SC/CSE 3213 Winter 2014

# L10: Physical Media Properties

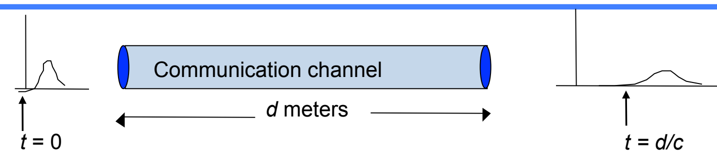
Sebastian Magierowski
York University



## Outline

- Key characteristics of physical media
- Wired
- Wireless
- Optical

# Fundamental Issues in Transmission Media

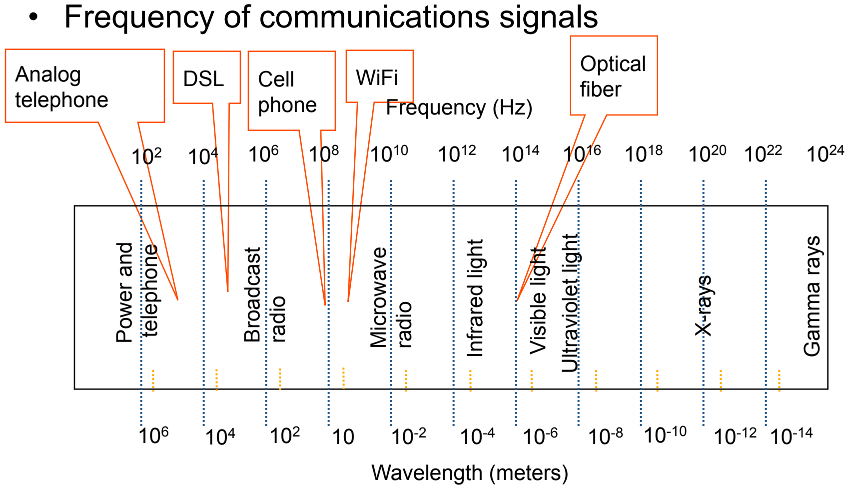



- Information bearing capacity
  - Amplitude response & bandwidth
    - dependence on distance
  - Susceptibility to noise & interference
    - Error rates & SNRs
- Propagation speed of signal
  - $c = 3 \times 10^8$ meters/second in vacuum
  - $v = c/\sqrt{\varepsilon}$ speed of light in medium
    - $\varepsilon > 1$ is the dielectric constant of the medium
    - $v = 2.3 \times 10^8$ m/sec in copper wire
    - $v = 2.0 \times 10^8$ m/sec in optical fiber



# Communications Systems & EM Spectrum

- Frequency of communications signals



## Wireless & Wired Media

**Wireless Media**

- Signal energy propagates in space, limited directionality
- Interference possible, so spectrum regulated
- Limited bandwidth
- Simple infrastructure: antennas & transmitters
- No physical connection between network & user
- Users can move

**Wired Media**

- Signal energy contained & guided within medium
- Spectrum can be re-used in separate wires (more scalable)
- Extremely high bandwidth
- Complex infrastructure: ducts, conduits, poles, right-of-way

