- Transmission Media
  - Physical path between transmitter and receiver
  - Guided or unguided (wireless)
  - Communication is in the form of electromagnetic waves
  - Characteristics and quality of data transmission are determined by characteristics of medium and signal
  - In guided media, medium characteristics is more important, whereas in unguided media, signal characteristics is more important

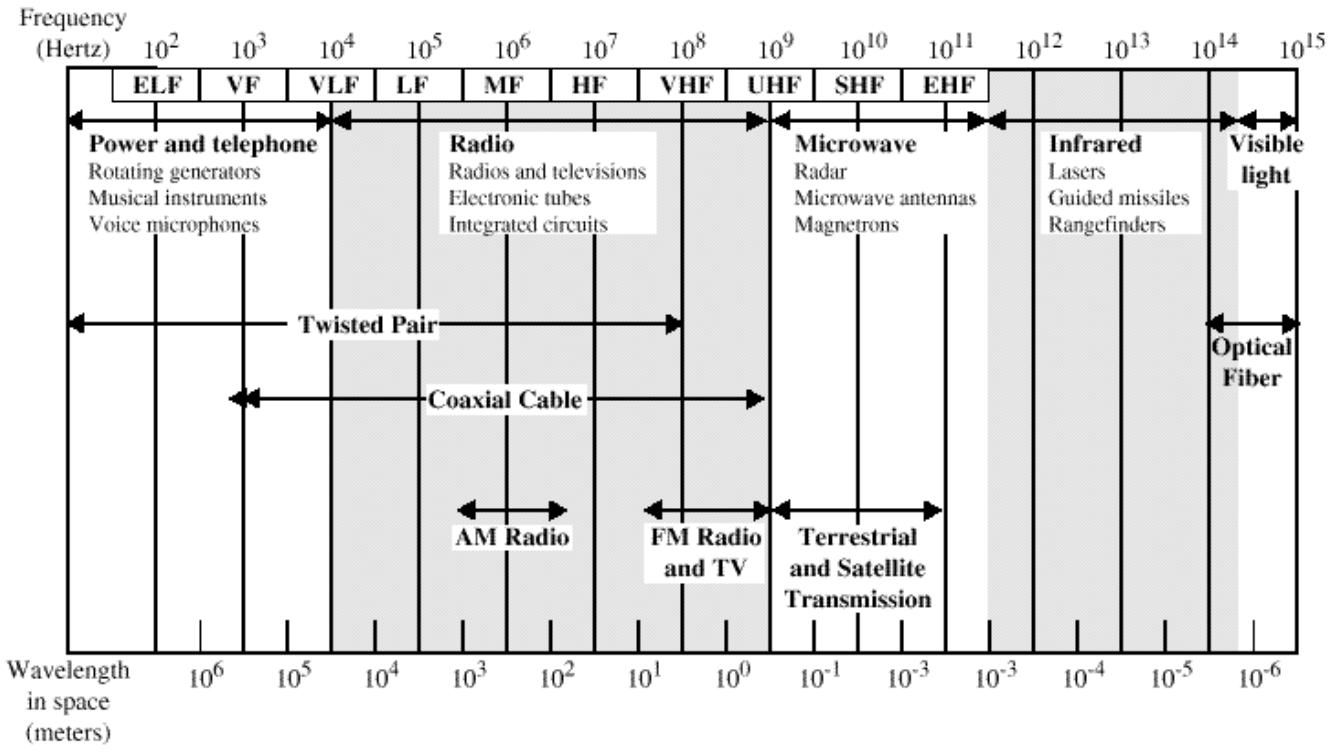


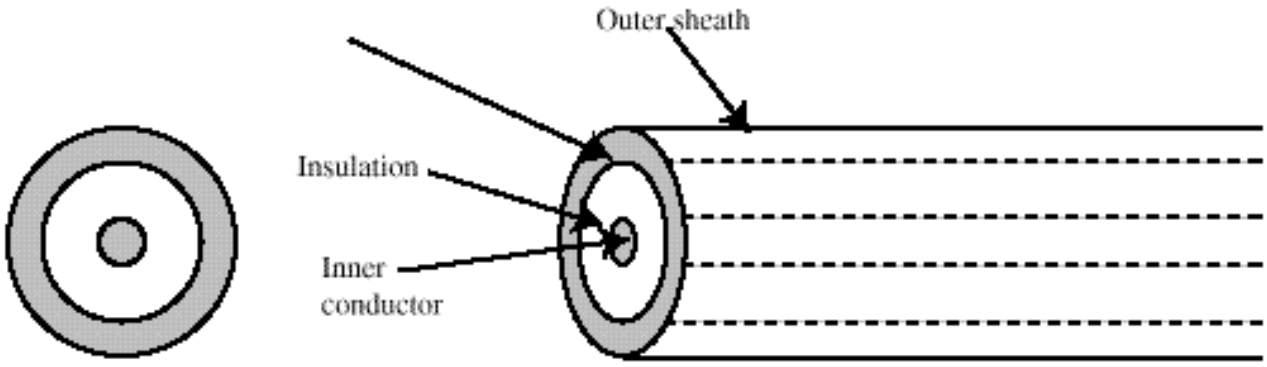
Figure 3.1 Electromagnetic Spectrum for Telecommunications

