

Bandwidth Utilization Transmission Media Switching

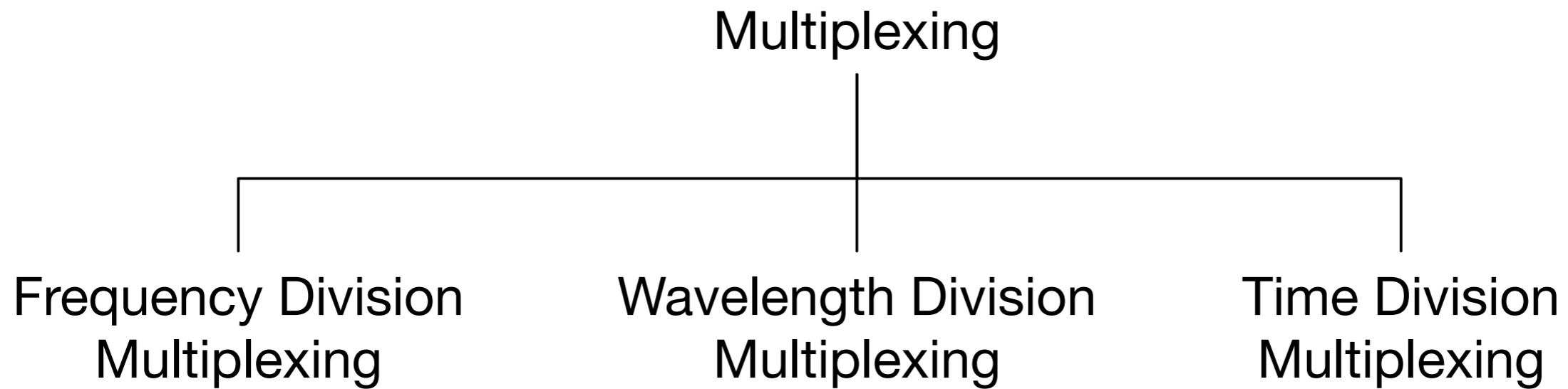
Thomas Schwarz, SJ

Bandwidth Utilization

- Limited bandwidth is a universal challenge
 - Saving bandwidth: Multiplexing:
 - Combine several channels into one
 - Using more bandwidth: Spectrum Spreading:
 - Add redundancy, privacy, and antijamming

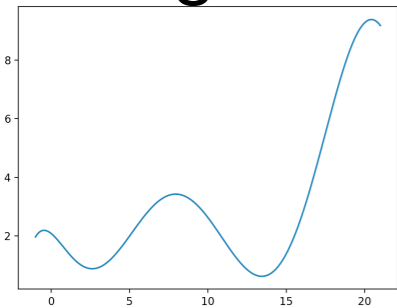
Bandwidth Utilization

- Multiplexing

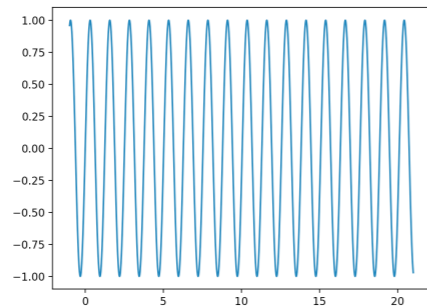


Bandwidth Utilization

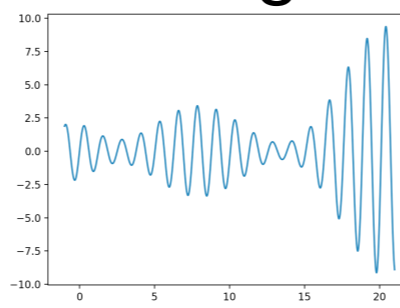
Signal



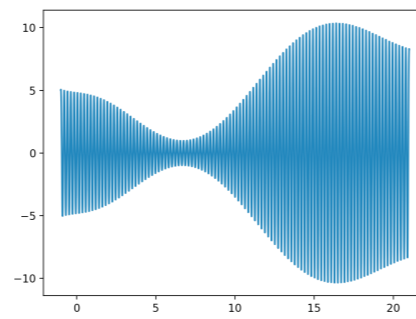
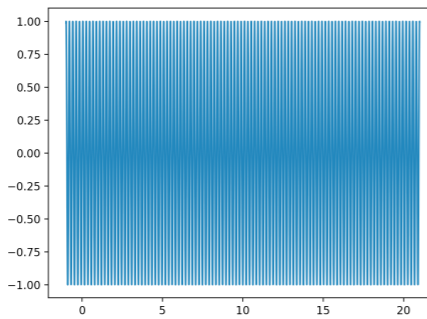
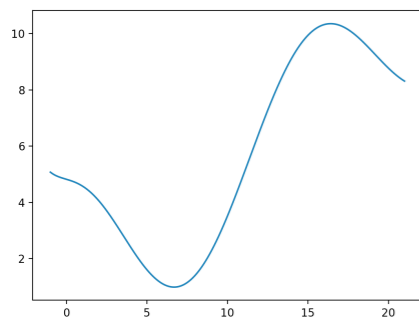
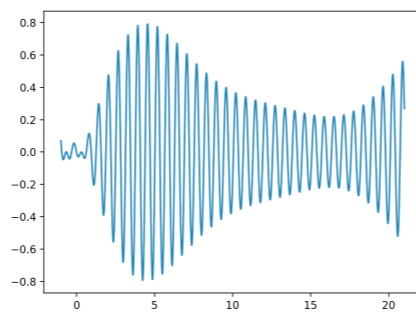
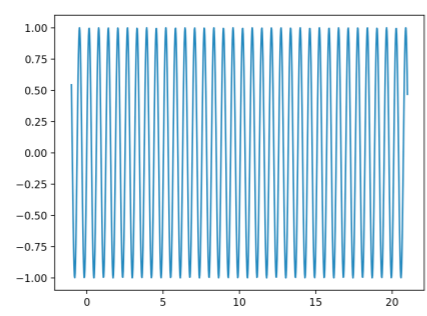
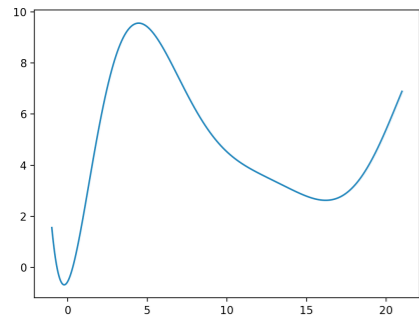
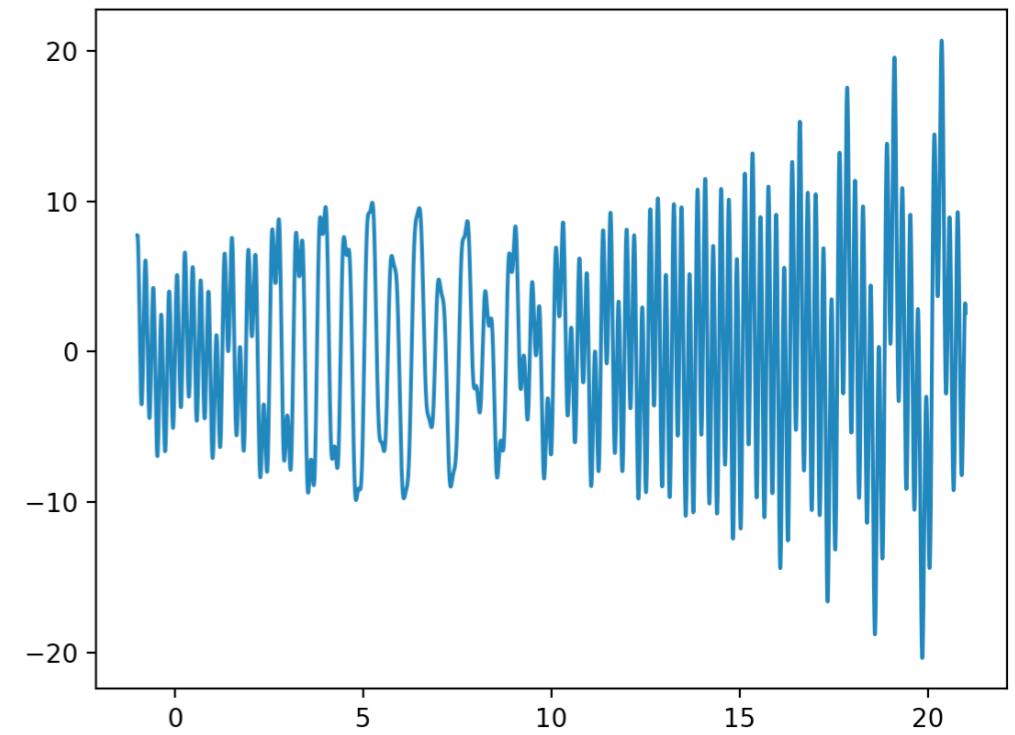
Carrier



AM Signal

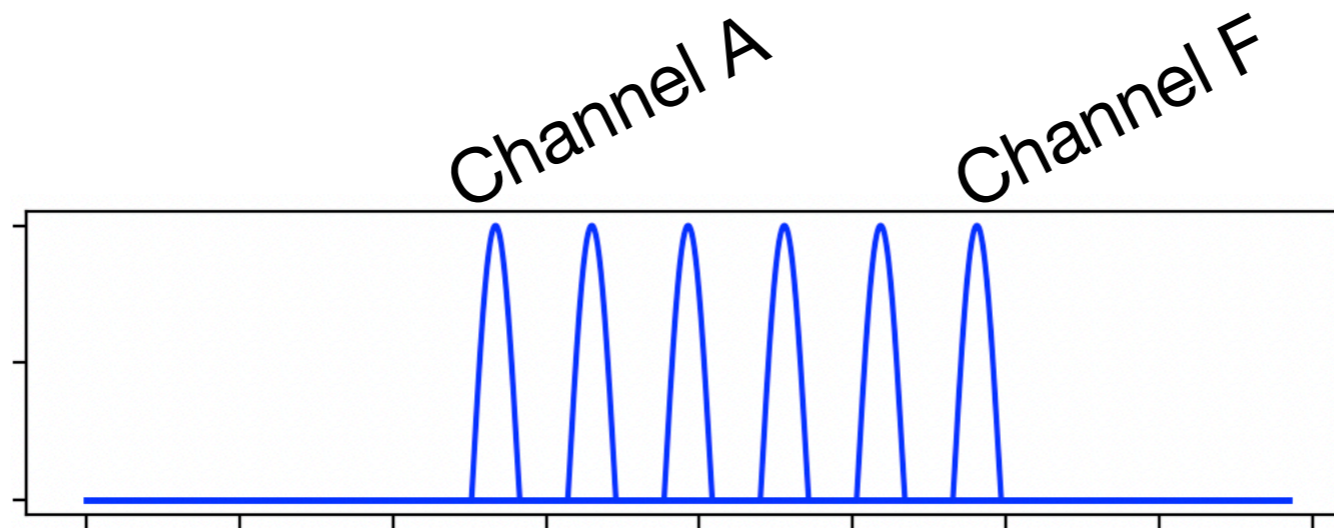


Frequency-Division Multiplexing



Bandwidth Utilization

- Frequency Division Multiplexing:



