Bandwidth Utilization Transmission Media Switching

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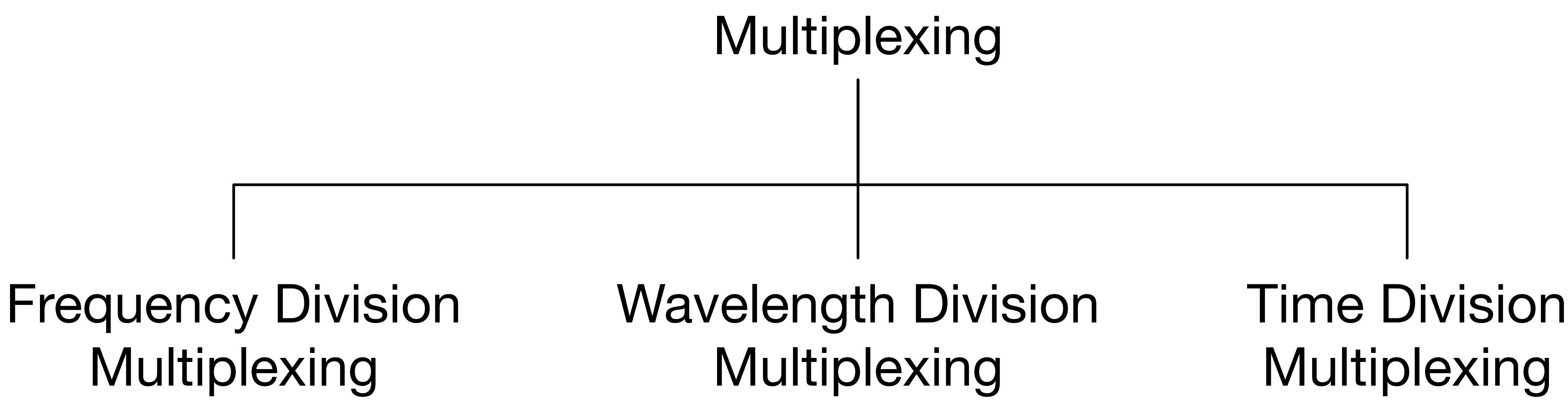
Bandwidth Utilization