1. Guided Transmission Media

- Twisted Pair
  - The oldest, least expensive, and most commonly used media
  - Pair of insulated wires twisted together to reduce susceptibility to interference (two straight parallel wires tend to act as an antenna and pick up extraneous signals
  - Quite highly susceptible to noise & interference
  - Up to 250 kHz analog and few Mbps digital signaling (for long-distance point-to-point signaling
  - Need repeater every 2-3 km (digital), and amplifier every 5-6 km (analog)
  - May be already installed (telephone usage)
  - Much efforts are undergoing to use it for high-speed (10-100 Mbps) LAN

—Separately insulated
—Twisted together
—Often "bundled" into cables
—Usually installed in buliding when built

- Coaxial Cable
  - Most versatile medium
    - LANs, Cable TV, Long-distance telephones, VCR-to-TV connections
  - Noise immunity is good
  - Very high channel capacity
    - few 100 MHz / few 100 Mbps
  - Need repeater/amplifier every few kilometer or so (about the same as with twisted pair)

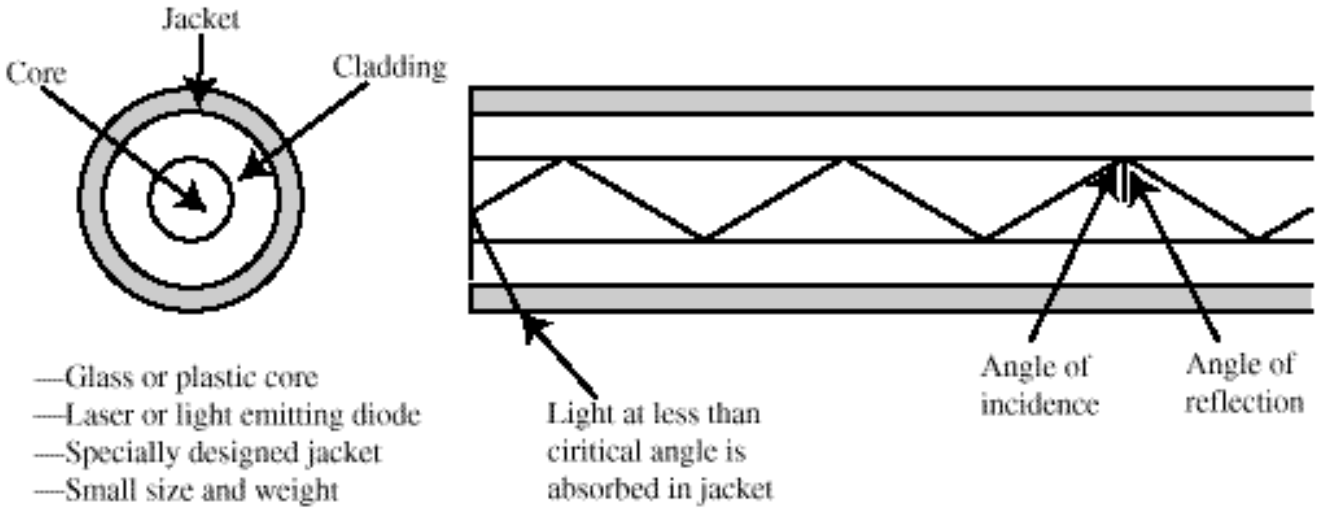


—Outer conductor is braided shield
—Inner conductor is solid metal
—Separated by insulating material
—Covered by padding

