EEE 432
Introduction to Data Communications

Asst. Prof. Dr. Mahmut AYKAÇ

TRANSMISSION MEDIA

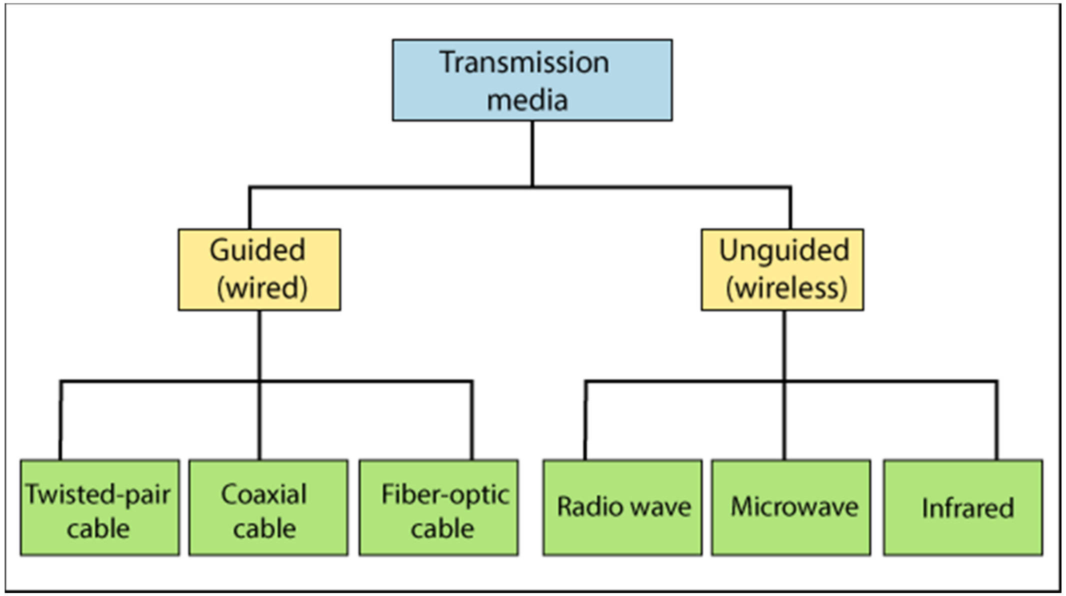
Course Information

1. Data Communications and Networks
2. Data Transmission
3. **Transmission Media**
4. Signal Encoding Techniques
5. Digital Data Communication Techniques
6. Multiplexing
7. Networking and Protocol Architectures
8. Switching
9. Routing in Switched Networks
10. LANs and WANs
11. Ethernet
12. The Internet

Transmission Media

Transmission media is a communication channel that carries the information from the sender to the receiver.

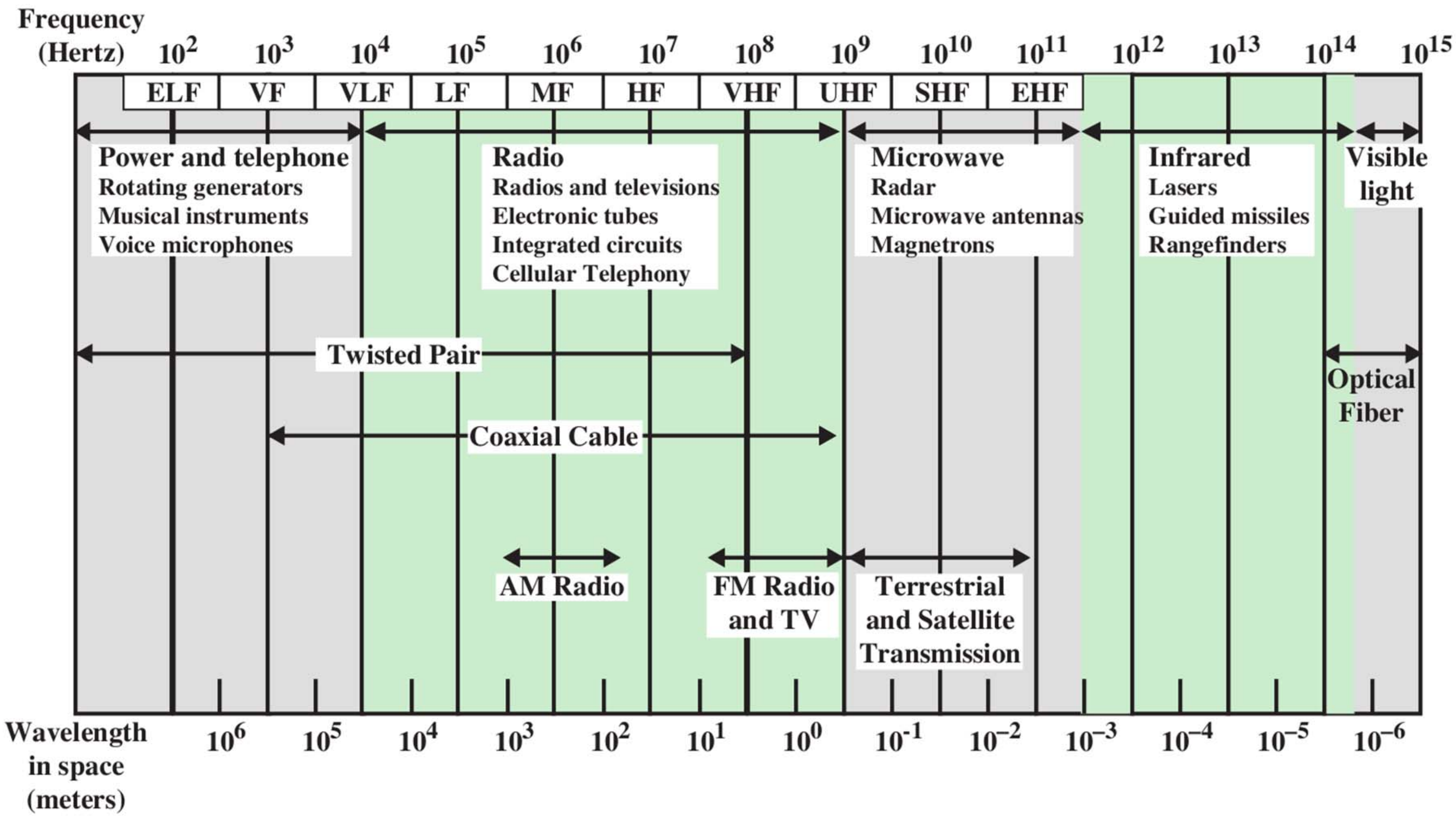
We go through wired and wireless or guided and unguided media.



