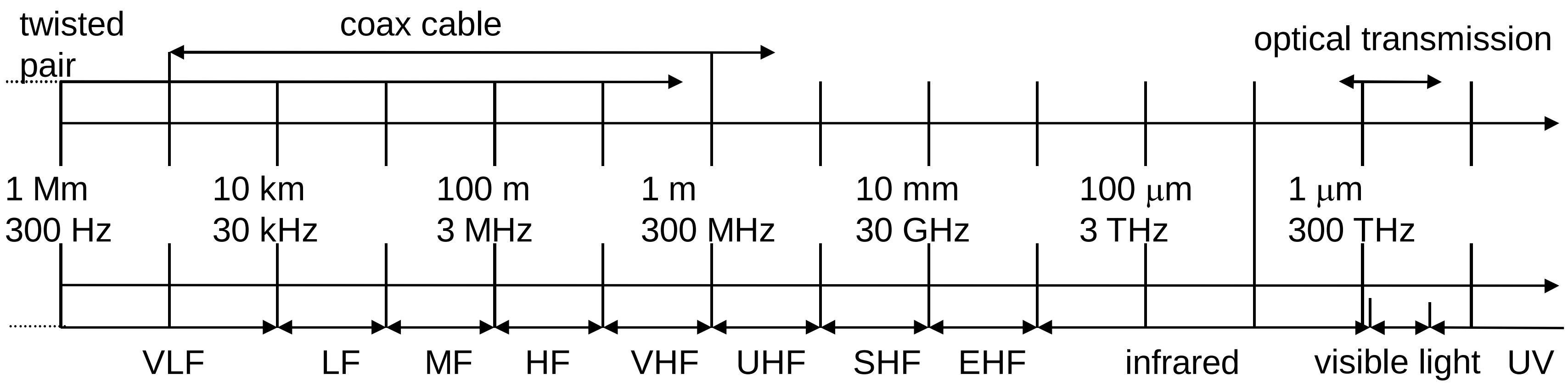
Disadvantages of Wireless Networking (continued)

- Health risks
  - High levels of RF can produce biological damage through heating effects
    - Wireless devices emit low levels of RF while being used

Factors affecting wireless system design

- Frequency allocations
  - What range to operate? May need licenses.
- Multiple access mechanism
  - How do users share the medium without interfering?
- Antennas and propagation
  - What distances? Possible channel errors introduced.
- Signals encoding
  - How to improve the data rate?
- Error correction
  - How to ensure that bandwidth is not wasted?

Frequencies for communication



- VLF = Very Low Frequency
- LF = Low Frequency
- MF = Medium Frequency
- HF = High Frequency
- VHF = Very High Frequency

UHF = Ultra High Frequency
SHF = Super High Frequency
EHF = Extra High Frequency
UV = Ultraviolet Light

- Frequency and wave length: $\lambda = c/f$
- wave length λ, speed of light $c \cong 3\text{x}10^8$m/s, frequency f

Wireless frequency allocation

- Radio frequencies range from 9KHz to 400GHZ (ITU)

- Microwave frequency range
  - 1 GHz to 40 GHz
  - Directional beams possible
  - Suitable for point-to-point transmission
  - Used for satellite communications
- Radio frequency range
  - 30 MHz to 1 GHz
  - Suitable for omnidirectional applications
- Infrared frequency range
  - Roughly, $3x10^{11}$ to $2x10^{14}$ Hz
  - Useful in local point-to-point multipoint applications within confined areas

