Knowledge Update Course
for Secondary School Computer and IT Teachers

Computer Networking and Data Communication

Transmission Media

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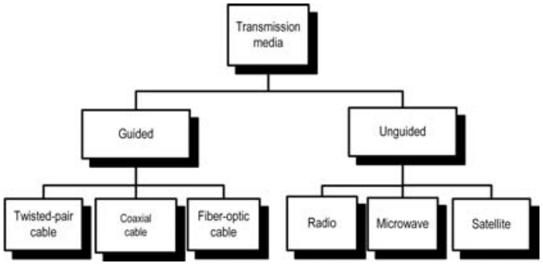
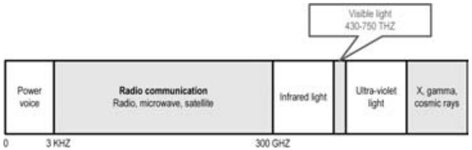
Transmission Media

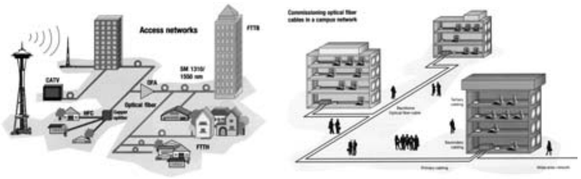


Transmission Media



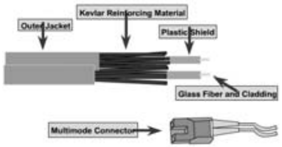
- Signals are transmitted from one device to another in form of electromagnetic energy traveling through a vacuum, air or other transmission media
- Voice-band frequencies are generally transmitted as current over metal cables
- Radio frequencies travel through air or space requiring transmitting and receiving mechanisms
- Visible light used for communications is harnessed using fiber-optic cable

Optical Fibers



Optical Fiber Network

Optical Fibers - basics



- a very thin glass rod (cylindrical dielectric waveguide made of SiO_2)
- Operate at optical frequency about 10^{14} Hz
- Compose of a core, cladding and jacket (a plastic sheathing for mechanical protection)
- Light injected into the core of a glass fiber will follow the physical path of the fiber due to the internal reflection of the light between the core and the cladding
- Fibers are classified by the way in which the light travels in them and is closely related to the diameter of the core and cladding

Optical Fibers - basics

- Advantages:
  - High bandwidth & large capacity: transmit large amount of information; over 2million simultaneous telephone conservations on two optical fibers, and a optical cable contains over 200 optical fibers. For microwave or satellite links, only 2000 conversations
  - Small size, light weight, flexible, easy installation
  - Immunity to interference: not effected by electrical magnetic interference (EMI) or radio frequency (RFI). It does not create its own interference.
  - Free of cross talk between fibers
  - Insulation & Hazardous environment resistant: optical fiber is an insulator, provide total electrical isolation for many applications. It eliminates inference caused by ground loop and electrical discharge

Optical Fibers - basics

- Security: signals cannot be tapped easily
- Stress and heat resistant & reliability and maintenance: constant medium, not subject to fading, adverse temperature, moisture and can be used for underwater cable, long service life span, not affected by short circuit, power surges or static electricity
- Versatility: available for most of data, voice and video communication formats
- Scalable: easily expanded. Only change electronics, no change on fibers
- Low cost, low loss and signal regeneration: optical fibers can travel over 70km before repeating the signals, save cost for repeater and maintenance

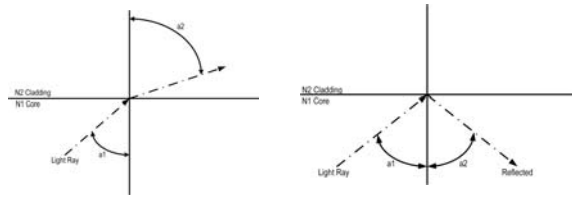
Optical Fibers - basics

- Disadvantages:
  - Electrical-to-optical conversion: signal must be converted to light wave and back to electrical signal. Cost on electronics in all applications
  - Physical right of way is required for the cable installation
  - Optical fiber is predominantly silica glass, special techniques are needed for engineering installation of the fiber cable
  - repairs: difficult to repair broken optical cable
  - Network interface card and cabling is expensive
  - Connection to network is difficult

Optical Fiber – nature of light

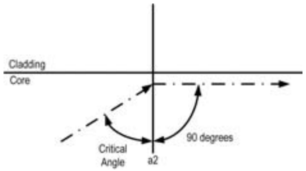
- Light travels at 300,000 K/s in a vacuum.
- The speed decrease when it travels through more dense medium
- Light travels in a straight through a single uniform medium
- Light changes speed , and hence, the direction when it travels from a one medium to other with different density.
- When it travels to a less dense medium, and reaches a “Critical Angle”, the angle of refraction will become 90 degree.
- If we increase the angle of incidence further, the light will completely reflected, and the reflection phenomenon occurs

Optical Fibers - principles



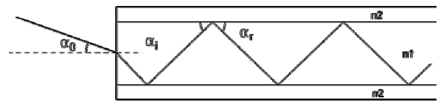
- For small a_1, $n_1 \sin a_1 = n_2 \sin a_2$ (Snell’s law)
- For large a_1, $n_1 \sin a_1 = n_2 \sin a_2$ ($a_1 = a_2$, and $n_1 = n_2$)

