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Data and Computer Communications

Chapter 4
Transmission Media

These slides are originally for W. Stallings.

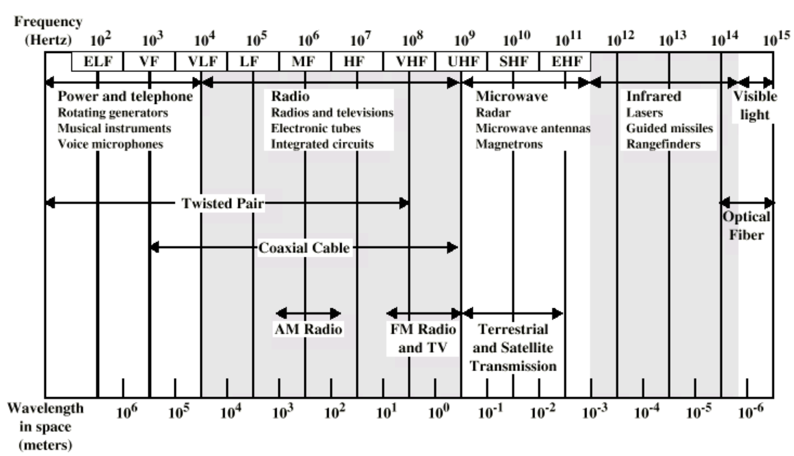
Overview

- Guided - wire
- Unguided - wireless
- Characteristics and quality determined by medium and signal
- For guided, the medium is more important
- For unguided, the bandwidth produced by the antenna is more important
- Key concerns are data rate and distance

Design Factors

- Bandwidth
  - Higher bandwidth gives higher data rate
- Transmission impairments
  - Attenuation
- Interference
- Number of receivers
  - In guided media
  - More receivers (multi-point) introduce more attenuation

Electromagnetic Spectrum



ELF = Extremely low frequency
VF = Voice frequency
VLF = Very low frequency
LF = Low frequency
MF = Medium frequency
HF = High frequency
VHF = Very high frequency
UHF = Ultrahigh frequency
SHF = Superhigh frequency
EHF = Extremely high frequency

Guided Transmission Media

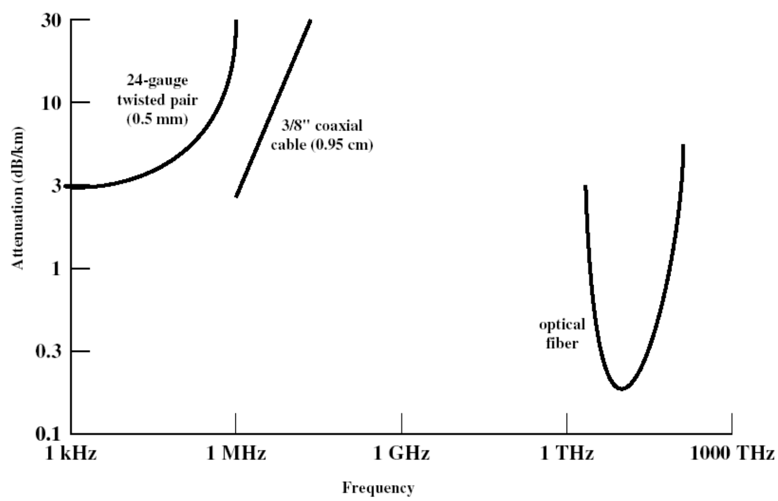
- Twisted Pair
- Coaxial cable
- Optical fiber

Table 4.1 Point-to-Point Transmission Characteristics of Guided Media [GLOV98]

	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 (multi-pair cables)	0 to 1 MHz	3 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	180 to 370 THz	0.2 to 0.5 dB/km	5 µs/km	40 km

THz = TeraHerz = 10^{12} Hz

Attenuation of Typical Guided Media



Twisted Pair

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

(a) Twisted pair

-Usually more than one pair bundled together
-Nearby pairs have different twist length to reduce crosstalk
-Twist length 5 cm to 15cm
-Wire thickness 0.4 to 0.9 mm

