EEC-484/584
Computer Networks

Lecture 3

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(Lecture nodes are based on materials supplied by Dr. Louise Moser at UCSB and Prentice-Hall)

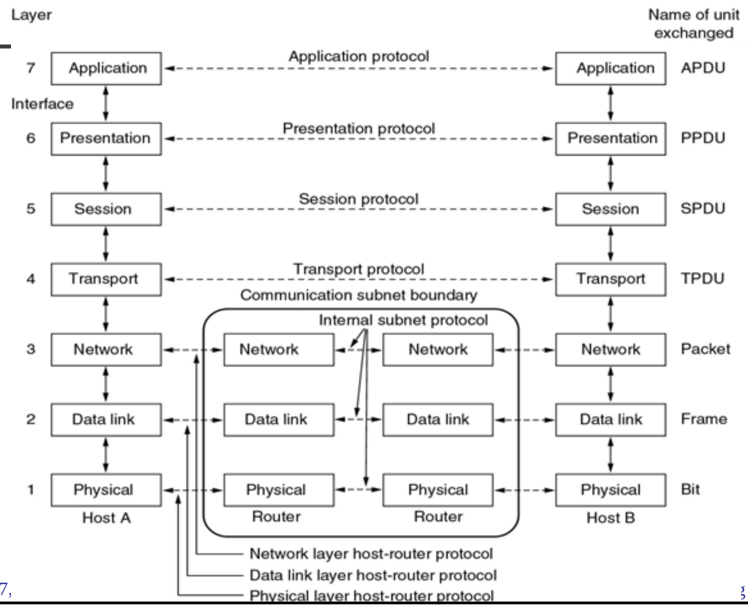
Outline

- Review of lecture 2
- Physical Layer
  - Theoretical basis for data communication
  - Guided transmission media
  - Wireless transmission
  - Communication satellites
- Textbook online:
  - Can be found at http://proquest.safaribooksonline.com/0130661023

Review of Lecture 2

- Reference models
- Example networks
- Network standardization

The OSI Reference Model

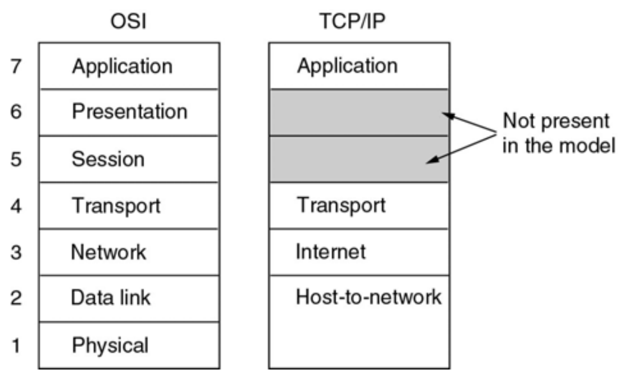


Concepts Central to the OSI Model

- Services – what layer does
- Protocols – how layer does it
- Interfaces – tells upper layer how to access services of lower layer

TCP/IP Reference Model

- TCP – Transmission Control Protocol
- IP – Internet Protocol
- Used in Internet and its predecessor ARPANET



TCP/IP Reference Model

- Internet Layer
  - Packet switched, Connectionless
  - Injects packets into the network; delivers them to the destination
  - May be delivered out-of-order
  - Packet routing and congestion control are key issues
- Transport layer, two protocols
  - TCP (Transmission Control Protocol) – Point-to-point, Connection-oriented, Reliable, Source ordered, Flow control, Bye stream
  - UDP (User Datagram Protocol) – Point-to-point, Connectionless, Unreliable, Not source ordered, No flow control, Preserve message boundary

Network Standardization

- Why standard?
  - Each vendor/supplier has its own ideas of how things should be done, the only way out is to agree on some network standards
  - Standards also increase the market for products adhering to them
  - Two kinds of standards
    - De facto – from the fact (standards that just happened)
    - De jure – by law (formal, legal standards adopted by authorized organization)