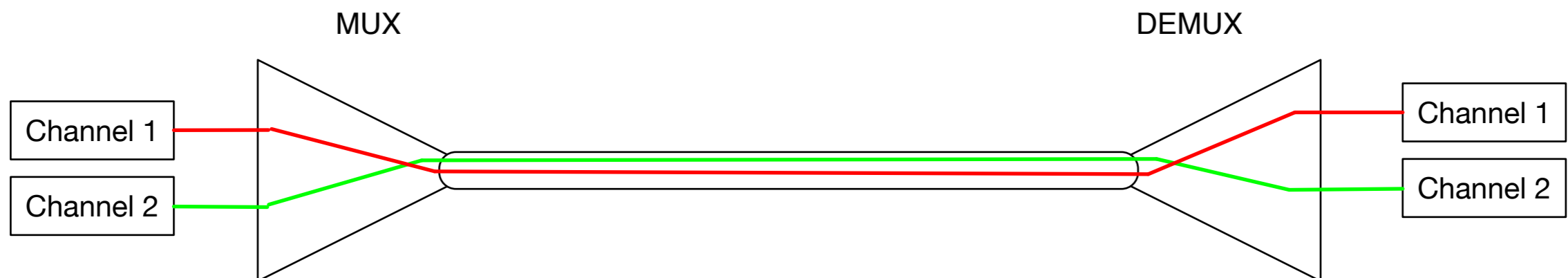
- Needs guard bands between channels
- Use frequency filters to de-multiplex
 - Effectively Discrete Fourier Transforms for mux and demux

Bandwidth Utilization

- Quiz:
 - Five channels with 100 kHz bandwidth
 - Multiplexed with guard bands of 10 kHz
 - What is the bandwidth needed for the channel?
- Answer:
 - $5 \times 100 \text{ kHz} + 4 \times 10 \text{ kHz} = 540 \text{ kHz}$

Bandwidth Utilization

- Wavelength Division Multiplexing (WDM)
 - Use high-data rate of fiber-optic cable
 - Similar as FDM, but using optics
 - Multiplexing / Demultiplexing uses Prisms

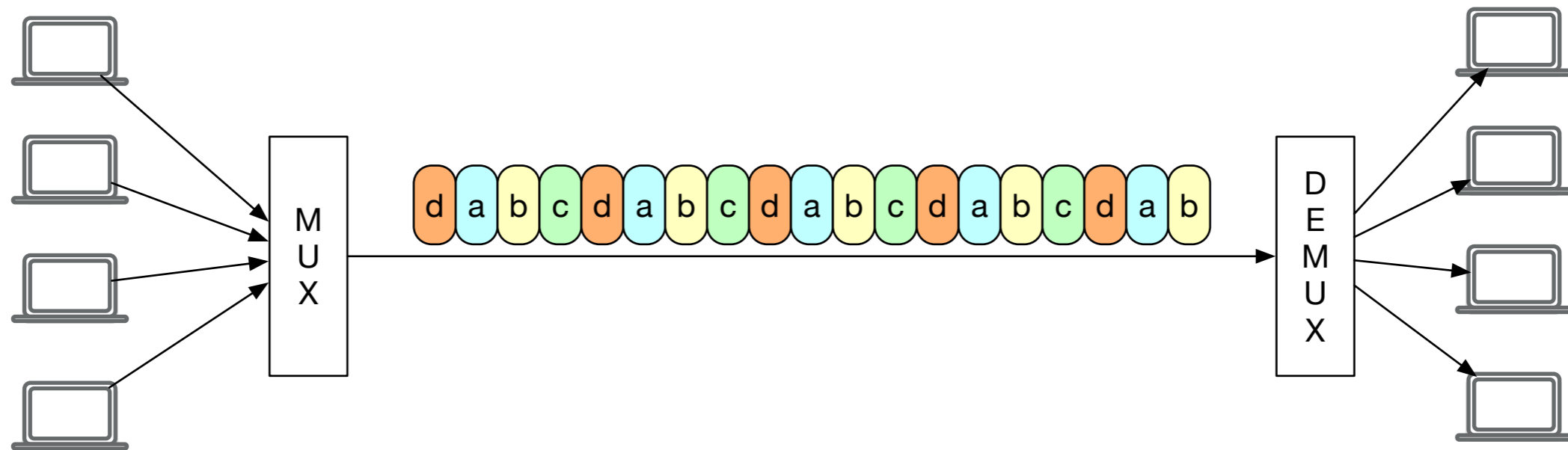


Aside: WDM

- Optical fiber has several windows defined by regions of low attenuation
 - Progress has de facto merged these bands
 - Normal WDM uses two windows with wavelength 1310 and 1550 nm
 - Coarse WDM uses up to 16 channels separated by guard bands
 - Dense WDM use typically 40 channels up to 160

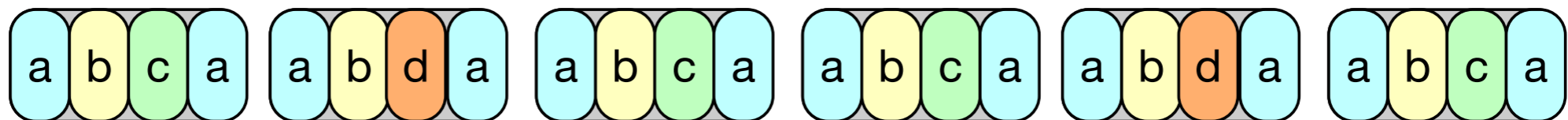
Bandwidth Utilization

- Time Division Multiplexing
 - Each flow gets a time-slice



Bandwidth Utilization

- Time Division Multiplexing
 - Becomes difficult if there are different stream rates
 - Multilevel Multiplexing:
 - Combine low rate streams into a higher rate stream, then combine those higher rate streams
 - High rate streams can occupy several slots in a frame:



a: 50 % , b: 25 % , c: 16.7 % , d: 8.3 % of capacity

Bandwidth Utilization

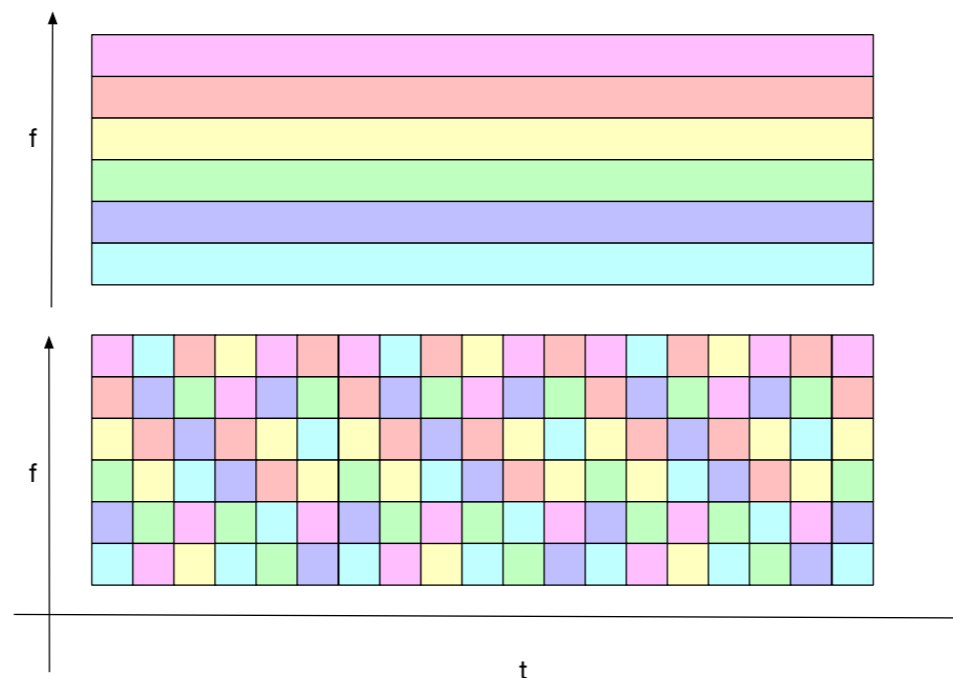
- Digital Signal Service / Digital Hierarchy:
 - Used by telephone companies
 - DS-0: 64 kbps
 - DS-1: 1.544 Mbps (24 ×) implemented by T1
 - DS-2: 6.312 Mbps (4 ×)
 - DS-3: 44,376 Mbps (7 ×)
 - DS-4: 0.27 Gbps (6 ×) implemented by T4

Spread Spectrum

- Used in wireless communication
 - Anti-eavesdropping
 - Anti-jamming
 - Anti-interference
- Requires much more bandwidth

Spread Spectrum

- Frequency Hopping Spread Spectrum
 - Use M different carrier frequencies
 - For a given signal:
 - Pick one of the M for signal transmission
 - Can be done independently or by synchronizing between channels



Code Division Multiplexing

- Narrowband signal is spread out over wider frequency band
 - More tolerant of interference
 - Allows multiple signals to share the same frequency band
 - A.k.a. Code Division Multiple Access (CDMA)

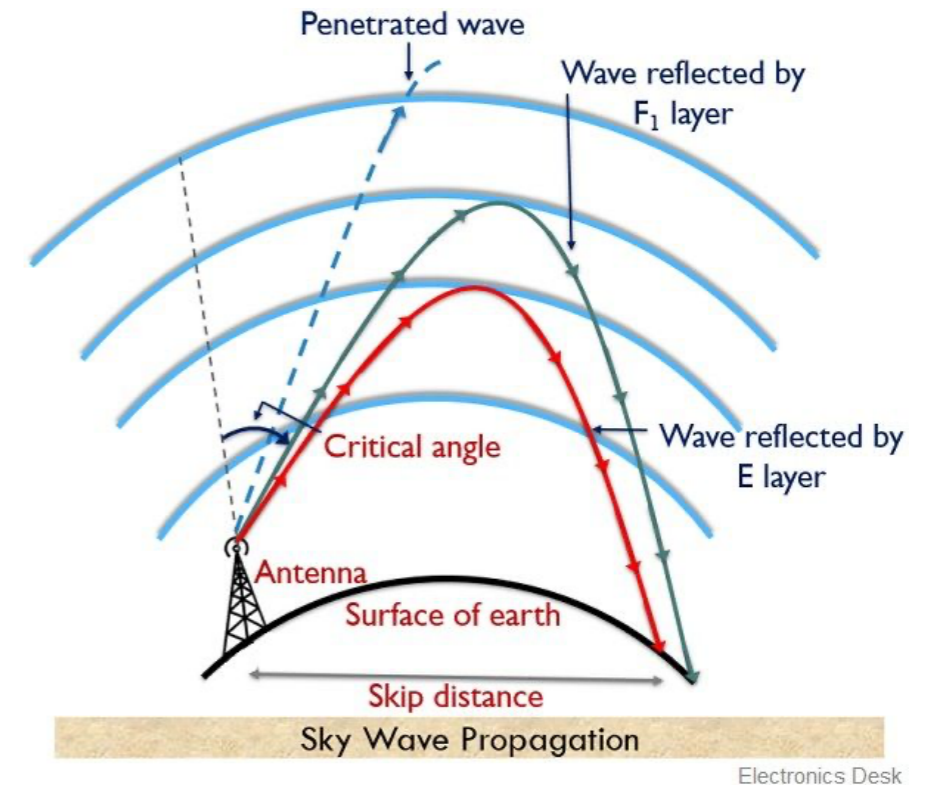
Code Division Multiplexing

- Each data bits is sent in m chips
 - Typically 64 or 128 chips/bit
 - Each station has a unique m -bit code called the chip sequence, consisting of positive + and negative - signal bits
 - To transmit a 1, station sends its chip sequence
 - To transmit a 2, station sends the negative of its chip sequence
 - Chips are selected according to *Walsh* codes
 - Receiver uses the mathematical properties of Walsh codes to recover the different station's messages