Twisted Pair - Applications

- Most common medium
- Telephone network
  - Between house and local exchange or end-office (subscriber loop)
- Within buildings
  - To private branch exchange (PBX)
- For local area networks (LAN)
  - 10Mbps or 100Mbps (for high rates – limited number of devices and distance)

Twisted Pair - Pros and Cons

- Cheap
- Easy to work with
- Low data rate
- Short range: repeaters required every few hundred meters

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Twisted Pair - Transmission Characteristics

- Analog
  - Amplifiers every 5km to 6km
- Digital
  - Use either analog or digital signals
  - repeater every 2km or 3km (<u>This may be wrong, few hundred meters is the answer</u>)
- Limited distance: highest attenuation relative to other guided media
- Limited bandwidth (1MHz)
- Limited data rate (100MHz)
- Susceptible to interference and noise

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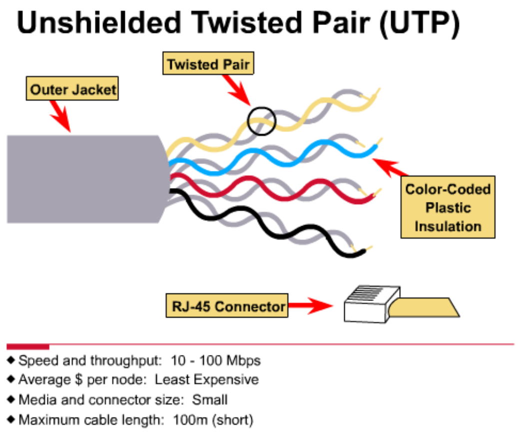
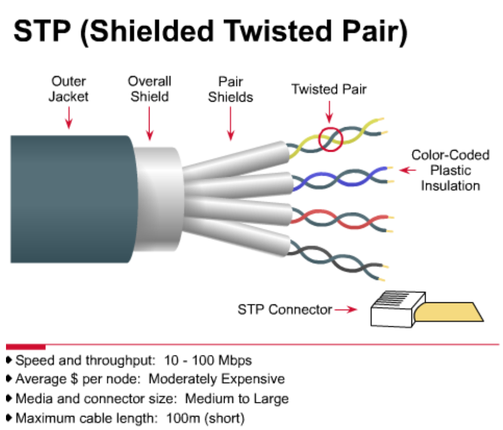
Unshielded and Shielded TP

- Unshielded Twisted Pair (UTP)
  - Ordinary telephone wire
  - Cheapest
  - Easiest to install
  - Suffers from external EM interference



Unshielded and Shielded TP

- Shielded Twisted Pair (STP)
  - Metal braid or sheathing that reduces interference
  - More expensive
  - Harder to handle (thick, heavy)



UTP Categories (Recognized by EIA-568)

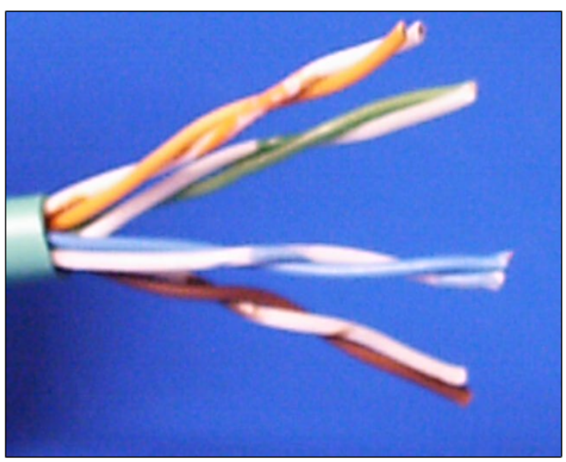
- Cat 3
  - up to 16MHz
  - Voice grade found in most offices
  - Twist length of 7.5 cm to 10 cm
- Cat 4
  - up to 20 MHz
- Cat 5
  - up to 100MHz
  - Commonly pre-installed in new office buildings
  - Twist length 0.6 cm to 0.85 cm

Cat 3 and Cat 5 are ones mostly used for LAN applications:
- Differ in number of twists