Design Factors

- The factors that we need to consider when we are choosing a technology our computers together.
- Key concerns are **data rate** and **distance**: maximize both
- Design factors:
  - Bandwidth
  - Transmission impairments
  - Interference
  - Number of receivers

Electromagnetic Spectrum for Telecommunications



Guided Media → Electrical Cables

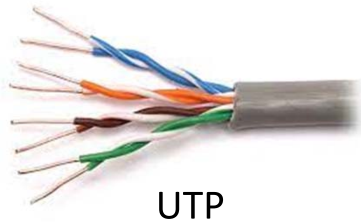
- Transmit electrical signals on a conductor, e.g. copper
- Cable carrying electrical current radiates energy, and can pick-up energy from other sources
  - Can cause interference on other cables
  - Other sources can cause interference on the cable
  - Interference results in poor quality signals being received
- To minimise interference:
  - Keep the cable lengths short
  - Keep the cables away from other sources
  - Design the cables to minimize radiation and pick-up
    - Use materials to shield from interference
    - Organise multiple wires so they don't interfere with each other

Twisted Pair

- Two insulated copper wires arranged in spiral pattern
- The reason to twist them is when the electrical current is sent along the pair’s that they effectively cancel each other’s electromagnetic field effect.
- Most commonly used and least expensive medium
  - Used in telephone networks and in-building communications
  - Telephone networks designed for analog signalling (but supporting digital data)
  - Also used for digital signalling
- Two varieties of twisted pair: shielded (STP) and unshielded (UTP); also multiple categories (CAT5)
- Cheap, relatively easy to find and use, supports moderate data rates.
- Shielding helps to get less interference therefore less errors.

—Separately insulated
—Twisted together
—Often "bundled" into cables
—Usually installed in building during construction

(a) Twisted pair

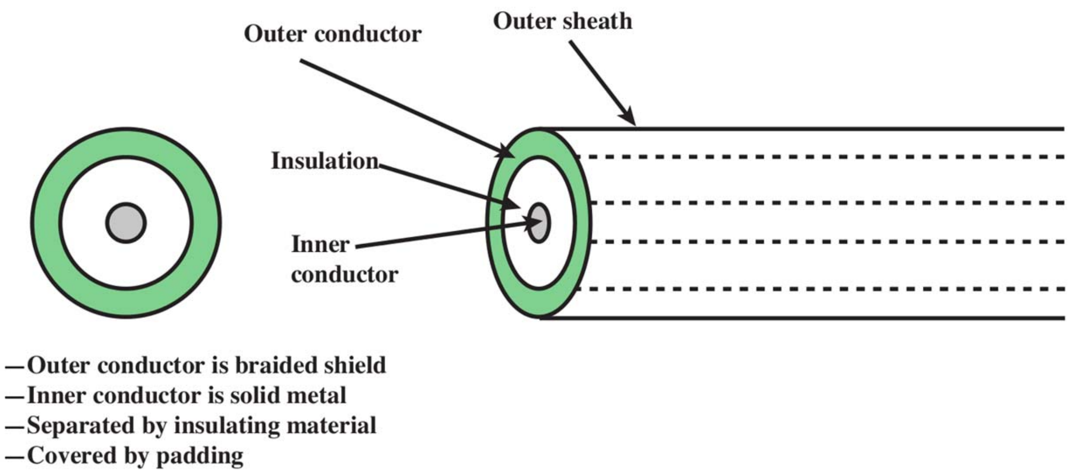


UTP

STP

Coaxial Cable

- Two conductors, one inside the other
- Provide much more shielding from interference than twisted pair: Higher data rates; More devices on a shared line; Longer distances.
- Widely used for cable TV, as well as other audio/video cabling
- Used in long-distance telecommunications, although optical fibre is more relevant now
- Compared to twisted pair, a bit more expensive and harder to deal with.

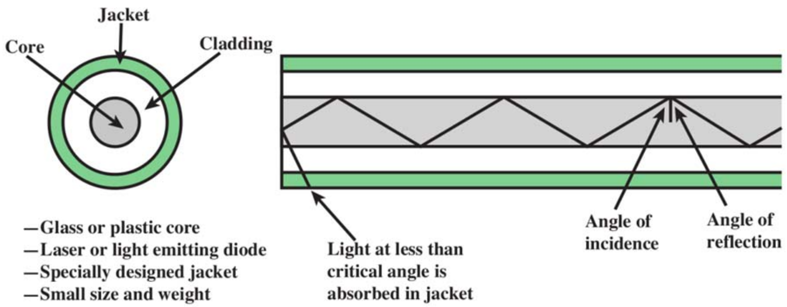


(b) Coaxial cable

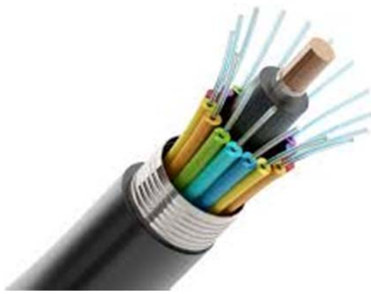

Coaxial cable for satellite TV

Optical Fiber

- Light (optical rays) is guided within glass or plastic fibres. Not an electrical signal.
- Used in long-distance telecommunications (across the cities and even between the countries), as well as telephone systems, LANs, and city-wide networks. They are also used in the data centers where there are a lot of servers which require very high data rates.
- Advantages of optical fiber over electrical cables:
  - 1. Lower loss: can transfer larger distances
  - 2. Higher bandwidth: a single fibre is equivalent to 10's or 100's of electrical cables
  - 3. Small size, light weight: lowers cost of installation
  - 4. Electromagnetic isolation, which yields no interferences from other electrical sources