Transmission Media

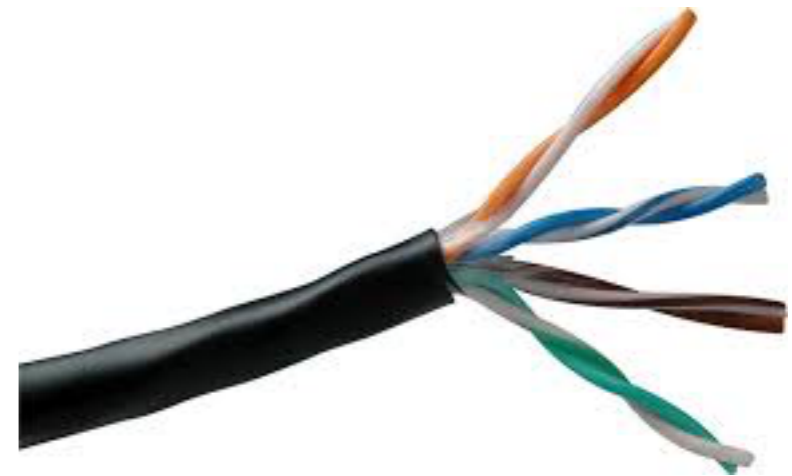
Transmission Media

- Guided Media:
 - twisted pair cable
 - coaxial cable
 - fibre optical cable
- Unguided Media:
 - Electro-magnetic spectrum
 - Ground propagation (below 2 Mhz)
 - Sky propagation (2-30 Mhz)
 - Line-of-sight propagation (above 30 Mhz)



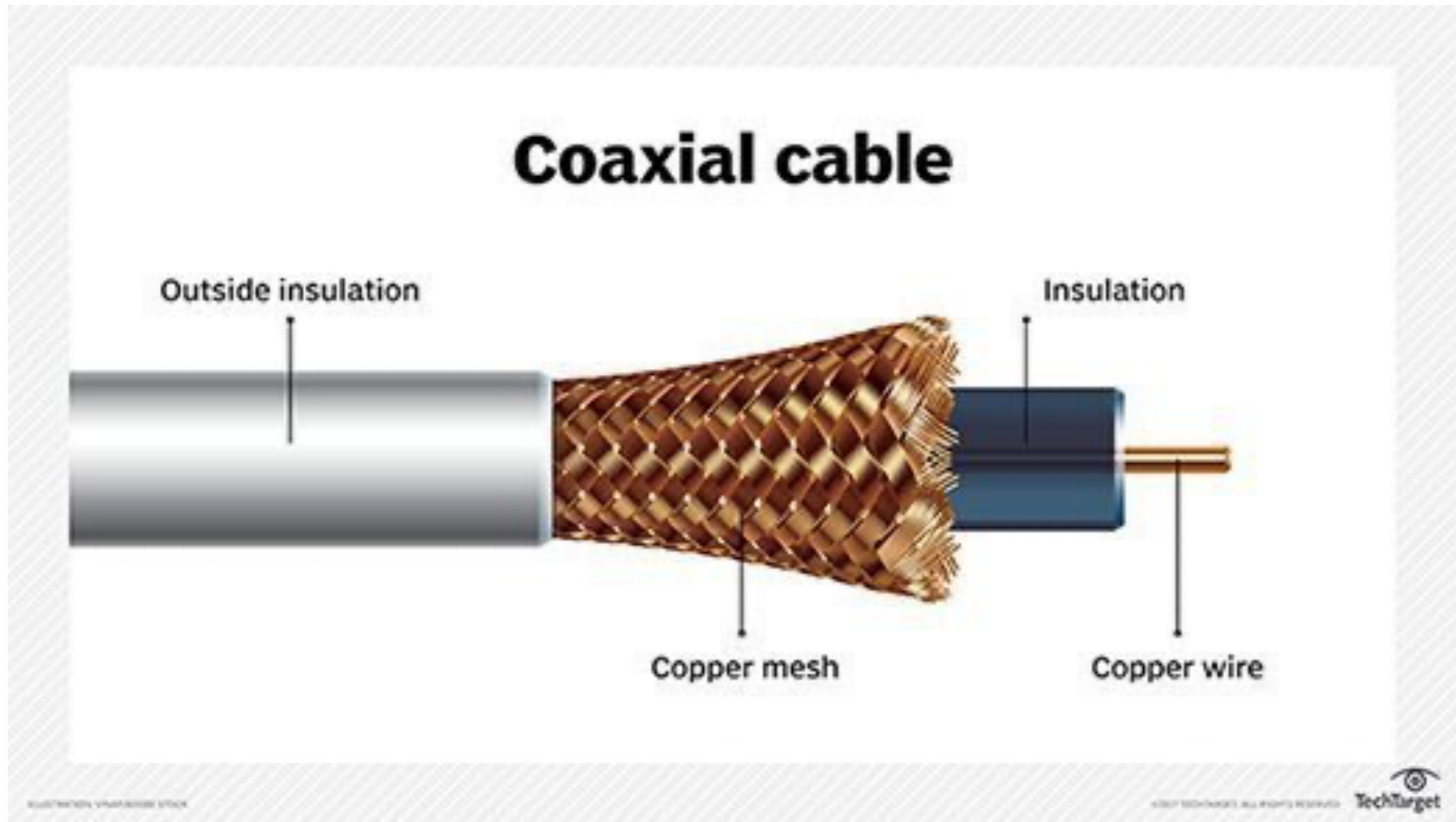
Twisted Pair

- Two / four insulated copper wires
 - Twisted to avoid noise: More twists less noise
 - 100Mbps uses one pair for each direction
 - 1-Gbps uses four pairs
 - Given by category
 - Category 7 is shielded



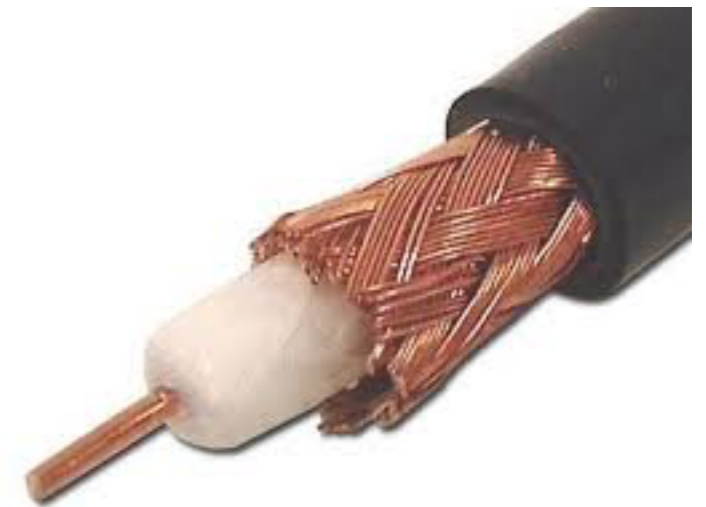
Cat 5 UTP with four twisted pairs

Coaxial Cables



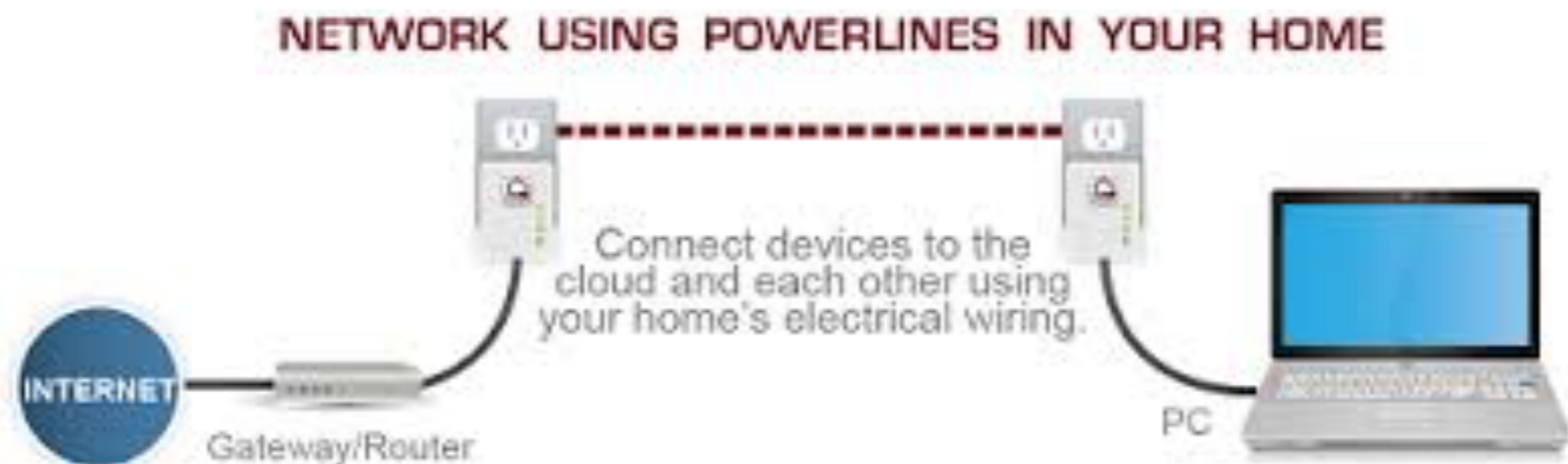
Coaxial Cable

- Because of shielding gives better bandwidth
- Spans longer distances without repeater
- 50-ohm cable:
 - Used for digital transmission
- 70-ohm cable:
 - Used originally for analog transmission



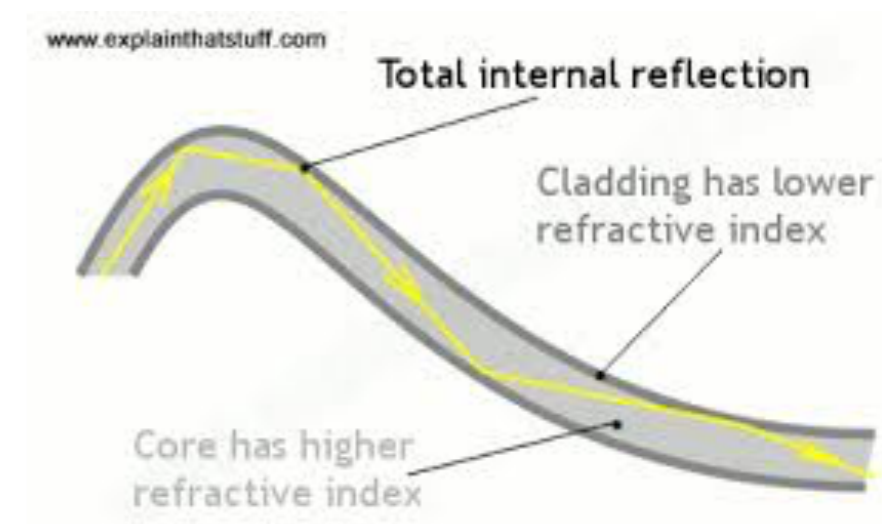
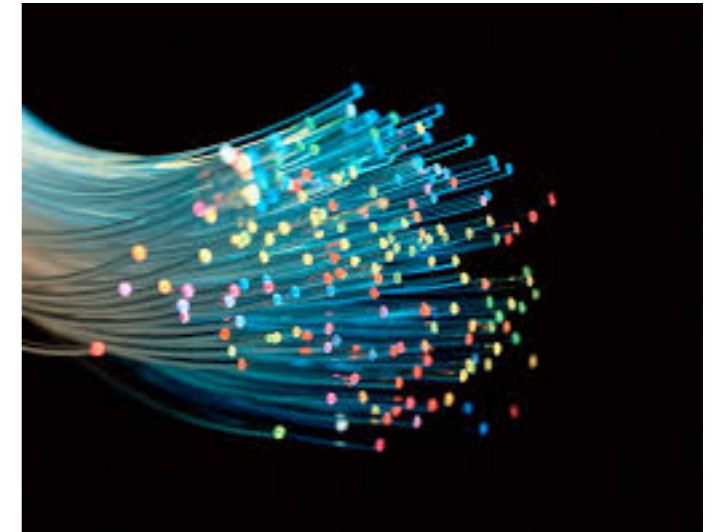
Home Electrical Wiring

- Use the power electrical wiring in a house
 - Superimpose high frequency signal
 - Suffers from bad attenuation and noise
 - Can be used for ≥ 100 Mbps