EIA = Electronic Industries Association

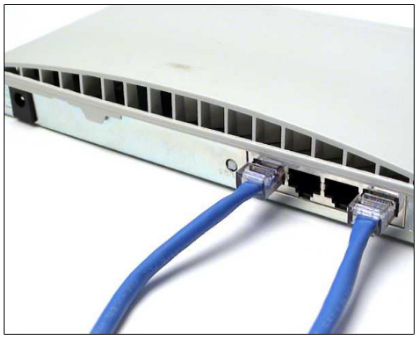
UTP Categories

CAT 5 Cable

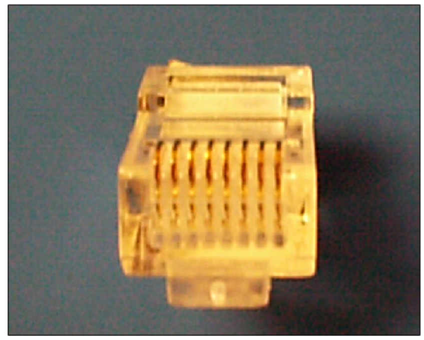


RJ-45 Connector

Multiport Repeaters (Hubs)



RJ-45 Front



Near End Crosstalk

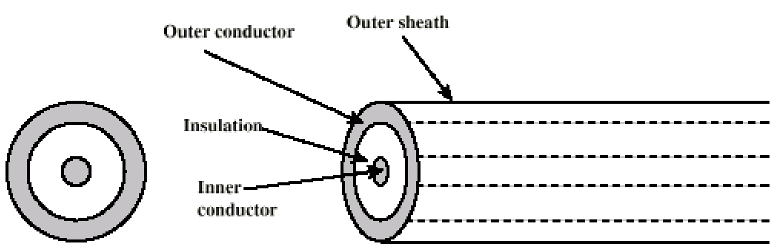
- Coupling of signal from one pair to another
- Coupling takes place when transmit signal entering the link couples back to receiving pair
- i.e. near transmitted signal is picked up by near receiving pair

STP vs. UTP

Table 4.2 Comparison of Shielded and Unshielded Twisted Pair

	Attenuation (dB per 100 m)			Near-end Crosstalk (dB)		
Frequency (MHz)	Category 3 UTP	Category 5 UTP	150-ohm STP	Category 3 UTP	Category 5 UTP	150-ohm STP
1	2.6	2.0	1.1	41	62	58
4	5.6	4.1	2.2	32	53	58
16	13.1	8.2	4.4	23	44	50.4
25	—	10.4	6.2	—	41	47.5
100	—	22.0	12.3	—	32	38.5
300	—	—	21.4	—	—	31.3

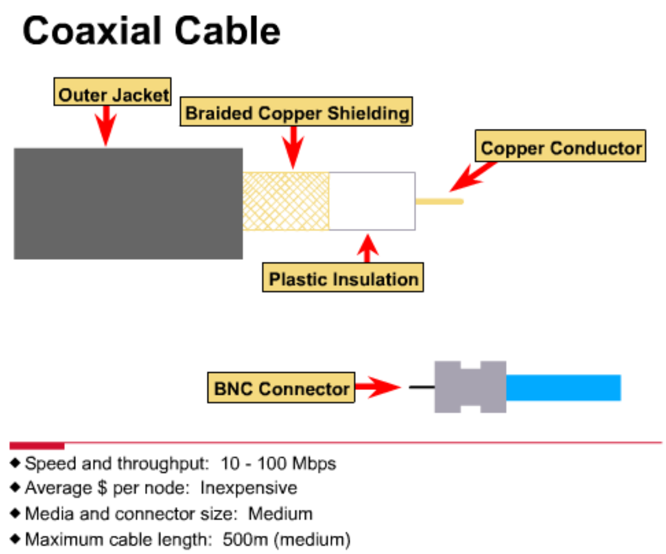
Coaxial Cable



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

-To allow operation over wider range of frequencies
-Diameter of 1 to 2.5 cm
-Because of shielding, much less susceptible to interference and crosstalk

Coaxial Cable



Coaxial Cable Applications

- Most versatile medium
- Television distribution
  - Ariel to TV
  - Cable TV
- Long distance telephone transmission
  - Can carry 10,000 voice calls simultaneously (using FDM)
  - Being replaced by fiber optic
- Short distance computer systems links
- Local area networks