(c) Optical fiber


Optical fiber cable

Comparison of Guided Media

- **Electrical Cables**

- Moderate data rates: 1Gb/s
- Maximum distance: 2km (twisted pair); 10km (coaxial)
- Cheapest for low data rates
- UTP: easy to install, susceptible to interference
- STP, Coaxial Cable: rigid, protection against interference

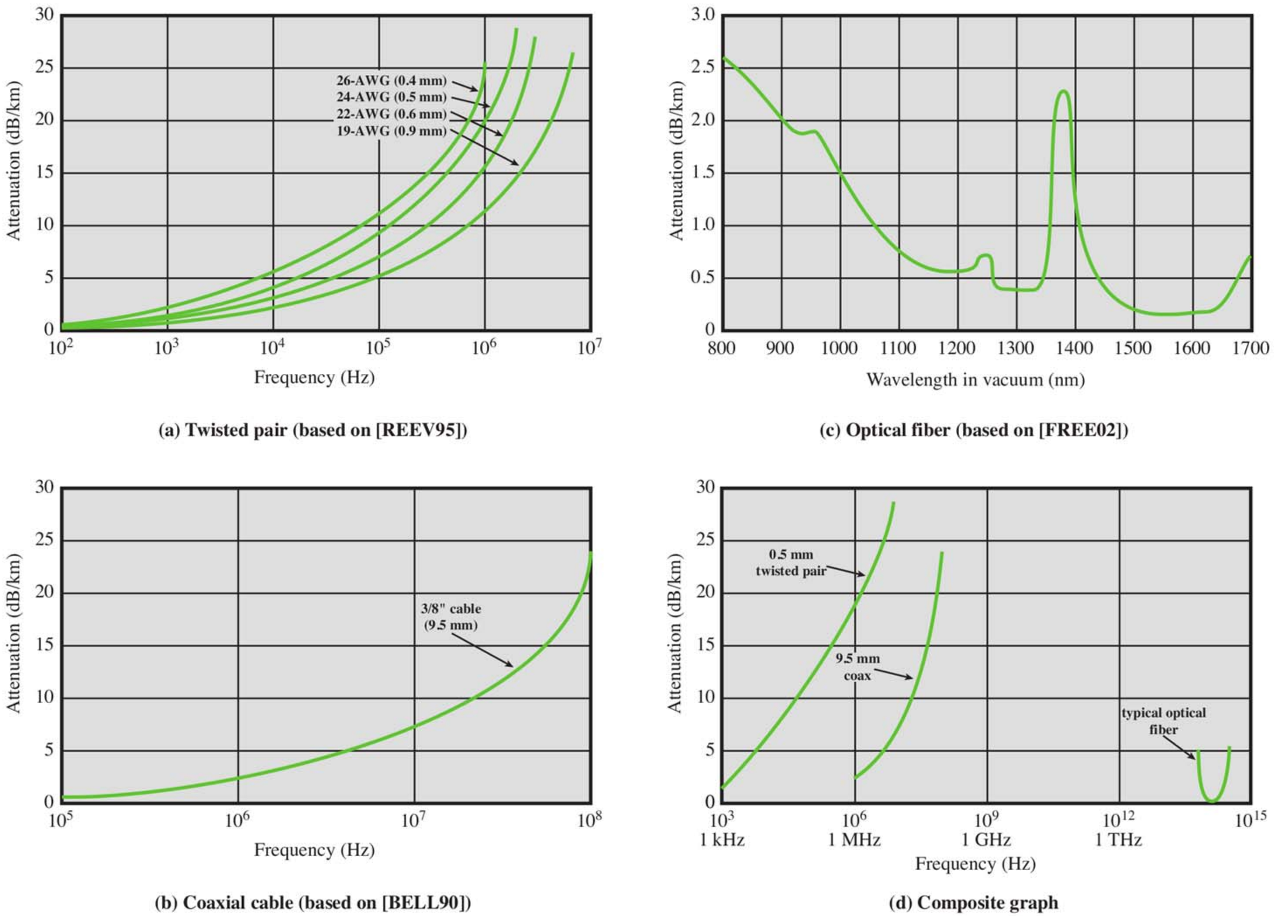
- **Optical Cables**

- Very high data rates: 100Gb/s+
- Maximum distance: 40km
- Expensive equipment and complex to join, but cost effective for high data rates
- Difficult to install

Point-to-Point Transmission Characteristics of Guided Media

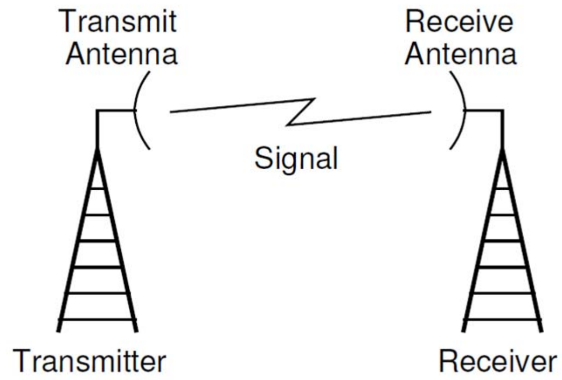
	Frequency Range	Typical Attenuation	Typical Delay	Repeater Spacing
Twisted pair (with loading)	0 to 3.5 kHz	0.2 dB/km @ 1 kHz	50 μs/km	2 km
Twisted pairs (multipair cables)	0 to 1 MHz	0.7 dB/km @ 1 kHz	5 μs/km	2 km
Coaxial cable	0 to 500 MHz	7 dB/km @ 10 MHz	4 μs/km	1 to 9 km
Optical fiber	186 to 370 THz	0.2 to 0.5 dB/km	5 μs/km	40 km

