TRANSMISSION MEDIA

Computer Communications

- Computer communications involve:
  - Encoding data in a form of energy
  - Sending the energy across a transmission medium
- Energy forms include:
  - Electric current
    * Direct Current (DC)
    * Alternating Current (AC)
  - Electromagnetic waves
    * Radio transmission
    * Microwave transmission
    * Infrared transmission
    * Visible Light

- Transmission medium include:
  - Media for offline transmission
    * Magnetic Media
      · Magnetic Tapes
      · Magnetic disks and diskettes
  - Media for online transmission
    * Wire (guided)
      · Copper wires
      · Fiber optics
    * Wireless (unguided)
      · No physical conductor is used; instead, signals (typically, electromagnetic waves) are broadcast through air, or vacuum, and thus are available to anyone who has a device capable of receiving them
- Note that: some transmission medium, but not all of them, are suitable for more than a form of energy, for example:
  - A coaxial cable, a type of copper wires, can carries electric signals, as well as electromagnetic waves, in this case, we call it a guided communication
  - Fiber optics can not carry electric signals

Magnetic Media

- Magnetic tapes and/or floppy disks are physically transported from source to destination
- Not sophisticated, as using satellite communications
- Provide much more cost effective way of communication
- Example:
  - 8-mm video tape (e.g., Exabyte) can hold 7 Giga bytes of data, i.e., 56 Giga bits of data per tape
  - A box of 50 cm × 50 cm × 50 cm can hold about 1000 of these tapes
  - Using Fed-Ex, this box can be sent anywhere in North America in 24 hours
  - The effective bandwidth of this transmission is $\frac{56{,}000 GigaBits}{86{,}400 second}$, i.e., 663 Mega bits per second, better than a high-speed ATM network!!!
  - If destination is only an hour away by road, the bandwidth is become over 15 Giga bits per second!!!
- Never underestimate the bandwidth of a station wagon full of tapes hurtling down the highway!!!
- *Is there any catch here?*

Copper Wires

- Why copper?
  - Copper has low resistance to electric current
  - Inexpensive
  - Easy to install
- Copper wires include:
  - Twisted Pair
  - Coaxial cable

Twisted-pair Cable

- The oldest, and still most common, transmission medium
- Consists of two insulated copper wires, typically about 1 mm thick
- The signal is transmitted through one wire, while a ground reference is transmitted through the other
- A pair of wires are twisted together to reduce electrical inference
  - An electro-magnetic field can be emitted from a traveling current in a wire, or some sort of devices, e.g., motors
  - Electro-magnetic field travels through the air
  - Whenever it encounters another wire, it generates electric current in it (noise)
  - Two parallel wires may receive different amount of noise, based on the distance between the source of the field and each of them
  - In case of twisted pair, both wires will got almost the same amount of noise, but in opposite directions, hence, the noise impact will be reduced

- If the source of the electro-magnetic field is external, e.g., from a motor, or so, we end up with a *noise*
- However, if the source of the electro-magnetic field is another nearby circuit (or channel), we end up with what so called *crosstalk*
- *Crosstalk* is the undesired effect of one circuit (or channel) on another circuit (or channel)
- This effect can be experienced during telephone conversations when one can hear other conversation in the background
- Metal shielding each pair of a twisted-pair cable, where this shield is grounded, can prevent the penetration of electro-magnetic noise, and hence eliminating most of crosstalk
- Shielded twisted-pair cables are less susceptible to noise than Unshielded twisted-pair cables, but they are more expensive
- Twisted-pair cables are suitable for transmitting both digital and analog signals ranged from 100 Hz to 5 MHz
- Nearly all telephones are connected to the telephone company office by a twisted pair

Coaxial Cable (Coax)

- Instead of having two wires, a coax cable has
  - A central core conductor of stiff copper wire
  - This wire is enclosed in an insulator,
  - This insulator is, in turn, encased by an outer cylindrical conductor of metal,
  - The outer conductor is covered by a protective plastic covering

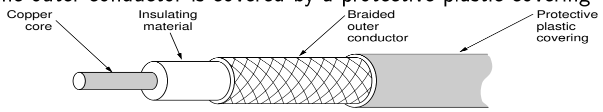


Illustration of a coaxial cable

- The outer metallic conductor serves both as a shield against noise, and as the second conductor, which completes the circuit
- Coax cables carry both digital and analog signals of higher frequency ranges than twisted-pair cables, (from 100 KHz to 500 MHz)
- A TV cable is an example for one type of coax cables