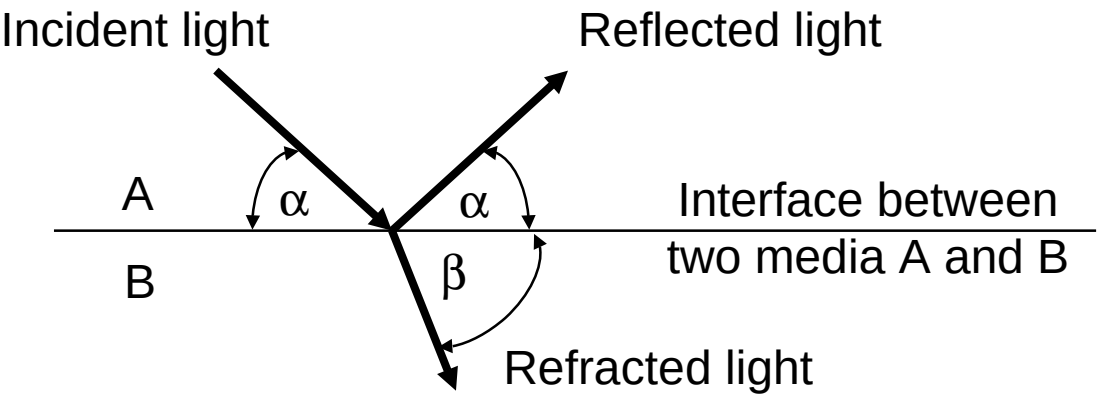
Point-to-point transmission characteristics of guided media

Transmission medium	Total data rate	Bandwidth	Repeater spacing
Twisted pair	4 Mbps	3 MHz	2 to 10 km
Coaxial cable	500 Mbps	350 MHz	1 to 10 km
Optical fiber	2 Gbps	2 GHz	10 to 100 km

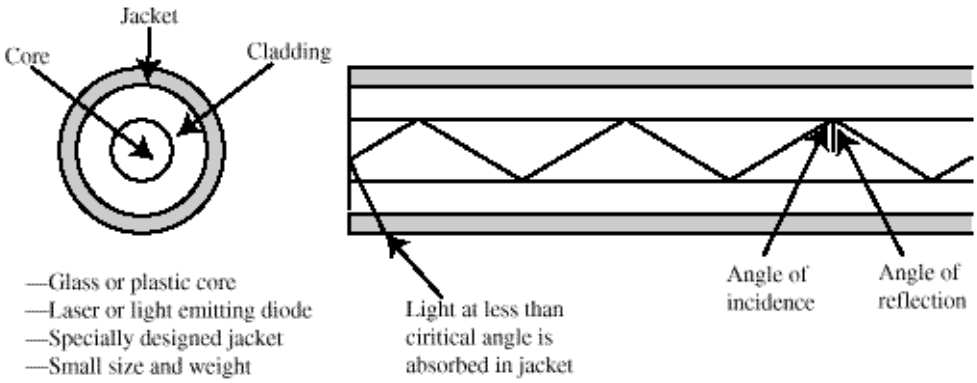
- Optical Fiber
  - Flexible, thin (few to few hundred μm), very pure glass / plastic fiber capable of conducting optical rays
  - Extremely high bandwidth: capable of ≥ 2Gbps
  - Very high noise immunity, resistant to electromagnetic interference
  - Does not radiate energy/cause interference
  - Very light
  - Need repeaters only 10's or 100 km apart
  - Very difficult to tap
    - Better security but multipoint not easy
  - Need optical-electrical interface (more expensive than electrical interface)



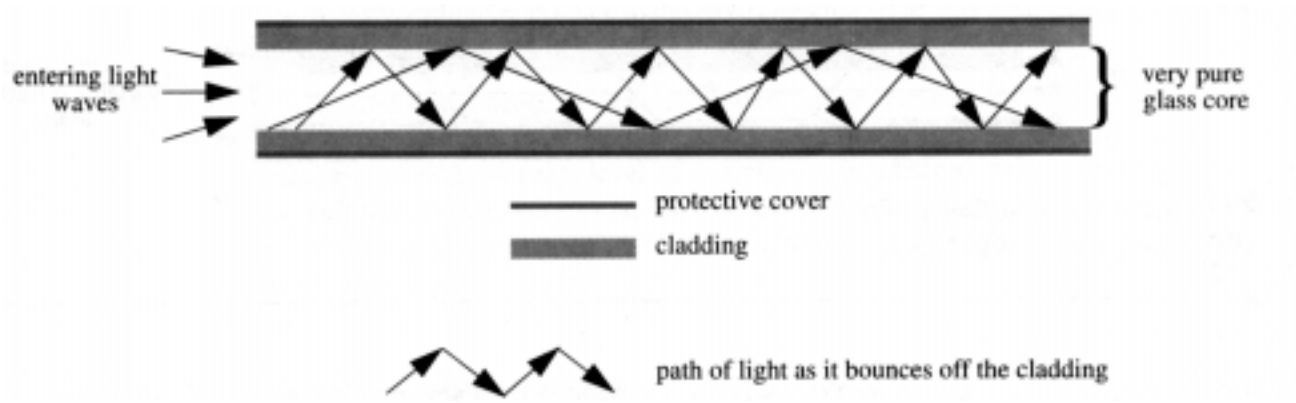
- Principle of optical fiber transmission
  - Based on the principle of **total internal reflection**