Optical Fibers - principles



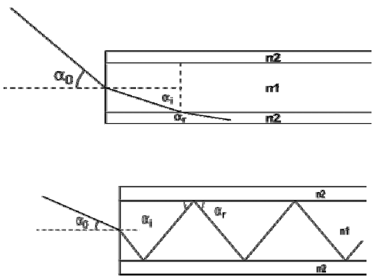
- Critical angle = $\sin^{-1}(n_{cladding} / n_{core})$
- Where angle of reflection = 90 degree

Optical Fiber - principals



- A ray of light enters into the fiber at a small angle α
- The capacity (max acceptable value) of the fiber cable to receive light on its core is determined by its numerical aperture NA = $\sin \alpha_0 = \sqrt{(n_1^2 - n_2^2)}$
- $\alpha_0 = \arcsin \sqrt{(n_1^2 - n_2^2)}$, and 2 α_0 is the full acceptance angle

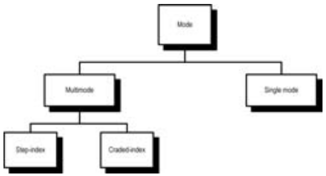
Optical Fiber - principles



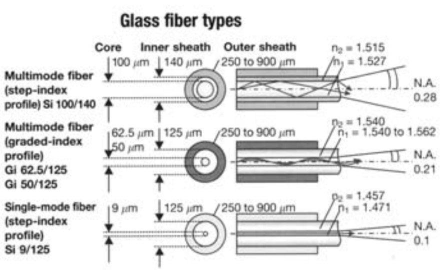
- Refraction
  - $n_1 \sin\alpha_i = n_2 \sin\alpha_r$
- Reflection
  - $\alpha_i = \alpha_r$
- Where n= c/V
  - C, speed of light in vacuum
  - V, speed of light in medium n
  - n is refractive index of the medium n

Optical Fibers

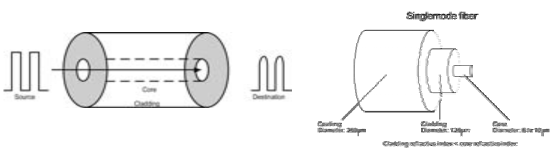
- By index profile
  - Step-index fiber: refractive index of fiber core is a step function
  - Graded-index fiber: refractive index of fiber core is a function of radius distance
- By sustainable propagation mode
  - Single-mode fiber: single propagation mode
  - Multi-mode fiber: multiple propagation mode



Optical Fibers



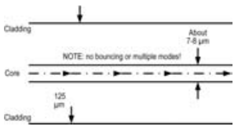
Optical Fibers – Single Mode step-index



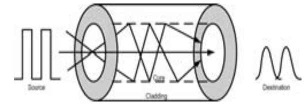
- Uses step-index fiber and highly focused source of light that limits beams to a small angle of angles, all close to the horizontal
- The smaller in diameter and the lower index of refraction
- Low density results in a critical angle close to 90 degrees to make the propagation beams almost horizontal
- Propagation of different beams is almost identical and delays are negligible
- All beams recombine at the destination without distortion to the signal

Optical Fibers – Single Mode step-index

- Highest bandwidth: 100Gbps per km for a long distant communication
- Bandwidth limitation is due to Chromatic Dispersion (different light colors)
- Used in long haul applications such as Wide Area Networks (WANs), Metropolitan Networks (MANs), intercity and undersea applications
- Each undersea optical fiber cable currently being installed has more bandwidth than all operational communication satellites in orbit
- Copper is no longer installed in undersea applications
- The only disadvantage of the single-mode fiber is its small core for light coupling



Optical Fiber – Multimode Step-index

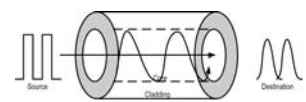


- Multiple beams from a light source move through the core in different paths
- Density of the core is constant from the center to the edges, core diameter is comparatively large
- A beam of light moves through the core in a straight line until it reaches the interface of the core and cladding
- At the interface, a sudden change of density alters the angle of beam's motion
- Beams in the centre travel in straight line without reflection & refraction
- Beams with incident angle smaller than the critical angle will penetrate the cladding and are lost

Optical Fibers – Multimode Step-index

- Beams with incident of angle greater than the critical angle will bounce back and forth down the channel to reach the destination
- Light traveling longer paths will take longer to reach the fiber end than the light traveling shorter paths
- Light traveling down the fiber core will reach the end first
- Light bouncing down the fiber at the critical angle will arrive last
- Different beams will recombine constructively or destructively at different time resulting a signal distortion by propagation delay
- It is not possible to distinguish the individual light pulses when a closely spaced pulses sent down the fiber
- This distortion limits data rate and bandwidth (typically 20Mbps)
- The fiber is the cheapest and has least bandwidth

Optical Fibers – Multimode Graded-index

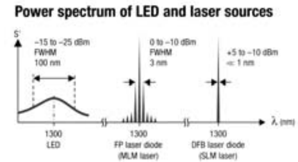


- This fiber decreases the distortion of the signal through the cable
- Varying densities gradually from the center of the core to the lowest at the edge
- Light beams moves horizontally and in a straight line through the constant density at the centre
- Beams at other angles move through a series of constantly changing densities
- Each density difference causes each beam to refract into a curve
- Varying refraction varies the distance each beam travels in a given period of time resulting in different beams intersecting at regular intervals
- Greater precision signal can be reconstructed with a receiver placing at suitable intersecting position
- Bandwidth-distance is 1GBps per km