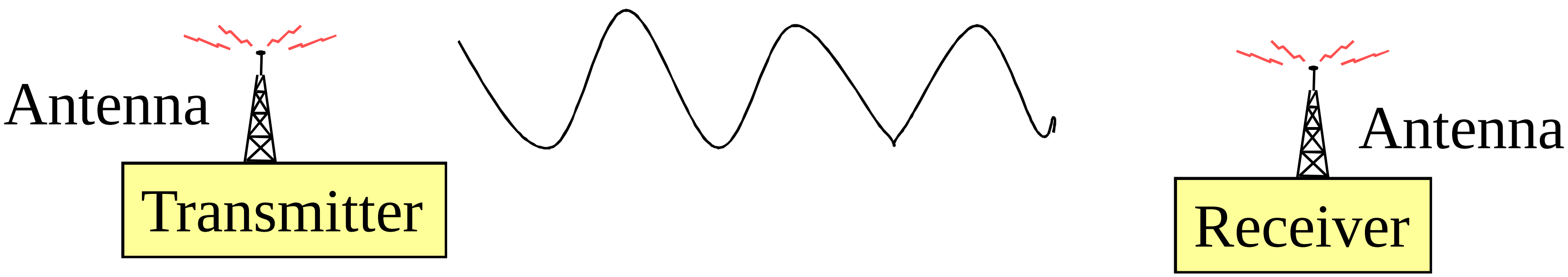
Frequencies for mobile communication

- VHF-/UHF-ranges for mobile radio
  - simple, small antenna for cars
  - deterministic propagation characteristics, reliable connections
- SHF and higher for directed radio links, satellite communication
  - small antenna, focusing
  - large bandwidth available
- Wireless LANs use frequencies in UHF to SHF spectrum
  - some systems planned up to EHF
  - limitations due to absorption by water and oxygen molecules (resonance frequencies)
    - weather dependent fading, signal loss caused by heavy rainfall etc.

Frequency regulations

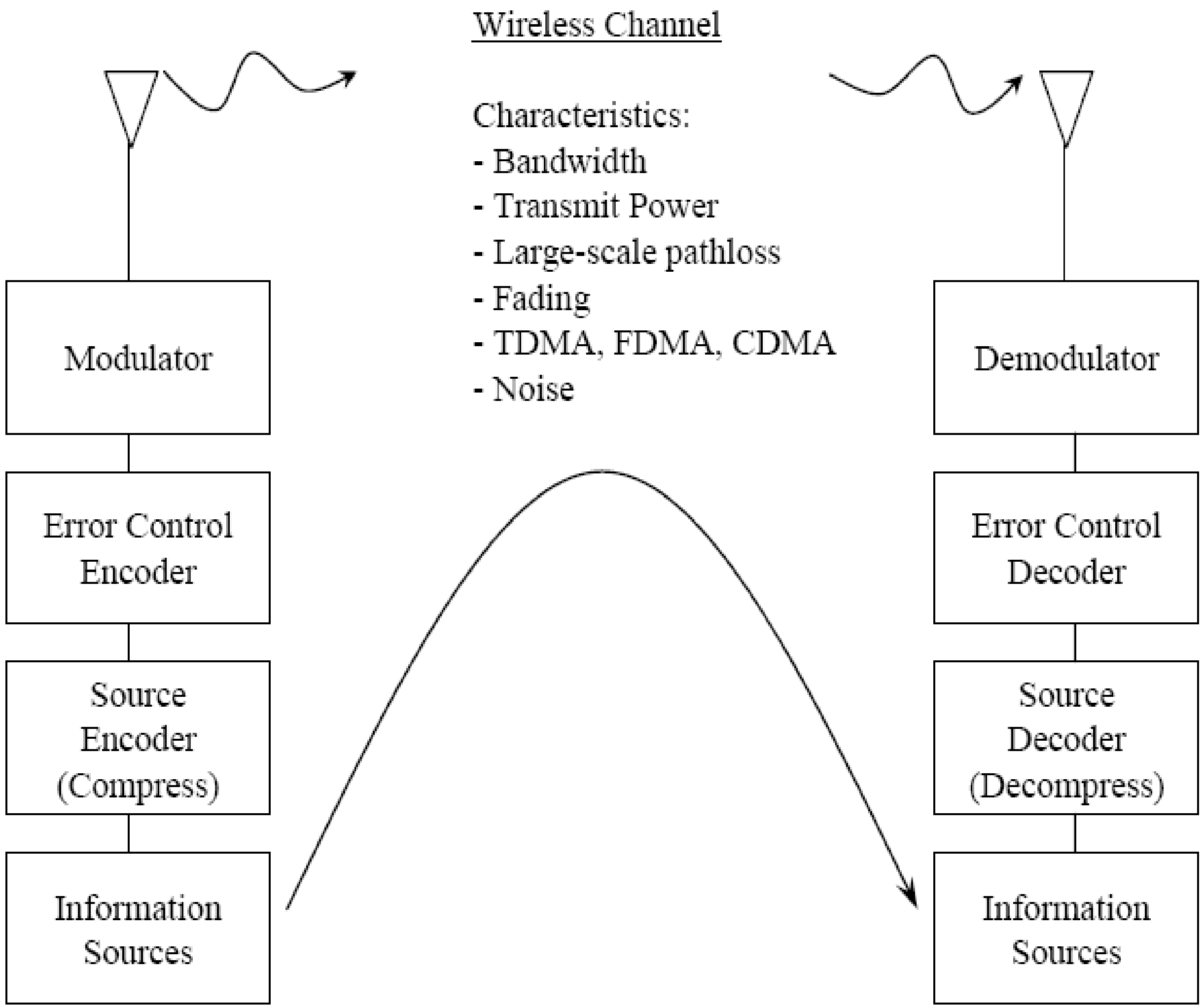
- Frequencies from 9KHz to 300 MHZ in high demand (especially VHF: 30-300MHZ)
- Two unlicensed bands
  - Industrial, Science, and Medicine (ISM): 2.4 GHz
  - Unlicensed National Information Infrastructure (UNII): 5.2 GHz
- Different agencies license and regulate
  - www.fcc.gov - US
  - www.etsi.org - Europe
  - www.wpc.dot.gov.in - India
  - www.itu.org - International co-ordination
- Regional, national, and international issues
- Procedures for military, emergency, air traffic control, etc