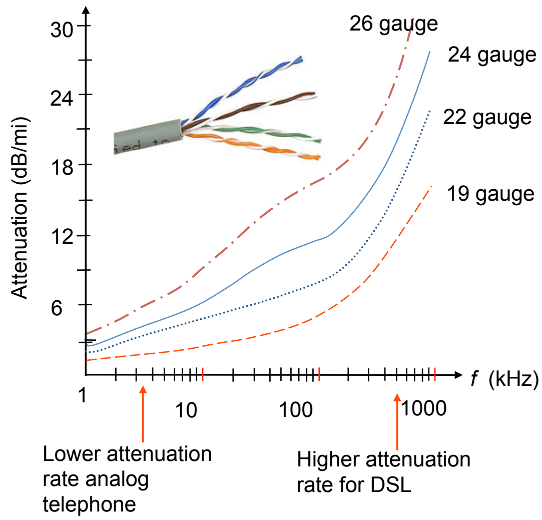


## Attenuation

- Attenuation varies with media
  - Dependence on distance of central importance
- Wired media attn. has *exponential function of distance*
  - Received power at *d* meters proportional to $10^{-kd}$
  - Attenuation in dB is $k \cdot d$, where *k* is dB/meter
- Wireless media attn. has *power function of distance*
  - Received power at *d* meters proportional to $d^{-n}$
  - Attenuation in dB is $n \log d$, where *n* is path loss exponent
    - $n=2$ in free space
  - Signal level maintained for much longer distances
  - Space communications possible

# Twisted Pair

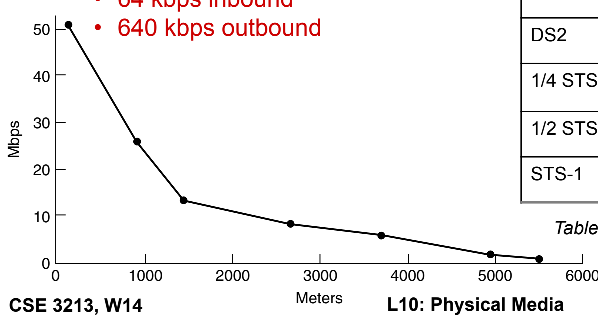
- Two insulated copper wires arranged in a spiral pattern to minimize interference
- Various thicknesses, e.g. 0.016 inch (24 gauge)
- Low cost
- Telephone subscriber loop from customer to CO
- Intra-building telephone from wiring closet to desktop
- In old installations, loading coils added to improve quality in 3 kHz band, but more attenuation at higher frequencies






# Twisted Pair Bit Rates

- Twisted pairs provide high bit rates at short distances
- Asymmetric Digital Subscriber Loop (ADSL)
  - High-speed Internet Access
  - Lower 3 kHz for voice
  - Upper band for data
    - 64 kbps inbound
    - 640 kbps outbound



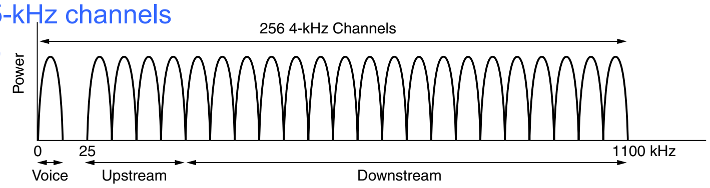

- Much higher rates possible at shorter distances
  - Strategy is to bring fiber close to home & then twisted pair
  - Higher-speed access + video

| Standard | R (Mbps) | Distance |
|---|---|---|
| T-1 | 1.544 | 18,000 feet, 5.5 km |
| DS2 | 6.312 | 12,000 feet, 3.7 km |
| 1/4 STS-1 | 12.960 | 4500 feet, 1.4 km |
| 1/2 STS-1 | 25.920 | 3000 feet, 0.9 km |
| STS-1 | 51.840 | 1000 feet, 300 m |

*Table 3.5 Data rates of 24-gauge twisted pair*

## ADSL Signals

- Telephone wire has ~1-MHz reasonable bandwidth
  - 3-kHz voice bandwidth created by load coils
- ADSL divides into channels
  - 256, 4.3125-kHz channels
  - OFDM (4G)