Optical Fiber – emitters

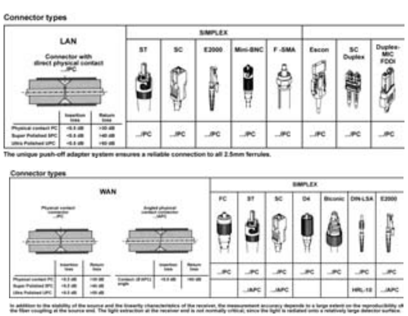
- Light Emitting Diodes (LEDs)
  - Cheap, a wide spectrum, wide emitting angle
  - Used of low date rates (10Mbps)
  - Used with plastic, multi-mode, and graded index optical fiber with wide angle of acceptance
- Laser Diodes
  - Much expensive, much faster data rates (more than 2.5 GBps)
  - Narrow spectral band, higher power
  - Narrow angular output make them a good choice for high data rate, long haul, single-mode optical fiber systems
  - Narrow angle of acceptance

Optical Fibers – detectors



- Photodiodes are used for signal conversion
- Photodiodes have different spectral characteristics, depending on the type of semiconductors (Germanium Ge, indium gallium arsenide InGeAs)
- Ge is low cost but sensitive to temperature

Optical Fibers – connectors

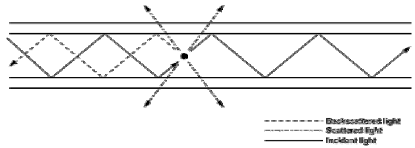


Optical Fibers - attenuation

- Light entering with different angles does not follow the same path
- Light entering the center of the fiber core at very low angle will take a relatively direct path through the center of the fiber
- Light injected at a higher angle of incidence or near the outer edge of the fiber core will take a less direct , longer path through the fiber and therefore travel more slowly down the length of the fiber
- Each path resulting from a given angle of incidence and entry point give rise to a mode
- As they travel along the fiber , all modes are attenuated

Optical Fibers - attenuation

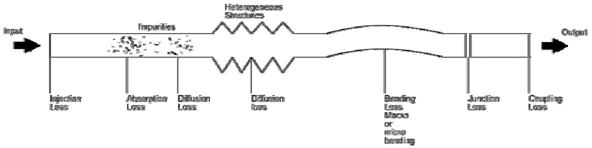
- Light Absorption
  - Intrinsic absorptions due to fiber material and molecular resonance
  - Extrinsic absorptions due to impurities at around 1240nm and 1390nm
- Rayleigh Scattering
  - Scattering causes the light energy to be dispersed in all directions, with some light escaping the fiber core
  - A small portion of this light energy is returned down the core and is termed “backscattering”



Optical Fibers - attenuation

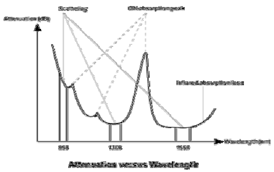
- Bending Losses
  - Light escaping the core due to imperfections at the core/cladding boundary
  - angle of incidence of the light energy at the core/cladding boundary exceeding the Numerical Aperture of the fiber due to bending of the fiber
  - Singlemode fibers may be bent to a radius of 10cm with no significant losses, however, after the min bend radius is exceeded, losses increase exponentially with increasing radius
  - Min bend radius is dependent on fiber design and light wavelength

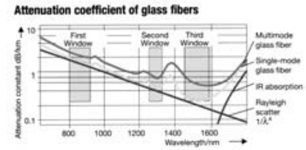
Optical Fibers - attenuation



- Total signal attenuation is sum of passive components and connection losses
- For a given wavelength, the attenuation is defined as the ratio between the input power and the output power of the fiber being measured
- Attenuation depends on the fiber and on the wavelength
- Rayleigh scattering is inversely proportional to the fourth power of the wavelength

Optical Fibers - attenuation





- Three 3 regions with min attenuation
  - 820 to 880 nm, 1285 to 1330nm, and 1525 to 1575nm

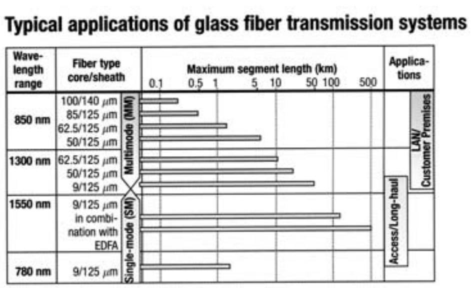
Optical Fibers - dispersion

- Dispersion reduces the effective bandwidth available for transmission
- Modal dispersion
  - A very short pulse is injected into the fiber within the numerical aperture, all energy does not reach the end of the fiber at the same time
  - Different modes, an oscillation carry energy down the fiber down different paths
  - This pulse spreading by virtue of different light path lengths is called modal dispersion
- Chromatic dispersion
  - A pulse sent down the fiber is usually composed of a small spectrum of wavelengths
  - They go through the fiber at different speeds
  - Because speed is dependent on refractive index and therefore the wavelength. This effect is known as chromatic dispersion

Optical Fibers - applications

- Long-haul transmission systems
- Intercontinental and undersea transmission systems
- Trunking between local central offices
- Metropolitan area backbone systems
- Local area networks
- Cable television backbone transmission systems
- Private network backbone systems
- Interconnection of PBXs with remote switch units
- Short-haul data-transmission systems through noisy environments
- Fiber channel for high-speed computer communications

Optical Fibers - applications



Optical Fibers – selection

Type	Core/cladding Diameter (um)	850nm	Attenuation (db/km) 1300nm	1550nm	Bandwidth (MHz/Km)
Multimode	62.5/125	3.0-4.0	1.0-2.0		150-800
Multimode	50/125	2.4-4.0	0.75-2.0		400-1000
Single mode	9/125		0.35-1.0	0.25-1.0	