Theoretical Basis for Data Communication

- Fourier analysis
- Bandwidth-limited signals
- Maximum data rate of channel

Fourier Analysis

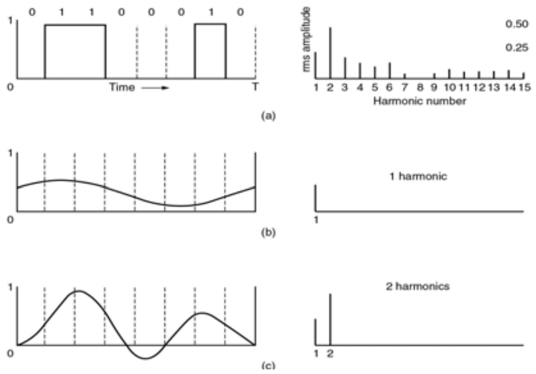
- Info is transmitted by varying voltage or current
- Let f(t) be value of voltage or current at time t, any well-behaved periodic function g(t) with period T can be represented as Fourier series

$$g(t) = \frac{1}{2}c + \sum_{n=1}^{\infty} a_n \sin(2\pi nft) + \sum_{n=1}^{\infty} b_n \cos(2\pi nft)$$

  where f=1/T, the fundamental frequency, a_n and b_n are sine and cosine amplitudes of nth harmonics (terms)
- The amplitudes and constant are given by

$$a_n = \frac{2}{T}\int_0^T g(t)\sin(2\pi nft)\,dt \qquad b_n = \frac{2}{T}\int_0^T g(t)\cos(2\pi nft)\,dt \qquad c = \frac{2}{T}\int_0^T g(t)\,dt$$

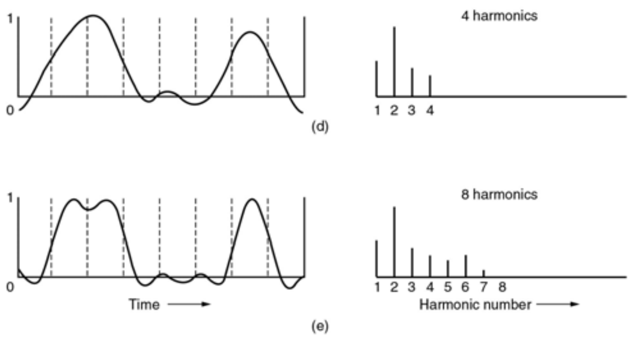
Bandwidth-Limited Signals



A binary signal and its root-mean-square Fourier amplitudes.

(b) – (c) Successive approximations to the original signal.

Bandwidth-Limited Signals



(d) – (e) Successive approximations to the original signal.

Bandwidth-Limited Signals

- **Cutoff frequency**: The amplitudes are transmitted undiminished from 0 up to some frequency *fc* [measured in cycles/sec or Hertz (Hz)] with all frequencies above this attenuated
- **Bandwidth**: The range of frequencies transmitted without being strongly attenuated
  - Often the quoted bandwidth is from 0 to the frequency at which half the power gets through
  - The bandwidth is a physical property of the transmission medium and usually depends on the construction, thickness, and length of the medium

Bandwidth-Limited Signals

- In some cases a filter is introduced into the circuit to limit the amount of bandwidth available to each customer
  - For example, a telephone wire may have a bandwidth of 1 MHz for short distances, but telephone companies add a filter restricting each customer to about 3100 Hz
- Voice line cut off frequency ~ 3000Hz
  - Number of highest harmonic ~ 3000/(b/8) = 24000/b = 2.5 for b = 9600 => poor reception
- Bottom line: limiting bandwidth limits data rate even if transmission medium is noiseless

Bandwidth-Limited Signals

Relation between data rate and harmonics

Bps	T (msec)	First harmonic (Hz)	# Harmonics sent
300	26.67	37.5	80
600	13.33	75	40
1200	6.67	150	20
2400	3.33	300	10
4800	1.67	600	5
9600	0.83	1200	2
19200	0.42	2400	1
38400	0.21	4800	0