  - If $\beta > \alpha$, medium B (water) has a higher optical density than medium A (air)
  - Index of refraction is defined by $\cos(\alpha)/\cos(\beta)$
  - In case the index of refraction < 1 ($\alpha > \beta$), if α is less than a certain critical angle, there is no refracted light. I.e., all the light is reflected. This is what makes fiber optics work.
  - The cladding surrounding the core is also glass but is optically less dense than the core

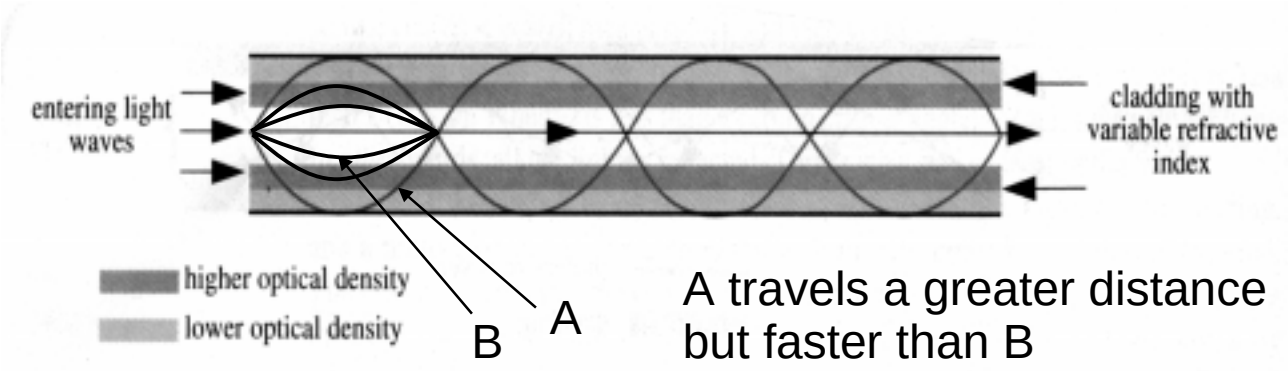


- Three types of fiber transmission
  - Step index multimode
    - Variety of angles that reflect. Each angle defines a path or a mode
    - Limited data rate due to the different path lengths



  - Single mode
    - The diameter of the core is reduced to the order of wavelength s.t. only a single angle or mode can pass
    - Superior performance

– Graded index multimode
  - Use the fact that speed of light depends on the medium; light travels faster through less optically dense media
  - The boundary between core and cladding is not sharply defined; Moving out radially from the core, the material becomes gradually less dense



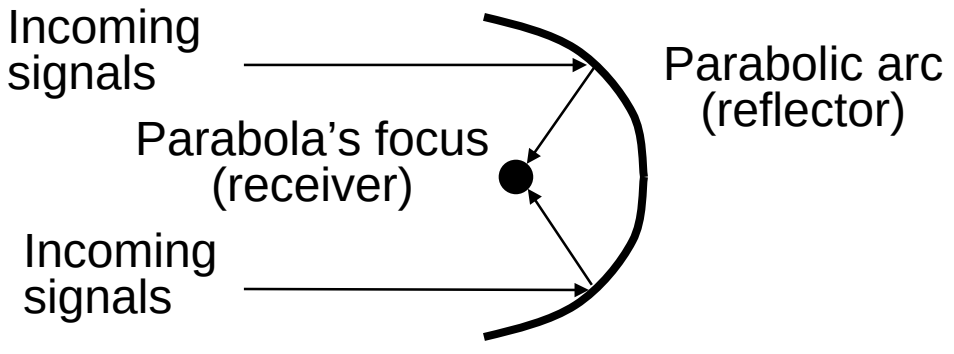
Typical fiber characteristics

Fiber type	Core diameter (μm)	Cladding diameter (μm)	Attenuation (dB/km) (Max)			Bandwidth (MHz/km) (Max)
			850 nm	1300 nm	1500 nm	
Single Mode	5.0	85 or 125	2.3			5000 @ 850 nm
	8.1	125		0.5	0.25	
Graded-index	50	125	2.4	0.6	0.5	600 @ 850 nm 1500 @ 1300 nm
	62.5	125	3.0	0.7	0.3	200 @ 850 nm 1000 @ 1300 nm
	100	140	3.5	1.5	0.9	300 @ 850 nm 500 @ 1300 nm
Step-index	200 or 300	380 or 440	6.0			6

