Transmission Media

ITS323: Introduction to Data Communications
CSS331: Fundamentals of Data Communications

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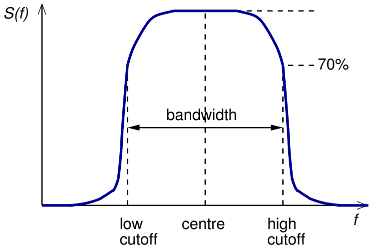
Transmission Media

"the thing between the transmitter and receiver"

- Signal propagates from transmitter to receiver via some medium
- Which medium should be used?
  - Maximise data rate
  - Maximise distance
  - Minimise bandwidth
  - Minimise transmission impairments
  - Minimize cost
- Guided (wired) vs unguided (wireless)

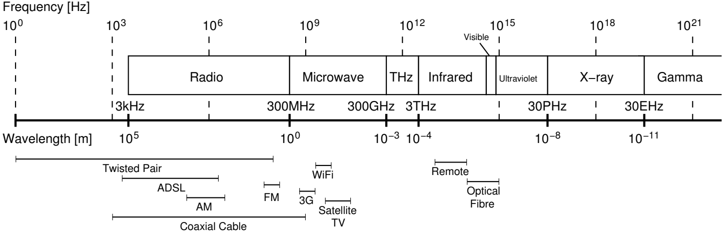
Signals and Spectrum

- Communication signals contain components with different frequencies, spectrum of signal
- Often refer to center frequency and bandwidth of signal

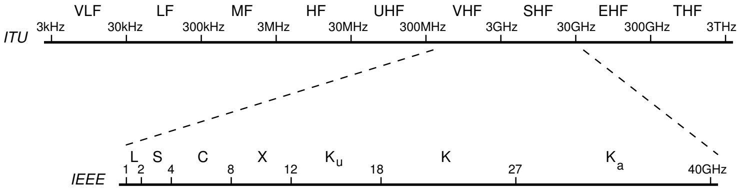


- Electromagnetic spectrum is used by many applications
- International and national authorities regulate usage of spectrum
- Aim: minimize interference between applications/users, while allowing many applications/users

Electromagnetic Spectrum for Communications



ITU and IEEE bands:



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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 minimise radiation and pick-up
    - Use materials to shield from interference
    - Organise multiple wires so they dont interfere with each other

Twisted Pair

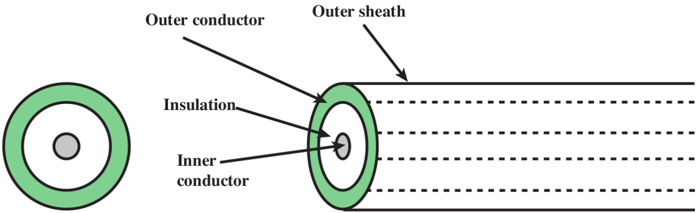
- Two insulated copper wires arranged in spiral pattern
- Most commonly used and least expensive medium
  - Used in telephone networks and in-building communications
  - Telephone networks designed for analog signalling (but supporting digital data)
  - Also used for digital signalling
- Two varieties of twisted pair: shielded (STP) and unshielded (UTP); also multiple categories (CAT5)

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

(a) Twisted pair

Coaxial Cable

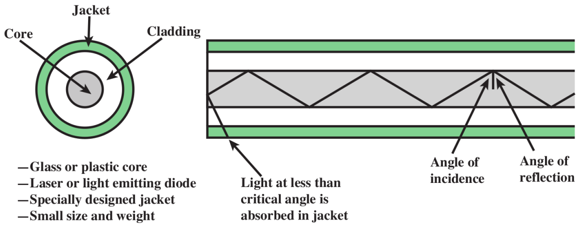
- Two conductors, one inside the other
- Provide much more shielding from interference than twisted pair: Higher data rates; More devices on a shared line; Longer distances
- Widely used for cable TV, as well as other audio/video cabling
- Used in long-distance telecommunications, although optical fibre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



—Outer conductor is braided shield
—Inner conductor is solid metal
—Separated by insulating material
—Covered by padding

Optical Fibre

- Light (optical rays) is guided within glass or plastic fibres
- Used in long-distance telecommunications, as well as telephone systems, LANs, and city-wide networks
- Advantages of optical fibre 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