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

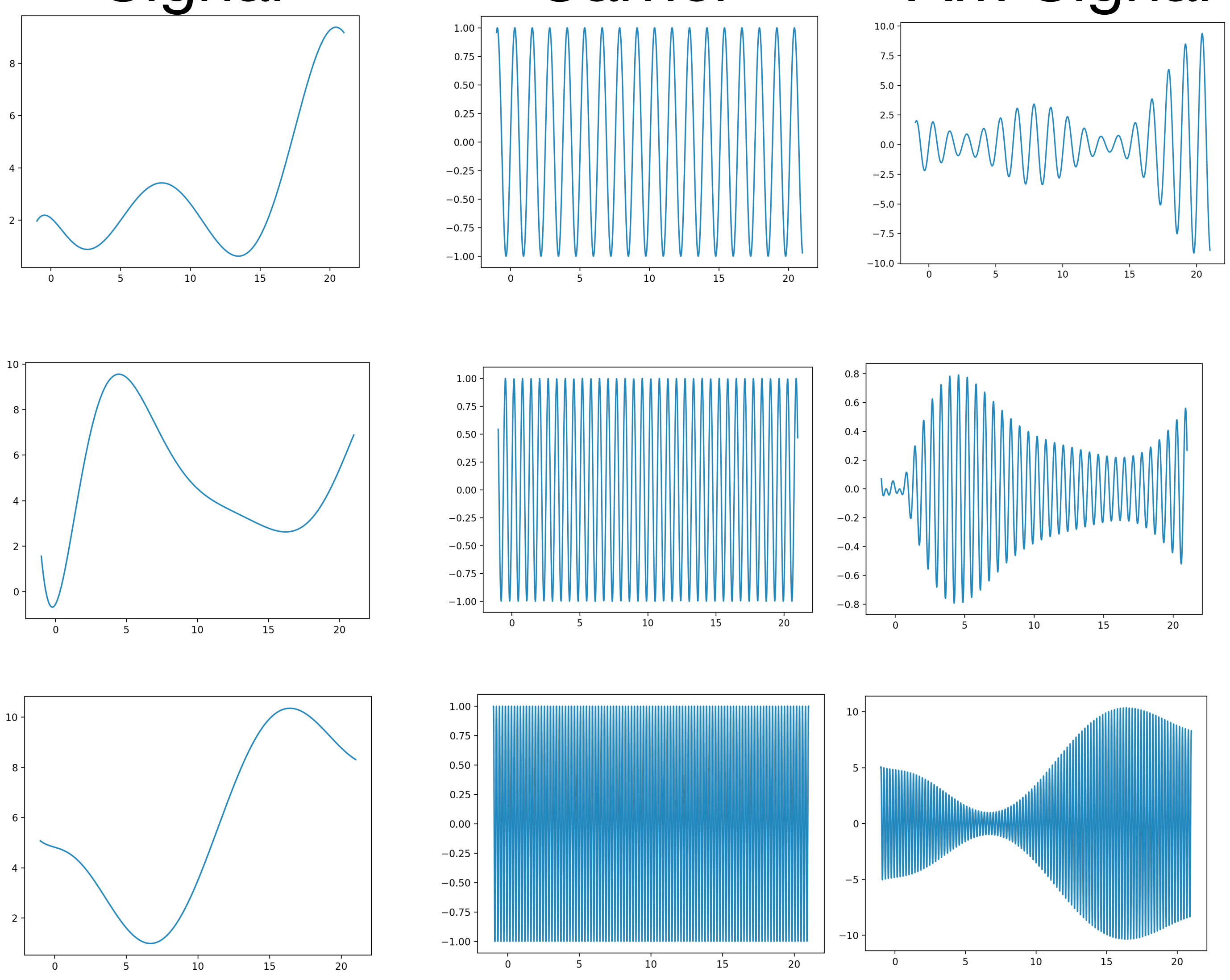
Bandwidth Utilization

- Multiplexing

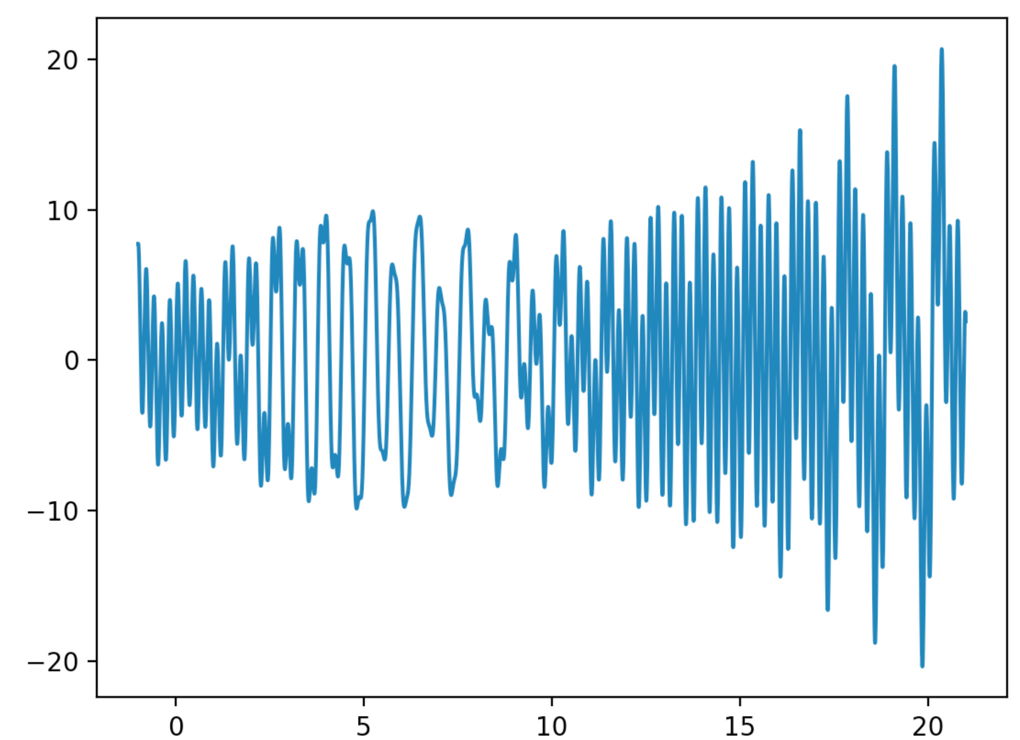


Bandwidth Utilization

Signal | Carrier | AM Signal



Frequency-Division Multiplexing



Bandwidth Utilization

- Frequency Division Multiplexing:
  - Needs guard bands between channels
  - Use frequency filters to de-multiplex