Coaxial Cable - Transmission Characteristics

- Analog
  - Amplifiers every few km
  - Closer if higher frequency
  - Up to 500MHz
- Digital
  - Repeater every 1km
  - Closer for higher data rates

Performance limited by attenuation, thermal noise, and intermodulation noise

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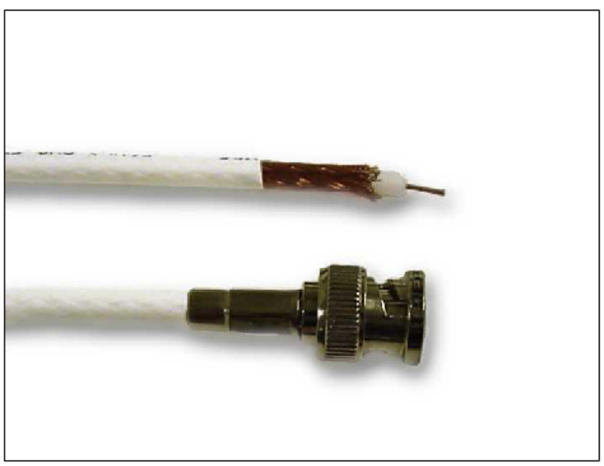
Coaxial Cable - Transmission Characteristics

10BASE2 50 Ohm Coax Cable



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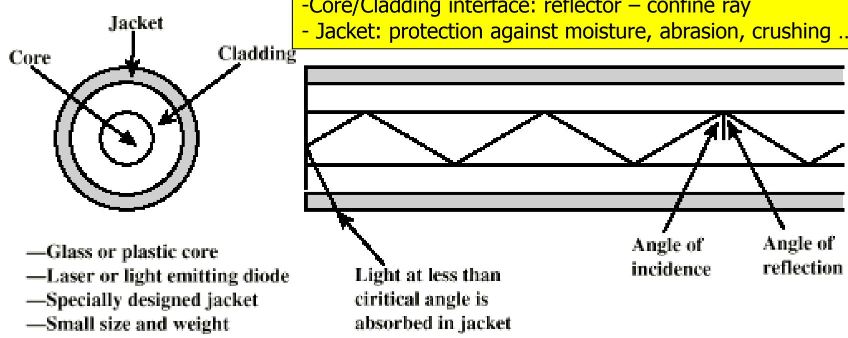
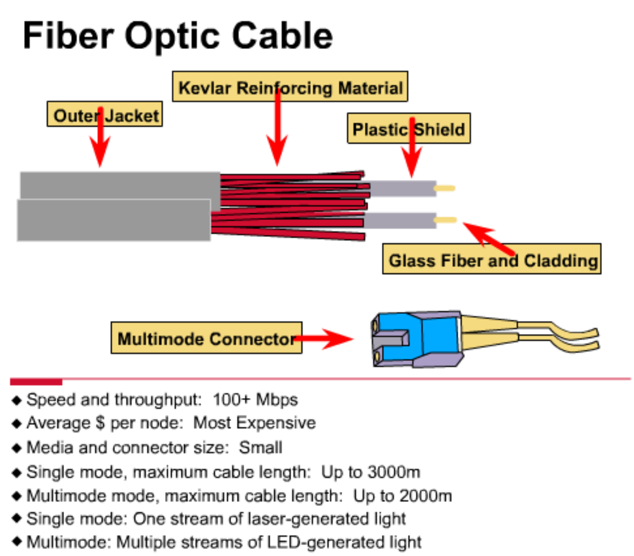
Optical Fiber

- Core: one or more thin strands or fibers (8 to 100 mm)
- Cladding: glass or plastic coating with different optical properties than the core
-Core/Cladding interface: reflector – confine ray
- Jacket: protection against moisture, abrasion, crushing …



-Lowest losses using ultrapure fiber – difficult to manufacture
-Higher loss mutlicomponent glass fibers are more economical
-Plastic fiber is the cheapest – used for short-haul links

Optical Fiber



Optical Fiber - Benefits

- Greater capacity
  - Data rates of hundreds of Gbps
- Smaller size & weight
- Lower attenuation
- Electromagnetic isolation
- Greater repeater spacing
  - 10s of km at least