(c) Optical fiber

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, but cost effective for high data rates
- Difficult to install

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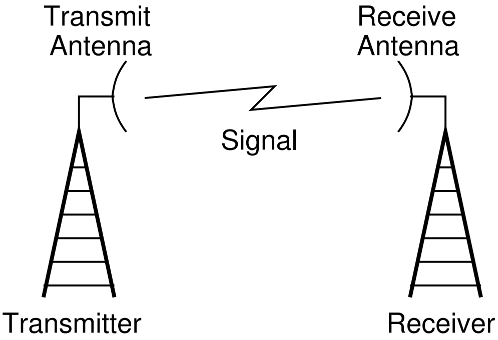
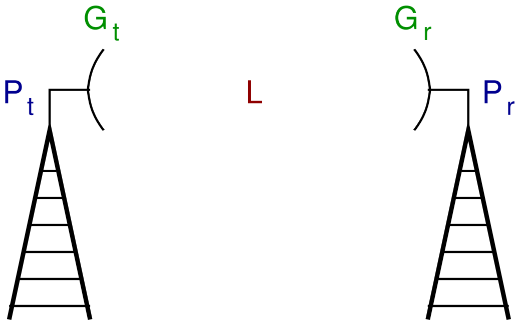
Wireless Transmission Model

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



Wireless Transmission Model



- Transmit electrical signal with power P_t
- Tx antenna converts to electromagentic wave; introduces a gain G_t
- Signal loses strength as it propagates; loss L
- Rx antenna converts back to electrical signal, gain G_r
- Receive signal with power P_r

Wireless Transmission Issues

- What is the role of an antenna?
- What is antenna gain?
- How does the signal propagate in different environments?
- How much power is lost when it propagates?

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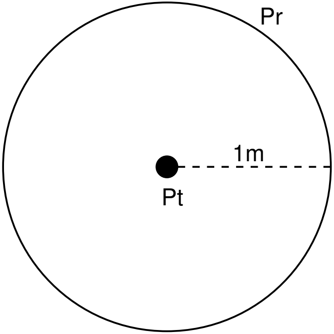
Antennas

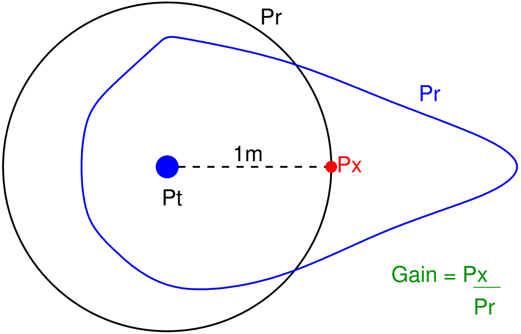
- Antenna converts between electrical current and electromagnetic waves
- Waves are within the Radio and Microwave bands of 3 kHz to 300 GHz
- Antenna characteristics are same for sending or receiving
- Direction and propagation of a wave depends on antenna shape
- Isotropic antenna: power propagates in all directions equally (spherical pattern, ideal)
- 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]

Example: Isotropic Antenna (2D)



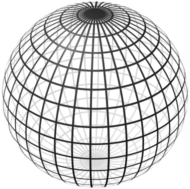
- Transmit with power P_t
- Measure received power 1m away to be P_r
- Received power is same at any point equidistant from transmitter (black circle)

Example: Directional Antenna (2D)

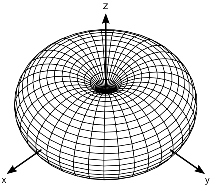


- Transmit with same power P_t
- Blue shape: at each point, received power is P_r
- Measure received power 1m away to be P_x
- Gain of antenna (compared to isotropic) is P_x/P_r

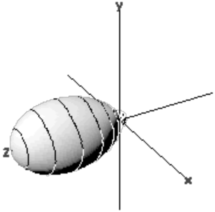
Antenna Patterns



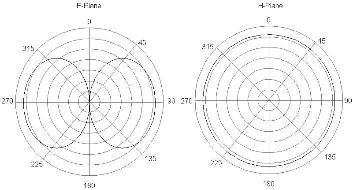
Isotropic



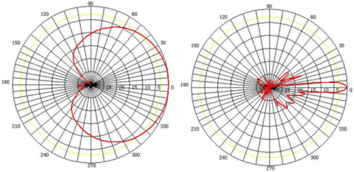
Dipole



Horn



Dipole



Horizontal **Vertical**

Sector

Antenna Examples

See pictures and specifications at:
www.cisco.com/c/en/us/products/collateral/wireless/aironet-antennas-accessories/product_data_sheet09186a008008883b.html
and
en.wikipedia.org/wiki/Antenna_%28radio%29