Attenuation of Typical Guided Media



Wireless Transmission →Wireless Transmission Model

Common wireless systems for communications include:

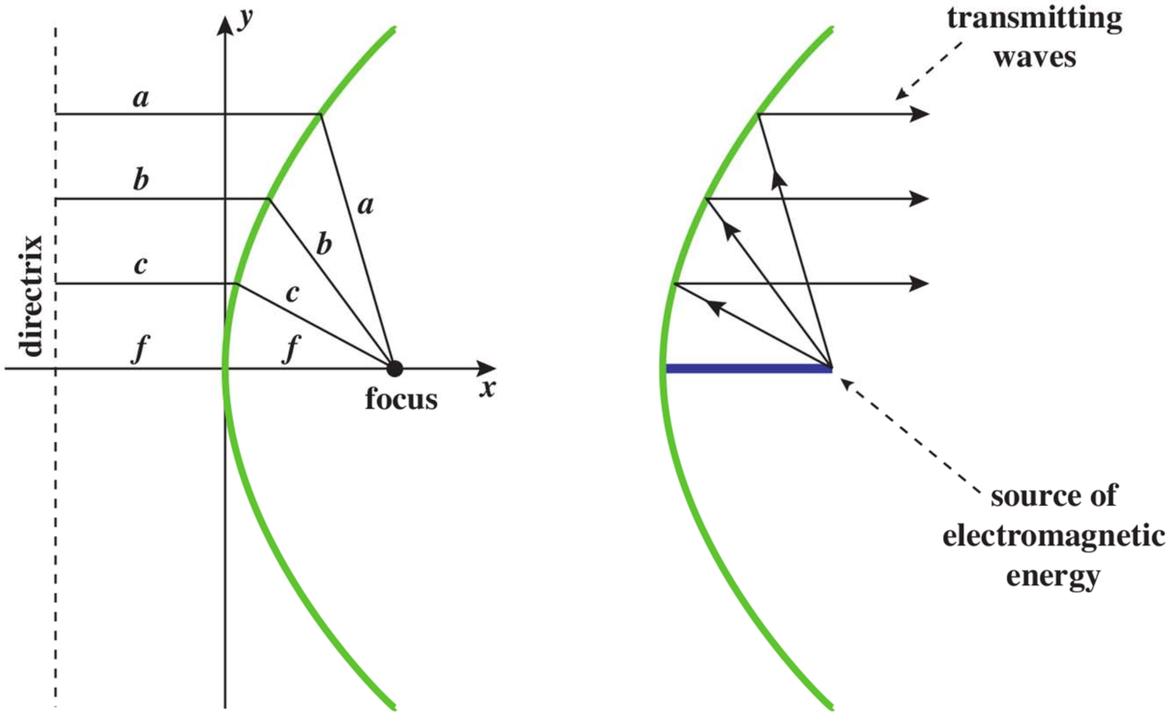


- Terrestrial microwave, e.g. television transmission
- Satellite microwave, e.g. IPstar
- Broadcast radio, e.g. IEEE 802.11 WiFi (wireless LAN)
- Infrared, e.g. in-home communications
- In the wireless communication, what we do is to take some electrical signals, and some other device called antenna converts the electrical signal into some radio signal which propagates through the air (or any other medium). On the receiver side, reverse process is applied.
- What we care are:
  - How fast we can send the data (date rate)
  - How far we can send the data

Antennas

- Antenna converts between electrical current and electromagnetic waves. They have an important role in how good our communication is
- Waves are within the Radio Frequency (RF) band of 3 kHz to 300 GHz
- Antenna characteristics are same whether sending or receiving
- Direction and propagation of a wave depends on antenna shape (and also size)
- **Isotropic antenna:** power propagates in all directions equally (spherical pattern, ideal and not existing in real life)
- **Omni-directional antenna:** power propagates in all directions on one plane (donut)
- **Directional antenna:** power concentrated in particular direction
- Power output in particular direction compared to power produced by isotropic antenna is antenna gain (dBi)

Antennas



(a) Parabola

(b) Cross-section of parabolic antenna showing reflective property

Calculating Antenna Gain

- Relationship between effective area of antenna and its gain:

$$G = \frac{4\pi A_e}{\lambda^2}$$

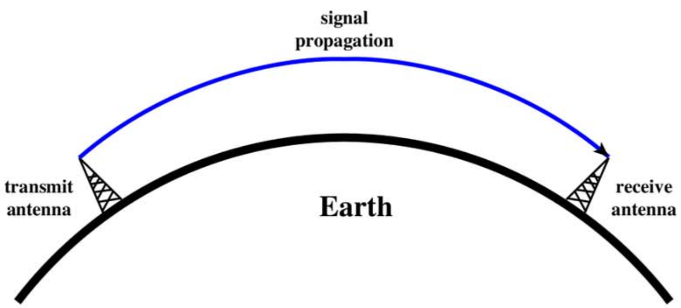
where λ is signal carrier wavelength. $\lambda = c/f$

- Effective area is related to physical size, but differs among antenna designs
- E.g. parabolic antenna may have effective area of 0.5×physical area

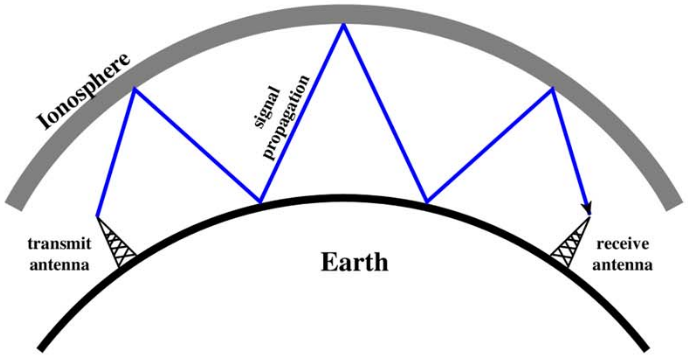
Wireless Propagation

- **Ground Wave Propagation (below 2 MHz):** Signal follows contour of Earth, e.g. AM radio
- **Sky Wave Propagation (2 - 30 MHz):** Signal reflected between ionosphere and Earth, e.g. amateur radio, international radio stations
- **Line-of-Sight Propagation (above 30 MHz):** Signal not reflected; antennas must be in effective line-of-sight; used for most communications
- Aware of that while the signaling frequency is getting greater, tolerating the losses is getting less.