Optical Fiber - Applications

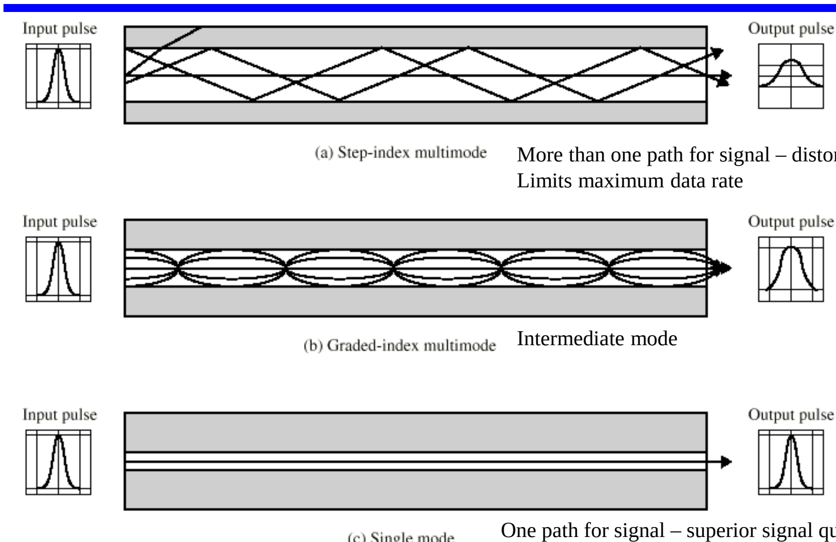
- Long-haul trunks
- Metropolitan trunks
- Rural exchange trunks
- Subscriber loops
- LANs

Optical Fiber - Transmission Characteristics

- Act as wave guide for 10^{14} to 10^{15} Hz
  - Portions of infrared and visible spectrum
- Light Emitting Diode (LED)
  - Cheaper
  - Wider operating temp range
  - Last longer
- Injection Laser Diode (ILD)
  - More efficient
  - Greater data rate
- Wavelength Division Multiplexing

LED – ILD: semiconductor devices that emit a beam when voltage is applied

Optical Fiber Transmission Modes

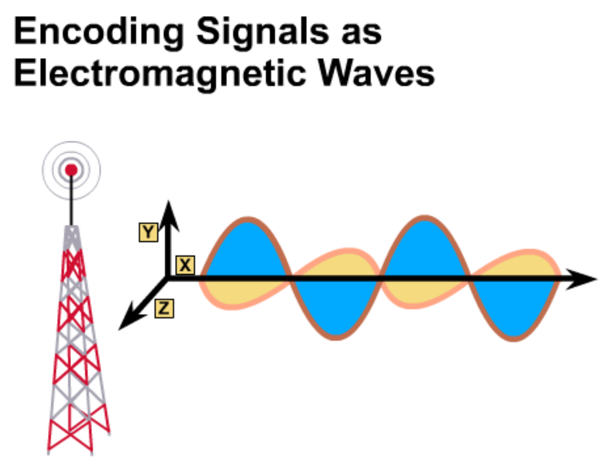


More than one path for signal – distortion
Limits maximum data rate

Intermediate mode

One path for signal – superior signal quality
Used for long-haul telephone and TV comm

Wireless Transmission



Wireless Transmission

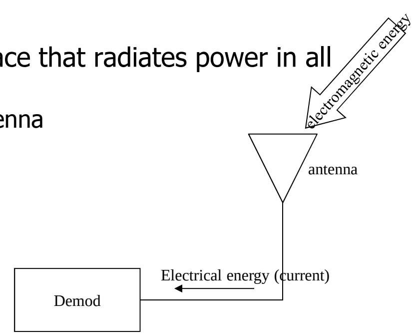
- Unguided media
- Transmission and reception via antenna
- Directional
  - Focused beam
  - Careful alignment required
- Omnidirectional
  - Signal spreads in all directions
  - Can be received by many antennae