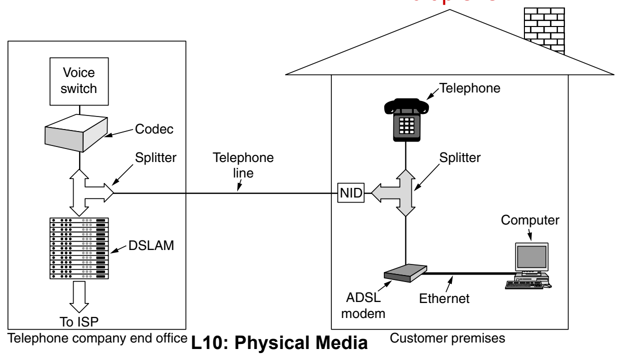



  - Typically 32 for upstream and 218 for downstream
    - ADSL2: 1 Mbps upstream and 12 Mbps downstream
    - 4000 symbols/s per channel
    - 1-15 bits per symbol depending on SNR



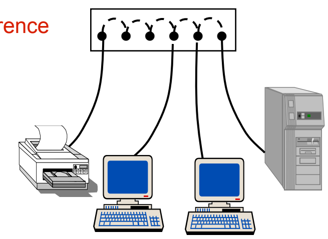
## ADSL Arrangement

- Splitter combines voice and data
  - NID: Network Interface Device
  - Applies necessary filtering to isolate them
- At company office voice and data split
  - DSLAM aggregates customer data and sends to ISP
    - Digital Subscriber Line Access Multiplexer



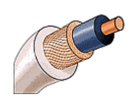
# Ethernet LANs

- Office building telephone wires a great candidate for LANs
- Several categories have been defined…
  - Cat3 UTP: ordinary telephone wires
  - Cat5 UTP: tighter twisting to improve signal quality
  - STP: metallic braid around each pair
    - to minimize interference
    - costly
    - Cat7
- 10BASE-T Ethernet
  - 10 Mbps
    - Two Cat3 pairs
    - Manchester coding, 100 meters
- 100BASE-T4 Fast Ethernet
  - 100 Mbps
    - Four Cat3 pairs
    - Three pairs for one direction at-a-time
    - 100/3 Mbps per pair;
    - 8B10B line code, 100 meters

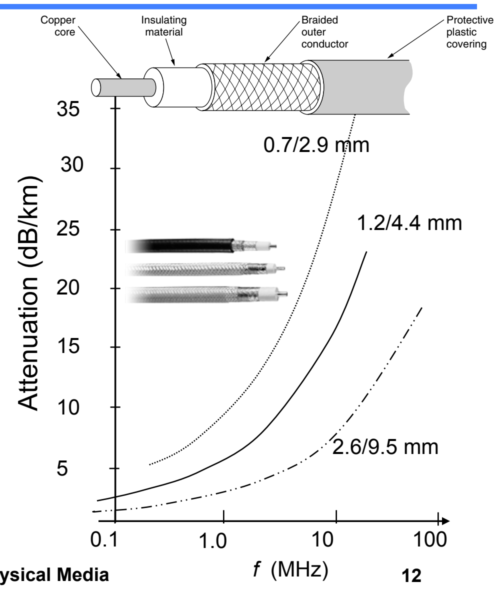




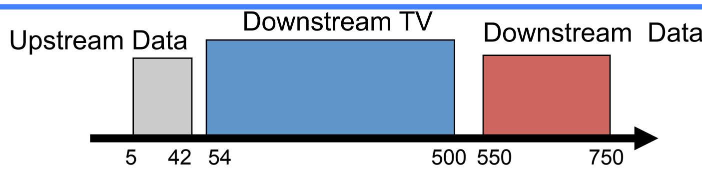
# Coaxial Cable



- Cylindrical braided outer conductor surrounds insulated inner wire
- High interference immunity
- Higher bandwidth than twisted pair
- Hundreds of MHz
- Cable TV distribution
- Long distance telephone transmission
- Original Ethernet LAN medium