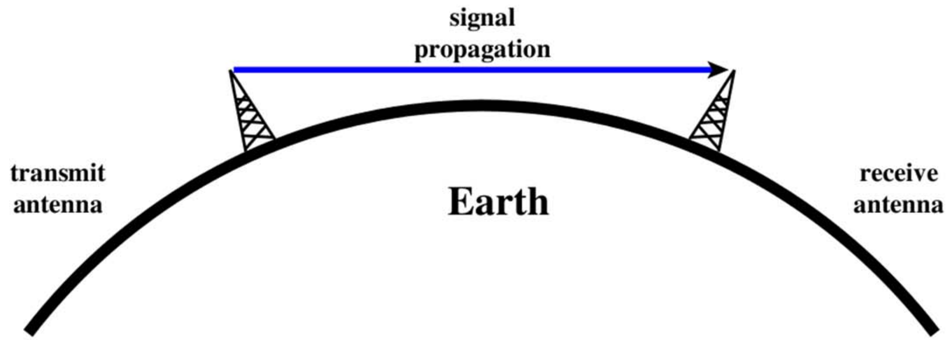
Different Propagation Characteristics



(a) Ground-wave propagation (below 2 MHz)



(b) Sky-wave propagation (2 to 30 MHz)



(c) Line-of-sight (LOS) propagation (above 30 MHz)

Frequency Bands

Band	Frequency Range	Free-Space Wavelength Range	Propagation Characteristics	Typical Use
ELF (extremely low frequency)	30 to 300 Hz	10,000 to 1000 km	GW	Power line frequencies; used by some home control systems.
VF (voice frequency)	300 to 3000 Hz	1000 to 100 km	GW	Used by the telephone system for analog subscriber lines.
VLF (very low frequency)	3 to 30 kHz	100 to 10 km	GW; low attenuation day and night; high atmospheric noise level	Long-range navigation; submarine communication
LF (low frequency)	30 to 300 kHz	10 to 1 km	GW; slightly less reliable than VLF; absorption in daytime	Long-range navigation; marine communication radio beacons
MF (medium frequency)	300 to 3000 kHz	1,000 to 100 m	GW and night SW; attenuation low at night, high in day; atmospheric noise	Maritime radio; direction finding; AM broadcasting.
HF (high frequency)	3 to 30 MHz	100 to 10 m	SW; quality varies with time of day, season, and frequency.	Amateur radio; military communication
VHF (very high frequency)	30 to 300 MHz	10 to 1 m	LOS; scattering because of temperature inversion; cosmic noise	VHF television; FM broadcast and two-way radio, AM aircraft communication; aircraft navigational aids
UHF (ultra high frequency)	300 to 3000 MHz	100 to 10 cm	LOS; cosmic noise	UHF television; cellular telephone; radar; microwave links; personal communications systems
SHF (super high frequency)	3 to 30 GHz	10 to 1 cm	LOS; rainfall attenuation above 10 GHz; atmospheric attenuation due to oxygen and water vapor	Satellite communication; radar; terrestrial microwave links; wireless local loop
EHF (extremely high frequency)	30 to 300 GHz	10 to 1 mm	LOS; atmospheric attenuation due to oxygen and water vapor	Experimental; wireless local loop; radio astronomy
Infrared	300 GHz to 400 THz	1 mm to 770 nm	LOS	Infrared LANs; consumer electronic applications
Visible light	400 THz to 900 THz	770 nm to 330 nm	LOS	Optical communication

Wireless Transmission Impairments

- **Free Space Loss:** Signal disperses with distance; therefore signal attenuates over distance
- **Atmospheric Absorption:** Water vapour and oxygen in atmosphere may attenuate signals; only significant for specific frequencies (e.g. 22GHz, > 30 GHz)
- **Multipath:** Signals reflect obstacles; multiple copies of signal arrive at receiver with varying delays causing reinforcement or cancellation
- **Refraction:** Signals are refracted through atmosphere; only part of wave received

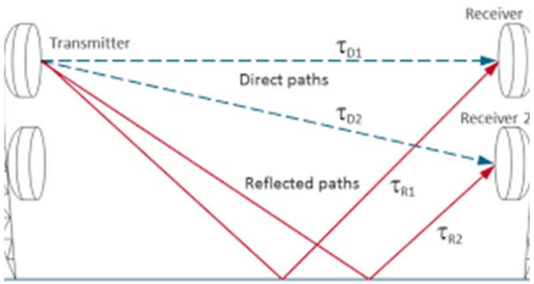


Figure 1. Multipath, transmitted signal may be received by the receiver from different directions, which leads to distortion in the signal