Typical Optical Fiber Characteristics

Optical Fibers – selection

- System gain
  - The higher system gain, the better to overcome cable and other losses
  - Cost is higher for system gain, high output laser, high-sensitivity diodes
- Cable characteristics
  - Cable is graded according to its loss and bandwidth
  - System operating at 100Mbps or more on multimode fiber, bandwidth becoming limiting factors as opposed to loss
  - For public networks, single mode fiber is cheaper, greater bandwidth and lower loss, better for future expansion
  - If application is fixed, 62.5/125um is better choice than 50/125um cable

Optical Fibers – selection

- Wavelength
  - Most feasible wavelength is multimode fiber 1300nm
  - For use with WDM (wavelength Division Multiplexing), 1550nm is a choice
  - 850nm should be avoided because of its greater loss
- Light source
  - Laser is much higher power and operates at a higher bit rates
  - LED is lower in cost and a longer life, wavelength is broader than that of a laser
  - LEDs used in shorter distance (<10km) and bandwidth lower than 150Mbps
- Wavelength Division Multiplexing
  - WDM can multiply the capacity of a fiber with little additional cost, can be full-duplex mode.
  - For short distance, it is not a choice due to the high WDM equipment cost

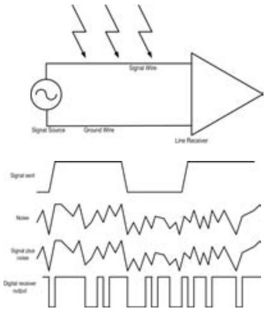
Optical Fibers - loss budget

- When installing a fiber network, network topology and equipment specification needed to be considered
- Optical loss budget or end-to-end optical link loss
  - Source
  - Detector
  - Optical transmission line
  - Fiber attenuation loss
  - Source-to-fiber coupling loss
  - Fiber attenuation loss
  - Loss of all components: connectors, splices and pass components

Transmission Impairment

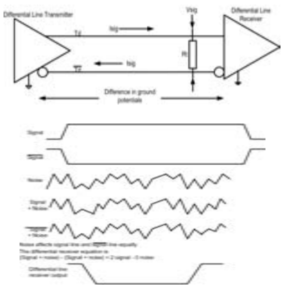
- Signal received is different from signal sent
- 3 causes: attenuation, distortion and noise
- Attenuation
  - Loss of energy for overcoming resistance of the media, amplifier is used to compensate the loss
- Distortion
  - Signal change shape or form
  - Occurs in a composite signal, each signal has its own propagation speed through a medium, so has its own delay to arrive destination
- Noise
  - Thermal noise, induced noise, crosstalk and impulse noise may corrupt the signal
  - Thermal noise caused by the random motion of electronics
  - induced noise comes from sources: motors, appliances and other devices
  - Crosstalk is the effect of one wire on the other
  - Impulse noise is a spike from high energy in a very short period, e.g. lighting

Unbalanced Cable System



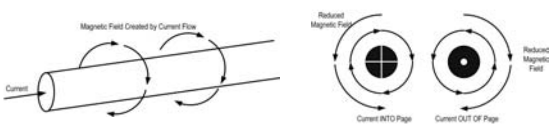
- RS-232, is an unbalanced system
- Signal wire, carries signal voltage and the signal ground wire is at or near zero volts
- Electrical noise can be coupled onto the signal wire, and the line receiver cannot separate the signal from the noise
- Transmitter and receiver may be at different ground potentials
- It limits the data rate to 19.6kbps and max transmission distance to 15m

Balanced Cable System



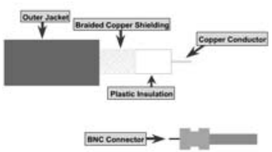
- RS-422A, is a balanced or differential transmission system
- Transmitter, has two output lines
- Differential line receiver voltage Vsig is developed across the line terminating resistor Rt
- Different receiver has two inputs: inverting and non-inverting
- External noise affects both lines equally and the differential line receiver cancels out the noise voltage

Twisted Cable



- Current flowing in a conductor creates a magnetic field which will enter into adjacent conductors and cause interference
- Magnetic field created by the opposite direction equal current flows create nearly canceling magnetic fields away from the conductors and reducing interference
- Signals can also be coupled through stray capacitance into adjacent wires. This will be minimized in twisted pair

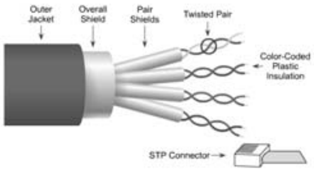
Coaxial Cable



- Speed : 10 – 100Mbps
- Cost: inexpensive
- Size: medium
- Max cable length: 500m

- Distance can be extended using repeater
- In past, thick cable is used for backbone cable and is referred to as Thicknet cable
- Coaxial cable with outside diameter 0.35 cm is referred as Thinnet and was used for Ethernet network

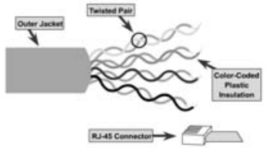
Shielded Twisted Pair (STP)



- Speed: 10 – 100Mbps
- Cost: moderate expensive
- Size: medium to large
- Max cable length: 100m

- Combine the techniques of shielding, cancellation and twisted of wires
- The 4 pairs of cable are wrapped in metallic foil braid and is usually 150 ohm
- STP reduce electrical noise both within cable (coupling and crosstalk) and outside cable (electromagnetic interference)
- STP needed to be grounded at both end

Unshielded Twisted Pair (UTP)



- Speed: 10 – 100Mbps
- Cost: least expensive
- Size: small
- Max cable length: 100m