# Cable Modem & TV Spectrum

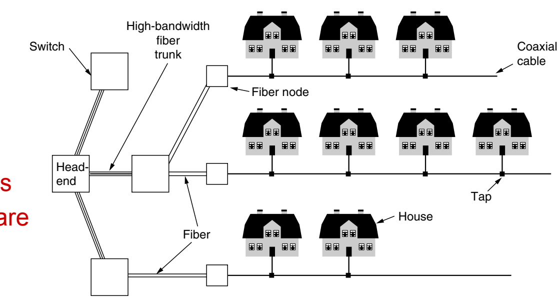


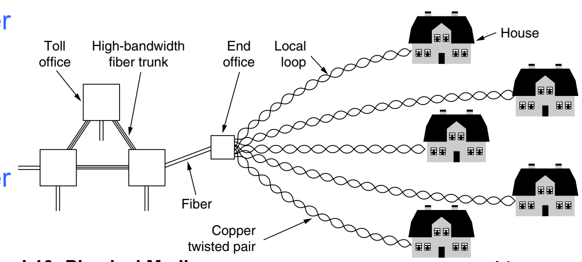

- Cable TV network originally unidirectional
  - 54-500 MHz TV service
    - 6 MHz = 1 analog TV channel or several digital TV channels
- Cable Modem: shared upstream & downstream
  - Open DOCSIS standard
  - 5 – 42 MHz upstream into network
    - 2 MHz channels
    - 500 kbps to 4 Mbps
  - > 550 MHz downstream from network
    - 6 MHz channels
    - 36 Mbps



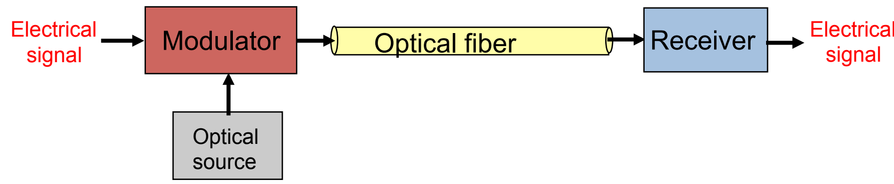
# Cable/DSL Network Topology

- Cable
  - Users share medium
    - Managed by “Head-end”
    - FDMA: 6-MHz channels
    - TDMA: Users get minislots
    - CDMA/ALOHA: Users share minislots
    - 500-2000 users per cable
  - Data aggregated on fiber
- DSL
  - No sharing
    - But lower quality link
  - Data aggregated on fiber



## Optical Fiber

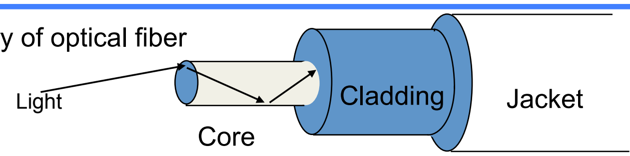



- Light sources (lasers, LEDs) generate pulses of light that are transmitted on optical fiber
  - Very long distances (>1000 km)
  - Very high speeds (>40 Gbps/wavelength)
  - Nearly error-free (BER of $10^{-15}$)
- Profound influence on network architecture
  - Dominates long distance transmission
  - Distance less of a cost factor in communications
  - Plentiful bandwidth for new services

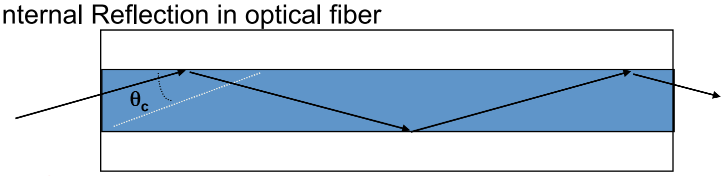


## Transmission in Optical Fiber

Geometry of optical fiber



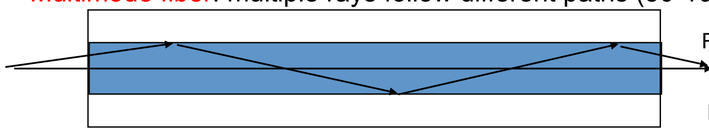

Total Internal Reflection in optical fiber



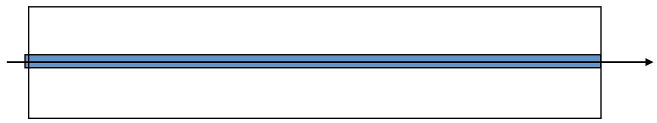

- Very fine glass cylindrical core surrounded by concentric layer of glass (cladding)
- Core has higher index of refraction than cladding
- Light rays incident at less than critical angle $\theta_c$ is completely reflected back into the core