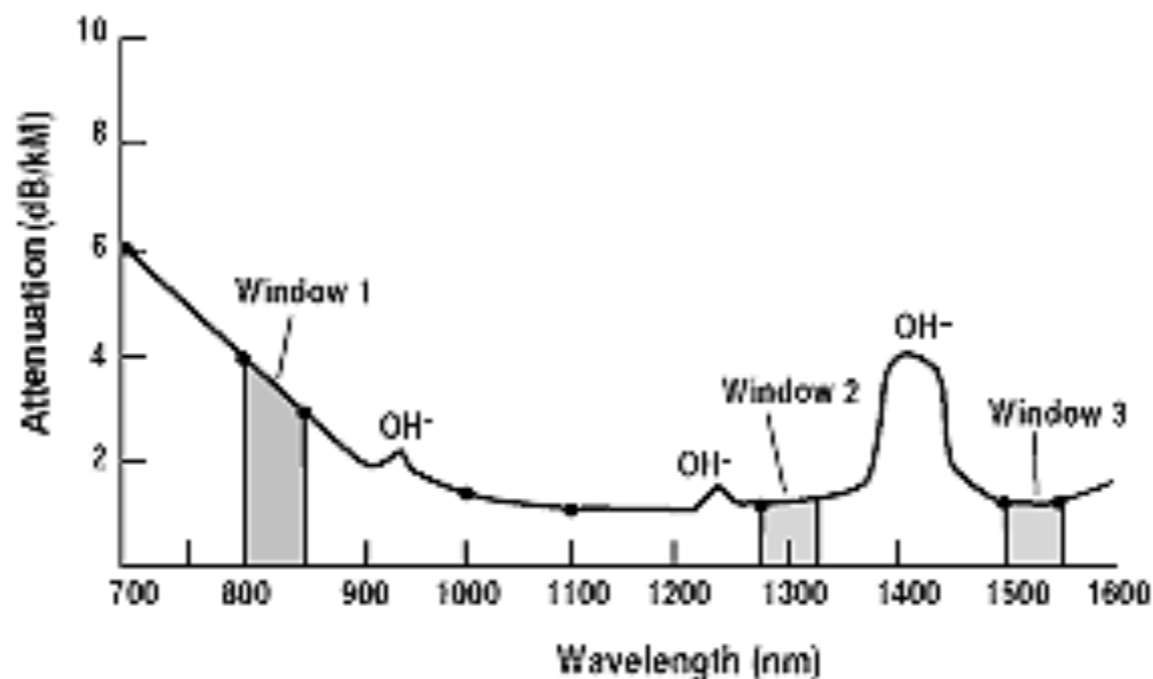
Fiber Optics

- Use glass for propagation of light
 - Diameter about 50 microns ($50 \times 10^{-6}m$)
 - Protected by cladding and jacket
 - Several strands bundled in a sheath
- Light sources are
 - LED
 - Semiconductor laser (high data rate, long distance)



Fiber Optics

- Fiber Optics
 - Attenuation depends on wavelength
 - Three 25GHz bands are used
- Signals can be generated via LED or semi-conductor laser



Fiber Optics

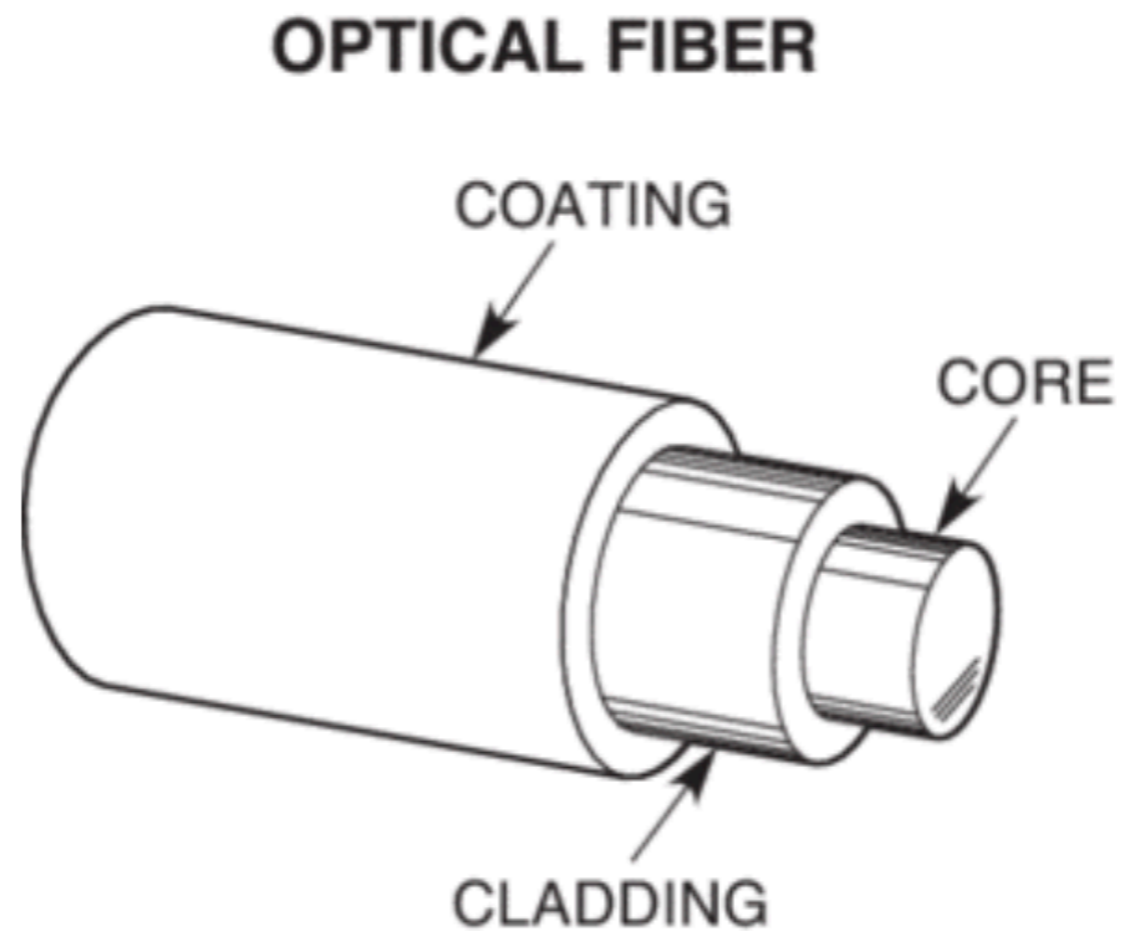


Figure 1. Cross section view of an optical fiber.

Fiber Optics

- Attenuation depends on frequency

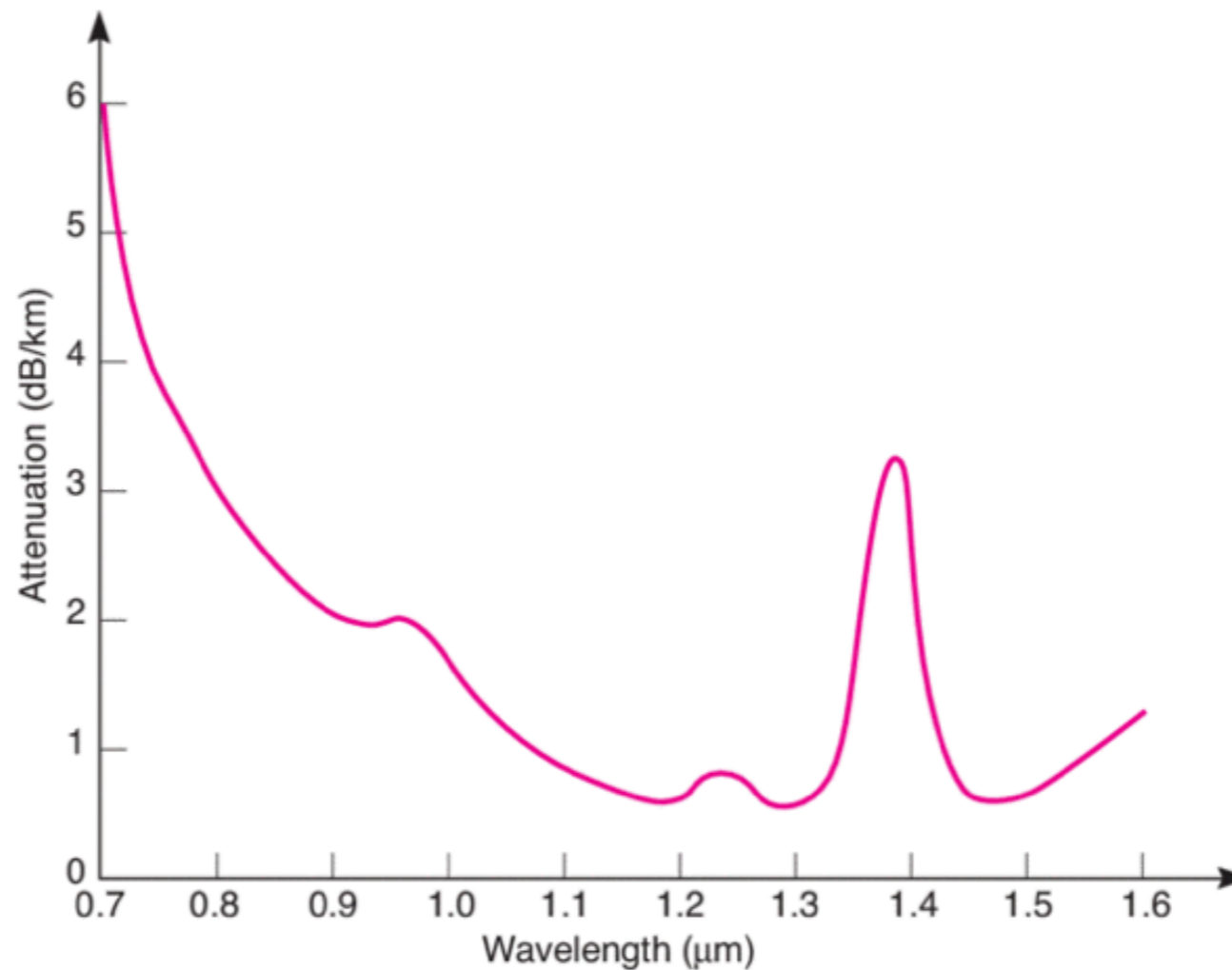


Figure 5. Typical spectral attenuation in silica.