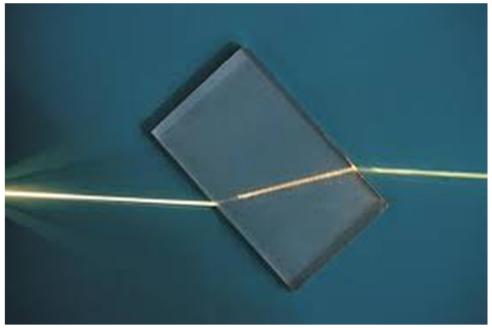
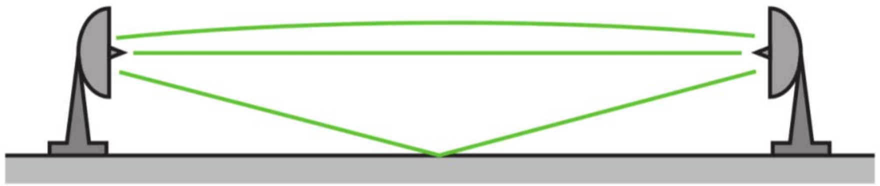
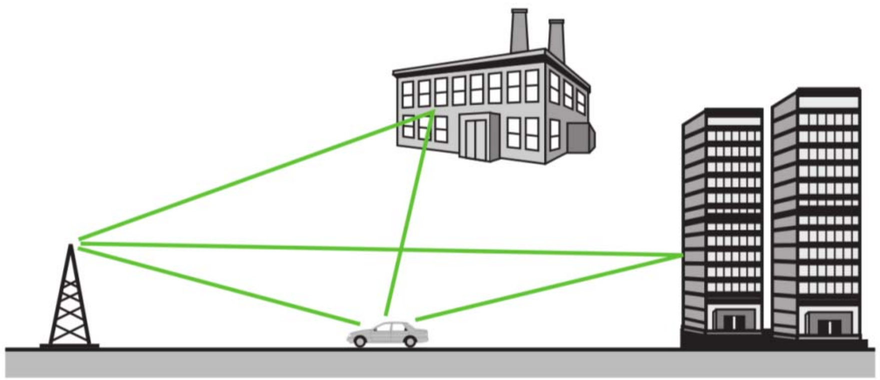


Figure 2: Refraction, if transmitted signal is passing through different mediums, direction of the propagation of the signal changes

Examples of Multipath Interference



(a) Microwave line of sight



(b) Mobile radio

Free Space Loss Model

- Ideal model to determine amount of power loss between transmitter and receiver

$$\frac{P_t}{P_r} = \frac{(4\pi d)^2}{G_t G_r \lambda^2} \text{ (Friis transmission equation)}$$

where…

P_t: Transmitted power in W

P_r: Received power in W

d: Distance between the receiver and the transmitter

G_t: Transmitter antenna gain

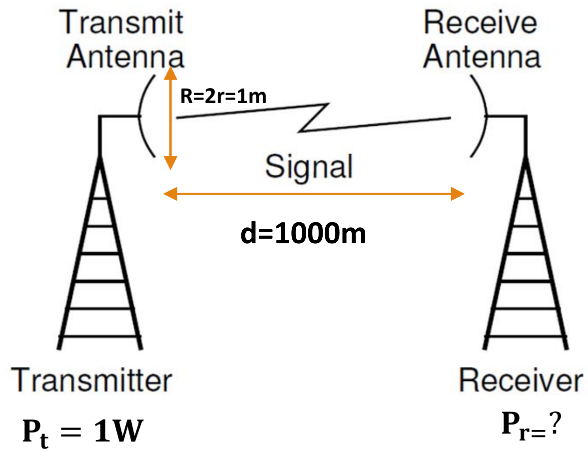
G_r: Receiver antenna gain

λ: Wavelength of the communication signal

- Assumes no obstacles, operating in vacuum and perfect antennas
- Other models: Okumura-Hata (urban, suburban); Longley-Rice (TV broadcast); Log-distance (indoor)

Example of Path Loss

Ex: Two parabolic antennas with diameter 1m; frequency 5GHz; transmit power 1W; distance 1 km. What is required receive power threshold of receiver?



$$A_e = 0.5 * \text{Area of Circle}$$
$$A_e = 0.5\pi r^2 = 0.5\pi 0.5^2 = 0.392m^2$$

$$\lambda = \frac{c}{f} = \frac{3*10^8}{5*10^9} = 0.06m$$

$$G_t = \frac{4\pi A_e}{\lambda^2} = 1370 = 31.4 \text{ dBi}$$

$$G_t = G_r = 1370$$

$$P_r = \frac{P_t G_t G_r \lambda^2}{(4\pi d)^2} = \mathbf{0.0428mW}$$

$P_{rdBmW} = 10log_{10}(P_{r\ in\ mW}) = 10log_{10}(0.0428) =$ **-13.68dBmW or mostly -13.68dBm**

Decibel

The decibel **(dB)** is a relative unit of measurement that expresses the ratio of two values of a power or root-power quantity on a logarithmic scale.

$dBx = 10\log(x)$ (Anything, X in dB)
$dbW = 10\log(P_W)$ (Power in dB)

$dBm = 10\log(P_{mW})$ (Power in dBm, or Power in decibel−miliwatt)

$dBi = 10\log(G)$ (Antenna Gain in dB, can be transmitter or receiver)

Decibel allows the user to calculate the target power by addition instead of multiplications

$P_{received} = P_{transmitted} - P_{losses} + P_{gains}$ (Friis transmission equation in dB)

P_{losses}: Losses due to tranmission media

P_{gains}: Gains thanks to antennas, routers or repaters

Free Space Path Loss(FSPL)=$(\frac{4\pi d}{\lambda})^2$; Antenna Gain=G=$\frac{4\pi A_e}{\lambda^2}$

Example

A satellite in geosynchronous orbit (36,000 km above the earth's surface) radiates 100 W of power (20 dBW). The transmitting antenna has a gain of 18 dBi. The earth station employs a 3-m parabolic antenna, and the downlink is transmitting at a frequency of 4 GHz. Determine the received power. Assume antenna efficiency is 0.55.