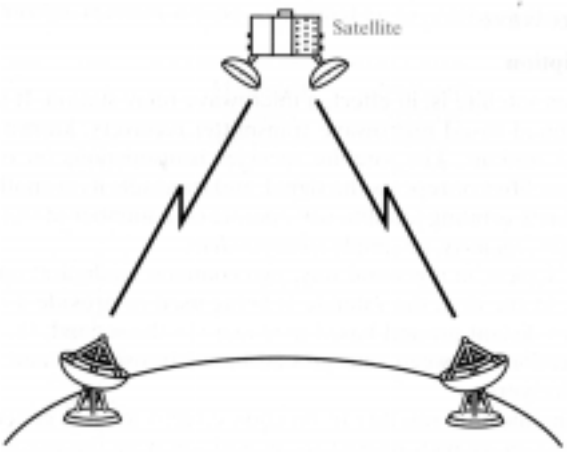
2. Wireless Transmission

- (Terrestrial) Microwave
  - Typically used where laying a cable is not practical (No right-of-way needed)
  - Parabolic dish shaped antenna (≈10 ft dia) transmits/receives electromagnetic waves in the 2-40 GHz range
  - Travels in a straight line (line-of-sight propagation)
  - Maximum distance bet antenna in km

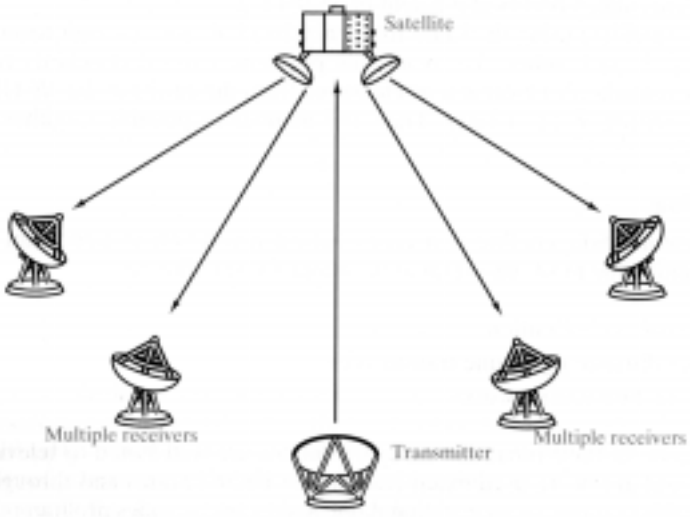
    $d = 7.14\sqrt{(4/3)h}$ h : antenna ht in meters
  - High data rates: 100's Mbps
  - Attenuation $10 \log\left(\frac{4\pi d}{\lambda}\right)^2$ dB d: distance, λ: wavelength
  - Repeaters spaced 10 - 100 km apart
  - Applications
    - Long-distance telephone communication



- Satellite Microwave
  - Uses satellite in geostationary (geosynchronous) orbit (≈ 36,000 km)
  - Source transmits signal to satellite which amplifies or repeats it, and retransmits down to destinations
  - Optimum transmission in 1 - 10 GHz range; Bandwidth of 100's MHz
  - Significant propagation delay ≈ 270ms
  - Total propagation delay is independent of distance between sender and receiver
  - Applications:
    - Long-distance telephones
    - Television distribution
    - Private business networks