Bandwidth-Limited Signals

- Time T to transmit a character depends on encoding method and signaling speed (number of times signal changes its value)
- **Baud** = number of changes /sec
  - Not necessarily bits/sec since each signal might convey several bits, e.g., v = 0, 1, 2, …, 7; each signal value can be used to convey 3 bits => bit rate = 3× baud rate
  - If bit rate = b bits/sec, T = 8/b sec to transmit 8 bits, $f = b/8$ Hz

Maximum Data Rates of a Channel

- **Theorem (Nyquist 1924) for noiseless channels**
  - If an arbitrary signal is run through a low-pass filter of bandwidth H, then the filtered signal can be completely reconstructed by making on 2H samples per second
  - **Max data rate = 2H $\log_2$V bits/sec**, where signal consists of V discrete lines
  - Ex: H = 3000 Hz, V = 2 (binary)
    max data rate = 2*3000*$\log_2$2 = 6000 bits/sec
  - Ex: H = 3000 Hz, V = 64
    max data rate = 2*3000*$\log_2$64 = 36,000 bits/sec

Maximum Data Rates of a Channel

- **Theorem (Shannon 1948) noisy channels**
  - Amount of thermal noise = signal to noise ratio = signal power / noise power = S/N
  - Decibel (dB): 10 $\log_{10}$S/N
  - **Max data rate = H $\log_2$(1+S/N) bits/sec**
  - Ex: H = 3000 Hz, S/N = 30dB = 1000
    max data rate = 3000*$\log_2$(1+1000) = 30,000
    upper bound is hard to reach, 9600 bits/sec is good

Guided Transmission Data

- Magnetic Media
- Twisted Pair
- Coaxial Cable
- Fiber Optics

Magnetic Media

- Tapes and disks
  - high bandwidth, low cost, long latency (delay)
  - An industry standard Ultrium tape can hold 200GB

Twisted Pair

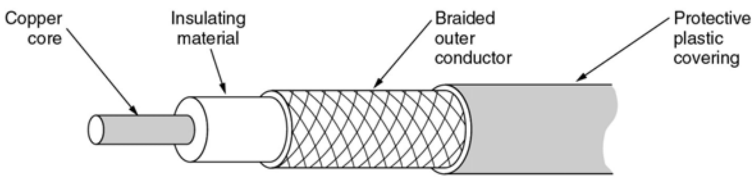
- 2 copper wires twisted in helix (often called unshielded twisted pair, or UTP)
  - E.g., telephone system
  - Analog or digital
  - Bandwidth depends on thickness of wire and distance traveled
    - Several Mbps for few km
  - Need repeaters for long distances
    - Encase many twisted pair in protective sheath
  - Good performance, low cost

(a) Category 3 UTP

(b) Category 5 UTP

Coaxial Cable

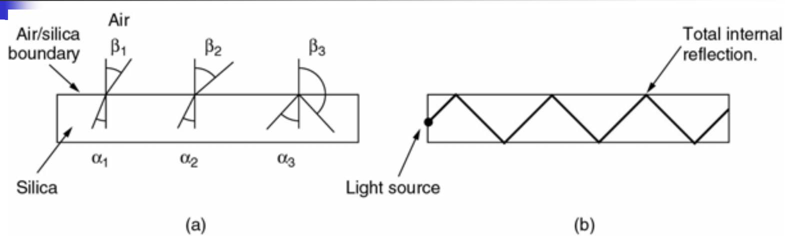
- Baseband – 50 ohm cable for digital transmission
- Broadband – 75 ohm cable for analog transmission and cable TV



Fiber Optics

- Very high bandwidth – achievable bandwidth 50 Tbps
- Conventionally, 1 – light pulse, 0 – absence of light pulse

Fiber Optics



(a) Three examples of a light ray from inside a silica fiber impinging on the air/silica boundary at different angles

(b) Light trapped by total internal reflection. Each ray is said to have a different mode

- ✓ Multimode fiber – short distance
- ✓ Single-mode fiber – long distance

Fiber Optics

- Optical transmission system comprises
  - Transmission medium – fiber
  - Light source – LED or laser diode
  - Detector – photodiode generates an electrical pulse when light falls on it