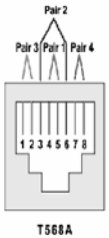
- 4 pairs of wires used in variety of networks.
- Each individual wires is covered by insulating material.
- each pair twisted around each other to provide a cancellation effect for EMI, crosstalk between pairs
- Wire size is either 22 or 24 gauge with external diameter 0.43cm
- Good size and cheap for installation

UTP cable categories

The Electronic Industries Association (EIA) has developed standards to grade UTP cables by qualities

- Category 1, basic twisted pair cabling used in telephone systems, fine for voice but inadequate for all but low-speed data communication
- Category 2, suitable for voice and for data transmission of up to 4 Mbps
- Category 3, three twists per foot, can be used for data transmission up to 10Mbps, standard telephone cable
- Category 4, twists per foot and other conditions for transmission rate up to 16Mbps
- Category 5, used for data transmission up to 100Mbps

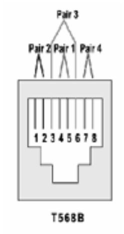
UTP T568-A RJ-45 connector



Pin No	Pair No	Function	Wire Color
1	3	Transmit	White/Green
2	3	Transmit	Green/White
3	2	Receive	White/Orange
4	1	Not used	Blue/White
5	1	Not used	White/Blue
6	2	Receive	Orange/White
7	4	Not used	White/Brown
8	4	Not used	Brown/White

ISDN standard

UTP T568-B RJ-45 connector



Pin No	Pair No	Function	Wire Color
1	2	Transmit	White/Orange
2	2	Transmit	White/Green
3	3	Receive	Blue/White
4	1	Not used	White/Blue
5	1	Not used	Green/White
6	3	Receive	Green/White
7	4	Not used	White/Brown
8	4	Not used	Brown/White

AT & T Standard

UTP Straight-through Cable

	Hub/Switch		Server/Router
Pin	Label	Pin	Label
1	RD+	1	TD+
2	RD-	2	TD-
3	TD+	3	RD+
4	NC	4	NC
5	NC	5	NC
6	TD-	6	RD-
7	NC	7	NC
8	NC	8	NC

- Connection between switch and server
- Connection between switch and workstation

UTP Crossover Cable

	Hub/Switch		Server/Router
Pin	Label	Pin	Label
1	RD+	3	TD+
2	RD-	6	TD-
3	TD+	1	RD+
4	NC	4	NC
5	NC	5	NC
6	TD-	2	RD-
7	NC	7	NC
8	NC	8	NC

- Connection between switches
- Connection between routers
- Connection between workstations

UTP cable

Strip off Jacket

Clip wires

Insert wires into RJ-45 plug

Crimp down wires

UTP cable



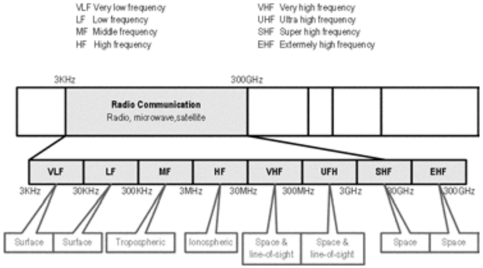


Coaxial and UTP Summary

UTP	Performance	Application
CAT-1	none	none
CAT-2	1MHz	Telephone
CAT-3	16MHz	10BaseT, Token Ring 4 Mbps, ISDN low speed
CAT-4	20MHz	Token ring 16
CAT-5	100MHz	100BaseT, 100VG-AnyLAN, Token Ring 20 Mbps

Coax	Impedance	Application
RG-59	75 ohms	Cable TV
RG-58	50 ohms, 5mm diameter	10Base2 or ThinNet
RG-11 and RG-8	50 ohms, 5mm diameter	10Base5, ThickNet

Radio Frequency Allocation

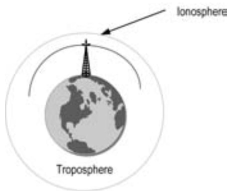


The section of the electromagnetic spectrum defined as radio communication is divided into eight ranges, called bands, each regulated by government authorities

Propagation of Radio Waves

- The earth is surrounded by two layers:
  - Troposphere and Ionosphere
  - Troposphere is the portion of the atmosphere extending 30 miles from the earth's surface, and contains clouds, wind, temperature variations and jet plane
  - Ionosphere is the layer above the troposphere and below the space, and contains free electrically charged particles

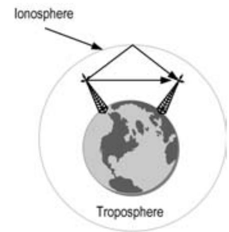
Propagation of Radio Waves



Surface propagation

- Surface Propagation
  - Radio waves travel through the lowest portion of the atmosphere, hugging the earth
  - At lowest frequencies, signals emanate in all directions from the transmitting antenna and follow the curvature of the planet
  - Greater the power, greater the distance
  - Also taken in seawater

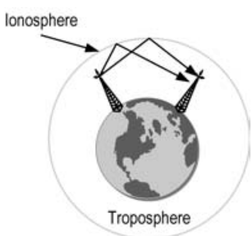
Propagation of Radio Waves



Tropospheric propagation

- Tropospheric Propagation
  - Signals can be antenna to antenna
  - Limited by the curvature of the earth
  - Or broadcast into the upper layers of the tropospheric and reflected back down to the earth's surface
  - Allow greater coverage of distance