Antenna Gain Mathematical Model

- Relationship between effective area of antenna and its gain:

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

  where λ is signal carrier wavelength
- Effective area is related to physical size, but differs among antenna designs
- E.g. parabolic antenna may have effective area of $0.5\times$ physical area where physical area is approx πr^2

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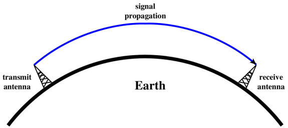
Wireless Propagation

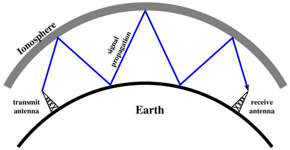
- Frequency of signals affect how signal propagates
- Different frequencies impacted by water, atmospheric noise, cosmic noise, temperature

Ground Wave signal follows contour of Earth, e.g. AM radio



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

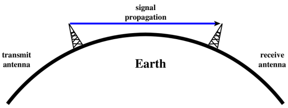
Sky Wave signal reflected between ionosphere and Earth, e.g. amateur radio, international radio stations



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

Wireless Propagation

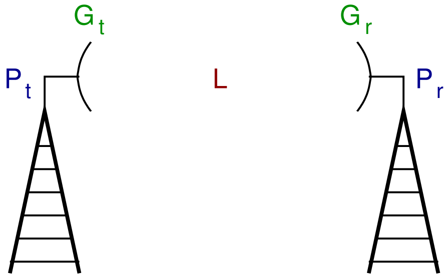
Line-of-Sight signal not reflected of earth/atmosphere; antennas must be in effective line-of-sight; used for most communications



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

- Increased frequency, increased attenuation
- Obstacles affect signals differently
- Signals may reflect off obstacles, multiple copies of same source signal received at different times (multipath)

Transmission and Path Loss Model



- General model:

$$P_r = \frac{P_t G_t G_r}{L}$$

or in dB form:

$$P_{r_{dB}} = P_{t_{dB}} + G_{t_{dB}} + G_{r_{dB}} - L_{dB}$$

- Use mathematical or experimental models to calculate L

Free Space Path Loss

- Ideal case assuming no obstacles, operating in vacuum and perfect antennas
- Free space path loss:

$$L = \left(\frac{4\pi d}{\lambda}\right)^2$$

- Combined with general model (Friis transmission equation):

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

- Other models: Okumura-Hata (urban, suburban); Longley-Rice (TV broadcast); Log-distance (indoor)

Example of Path Loss

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Satellite Communications

- Applications: TV broadcast, remote/marine communications, positioning, private data networks, Internet
- Configuration: point-to-multipoint; point-to-point
- Orbits: geostationary (GEO, 36000km), low earth (LEO, 100's km), ...
- Antennas: parabolic (dish), metre to 10's of metres
- Frequency bands: C, Ka, Ku bands
- See example of IPStar

Terrestrial Wireless

- Applications: long distance links, TV broadcast, AM/FM, Internet
- Configuration: point-to-point; point-to-multipoint
- Example: IEEE 802.16 (WiMax)
  - 11 GHz, 10-20 Mb/s, 10-20 km line of sight

Mobile Phones

- Applications: personal communications, Internet, monitoring
- Frequency bands: 2.1 GHz, 1.8/1.9 GHz, 850/900 MHz; licensed
- Bandwidth: 5 MHz for 3G
- Distance: 100's of metres to kms
- Data Rates: 100's kb/s to 10's Mb/s

Local Networks

- Applications: local area network, connect portable devices
- Standards: IEEE 802.11 (WiFi) a/b/g/n/ac/. . . ; Bluetooth
- Frequency bands: 2.4 GHz and 5.2–5.7 GHz; unlicensed
- Bandwidth: 20 MHz channels (increased for optional higher data rates)
- Distance: metres to 10's of metres
- Data Rates: 10's Mb/s to 100's Mb/s