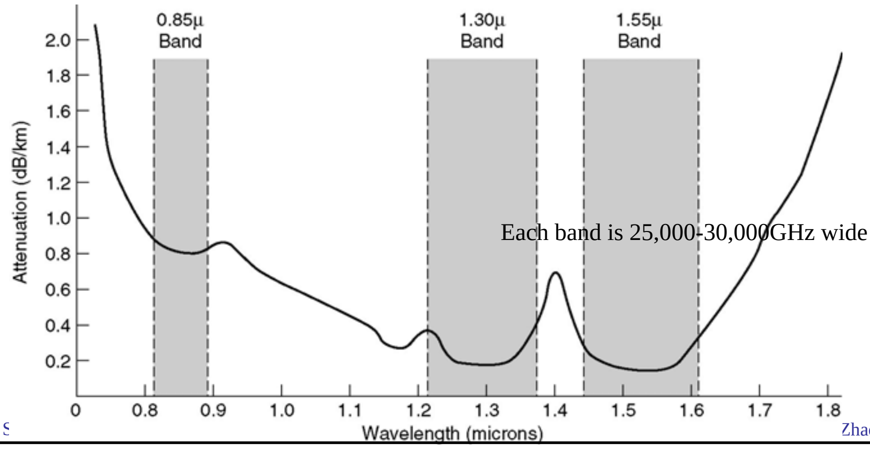
Transmission of Light through Fiber

- **Attenuation** of light through glass depends on wavelength
- Attenuation in dB = $10 \log_{10} \frac{\text{transmitted power}}{\text{received power}}$
  - Ex: attenuation = $10 \log_{10} 2$ = 3dB (for loss factor of 2)

Transmission of Light through Fiber

Higher attenuation but
Both lasers and detectors
made from GaAs

Good attenuation
< 5% loss per km

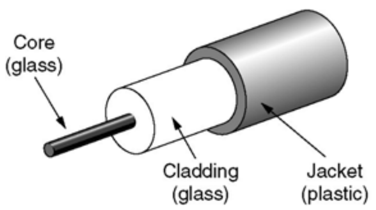


Transmission of Light through Fiber

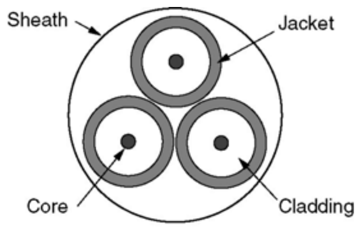
- **Dispersion** – spreading out of light pulses as they propagate down fiber depends on wavelength
- To keep spread out pulses from overlapping
  - (1) increase distance between them => reduce signaling rate
  - (2) use solitons to cancel dispersion effect
    - Soliton – special shape pulses related to 1/cos

Fiber Cables

- Fiber cable construction
  - Core 50 micron for multimode fiber
  - 8-10 micron for single mode fiber
  - Cladding – lower index of refraction than core
  - Jacket – protects cladding



(a)



(b)

Fiber Cables

- On land, fiber laid 1m deep
- In ocean, fiber laid on bottom
- Three ways of connecting fibers
  - Plug into fiber sockets, terminate in connectors – 10-20% light loss but easy to reconfigure
  - Mechanically splice fibers – 10% light loss
  - Fuse fibers to form solid connection

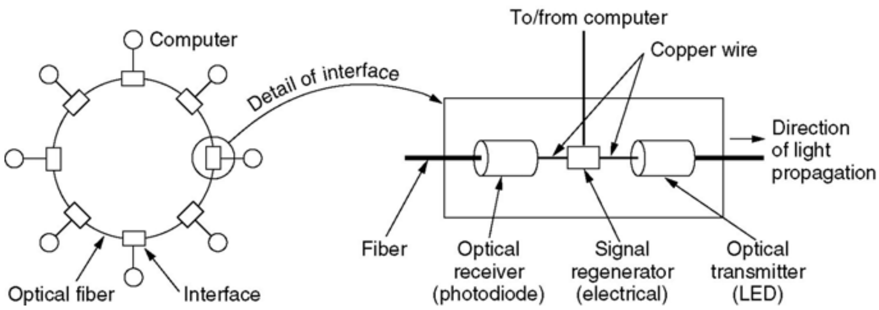
Fiber Cables

- Light sources
  - Light Emitting Diode (LED)
  - Semiconductor Laser
- Receiver – photodiode
  - Gives off electrical pulse when struck by light
  - Response time 1 nsec => data rate ~ 1 Gbps