## Multimode & Single-Mode Fiber

Multimode fiber: multiple rays follow different paths (50-100 um diameter)




Single-mode fiber: only direct path propagates in fiber (8-10 um diameter)



- Multimode: Thicker core, shorter reach
  - Rays on different paths interfere causing dispersion & limiting bit rate
- Single mode: Very thin core supports only one mode (path)
  - More expensive lasers, but achieves very high speeds
    - 100 Gbps for 100 km without amplification



## Fiber Connections

- Connectors
  - Fiber sockets

- Mechanical splicing
  - Align two cut pieces closely in a sleeve and clamp together
  - 10% light loss

- Fused (melted) together
  - Fusion splice

# Optical Fiber Properties

## Advantages

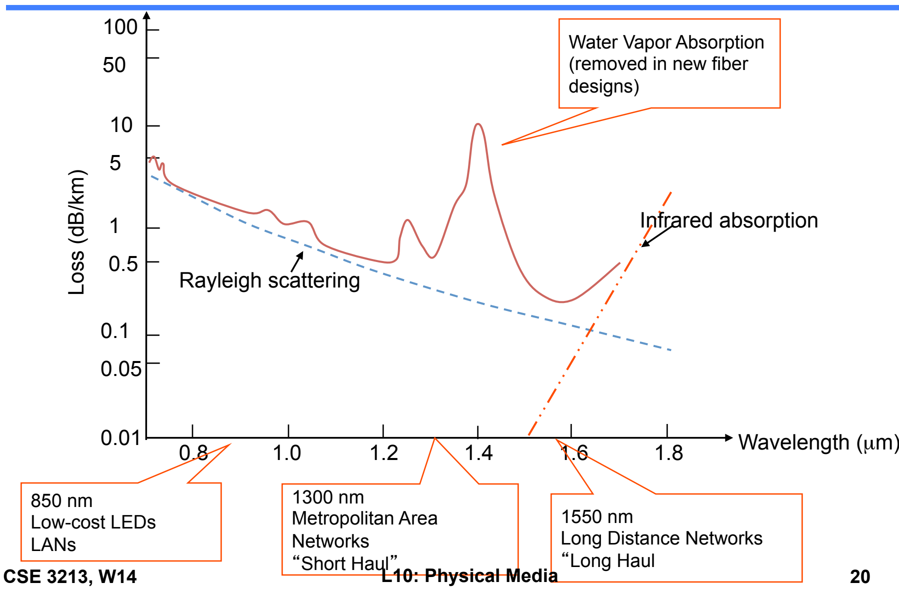
- ***Very low attenuation***
- ***Noise immunity***
- ***Extremely high bandwidth***
- Security: Very difficult to tap without breaking
- No corrosion
- More compact & lighter than copper wire

## Disadvantages

- New types of optical signal impairments & dispersion
  - Polarization dependence
  - Wavelength dependence
- Limited bend radius
  - If physical arc of cable too high, light lost or won't reflect
  - Will break
- Difficult to splice
- Mechanical vibration becomes signal noise