Frequencies

- 2GHz to 40GHz - Microwave
  - Highly directional
  - Point to point
  - Satellite
- 30MHz to 1GHz - Radio
  - Omnidirectional
  - Broadcast radio
- 3×10^{11} to 2×10^{14} - Infrared
  - Local point-to-point or point-to-multipoint in indoor applications

Antenna

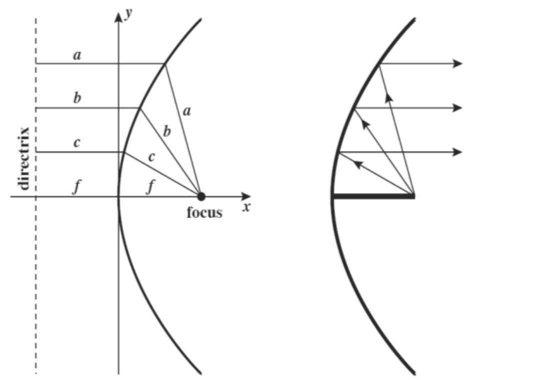
- Definition: An electrical conductor or system of conductors used either for radiating electromagnetic energy or for collecting electromagnetic energy.
- General receiver/Transmitter structure
- Receiver/transmit characteristics of an antenna are the same
- Isotropic antenna – is a point in space that radiates power in all directions equally.
  - Referred to as omni-directional antenna



General Receiver Structure

Parabolic Reflective Antenna

- Used in terrestrial microwave and satellite applications



(a) Parabola

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

Antenna Gain

- Definition: the power output, in a particular direction, compared to that produced in any direction by a perfect omni-directional antenna.
- It is a measure of directionality.
- Effective Area – a concept related to the physical size and shape of antenna
- Gain is given by

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

Where G – antenna gain
Ae – effective antenna area
λ – carrier wavelength

- For an ideal isotropic antenna – $A_e = \lambda^2 / (4 \pi)$ ➔ G = 1 or 0 dB
- For a parabolic antenna with face area of A – Ae = 0.56A ➔ $G = 7A / \lambda^2$

Antenna Gain - Example

- Problem: Consider a parabolic reflective antenna with a diameter of 2 m operating at 12 GHz, what is the effective area and the antenna gain?

- Solution:

face area, $A = \pi r^2 \rightarrow \pi m^2$

effective area, $Ae = 0.56 A = 0.56 \pi m^2$

wavelength, $\lambda = c/f = 3x10^8/12x10^9 = 0.025$ m

then Gain, $G = 4 \pi Ae/ \lambda^2 = 35{,}180$, or

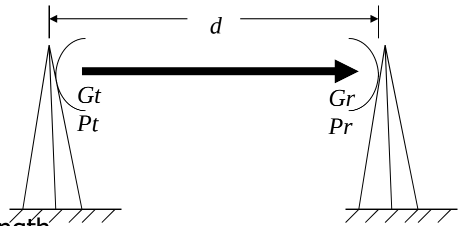
$GdB = 10log10(35{,}180) = 45.46$ dB

Terrestrial Microwave

- Parabolic dish
- Focused beam
- Line of sight
- Long haul telecommunications (4-6 GHz and 11 GHz)
- Higher frequencies give higher data rates

Transmission Characteristic

- Free-Space loss model



$Pr/Pt = Gt\,Gr * [\lambda/(4\pi d)]^2$

where: Pt – transmitted power level
Pr – received power level
Gr – receive antenna gain
Gt – transmit antenna gain
λ – carrier frequency wavelength
d – distance between transmitter and receiver

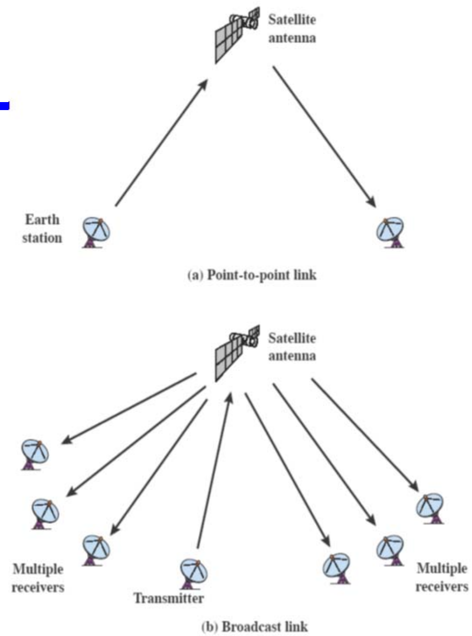
- **<u>Path loss</u>** is defined as L = Pt/Pr – usually measured in dBs (i.e. $LdB = 10\log_{10}(L)=10\log_{10}(Pt/Pr)$)
- If Gt and Gr are not given – assume Gt = Gr = 1.