Fiber Cables

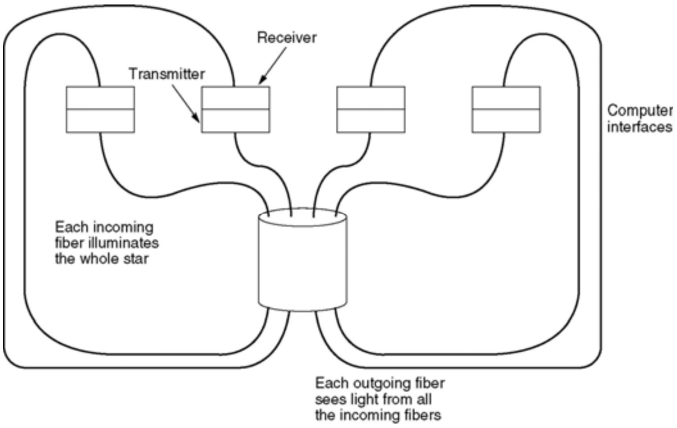
Item	LED	Semiconductor laser
Data rate	Low	High
Fiber type	Multimode	Multimode or single mode
Distance	Short	Long
Lifetime	Long life	Short life
Temperature sensitivity	Minor	Substantial
Cost	Low cost	Expensive

Fiber Optic Networks



A fiber optic ring with active repeaters

Fiber Optic Networks



A passive star connection in a fiber optics network

Fiber Optics vs. Coax

- Advantages of fiber optics over coax
  - High bandwidth with little power loss => long distance between repeaters
  - Not affected by power line surges, electromagnetic interferences, corrosive chemicals
  - Thin – an advantage when need lots of fiber
  - Good security features

Fiber Optics vs. Coax

- Disadvantages
  - Unidirectional
  - Interfaces are expensive
  - Requires special skills to install and maintain

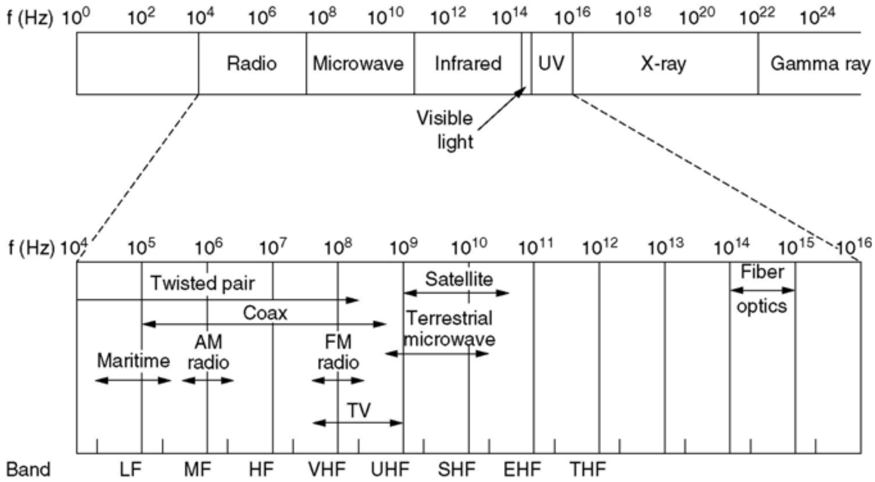
Wireless Transmission

- The electromagnetic spectrum
- Radio transmission
- Microwave transmission
- Infrared and millimeter waves
- Lightwave transmission

Wireless Transmission

- When electrons move, they create electromagnetic waves
- Wireless communication is based on principle of attaching an antenna to an electrical circuit to broadcast electromagnetic waves to destination(s)