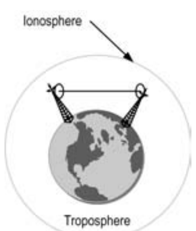
Propagation of Radio Waves



Ionospheric propagation

- Ionospheric Propagation
  - Higher-frequency radio waves radiate upward into the ionosphere where they reflected back to earth
  - Density difference between the troposphere and the ionosphere causes each radio wave to speed up and change direction, bending back to earth
  - Greater coverage of distance with lower power output

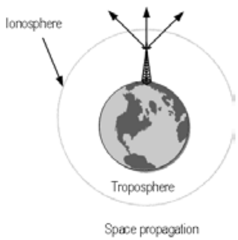
Propagation of Radio Waves



Line-of-sight propagation

- Line-of-sight Propagation
  - Very high frequency signals transmitted in straight line from antenna to antenna
  - Antennas must be directional and facing each other, tall enough or close enough and not affected by the curvature of the earth
  - Waves emanate upward, downward and forward, and can be reflect off the surface of the earth or parts of the atmosphere
  - Receiving signals can be corrupted by the reflected waves

Propagation of Radio Waves

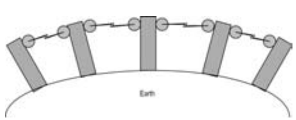


- Space Propagation
  - Utilize satellite relays in place of atmospheric refraction
  - Broadcast signal is received by an orbiting satellite which is rebroadcasts the signal to the intended receiver back on the earth
  - Satellite is in line-of-sight transmission with other satellite
  - Satellite distance from earth equivalent to a super-high-gain antenna

Microwave Communication

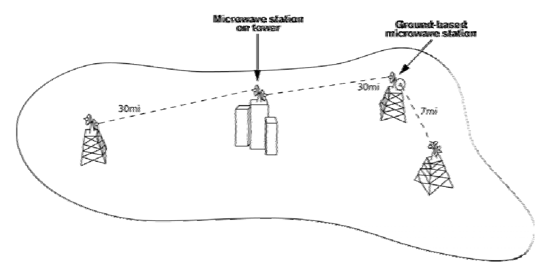
- Factors affecting microwave communication:
  - Free-space loss, signal attenuation when it travels through the atmosphere
  - Atmospheric attenuation, closely related to free-space attenuation. Changes in air density, absorption by atmospheric particles and water density attenuate the signal
  - Reflections, occurs when signal traverse a body of water or a fog bank. Signals takes multiple paths, which arrive at the receiving antenna out of phase and cause the signal to fade
  - Diffraction, which occurs as a result of the terrain the signal crosses
  - Rain attenuation, raindrops absorb or scatter the signal. The effect is greater at higher frequencies and varies with the size of raindrops

Microwave Communication

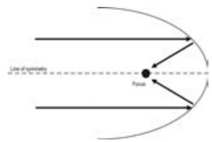


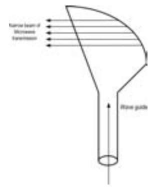
- Extremely high frequency (EHF)
- line-of-sight required
- Taller antenna for longer sight distance
- Signal travel farther without obstacles
- Two frequencies required for two-way communication
- System repeaters required for each antenna to increase the servicing distance

Microwave Communication



Microwave Communication





- Parabolic dish antenna is based on geometry of a parabola: parallel lines to the line of symmetry reflected off at angles to the focus where a wide range of waves is caught
- Horn antenna looks like a gigantic scoop. Outgoing signals are broadcasted up a stem and deflected outward in a series of narrow parallel beams by the curved head. Received transmissions are collected by the horn and deflected down into the stem.

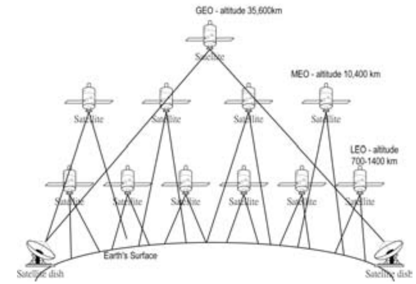
Microwave Communication

- Applications
  - Trunking between central offices
  - Wireless local loop
  - Temporary or emergency restoration of facilities
  - Connecting PBXs in a metropolitan network
  - Interconnecting local area networks
  - Providing diverse routing to protect against failure of the primary circuit route
  - Crossing obstacles such as highways and rivers
  - Implementing local data communications networks

Satellite Communication

- AT & T launched the first communication satellite , Telstar1 in 1962
- Long delay 300ms to make a return trip to satellite
- For most of data protocols, the delay is not significant but not for voice
- In 1998, the Iridium low earth orbit (LEO) satellites launched for practical use
- In 2002, Iridium with its 66 satellites joined the Teledesic to offer data service network with 288 satellites
- Other companies are offering medium earth orbit (MEO) satellites orbiting the earth at 6200 miles (10,390 km)
- More satellites needed for the better service coverage and lesser communication delay.

Satellite Communication Orbits



- GEO, Geosynchronous Satellites
- MEO, Medium earth orbit satellites
- LEO, Low earth orbit satellites

Principal Satellite Frequency Bands

Band	Uplink	Downlink
C	5925 – 6425 MHz	3700 – 4200 MHz
Ku	14.0 – 14.5 GHz	11.7 – 12.2 GHz
Ka	27.5 -31.0 GHz	17.7 – 21.2 GHz

- C-band is most desirable because they are least susceptible to rain absorption. Satellites share C-band frequencies with terrestrial microwave. Prevention of interference required by highly directional antennas.
- K-band frequencies are exclusive to satellites
- Ku band frequencies are susceptible to rain absorption
- Ka-band satellites are becoming more feasible for smaller antennas and low cost earth stations
- Lower frequencies are used from satellite to ground for less path loss
- Solar battery capacity limits satellite output power