Satellite Microwave

- Satellite is relay station
- Satellite receives on one frequency, amplifies or repeats signal and transmits on another frequency
- Requires geo-stationary orbit
  - Height of 35,784km
- Television
- Long distance telephone
- Private business networks

Satellite Communication Configurations

- Point-to-point link (uplink: 5.925-6.425 GHz, downlink: 3.7-4.2 GHz) – 4/6 GHz band
- Broadcast link
- Typical range 1-10GHz
  - Below 1 GHz – noise
  - Above 10GHz – atmospheric absorption
- 12/14 GHz and 20/30 GHz are also being used



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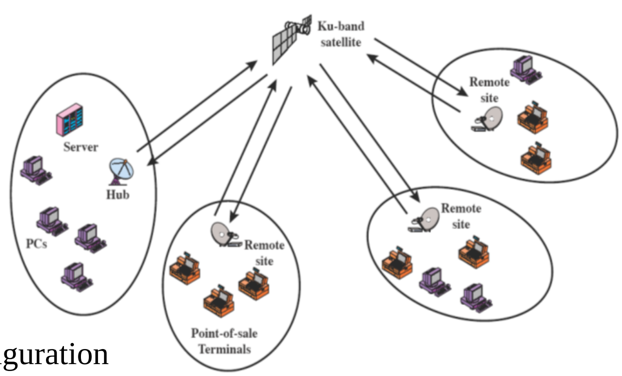
Applications

- Public Broadcasting services (PBS)
- Direct Broadcasting Satellite (DBS)
- Very Small Aperture Terminal (VSAT)



Typical VSAT Configuration

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Broadcast Radio

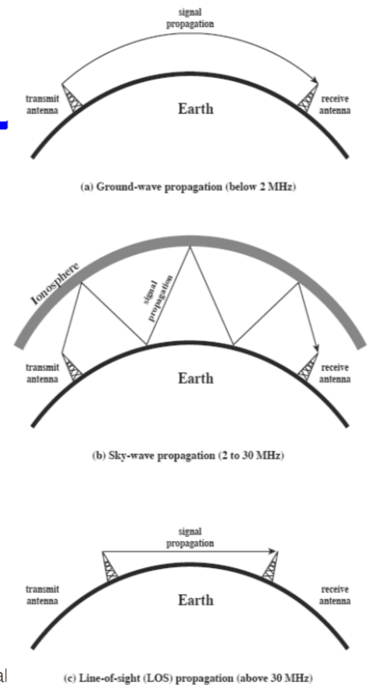
- Omnidirectional; 30 MHz ~ 1 GHz
- FM radio
- UHF and VHF television
- Line of sight
- Suffers from multipath interference
  - Reflections

Infrared

- Modulate noncoherent infrared light
- Line of sight (or reflection)
- Blocked by walls
- e.g. TV remote control, IRD port

Wireless Propagation

- Ground Wave propagation
  - Freq < 2 MHz
  - Signal tends to follow earths curvature – scattered by atmosphere
  - Application - AM radio
- Sky Wave propagation
  - 2 MHz < Freq < 30 MHz
  - Signal from earth is reflected by Ionsphere – perhaps several hops
  - Application: armature radio, CB, and international broadcasts
- Line of Sight (LOS) propagation
  - Freq > 30 MHz
  - Optical versus Effective LOS



Line Of Sight Propagation

- The optical LOS distance in kilometers, d, is given by

$$d = 3.57\sqrt{h}$$

where h is the antenna height in meters.