# Very Low Attenuation



## Huge Available Bandwidth

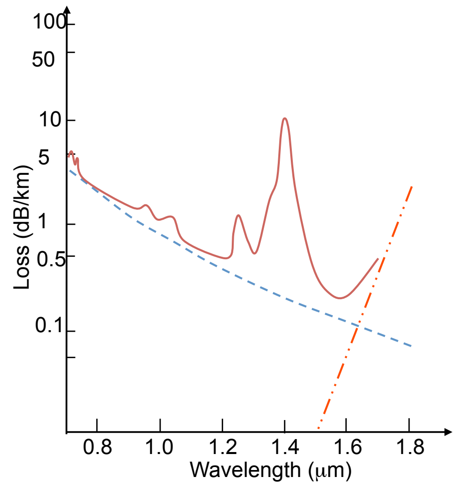
- Optical range from $\lambda_1$ to $\lambda_1 + \Delta\lambda$ contains bandwidth

$$B = f_1 - f_2 = \frac{v}{\lambda_1} - \frac{v}{\lambda_1 + \Delta\lambda}$$

$$= \frac{v}{\lambda_1}\left\{\frac{\Delta\lambda / \lambda_1}{1 + \Delta\lambda / \lambda 1}\right\} \approx \frac{v\,\Delta\lambda}{\lambda_1^2}$$

- Example: $\lambda_1$ = 1450 nm $\lambda_1 + \Delta\lambda$ =1650 nm:

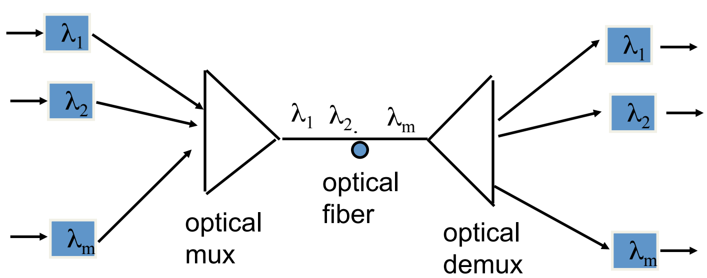
$$B = \frac{2(10^8)\text{m/s } 200\text{nm}}{(1450\text{ nm})^2} \approx 19\text{ THz}$$



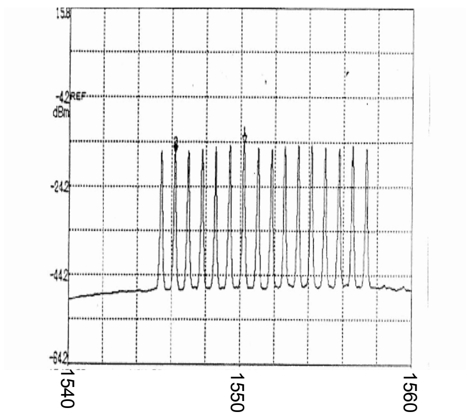



## Wavelength-Division Multiplexing

- Different wavelengths carry separate signals
- Multiplex into shared optical fiber
- Each wavelength like a separate circuit
  - 192 channels • 10 Gbps = 1.92 Tbps
  - 64 channels • 40 Gbps = 2.56 Tbps



# Coarse & Dense WDM




**Coarse WDM**

- Few wavelengths 4-18 with very wide spacing (~20 nm)
- Low-cost, simple

**Dense WDM**

- Many tightly-packed wavelengths
- ITU Grid: 0.8 nm separation for 10 Gbps signals
- 0.4 nm for 2.5 Gbps