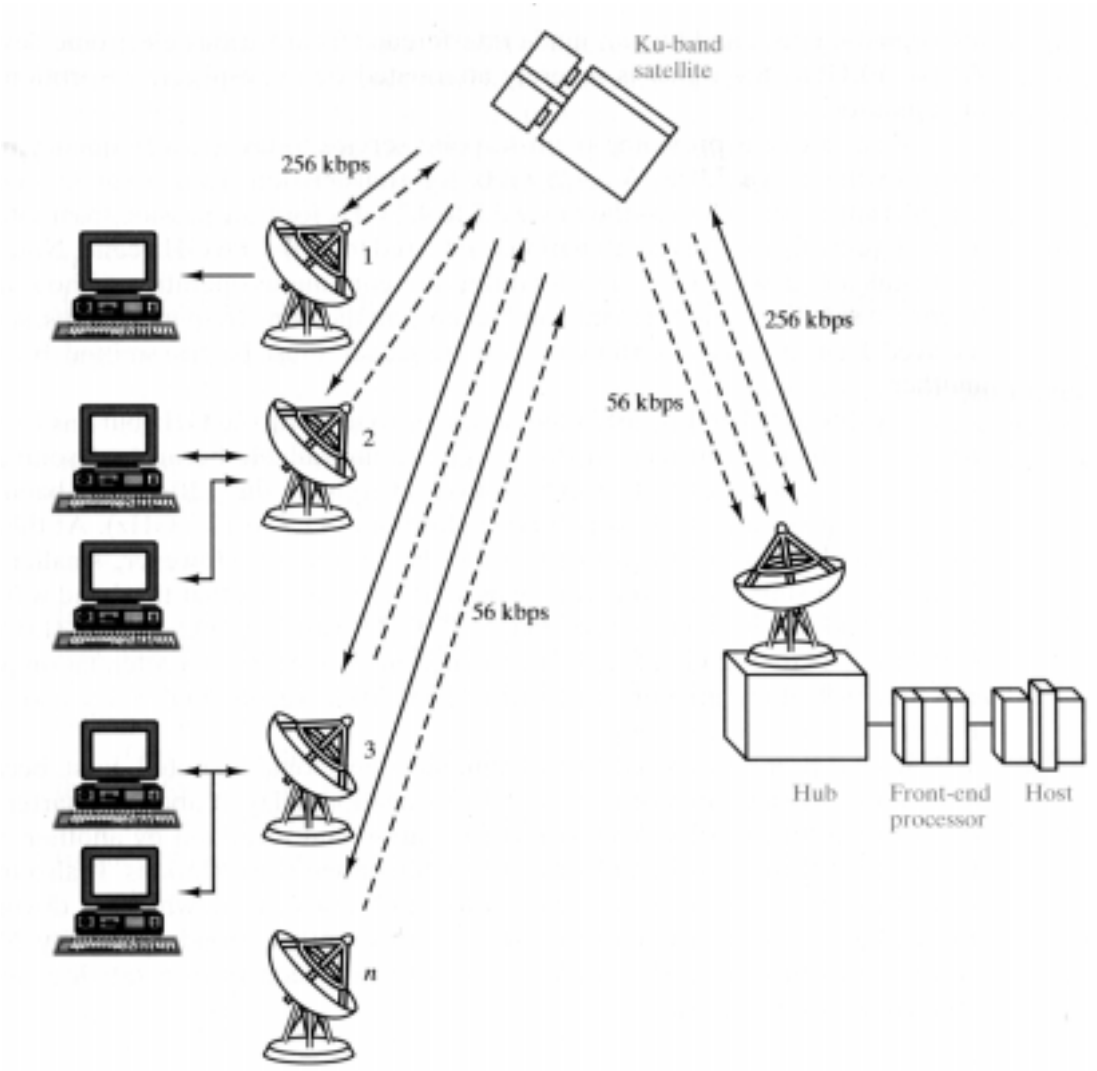


(a) Point-to-point link via satellite microwave



(b) Broadcast link via satellite microwave

- Satellite Microwave (Cont'd)
  - VSAT (Very Small Aperture System)
    - For business data applications requiring high data rates for short periods of time (National Weather Service, news services, credit card verification, automatic tellers, car rental agencies, …)
    - Commonly connects a central location with many remote ones
    - Communication between two sites is via a satellite and allows a low-cost small antenna dishes (≈ 5 ft)



- (Broadcast) Radio
  - Electromagnetic wave in the range 30MHz ~ 1GHz
  - Omnidirectional
  - As with microwave,

    $d = 7.14\sqrt{(4/3)h}$ h : antenna ht in meters

    $\text{Attenuation} = 10 \log \left(\frac{4\pi d}{\lambda} \right)^2$ dB d: distance, λ: wavelength
  - Less attenuation than microwave since λ is larger

- Infrared
  - For short-range communication
    - Remote controls for TVs, VCRs, and stereos
    - Indoor wireless LANs
  - Do not pass through solid walls
    - Better security and no interference (with a similar system in adjacent rooms)
  - No government license is needed
  - Cannot be used outdoors (due to the sunshine)