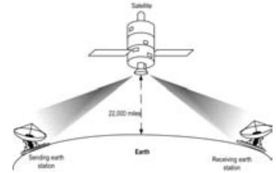
Satellite Communication- advantages

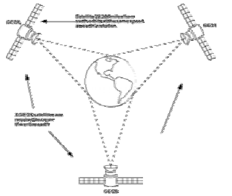
- Costs of satellite circuits are independent of distance within the coverage range of a single satellite
- Impairments that accumulate on a per-hop basis on terrestrial microwave circuits are avoided with satellites because the earth station-to-earth station path is a single hop through satellite repeater
- Coverage is independent of terrain and other obstacles that may block terrestrial communications
- Earth stations can verify their own transmission by a satellite returning signal
- Satellites signal can reach wide area simultaneously
- Wide satellite bandwidth facilitates high speed voice/video/data communications
- Satellite signal can brought directly to end users
- Multipath reflections that impair terrestrial microwave communications have little effect on satellite radio paths

Satellite Communication - limitations

- Lack of frequencies; atmospheric limitations prevent the use of higher frequencies for reliable paths
- Delay from earth station to satellite and back is 300ms
- Multihop satellite connections impose a delay if the distance between earth stations exceeds the satellite's footprint
- Path loss is high from earth to satellite
- Rain absorption affects path loss, particularly at higher microwave frequencies
- Frequency crowding in the c-band is high with potential for interference between satellites and terrestrial microwave operating on the same frequency

Geosynchronous Satellites



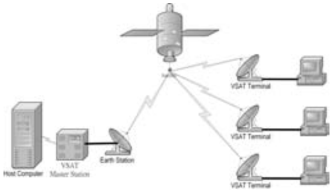


- Line-of-sight required the sending and receiving antennas be locked onto each other at all times
- Satellite must move at the same speed as the earth
- Orbital speed is based on distance from the plant, only one orbit can be geosynchronous.
- This occurs at the equatorial plane and is approx 22,400 miles (35,860 km) from the earth's surface.
- Min 3 satellites equidistant from each other in geosynchronous orbit to provide full global transmission
- GEOs covers both most of the areas of the earth, except the extreme polar regions

Low Earth Orbiting Satellites (LEOS)

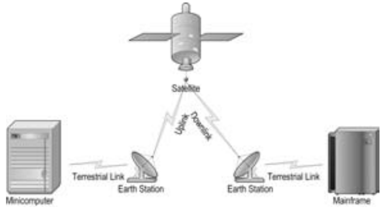
- LEO is a brand new service that avoids the delay inherent with satellite services
- Much closer to the earth than GEOS
- Do not need large antennas or power transmitters in either satellite or the ground station
- System cost is cheaper and ground station is more portable
- LEOS is constantly moving relative to a ground observer and may need steerable antennas
- LEOSs orbit between 600 and 1800 km above the ground level
- Less battery drain, cheaper satellites and lower launch costs, less subscriber costs must be launched to provide continuous coverage
- Many satellites used to create continuous coverage are called constellation

Very Small Aperture Terminal (VSAT)



- VSAT antennas are small 1.8m
- Easy to install on rooftops
- Star-connected with a hub at the center and dedicated lines running to the host computer
- The hub has a large antenna 4 – 11m and aims at the satellite
- Primary on data application, such as financial services and also voice and video
- C-band 9.6kb/s, ku-band 56kb/s
- Frequency used mostly in ka-band
- Advantage to support multiple locations, VSAT becomes more attractive

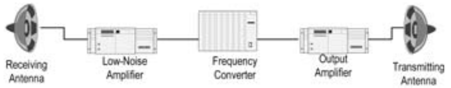
Satellite System



- Five elements: two terrestrial links, an uplink, a downlink and satellite repeater
- Satellite itself consists of six subsystems: physical structure, transponder, attitude control apparatus, power supply, telemetry equipment and stationkeeping apparatus

Satellite System

- Physical Structure
  - Solar batteries and fuel are the limitation for satellite size
  - Large physical size is desirable for carrying radio and support equipment and provide a platform for large antennas to obtain high gain for overcoming path loss between earth station and satellite
- Transponders
  - A radio-relay station on board the satellite
  - Receiving antenna picks up incoming signal from earth station and then amplified and converted to downlink frequency. The signal is amplified to the transmitting antenna for downlink



Satellite System

- Attitude Control apparatus
  - Must be stabilized to prevent them from tumbling through space and to keep antennas precisely aligned toward earth
  - Achieved by a spin-stabilized satellite rotating on its axis about 100 revolutions per minute and three-axis stabilization which consists of a gyroscopic stabilizer inside the vehicle
- Power supply
  - By solar batteries, a major factor limits the satellite working life
  - Power is conserved by turning off unused equipment
- Telemetry equipment
  - Monitor its position and attitude and initiate correction of any deviation from its assigned station
  - Monitors the signal strength and keep uplink and downlink paths signals balanced
- Stationkeeping equipment
  - Small rockets are installed on GEO to keep them on position
  - Fuel required to fire rocket limits the working life of satellite
  - MEO & LEO are tracked by moveable antennas, stationkeeping equipment not required