The Electromagnetic Spectrum



The Electromagnetic Spectrum

- Radio, microwave, infrared, visible light
  - Parts of electromagnetic spectrum used to transmit info by modulating amplitude, frequency, phase
- UV, X-ray, gamma rays are hard to produce and modulate, do not propagate well, are harmful to living things

Wireless Transmission

- **Frequency** f in Hz – number of oscillations per sec
- **Wavelength** λ – distance between consecutive maxima (minima)
- $\lambda f = c$, where c = speed of light in vacuum = 3×10^8 m/sec
- $df/d\lambda = -c/\lambda^2 \Rightarrow \Delta f = c\, \Delta\lambda/\lambda^2$
- Ex: $\lambda = 1.3 \times 10^{-6}$, $\Delta\lambda = 0.17 \times 10^{-6}$
  $\Delta f = (3\text{x}10^8)(0.17 \times 10^{-6})/(1.3 \times 10^{-6})^2 = 0.3 \times 10^{14}$
  $= 30 \times 10^{12} = 30$ THz

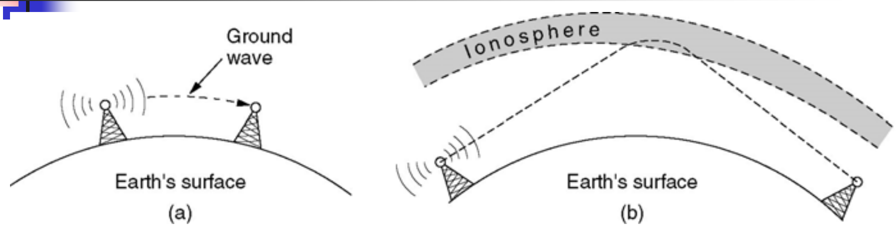
Wireless Transmission

- Smaller wavelength, *i.e.*, higher frequency =>
  - Higher bandwidth
  - Higher data rate
- **Spread spectrum** (uses a wide band)
  - Frequency hopping spread spectrum
    - Transmitter hops from frequency to frequency hundreds of times per second
  - Direct sequence spread spectrum
    - Spread signal over a wide frequency band

Radio Transmission Characteristics

- Easy to generate
- Travel long distances
- Penetrate buildings easily
- Omnidirectional
- Frequency dependent
  - At low frequencies, pass through obstacles easily, power ~ $1/r^3$ where r = distance from source
  - At high frequencies, travel in straight lines, bounce off obstacles, absorbed by rain
- Subject to interference from electrical equipment

Radio Transmission



(a) In the VLF, LF, and MF bands, radio waves follow the curvature of the earth
  - ✓ Low bandwidth

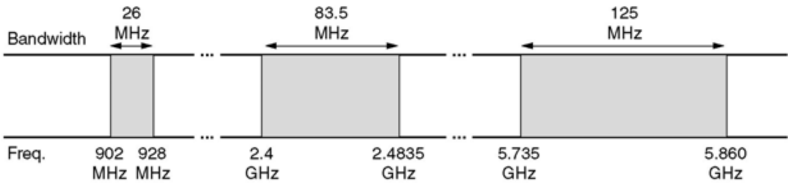
(b) In the HF band, they bounce off the ionosphere
  - ✓ absorbed by ground

Microwave Transmission

- Above 100MHz, EM waves travel in nearly straight lines
  - Can be narrowly focused
  - Allow multiple transmitters lined up in a row to communicate with multiple receivers in a row without interference
  - MCI built its entire system with microwave communications going from tower to tower tens of km apart
  - No right of way is needed
  - Relative inexpensive

Ways to Allocate Electromagnetic Spectrum

- Beauty contest – each carrier to explain why its proposal serves the public interest best, government officials decide which of the nice stories they enjoy most
- Lottery
- Auction
- ISM (Industrial, Scientific, Medical) – Unregulated bands: 900MHz, 2.4GHz, 5.7GHz