Wireless transmission



- Wireless communication systems consist of:
  - Transmitters
  - Antennas: radiates electromagnetic energy into air
  - Receivers
- In some cases, transmitters and receivers are on same device, called transceivers.

Here is a picture of the overall wireless transmission and receiving system:



- Modulation: Encoding information in a baseband signal and then translating (shifting) signal to much higher frequency prior to transmission
  - Message signal is detected by observing baseband to the amplitude, frequency, or phase of the signal.
  - Our focus is modulation for mobile radio.
  - The primary goal is to transport information through the mobile radio channel (MRC) with the **best quality** (low BER), **lowest power** & **least amount of frequency spectrum**
    - Must make tradeoffs between these objectives.

Cont..

- Must overcome difficult impairments introduced by MRC:
  - Fading/multipath
  - Doppler Spread
  - Adjust channel interference (ACI) & co channel interference (CCI)
- Challenging problem of ongoing work that will likely be ongoing for a long time.
  - Since every improvement in modulation methods increases the efficiency in the usage of highly scarce spectrum.

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 - the bandwidth of the transmitted signal as constrained by the transmitter and 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; transmit 0 and receive 1

Channel Bandwidth

- The bandwidth of a channel (medium) is defined to be the range of frequencies that the medium can support. Bandwidth is measured in Hz
- The bandwidth (in Hz) of the channel dictates the information carrying capacity of the channel (in bps)
- Calculated using:
  - Nyquist bit rate (noiseless channel)
  - Shannon's channel capacity formula (noisy channel)

Channel Capacity

- The bit rate of a channel increases with an increase in the number of bits we use to denote a signal element (symbol)
- A signal element can consist of a single bit or "n" bits
- The number of signal elements M= 2^n

Nyquist Bandwidth

- Nyquist gives the upper bound for the bit rate of a transmission system by calculating the bit rate directly from the number of bits in a signal element and the bandwidth of the system
- Nyquist theorem states that for a noiseless channel:

$$C = 2\,B \log_2 M$$

C= capacity in bps

B = bandwidth in Hz

Example

1. Consider a noise less channel with a band width of 3000Hz transmitting a signal with two signal elements. The maximum bit rate can be calculated as:

$$\text{BitRate} = 2 \times 3000 \times \log_2 2 = 6000 \text{ bps}$$

2. If the signal has four signal elements, the bit rate can be calculated as:

$$\text{BitRate} = 2 \times 3000 \times \log_2 4 = 12{,}000 \text{ bps}$$

Cont…

3. We need to send 280 kbps over a noise less channel with a band width of 20kHz. How many signal elements do we need?

Solution

We can use the Nyquist formula as shown:

$$C = 2\ B \log_2 M$$

$$280000 = 2*20000 \log M$$

$$M = 128 \text{ levels}$$

Signal-to-Noise Ratio (SNR)

- Real communication have some measure of noise.
- Shannon's theorem tells us the limits to a channel's capacity (in bits per second) in the presence of noise.
- Shannon's theorem uses the notion of signal-to-noise ratio (SNR or S/N) ,which is usually expressed in decibels (dB):

$$dB = 10 \times \log_{10}(S/N)$$

- SNR is the ratio of the strength (energy) of the signal to the strength (energy) of the noise