Bandwidth Utilization

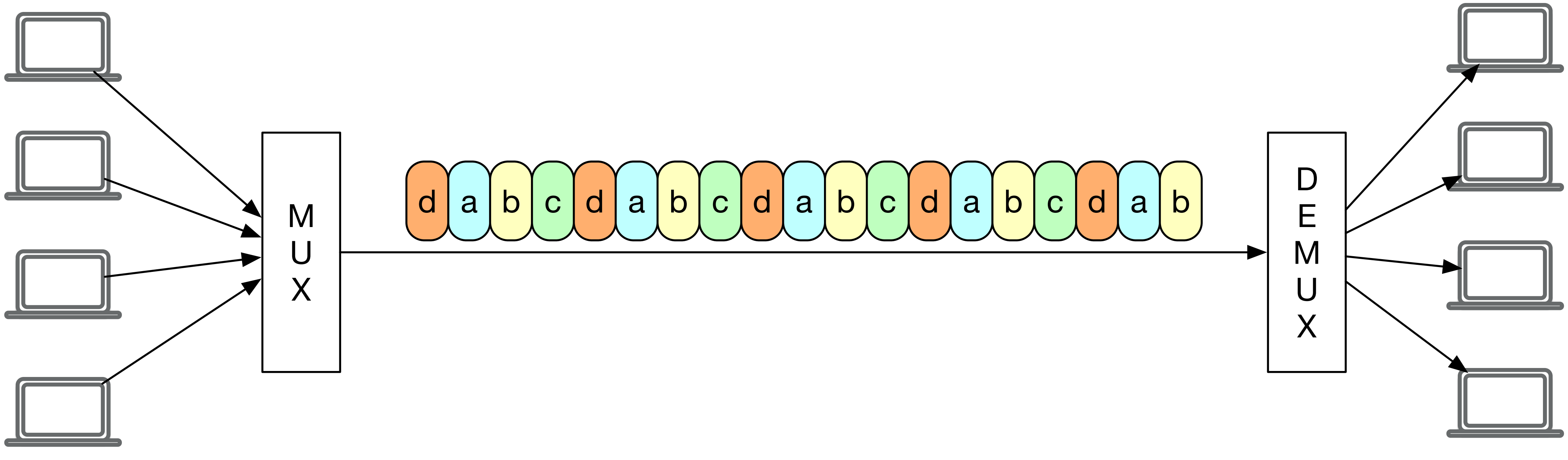
- Quiz:
  - Five channels with 100 kHz bandwidth
  - Multiplexed with guard bands of 10 kHz
  - What is the bandwidth needed for the channel?
- Answer:
  - 5×100 kHz $+ 4 \times 10$ kHz $= 540$ kHz

Bandwidth Utilization

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

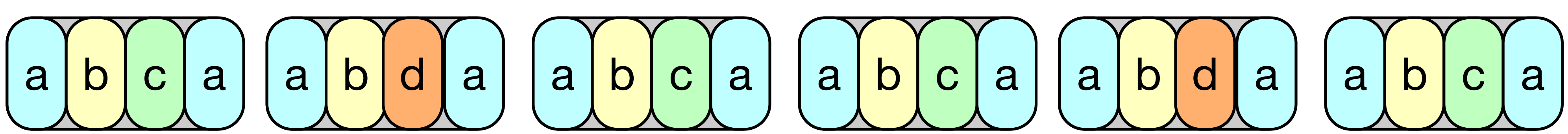
Bandwidth Utilization

- 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

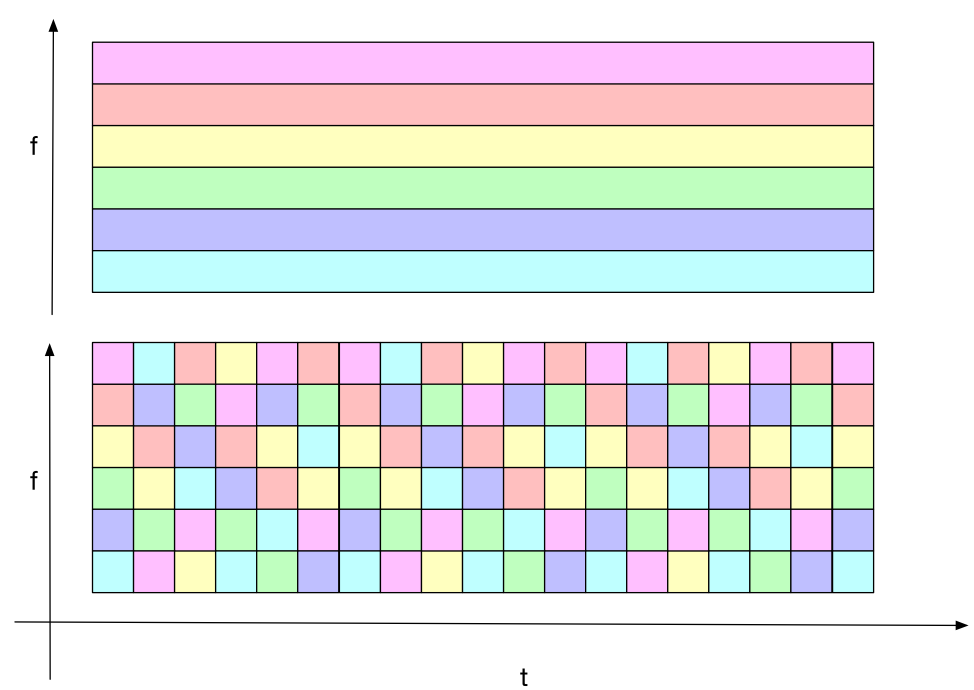
- Digital Signal Service / Digital Hierarchy:
  - Used by telephone companies
    - DS-0: 64 kbps
    - DS-1: 1.544 Mbps ($24\times$) implemented by T1
    - DS-2: 6.312 Mbps ($4\times$)
    - DS-3: 44,376 Mbps ($7\times$)
    - DS-4: 0.27 Gbps ($6\times$) implemented by T4