$\lambda = \frac{c}{f} = \frac{3*10^8}{4*10^9} = 0.075\text{m}$,$G_r = \eta\frac{4\pi A_e}{\lambda^2}$ = 8685= **39.39dBi**, FSPL= $(\frac{4\pi d}{\lambda})^2$= 3.64x$10^{19}$ = **195.61dB**

$P_t = 100$W= **20dB**

$P_{received} = P_{transmitted} - P_{losses} + P_{gains}$

$P_{received}$ = 20 – 195.61 + 18 + 39.39 = **-118.22dBW = 1.51x $\mathbf{10^{-12}}$** $\boldsymbol{W}$

Wireless Media → Terrestrial Microwave

- Parabolic antenna (usually 1-3 m) used to transmit point-to-point to another antenna
- Line-of-sight communications; often antennas are placed high (towers, buildings) to avoid obstacles
- Long-distance telecommunications (alternative to optical fibre, coaxial cable), e.g. voice and TV transmission
- Short communications between buildings (e.g. office buildings in city)

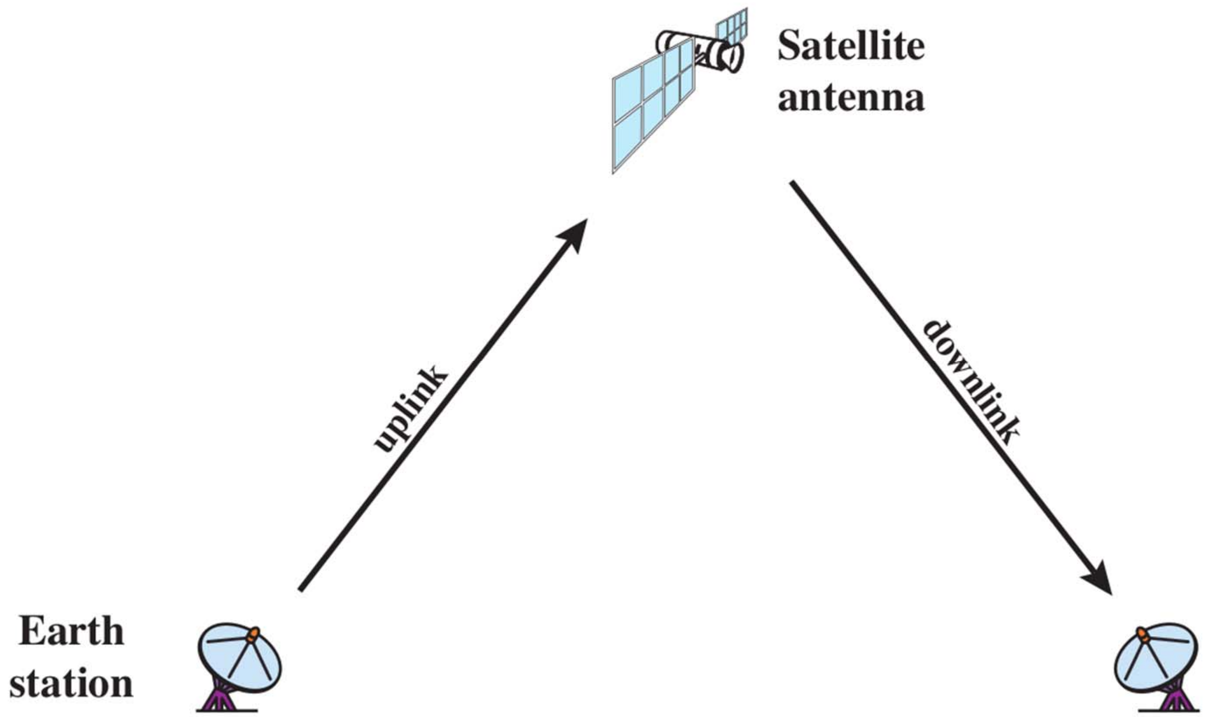
Mobile telephone systems (GSM, CDMA, 3G)