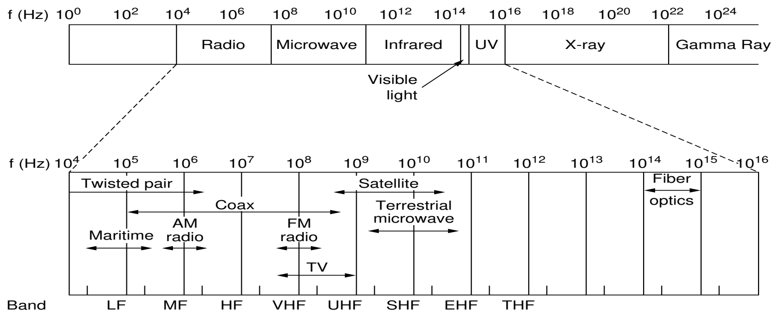
Optical Fiber

- Optical Fiber is made of glass, or plastic, but not from metals, and transmits signals in form of light
- A transmitter uses Light Emitted Diode (LED), or laser, to send pulses of light down the fiber
- A receiver uses photo-diode to detect these pulses
- A signal travels over a single fiber
- Advantages
  - *No interference*: External light, the only possible interference, is blocked from the channel by the outer jacket
  - *Less signal attenuation*: A signal can run for miles without requiring regeneration
  - *Higher bandwidth*: Currently, bandwidth utilization over fiber-optic cable are limited not by the medium, but by the signal generation and reception technology available

- Disadvantages
  - *Cost*: Fiber-optic cables and laser light sources are expensive
  - *Fragility*: Glass fiber is more easily broken than wire, hence, it is less useful for applications where hardware portability is required
  - *Installation*: Hard and expensive to install, if it is compared with metallic media
  - *Maintenance*:
    - ∗ Hard to detect breaks
    - ∗ Hard to repair breaks
- The backbones of most telephone networks are 100% fiber optics

Electromagnetic Spectrum

- *Frequency*, f: The number of cycles per second, measured in Hertz (Hz)
- *Wavelength*, λ: The distance between two consecutive maxima, or minima
- *the speed of light*, c: Approximately 3×10^8 meters/second
- The fundamental relation between f, λ, and c (in vacuum) is $\lambda \times f = c$



The electro-magnetic spectrum and its uses for communication

- The amount of information that an electromagnetic wave can carry is related to its frequency
- Since everyone wants a higher data rate, everyone wants more spectrum (bandwidth) and higher frequency
- To prevent total chaos, there are national and international agreements about who uses which frequencies
- Radio, microwave, infrared, visible light portions of the spectrum can all be used for transmitting information, by modulating the amplitude, frequency, or phase of the waves, as we will see in the next week, or so
- Ultraviolet light, X-rays, and gamma rays would be even better, due to their higher frequencies, but they are hard to produce and modulate, do not propagate well through buildings, and are dangerous to living things

Radio Transmission

- At low frequencies, radio waves penetrates obstacles well and travels in all directions from the source (omni-directional), but the power falls off sharply with distance from source
  - Transmitters and receivers do not have to be carefully aligned
  - The 1970's Cadillacs anti-lock breaks!!!
- At high frequencies (i.e., more toward the microwave) radio waves tend to travel in straight lines and bounce off obstacles, however, they can travel for a longer distance, unless they face obstacles
- The higher the frequency, the longer the distance a radio wave can travel, that is why a FM radio channel travel more than an AM radio channel
- Problems with radio data communication
  - The relatively low bandwidth they offer
  - Interferes with motors and other electrical equipment
- Radio waves are easy to generate/receive, e.g., soccer robots
  - An antenna is attached to each participating computer
  - This antenna can transmit and receive radio signal

Microwave Transmission

- Travels in straight lines and can therefore be narrowly focused
- Can not penetrate metal structure and bounces off obstacles
- Carry more data than radio transmission
- Before fiber optics, for decades these microwaves formed the heart of the long-distance telephone transmission system
- The main advantages of microwave over fiber optic are that
  - No right of way is needed; all what you need is small plot of ground every 50 km, or so, to put a microwave tower on it
  - Relatively inexpensive, putting up two simple towers and putting antennas on each one may be cheaper than burying 50 km of fiber through a congested urban area, or up over a mountain
- *MCI* stand for *Microwave Communication Inc.*, because its entire system was originally built on microwave towers;
  Currently, it has upgraded major portions of its network to fiber