Fiber Optics

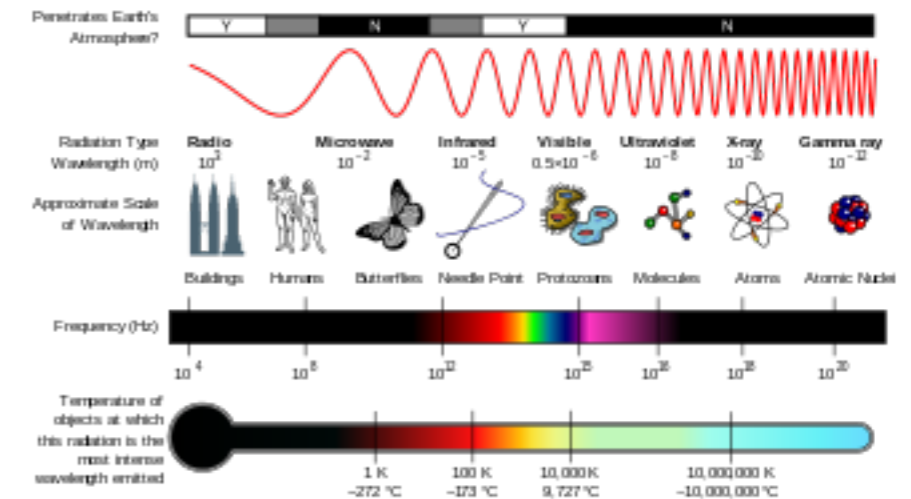
- Attenuation is very low (repeaters every 50 km)
- Not subject to power surges or electro-magnetic interference
- Resistant to corrosion

Wireless Transmission

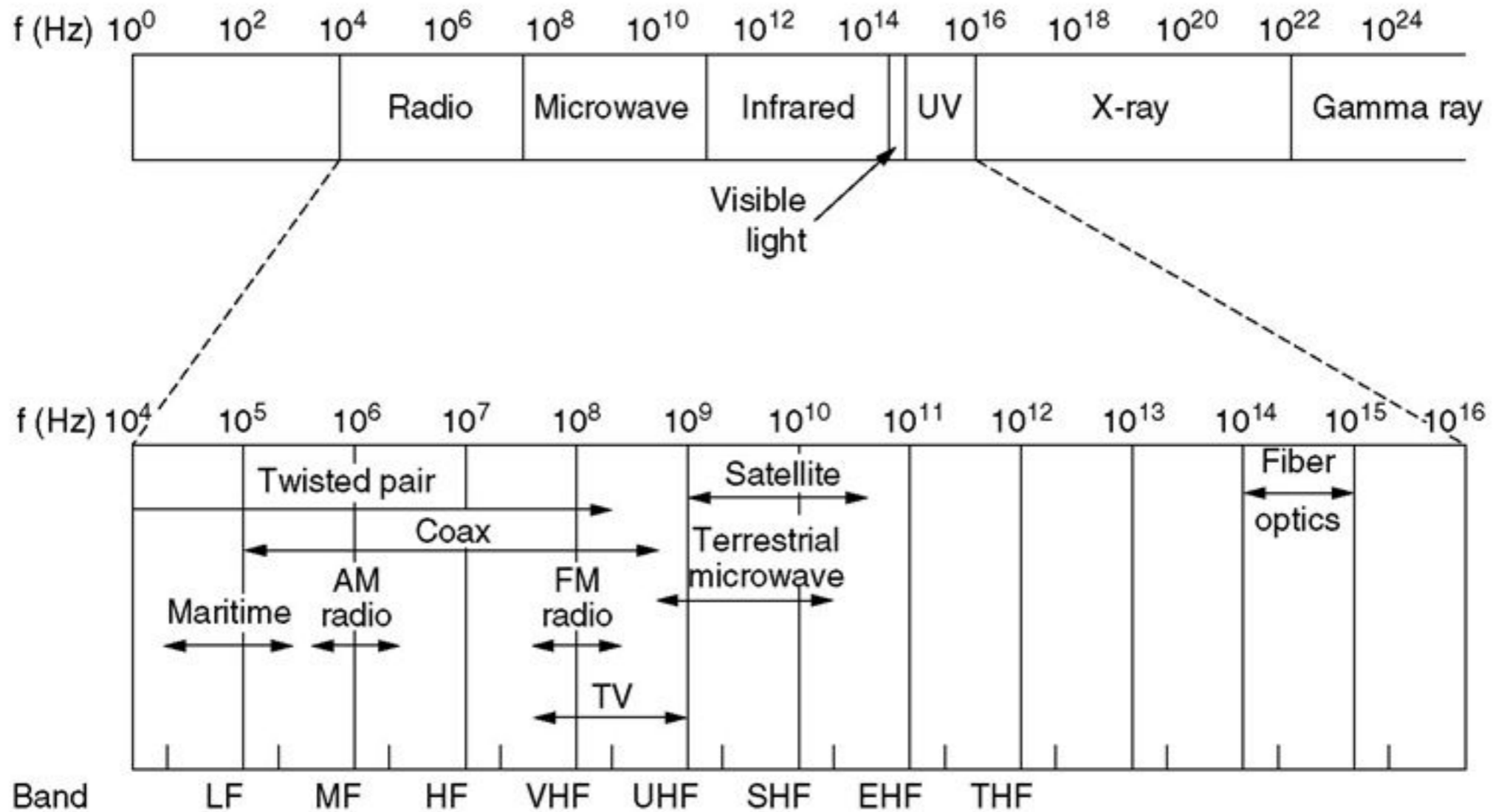
- Attenuation through spread and absorption
 - Spread: attenuation proportional to square of the distance
- Very susceptible to noise
 - Radio spectrum is strictly controlled
- Different interactions with earth, atmosphere depending on the frequency

Wireless transmission

- Communication can use certain wide bands of frequency
- Most uses concentrate signal in a small band
- However
 - Frequency hopping — used by the military and in order to avoid interference
 - Direct Sequence Spread Spectrum — uses a code sequence to spread signal (CDMA)
 - Ultra-Wide Band (UWB communication) — sends out a series of very short pulses in a wide band



The Electromagnetic Spectrum

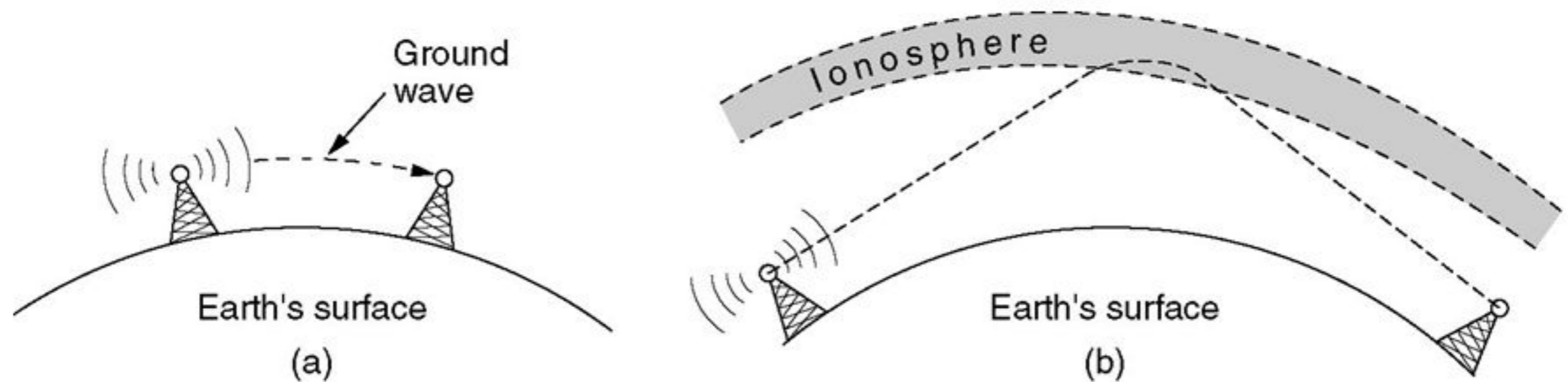


The electromagnetic spectrum and its uses for communication.

Wireless Transmission

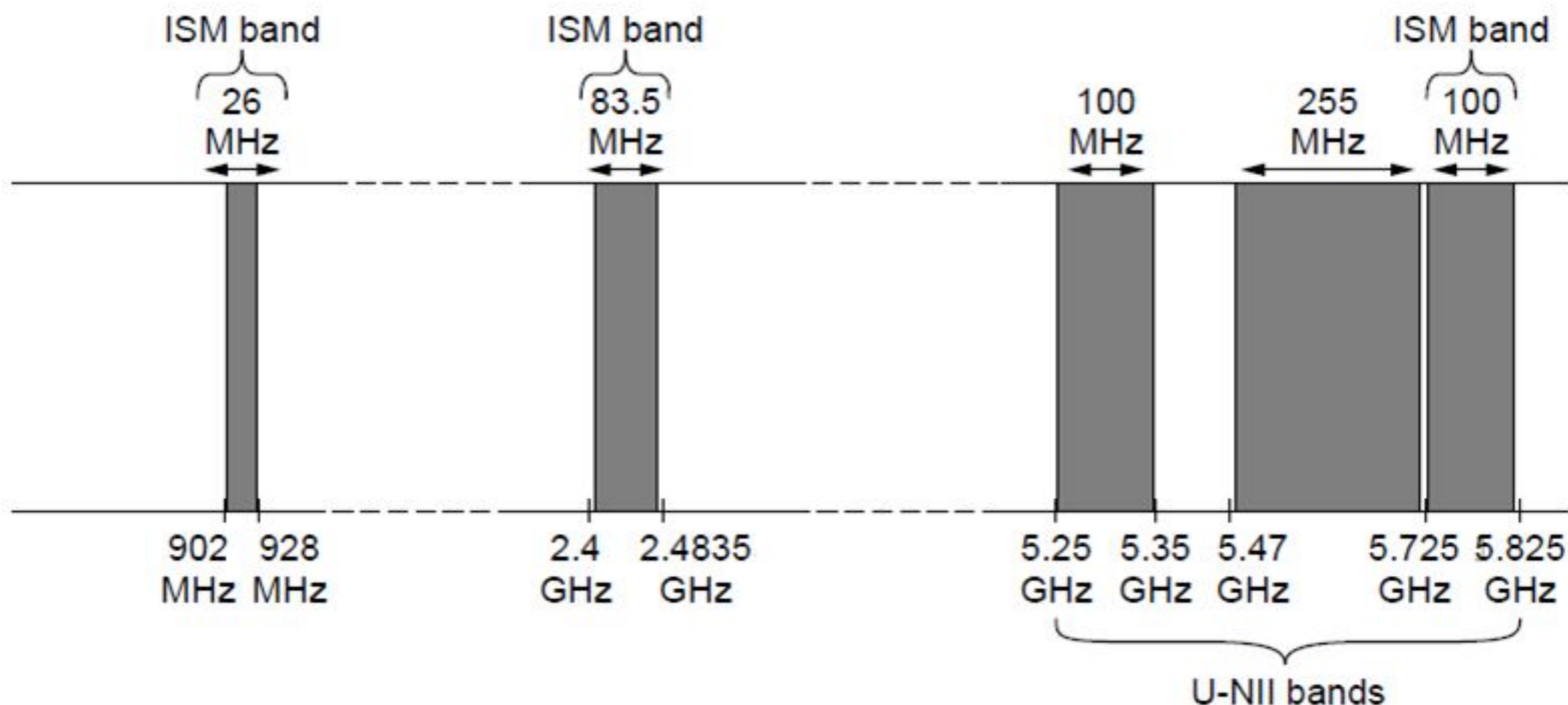
- Radio frequency waves
 - are easy to generate
 - can travel long distances
 - can penetrate buildings
 - are omnidirectional
 - attenuation is proportional to at least the square of the distance

Radio Transmission



- (a) In the VLF, LF, and MF bands, radio waves follow the curvature of the earth.
- (b) In the HF band, they bounce off the ionosphere.