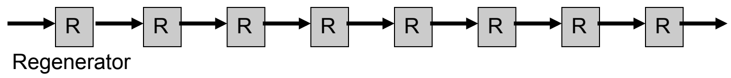


# Regenerators & Optical Amplifiers

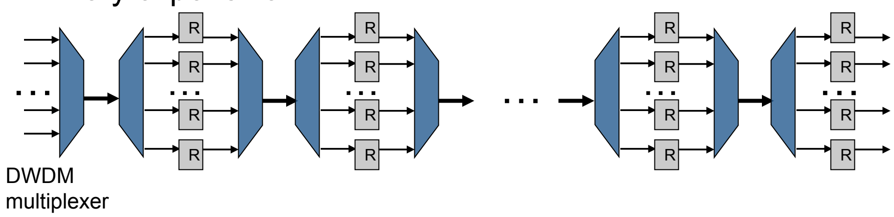
- The maximum span of an optical signal is determined by the available power & the attenuation:
  - Ex. If 30 dB power available,
  - then at 1550 nm, optical signal attenuates at 0.25 dB/km,
  - so max span = 30 dB/0.25 km/dB = 120 km
- Optical amplifiers amplify optical signal (no equalization, no regeneration)
- Impairments in optical amplification limit maximum number of optical amplifiers in a path
- Optical signal must be regenerated when this limit is reached
  - Requires optical-to-electrical (O-to-E) signal conversion, equalization, detection and retransmission (E-to-O)
  - Expensive
- Severe problem with WDM systems

## DWDM & Regeneration

- Single signal per fiber requires 1 regenerator per span



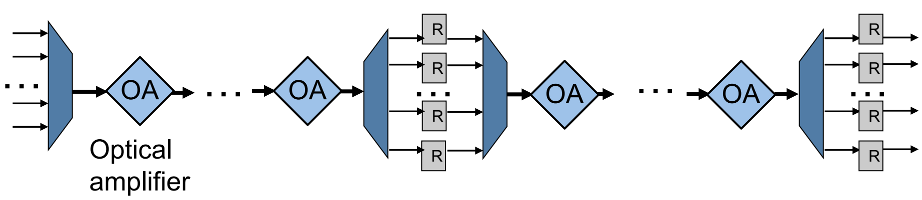

- DWDM system carries many signals in one fiber
- At each span, a separate regenerator required per signal
- Very expensive






## Optical Amplifiers

- Optical amplifiers can amplify the composite DWDM signal without demuxing or O-to-E conversion
- Erbium Doped Fiber Amplifiers (EDFAs) boost DWDM signals within 1530 to 1620 range
  - Spans between regeneration points >1000 km
  - Number of regenerators can be reduced dramatically
- Dramatic reduction in cost of long-distance communications

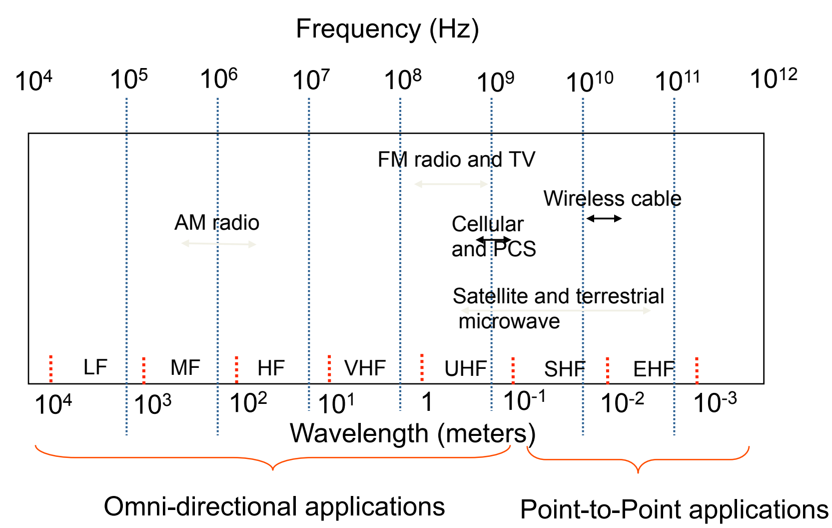


## Radio Transmission

- Radio signals: antenna transmits sinusoidal signal ("carrier") that radiates in air/space
- Information embedded in carrier signal using modulation, e.g. QAM
- Communications without tethering
  - Cellular phones, satellite transmissions, Wireless LANs
- Multipath propagation causes fading
- Interference from other users
- Spectrum regulated by national & international regulatory organizations



## Radio Spectrum



# Examples

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

## Wireless LAN
- Unlicensed 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