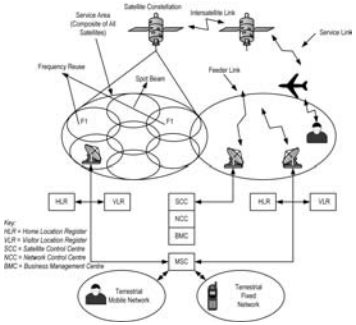
Mobile Telecommunication

- Two categories : Terrestrial & Satellite
- Mobility is achieved by a RF link between users and a relay station which is connected to a fixed network
- Terrestrial systems are best for urban environment
- Satellites provide effective solutions for remote areas such as high seas, air corridors and remote land masses
- The two systems are going to be merged due to the rapid development of Mobile Satellite Service

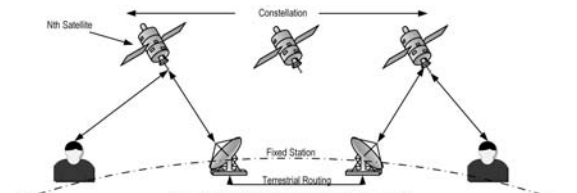
Mobile Telecommunication

- Terrestrial Systems
  - Begin from 1800 for maritime navigation and safety
  - 2nd world War for military users
  - 1950 VHF/FM radios for private mobile radio
  - 1970, growth is slow due to spectrum scarcity
  - 1940, “cellular radio” concept was proposed by Bell Laboratories
  - The concept offers a solution to support large numbers of users in a limited spectrum

Mobile Satellite System

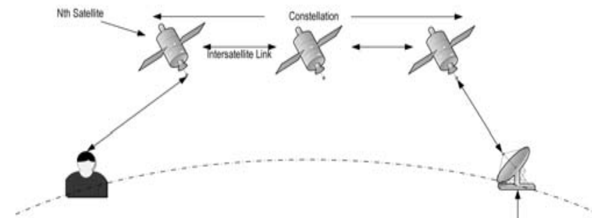


Mobile Satellite System



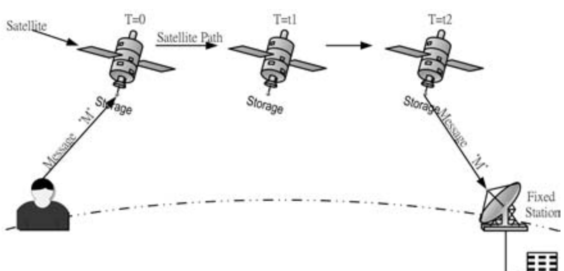
Non-geostationary Satellite Systems using satellite - ground hops

Mobile Satellite System



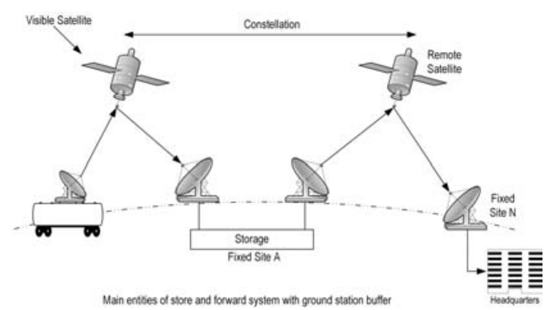
Non-geostationary Satellite Systems using Intersatellite links

Mobile Satellite System



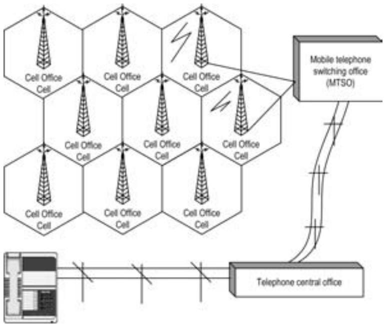
Main entities of store and forward system with satellite buffer

Mobile Satellite System



Main entities of store and forward system with ground station buffer

Cellular System



Cellular System

- Provide communications between two moving devices or between one mobile unit and one stationary unit
- A service provider must be able to locate and track a caller, assign a channel to the call, and transfer the signal from channel to channel as the caller moves out of the range of one channel and into the range of another
- Cellular service area consists of cells. Each cell contains antenna and under the control of a cell office.
- Each cell office is controlled by a mobile telephone switching office (MTSO)
- The MTSO co-ordinates all operation between cell offices and the central telephone central office
- Cell size is flexible and depends on the population
- High density area more small cells to meet the traffic demands
- Cell size is optimize to prevent interference of adjacent cells

Cellular System

- Transmitting
  - To make a call, mobile phone scans the band, seeking for strong signal, sends data to the closest cell office using that channel.
  - The cell relays data to MTSO, the MTSO sends the data to the central office.
  - Connection is made if the party is available
  - MTSO assigned an unused channel to the call and connection is established
  - The mobile is automatically turning the a new channel and voice communication begins
- Receiving
  - When a call is made, telephone office sends the number to the MTSO
  - MTSO search the mobile location, and
  - Once the location is found, MTSO sends a ring signal and assigns a voice channel
- In 1993, cellular was moving to a standard called cellular digital data

Cellular System

- Each band consists of 416 channel for full-duplex communication, channel width is 60Hz
- Some channels are reserved for control and setup data rather than voice communication
- To prevent interference, channels are distributed among the cells such that adjacent cells do not use the same channels.

Media Comparison

Medium	Cost	Speed	Attenuation	EMI	Security
UTP	Low	1-100 Mbps	high	high	low
STP	moderate	1-150Mbps	high	moderate	low
Coax	moderate	1Mbps – 1Gbps	moderate	moderate	low
Optical fiber	high	10Mbps-2Gbps	low	low	high
Radio	moderate	1-10Mbps	Low-high	high	low
Microwave	high	1Mbps-10Gbps	variable	high	moderate
Satellite	high	1Mbps-10Gbps	variable	high	moderate
Cellular	high	9.6-19.2Kbps	low	moderate	low

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