The Politics of the Electromagnetic Spectrum



ISM and U-NII bands used in the United States by wireless devices

Microwave Transmission

- Above 100 MHz, waves travel in (almost) straight lines
 - Use beams for communication
 - Need repeaters
 - Get absorbed by buildings/earth and water (above 4Ghz)



Microwave Transmission

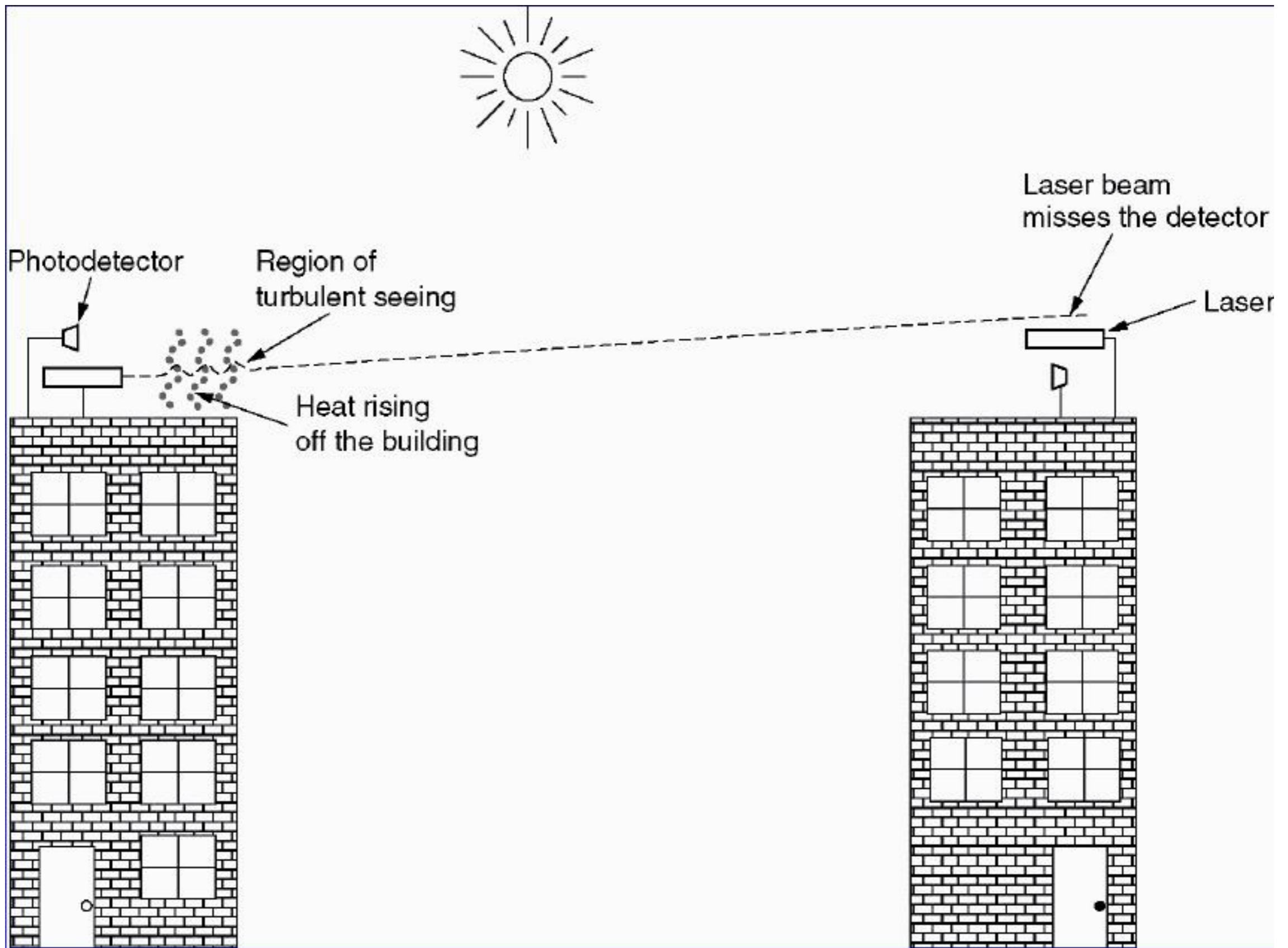
- MCI: Built a system of microwave towers
- Sprint: Owned by Southern Pacific Railroad with lots of stretched out real estate: Used fiber optics

Infrared

- Unguided, directional
 - Used for short distances
 - Remote control of stereos, tvs, VCR

Light Transmission

- Used for signaling:
 - E.g. in middle-earth to alert Rowan
- Laser can be used to combine two LANs in adjacent buildings

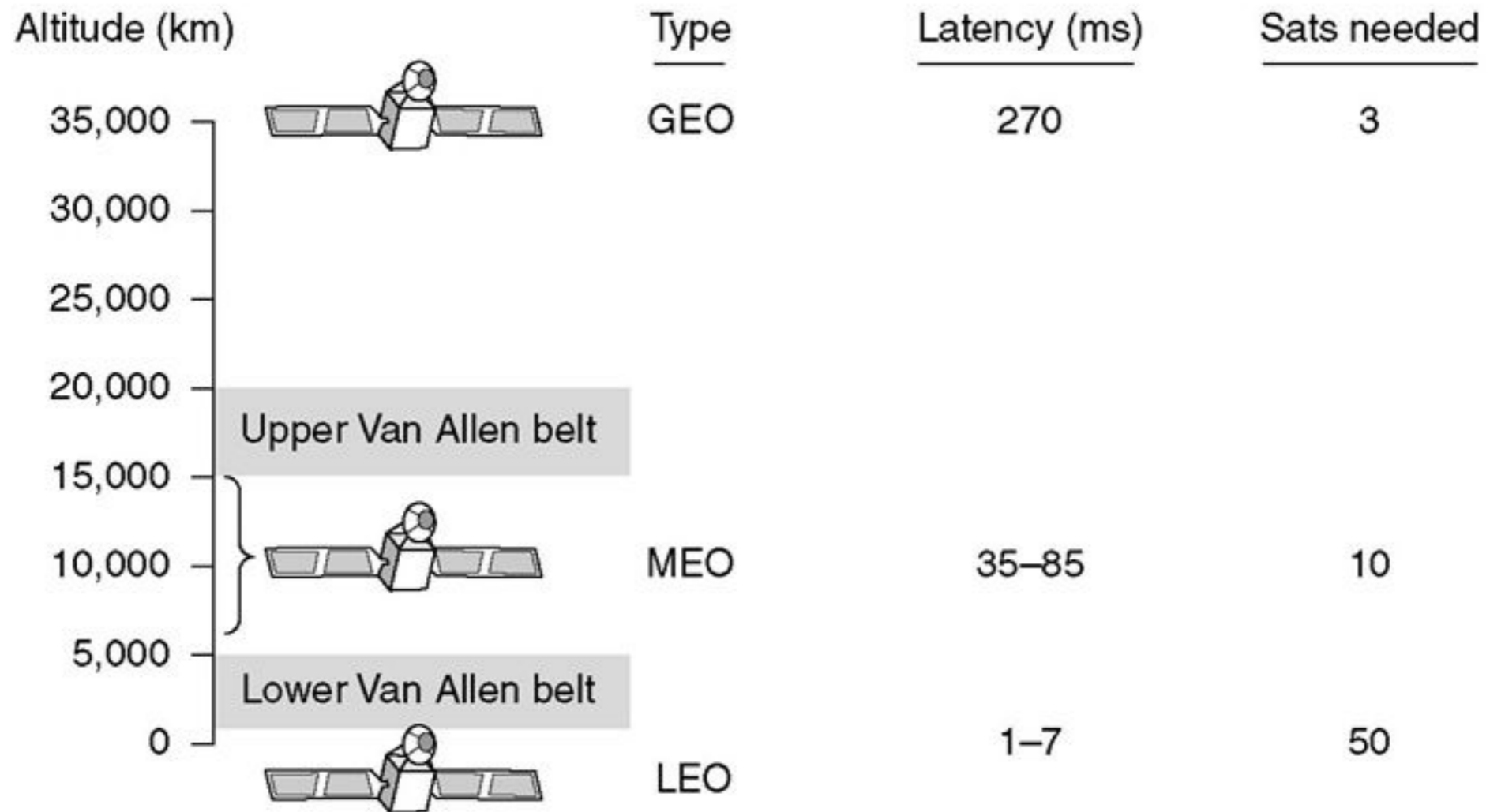


Light transmission with duplex lasers

Satellites

- Van Allen Belt Imposes three bands
 - GEO: geostationary, latency 270 msec
 - MEO: latency 35-85 msec (e.g. GPS)
 - LEO: latency 1-7 msec
- Distance from earth determines number of satellites needed for a global network
- Uses microwave communication in certain bands

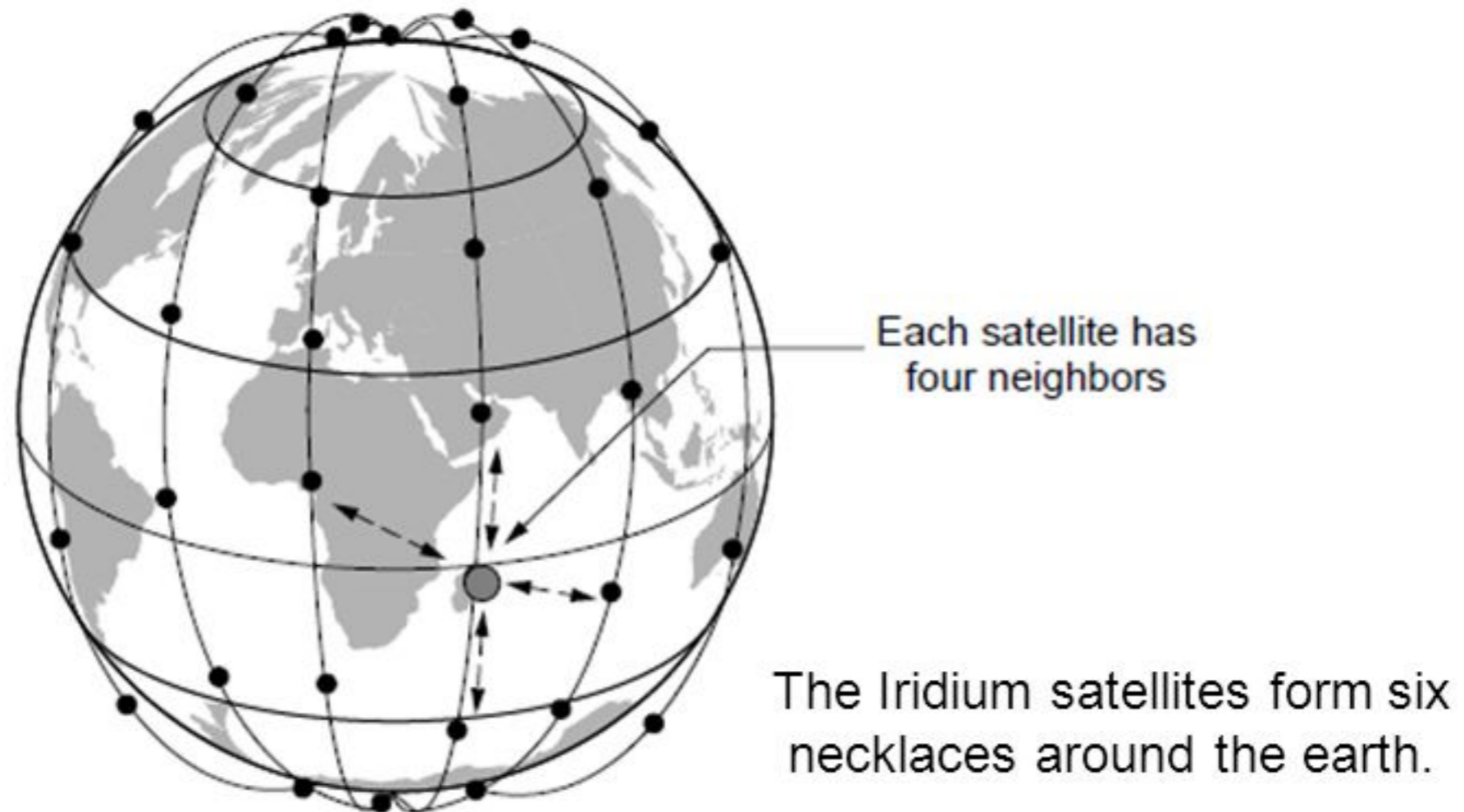
Communication Satellites



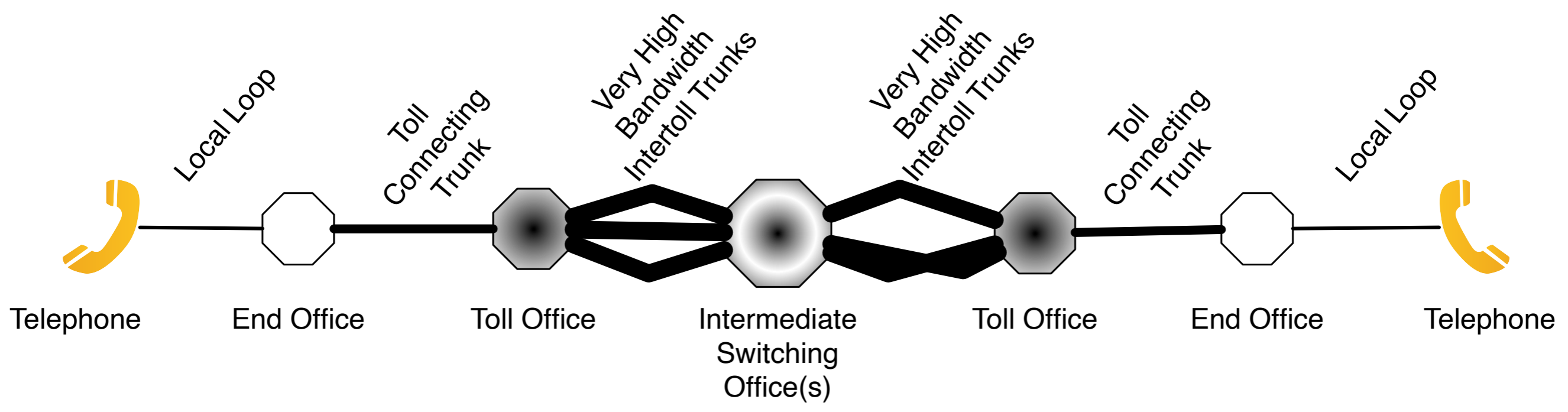
Communication satellites and some of their properties, including altitude above the earth, round-trip delay time and number of satellites needed for global coverage.