- *Sprint* went a different route: it was formed by the *Southern Pacific Railroad*, which already owned a large amount of right of way, and just buried fiber next to the tracks
- Microwave communication is so widely used in Long-distance telephone companies, where two towers that are taller than the surrounding buildings and trees; it is also widely used in TV satellite dishes (but carefully alignment is needed), and cellular telephones
- In addition, it is also used in cordless telephones, garage door openers, wireless hi-fi speakers, security gates, etc; all these applications use a frequency from one of the following range (government licensing is not required to used these ranges):
  - 2.400–2.484 GHz (worldwide)
  - 5.725–5.850 GHz (US and Canada only)
  - 902–928 MHz (US and Canada only)
- The 902–928 MHz band works best, but is crowded and equipment using it may only be operated in North America

Infrared Transmission

- Higher frequencies than microwave signal
- Its hardware is inexpensive, compared to other mechanisms
- No antenna is required
- Limited to a small area and can not pass through solid walls;
  Do you think it is a bad thing?
- Unlike radio and microwave, there is no government license needed to operate an infrared system; *Why?*
- Requires the transmitter to be pointed toward the receiver
- Especially convenient for small portable indoor equipment, e.g., remote control,
- Infrared communication can not be used outdoors, because the sun shine as brightly in the infrared as in the visible spectrum

Visible Light Transmission

- A very low cost way of communication, with a very high bandwidth, i.e., same as fiber optic, but without the fiber optic's cost!!
- You can connect the LANs in two buildings via lasers mounted on their rooftops
- Relatively easy to install
- Does not require government license to operate an visible light system
- Laser can not penetrate rain or thick fog, but they normally work well on sunny days
- FYI: According to Webster, "laser" stands for *Light Amplification by Stimulated Emission of Radiation*
  It is a device that utilizes the natural oscillations of atoms or molecules between energy levels for generating coherent electromagnetic radiation in the ultraviolet, visible, or infrared regions of the spectrum

Satellite

- Microwaves, combined with satellites, provide communication across longer distances; microwaves do not bend around the surface of the earth
- The satellite contains a transponder (transmitter + responder) that consists of transmitter and receiver

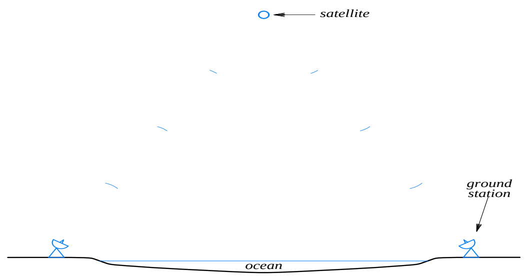


Illustration of a satellite used to provide communication across an ocean

- Because placing a communication satellite in an orbit is expensive,
  - A single satellite usually contains multiple transponders that operate independently (typically 6 to 12), each of them uses different frequency (channel)
  - A single satellite channel can be shared to serve many customers
- Communication satellites can be grouped into:
  - Geostationary (a.k.a. geosynchronous) Earth Orbit (GEO) satellites
  - Low Earth Orbit (LEO) satellites

Geostationary Earth Orbit (GEO) Satellites

- Synchronous with the earth rotation, i.e., completes an entire orbit in 24 hours
- Due to interference, only 45 to 90 satellites can be placed in the GEO (at least 4 to 8 degree between any two of them)
- Placed in an orbit approximately 36,000 KM above the earth (tenth the distance between earth and the moon)
  - Even though signals to, and from, a satellite travel at the speed of light, the large round-trip distance introduces a substantial delay; *What is the minimum time required to transmit a bit from location A to location B using a GEO satellite?*
  - For comparison purposes, coaxial cable, or fiber optic links have a delay of approximately 5×10^{-6} second / km; *Which is faster, electromagnetic signals travel in air, or electromagnetic signals travel in solid materials?*

- Satellite are inherently broadcast media; i.e., it does not cost more to send a message to thousands of stations within a transponder's footprint than it does to one
- From a security and privacy point of view, satellite are a complete disaster (e.g., analog cellular phones), hence encryption is essential when security is required
- The cost of transmitting a message, using satellite, is almost independent of the distance traversed; *According to Bill First rate, Spain $0.36/minute and Portugal $0.63/minute, WHY?*

Low Earth Orbit (LEO) Satellites

- Placed in an orbit approximately few hundreds KM above the earth
- Can complete an entire orbit in approximately 1.5 hours
- An array of LEO satellites is required, so that each point on the ground has at least one satellite overhead at any time
- LEO satellite array may communicate between each other