Band (GHz)	Bandwidth (MHz)	Data Rate (Mbps)
2	7	12
6	30	90
11	40	135
18	220	274

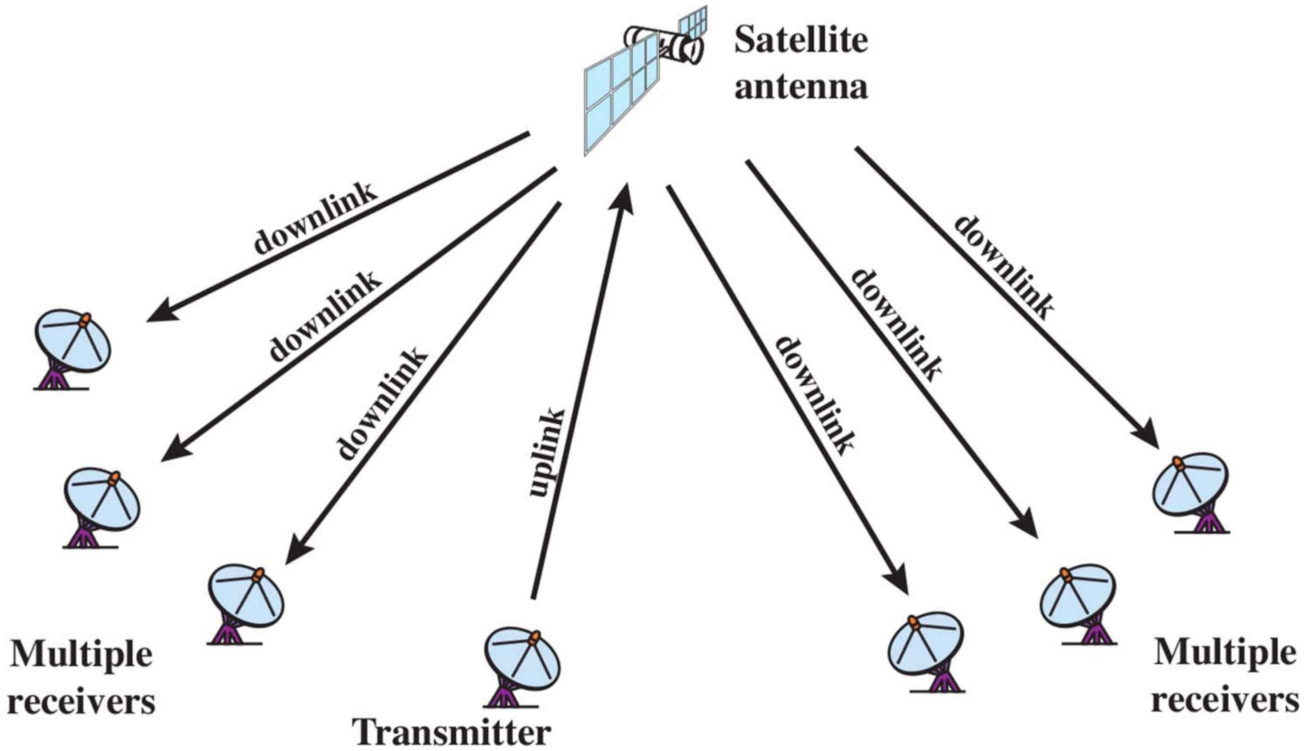
Satellite Microwave

- Communications satellite acts as microwave relay station
- Links two or more ground/earth stations
- Receives signal on one frequency (uplink), repeats or amplifies, and transmits on another frequency (downlink)
- Point-to-point or broadcast configuration
- Geostationary Orbit (GEO): satellite appears stationary from Earth; cover about 1
- Earth surface; 36,000 km above Earth
- Low Earth Orbit (LEO): 100's of km above Earth; orbit
- Earth every 1-2 hours; footprint with radius of 3000-4000 km

Satellite Communication Configurations: Point-to-point link



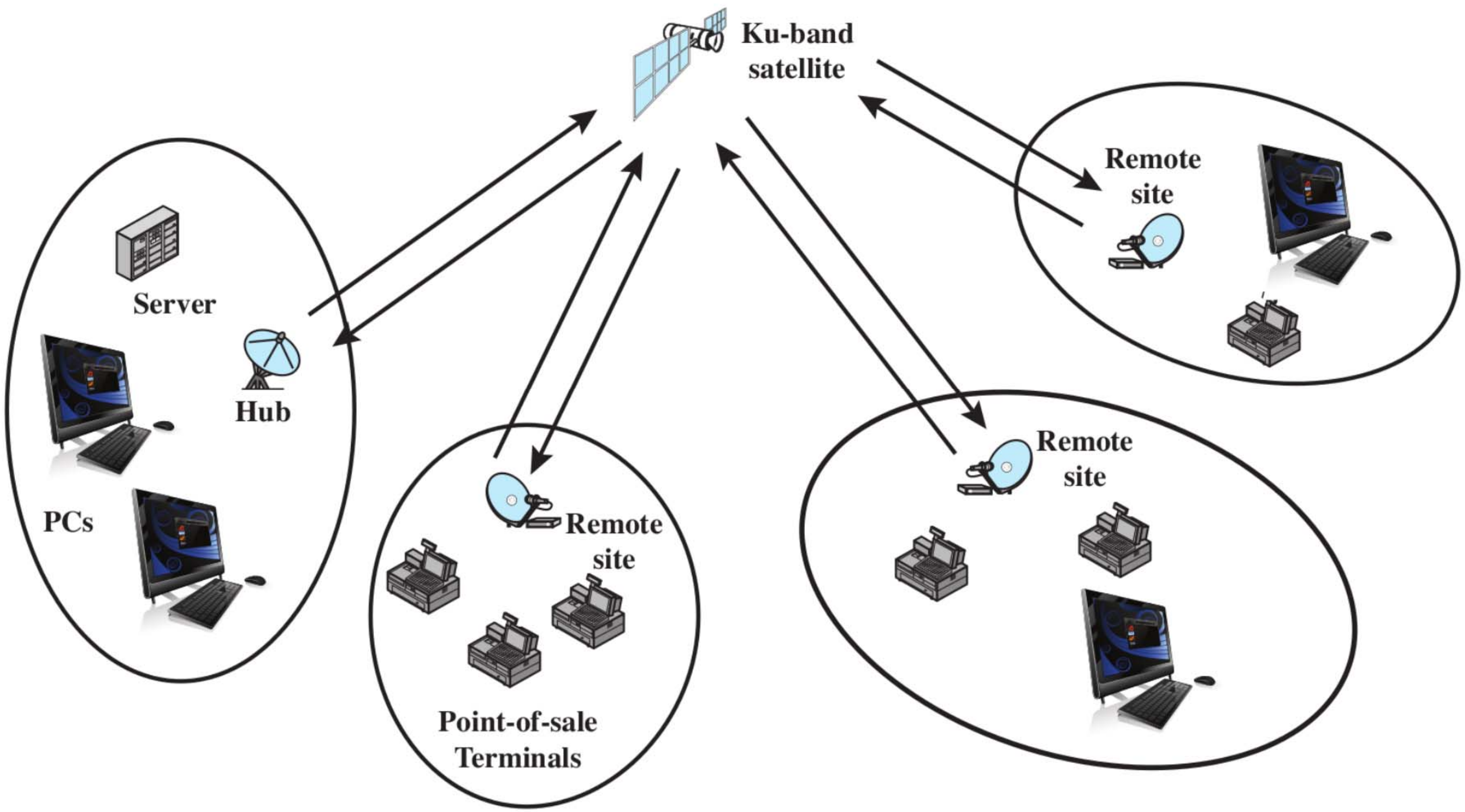
Satellite Communication Configurations: Broadcast link



Applications for Satellites

- TV distribution
- Long-distance telephone transmission
- Private business networks
- Very Small Aperture Terminals (VSATs) allow for low cost Earth stations
- Global positioning, e.g. GPS

Typical VSAT Configuration



Broadcast Radio

- Microwave uses directional antennas; broadcast radio can use omni-directional
- Frequencies from 30 MHz to 1 GHz
- FM radio
- UHF and VHF television
- Wireless networking