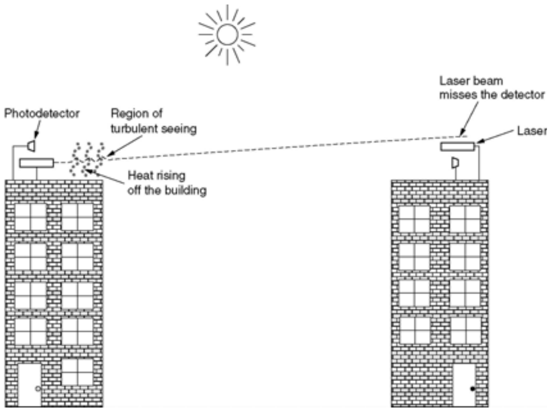
Infrared and Millimeter Waves

- Short range communication
  - Remote controls for TV, VCRs, DVD players etc.
  - An infrared system in one room will not interfere with a similar system in another room
  - Better security

Lightwave Transmission

Convection currents can interfere with laser communication systems

A bidirectional system with two lasers is pictured here.



Communication Satellites

- Geostationary satellites
- Medium-earth orbit satellites
- Low-earth orbit satellites
- Satellites versus fiber

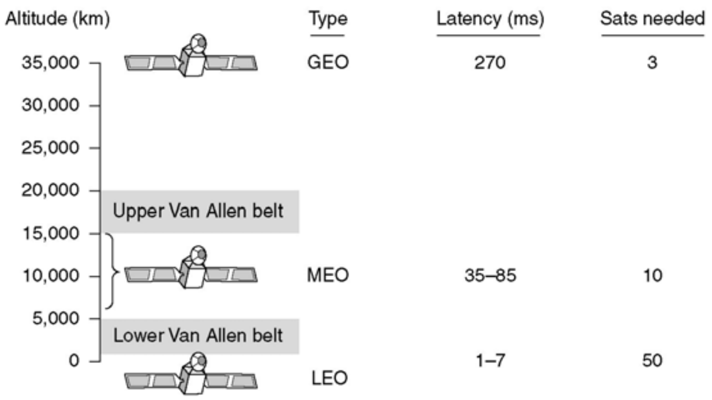
Communication Satellites

- Contains one or more **transponders**, each
  - Listens to some part of spectrum
  - Amplifies incoming signal
  - Rebroadcasts at another frequency to avoid interference with incoming signal
    - Downward beams can be broad, or
    - Narrow, covering an area only hundreds of km in diameter, this mode of operation is known as a **bent pipe**

Communication Satellites

- Where to place satellites
  - Van Allen belts – layers of highly charged particles trapped by the earth's magnetic field
  - Three regions in which satellites can be placed safely
    - Geostationary Satellites (GEO)
    - Medium-earth orbit satellites (MEO)
    - Low-earth orbit satellites (LEO)

Communication Satellites



Communication satellites and some of their properties, including altitude above the earth, round-trip delay time and number of satellites needed for global coverage.

Geostationary Satellites

- First described by a science fiction writer Arthur Clarke
  - 35,800km above equator
  - Period is 24 hours
  - Station keeping – need fine tuning using on-board rocket motors
- Need to be 2 degree apart to prevent interference => at most 180 satellites

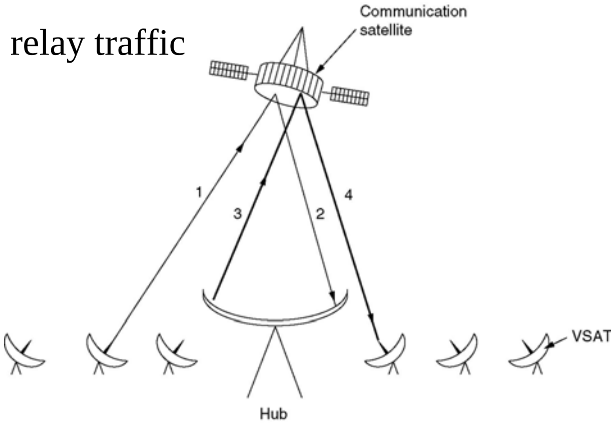
Geostationary Satellites

The principal satellite bands

Band	Downlink	Uplink	Bandwidth	Problems
L	1.5 GHz	1.6 GHz	15 MHz	Low bandwidth; crowded
S	1.9 GHz	2.2 GHz	70 MHz	Low bandwidth; crowded
C	4.0 GHz	6.0 GHz	500 MHz	Terrestrial interference
Ku	11 GHz	14 GHz	500 MHz	Rain
Ka	20 GHz	30 GHz	3500 MHz	Rain, equipment cost