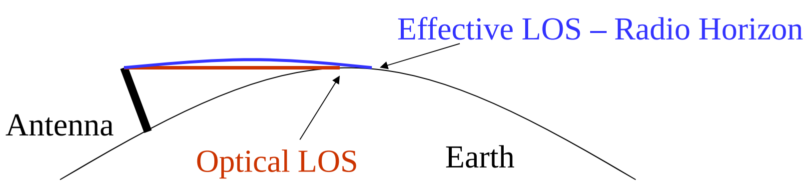
- The effective LOS distance in kilometers, d, is given by

$$d = 3.57\sqrt{(Kh)}$$

where K is an adjustment factor ~ 4/3

- The maximum distance between two towers for LOS is given by

$$dmax = 3.57[\sqrt{(Kh1)} + \sqrt{(Kh2)}]$$



Example

- Problem: Assume an earth station is transmitting 250 Watts directed to an asynchronous satellite at the height of 35,863 km. If the carrier frequency is 4 GHz, calculate:

a) the path loss assuming isotropic antennas

b) the path loss assuming the antenna gain for satellite and ground station to be 44 dB and 48 dB, respectively.

c) what is the power level received at the satellite?

Example – cont'd

- Solution:

Path Loss, $L = Pt/Pr = 1/\{Gt\ Gr * [\lambda /(4\pi d)]^2\}$
wavelength, $\lambda = c/f = 3x10^8/4x10^9 = 0.075$ m
a) for isotropic antennas ➔ Gt = Gr = 1;
$L = 1/\{1x1x[0.075/(4x\pi x35853x10^3)]^2\}$
$= 3.6087x10^{19}$
$L_{dB} = 10xlog_{10}(L) = 195.6$ dB
b) for Gr = 44 dB (or 1044/10 = 25,119) and Gt = 48 dB (or 63,096)
Therefore,
$L = 1/\{25119x63096x\ x[0.075/(4x\pi x35853x10^3)]^2\}$
$= 2.2769x10^{10}$
$L_{dB} = 10xlog10(L) = 103.6$ dB
c) Power received at satellite:
$L = Pt/Pr$ ➔ $Pr = Pt/L = 250/2.2769x10^{10}$
$= 1.0980x10^{-8}$ Watts
$Pr_{dBW} = 10xlog10(Pr) = -79.6$ dBW

Another way for
b) $LdB = L_{dB\_isotropic} – Gt_{dB} – Gr_{dB}$
$= 195.6 – 44 – 48$
$= 103.6$ dB

Another way for
c) Pt = 250 Watts ➔ $Pt_{dBW} = 10xlog10(250) = 24$ dBW
$Pr_{dBW} = Pt_{dBW} – L_{dB} = 24 – 103.6 = -79.6$ dBW

Required Reading

- Stallings Chapter 4

Dammam-Riyadh Microwave Link Design Problem:

		Parameter	Definition
Typical Inputs		d_total (km)	Overall distance between Dammam and Riyadh
	Shannon Capacity formula	C (b/s)	Desired capacity for link
		B (Hz)	Bandwidth of system
		T (degrees Kelvin)	Effective temperature of the transmit-receive system
	Free-space path loss model	Pt (Watts), Gt (dB)	Transmit power and transmit antenna gain for transmitter
		Gr (dB)	Receive antenna gain
		λ (m) or fc (Hz)	Wavelength or carrier frequency of the microwave signal
Main computed Quantities		d_1	Maximum distance between any two subsequent towers allowed by earth's curvature
		d_2	Maximum distance between any two subsequent towers allowed by Shannon's capacity formula
		d_max	Maximum distance between any two subsequent towers to satisfy both criteria (earth's curvature and capacity requirement)

Dammam-Riyadh Microwave Link Design Problem – cont'd:

- Details given in class (on board)
- Quiz problem

Dammam-Riyadh Microwave Link Design Problem – STEPS:

- Determine if the RF link is feasible or not
  - Using C, B, and T, compute the required SNR to obtain the required capacity
  - Using SNR, and the free-space path loss model, determine the needed received power Pr.
  - If Pr is greater than the transmit power, Pt ➔ Link is infeasible, i.e. can not be designed using the given parameter values
  - Else – link is feasible
- Compute d_1 using Path-loss Free-Space path loss model
- Compu