Low-Earth Orbit Satellites

Systems such as Iridium use many low-latency satellites for coverage and route communications via them



Public Switched Telephone Network



Public Telephone System

- 1878: Bell Telephone Company in New Haven, Connecticut
 - A wire to each subscriber
 - To make a call,
 - Subscriber cranks the phone
 - Operator uses jumper cable to connect caller to callee

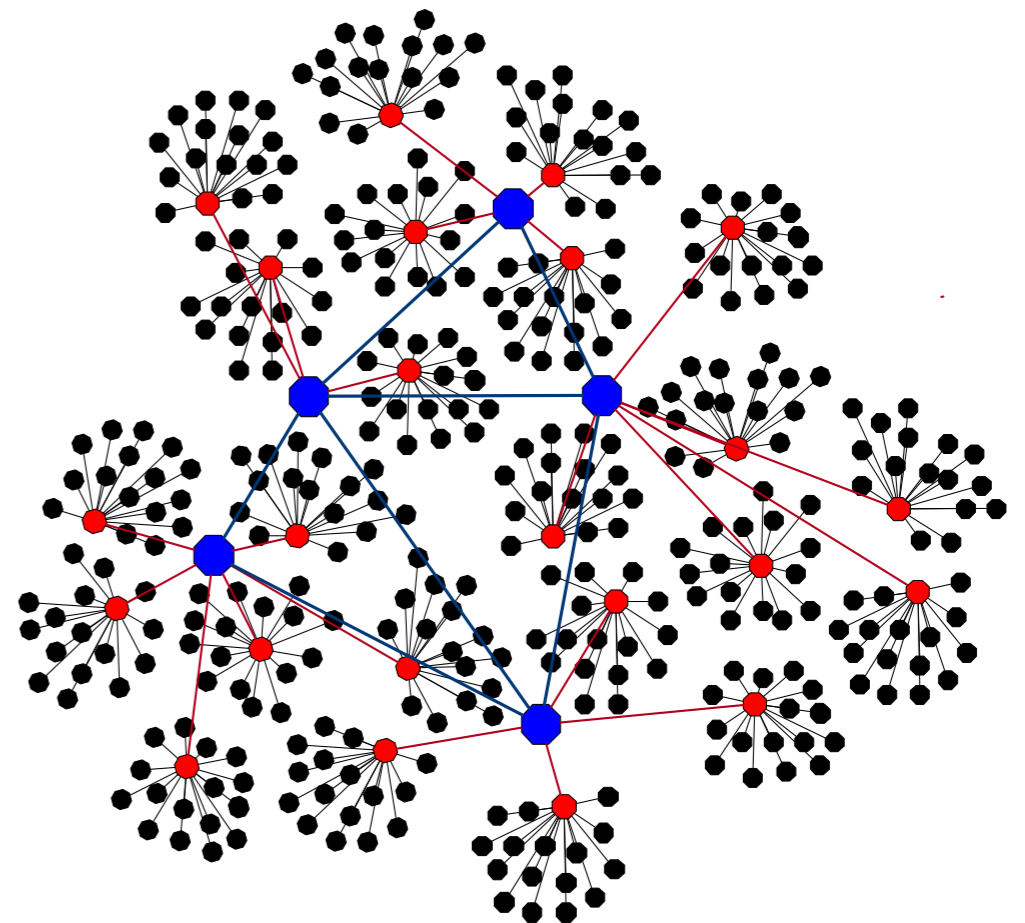


Public Telephone System

- ~ 1890: Long distance calls
 - Operator sets up circuit to another switching office
 - Need to set up a hierarchy of connections in order to avoid too many wires



Telefontornet Stockholm 1890



Public Telephone System

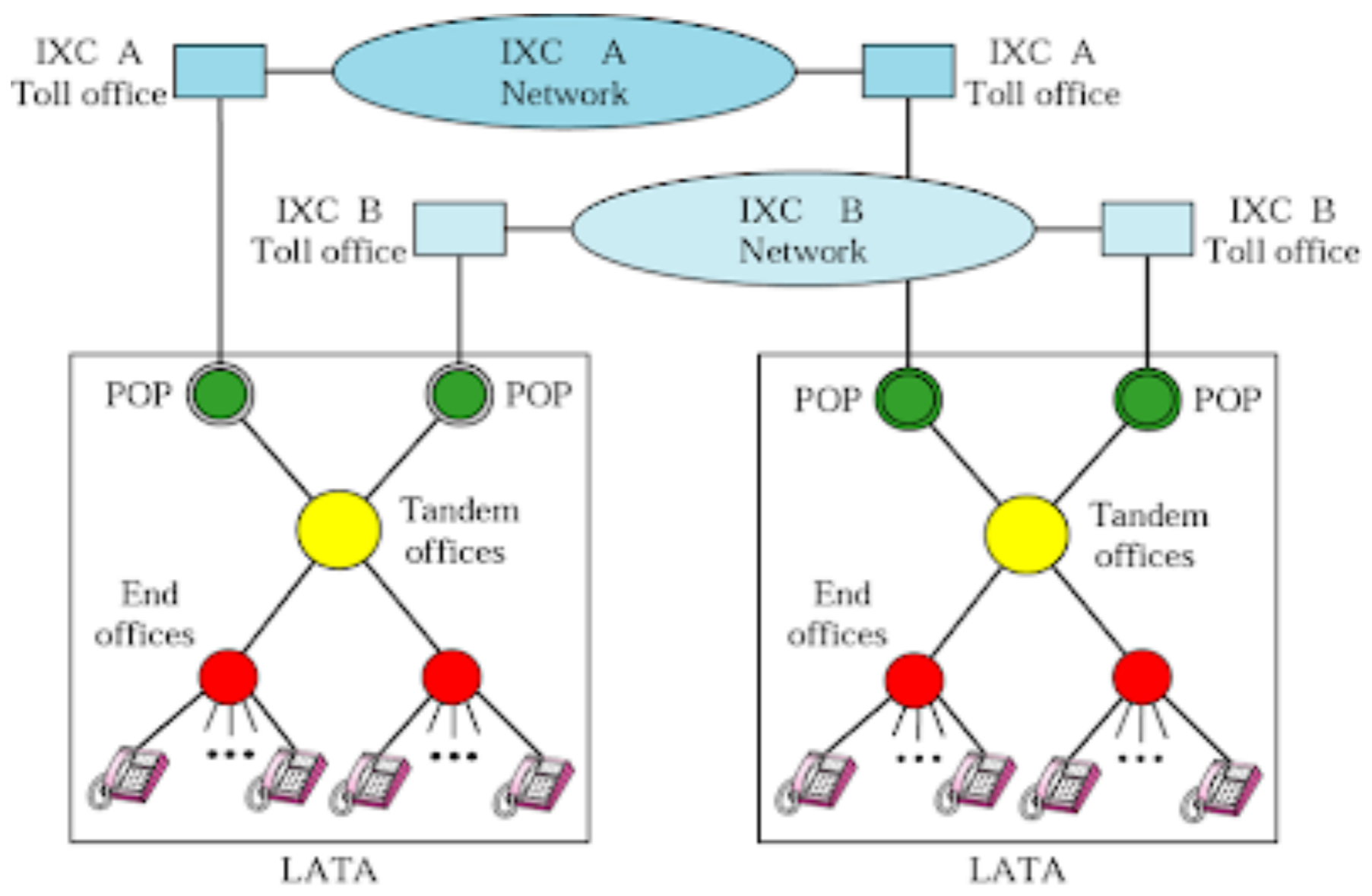
- Each telephone is connected to the *end office* aka local central office
 - Connection is the “local loop” (1-10 km)
 - Local calls are between subscribers attached to the same end office
- Each end office is connected to one or more switching centers, the *toll offices* or *tandem offices* in the same local area
 - Connections are called *toll connecting trunks*
- If caller and callee’s offices do not have a toll connecting trunk:
 - Toll offices communicate via *intertoll trunks* aka *interoffice trunks*