Communication Satellites

- Low cost microstations, called VSATs (Very Small Aperture Terminals
  - Need hub to relay traffic



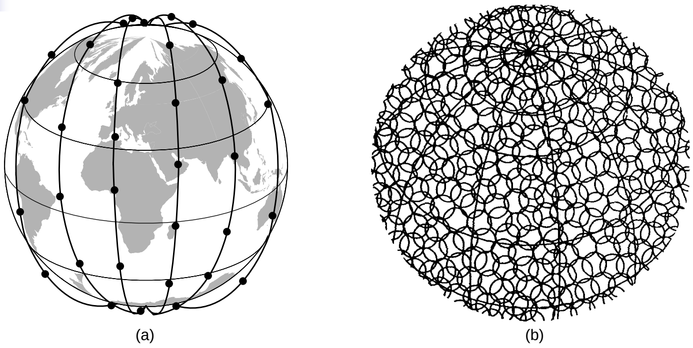
Medium-Earth Orbit Satellites

- Placed between two Van Allen belts
- Period is about 6 hours
- Smaller footprint on the ground, require less powerful transmitters to reach them
- Not used for telecomm
- 24 GPS (Global Positioning System) satellites at about 18,000 km

Low-Earth Orbit Satellites – Iridium

- **Goal: to provide worldwide telecomm service using hand-held devices that communicate directly with the Iridium satellites**
- 66 satellites, each satellite has 48 spot beams (that scan the earth as the satellites moves)
  - Total 1628 cells, each cell has 174 full-duplex channels => 253,440 total channels
- Both cells and users are mobile
- Attitude 750 km, 32 degree latitude between satellites
- Big financial disaster - $5 billion worth's asset sold to an investor for $25 million

Low-Earth Orbit Satellites – Iridium

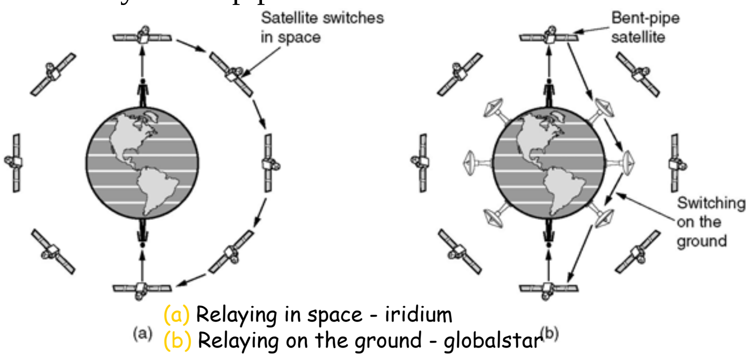


(a) The Iridium satellites from six necklaces around the earth.

(b) 1628 moving cells cover the earth.

Low-Earth Orbit Satellites – Globalstar

- Based on 48 LEO satellites
- Uses a traditional bent-pipe design – call is routed via a terrestrial network to the ground station nearest the callee and delivered by a bent-pipe connection



(a) Relaying in space - iridium
(b) Relaying on the ground - globalstar

Satellites vs. Fiber

- Terrestrial fiber connections looked like the long-term winner, nevertheless, communication satellites have some major niche markets
  - Fiber is not accessible to end users yet, while with antenna, a user can enjoy high bandwidth from satellite communication
  - Mobile communication, fiber obviously is not appropriate

Satellites vs. Fiber

- When broadcasting is essential, e.g., transmitting a stream of stock, bond prices to thousands of dealers using satellites might be cheaper
- Hostile terrain or a poorly developed terrestrial infrastructure
- Satellites can cover areas where obtaining the right of way for laying fiber is difficult or unduly expensive
- When rapid deployment is essential – e.g., military communication systems in time of war