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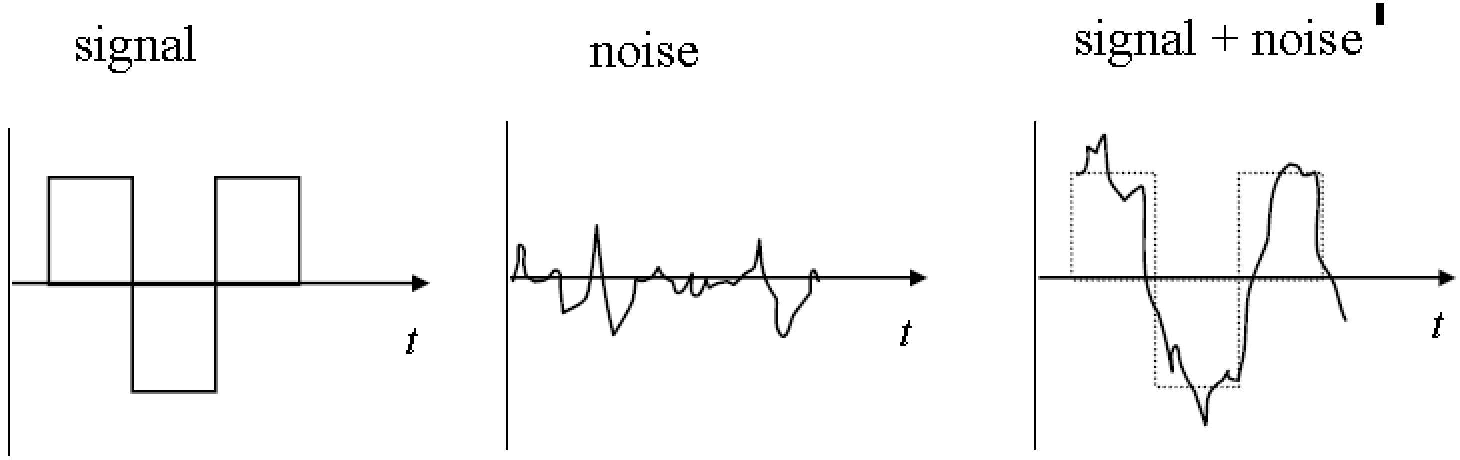

$$\text{SNR} = \frac{\text{Average Signal Power}}{\text{Average Noise Power}}$$

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

Example

1000W of signal power versus 20W of noise power is:
1000/20=50
In DB 10 log10 1000/20 = 16.9897 dB

Shannon's Theorem

$$C = B\log_2(1+(S/N))$$

Note that the log is base 2!

C: achievable channel rate (bps)

B: channel bandwidth (Hz)

S/N (unitless, not in dB)

$$dB = 10 \times \log_{10}(S/N)$$

$$S/N = 10^{dB/10}$$

SNR in decibels

SNR unitless

Example

- Consider an extremely noisy channel in which the value of the signal-to noise ratio is almost zero. In other words, the noise is so strong that the signal is faint. For this channel the capacity C is calculated as

$$C = B \log_2 (1 + \text{SNR}) = B \log_2 (1 + 0) = B \log_2 1 = B \times 0 = 0$$

- This means that the capacity of this channel is zero regardless of the band width. In other words, we can not receive any data through this channel

Example

- We can calculate the theoretical highest bit rate of a regular telephone . A telephone normally has a band width of 3000Hz. The signal-to-noise ratio is usually 3162. For this channel the capacity is calculated as

$$C = B \log_2 (1 + \text{SNR}) = 3000 \log_2 (1 + 3162) = 3000 \log_2 3163$$
$$= 3000 \times 11.62 = 34{,}860 \text{ bps}$$

- This means that the highest bit rate for a telephone line is 34.860kbps.
- What if we want to send data faster than this?
- We can either (a) increase the band width or (b)improve the signal-to-noise ratio

Example

- The spectrum of the channel is between 3 MHz and 4 MHz. The SNR for this channel is 63. What are the appropriate bit rate and signal elements?

Solution

B = 4 MHz –3 MHz = 1MHz

First, we use the Shannon formula to find the upper limit.

$$C = B \log_2 (1 + \text{SNR}) = 10^6 \log_2 (1 + 63) = 10^6 \log_2 64 = 6 \text{ Mbps}$$

Free-space Path-loss

- Power of wireless transmission reduces with square of distance (due to surface area increase of sphere)
- Reduction also depends on wavelength
  - Long wave length (low frequency) has less loss
  - Short wave length (high frequency) has more loss

$$P_L = \left(\frac{4\pi D}{\lambda} \right)^2$$

Free-space Path-loss in DB

$L = 20 \log_{10} (4\pi D / \lambda)$

where:

D = the distance between receiver and transmitter

λ = free space wavelength = c/f

c = speed of light (3×10^8 m/s)

f = frequency (Hz)

Or $L = (P_t/P_r)$

Measured in dB(decibel) = 10 log (Pt/P_r)

Example

1. Calculate free space path loss in decibels incurred by a 10 gigahertz wave over a distance of 10 kilometers.
2. Under a free space path loss model, find the transmit power required to obtain a received power of -30 dBw for a wireless system and a carrier frequency f = 5 GHz, assuming a distance d = 10m. Repeat for d = 100m.