Public Telephone System

- Before breakup of ATT:
 - Use a hierarchical system to close circuit

Public Telephone System

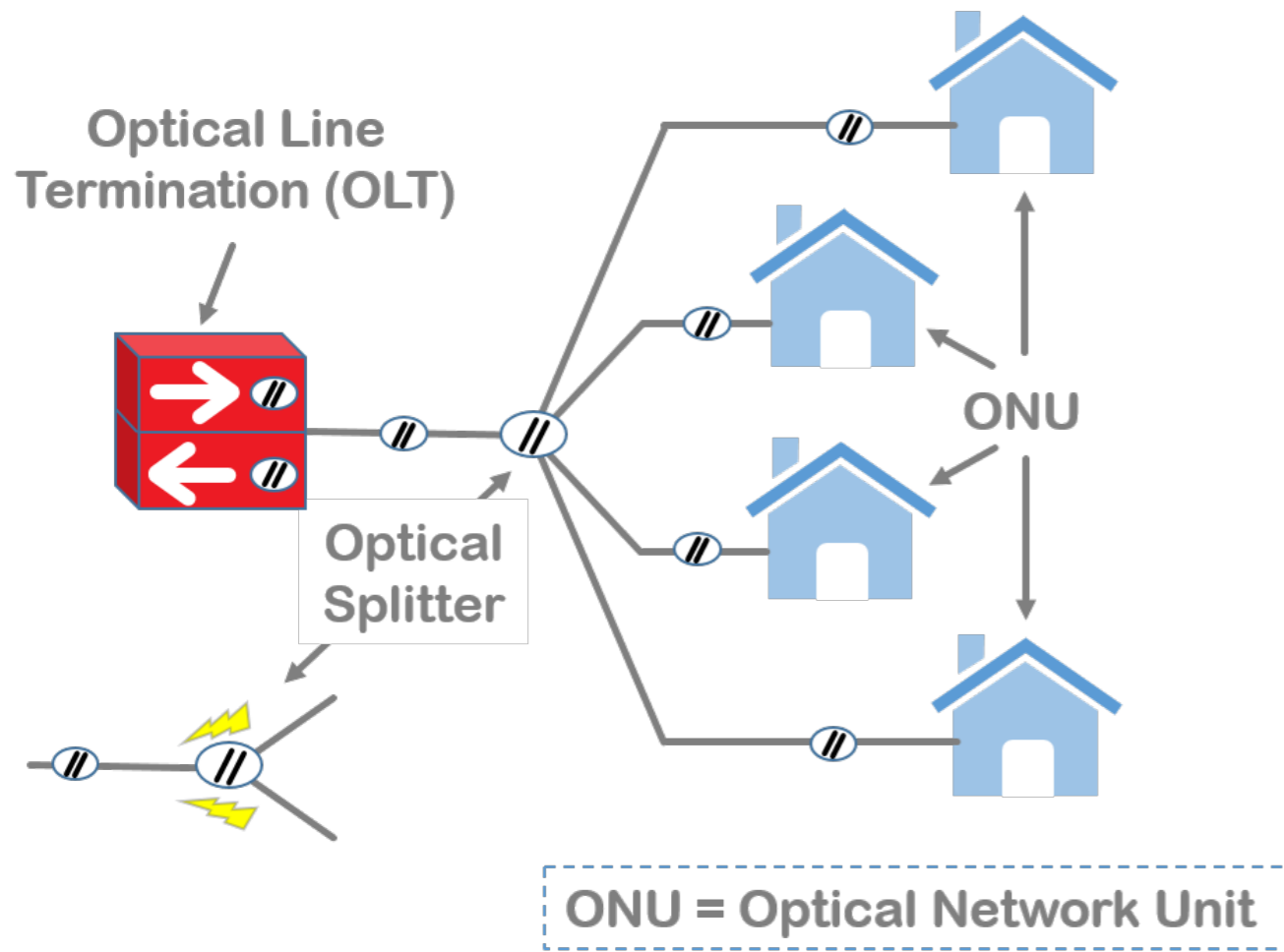
- After breakup
 - US divided into 164 Local Access and Transport Areas (LATAs)
 - Each LATA has a Local Exchange Carrier (LEC) with a monopoly on telephone service within a LATA
 - Often one of the 23 Bell Operating Companies (BOCs)
 - Inter-LATA traffic handled by an IntereXchange Carrier (IXC)
 - Originally, only AT&T Long Lines, later Verizon and Spring
 - Any IXC that wants to offer service in a LATA builds a switching office, the Point Of Presence (POP)
 - LECs have to connect each IXC to every end office
 - Connections must be identical (technically and financially)
 - IXCs were not allowed to work as LEC until 1996



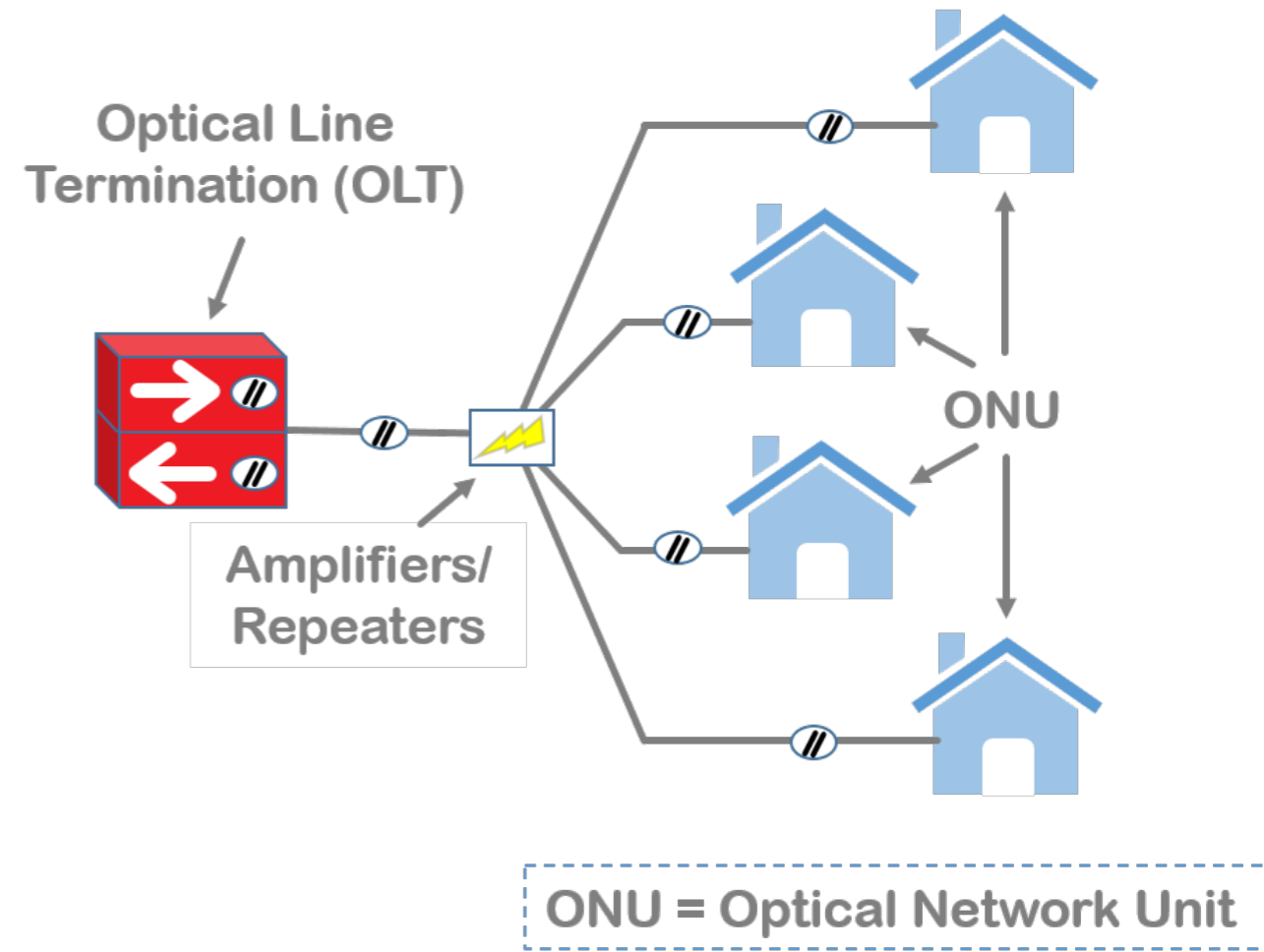
Public Telephone System

- Local loop
 - “The last mile” is most difficult to replace by optical fiber (Fiber to the Home — FttH, to the curb — FttC, ...)
 - Usual analog
 - Used for digital data transfer through modems
 - Local loop wire often filters everything below 300 Hz and above 3 KHz
 - ADSL (broadband technology)
 - Asymmetric Digital Subscriber Line
 - Without filtering has a bandwidth of ~ 1 MHz
 - Use OFDM to generate 256 channels of 43112.5 Hz each
 - Channel 0 is for Plain Old Voice (POV)
 - Most channels allocated for downloads

Passive Optical Network | PON



Active Optical Network | AON



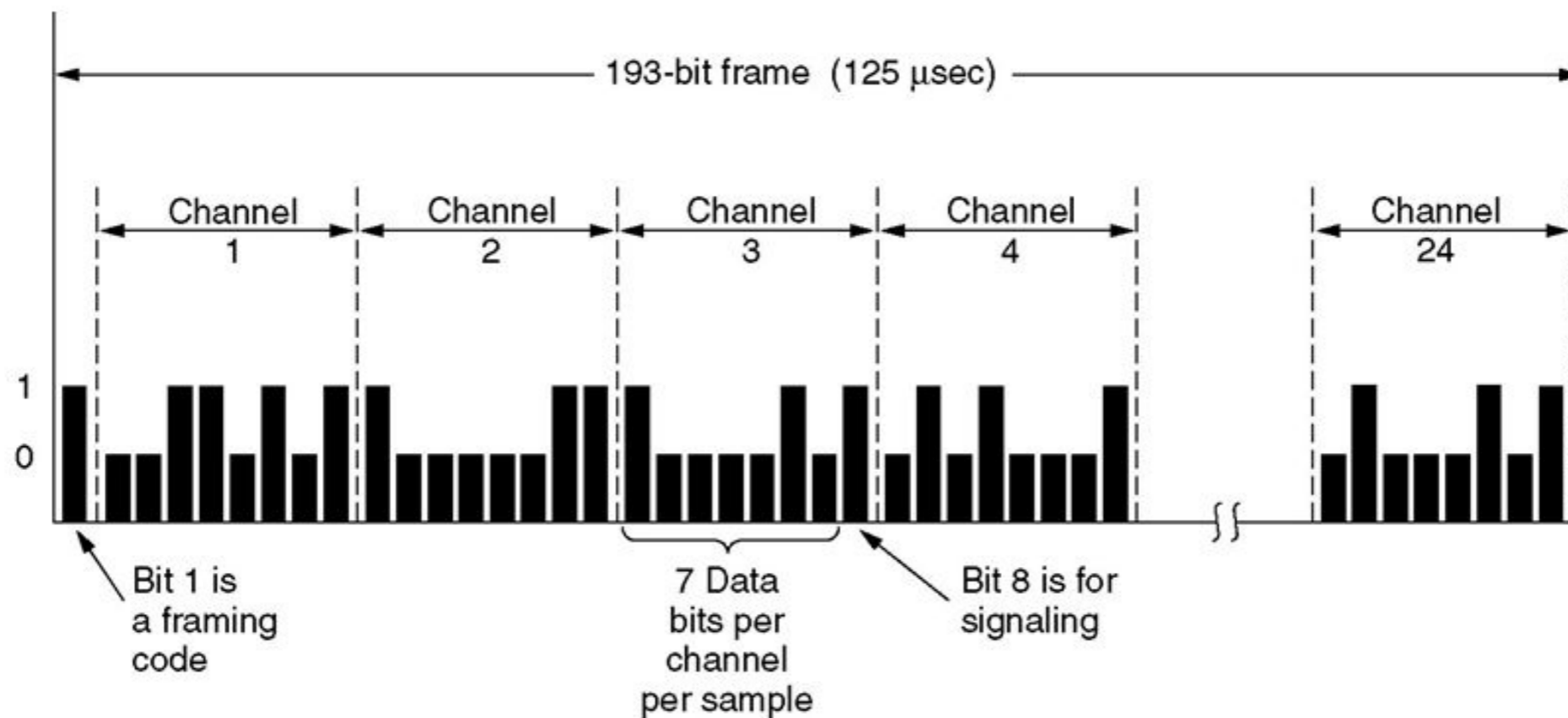
Public Telephone Network

- Trunks
 - Core of telephone network carries digital data
 - Use TDM and FDM multiplexing
 - Voice is digitized
 - End office has a **coder-decoder**
 - Codec samples incoming voice 8000 times per second (1/125 μ sec)
 - Nyquist sampling for up to 4 KHz bandwidth
 - Sample quantified as 8 bits — Pulse Code Modulation (PCM)
 - 64kbps without compression
 - At the other end, an analog signal is recreated

Public Telephone Network

- TDM is used to send samples for every call every $125\mu\text{sec}$
- North America and Japan: T1 carrier
 - 24 voice channels multiplexed together
 - Frames consists of 193 b, sent every $125\mu\text{sec}$
 - Data rate is 1.544 Mbps
 - 8bps is for signaling
 - 193d bit is used for signaling
- Elsewhere
 - Use the 2.048 Mbps E1 carrier with 32 data samples

Time Division Multiplexing



The T1 carrier (1.544 Mbps).

Public Telephone Network

- Can use TDM to multiplex several T1 carriers into a higher order carrier
 - US:
 - multiplex by 4: T2 is 4 T1 at 6.312 Mbps (with signaling and framing)
 - then by 7: T3 is 7 T2
 - then by 6: T4 is 6 T3

Public Telephone Network

- 1985: Bellcore begins work on a standard:
 - Synchronous Optical NETWORK (SONET)
 - ITU sets SONET standard in 1989