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 on 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)

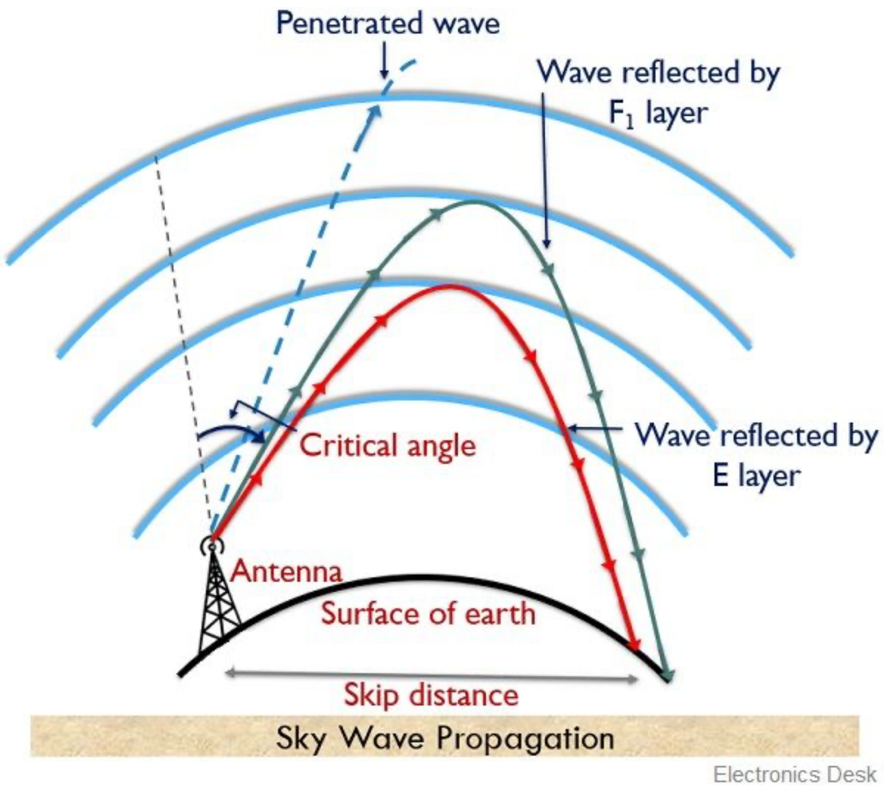
Code Division Multiplexing

- 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

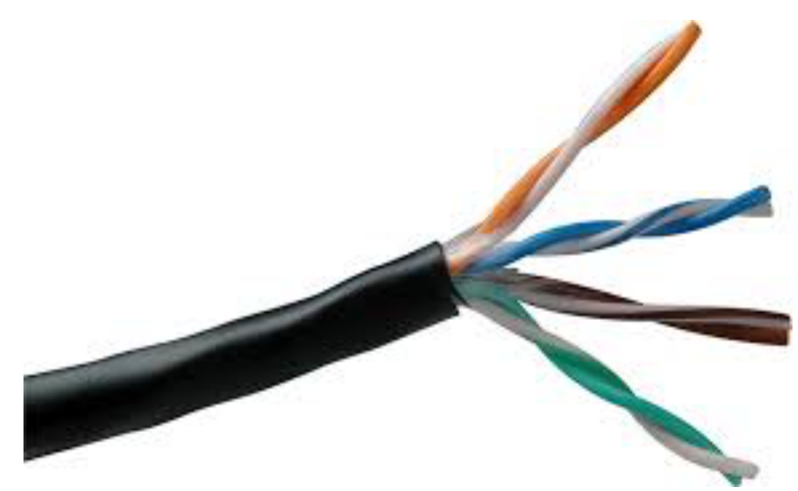
Transmission Media

- 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)



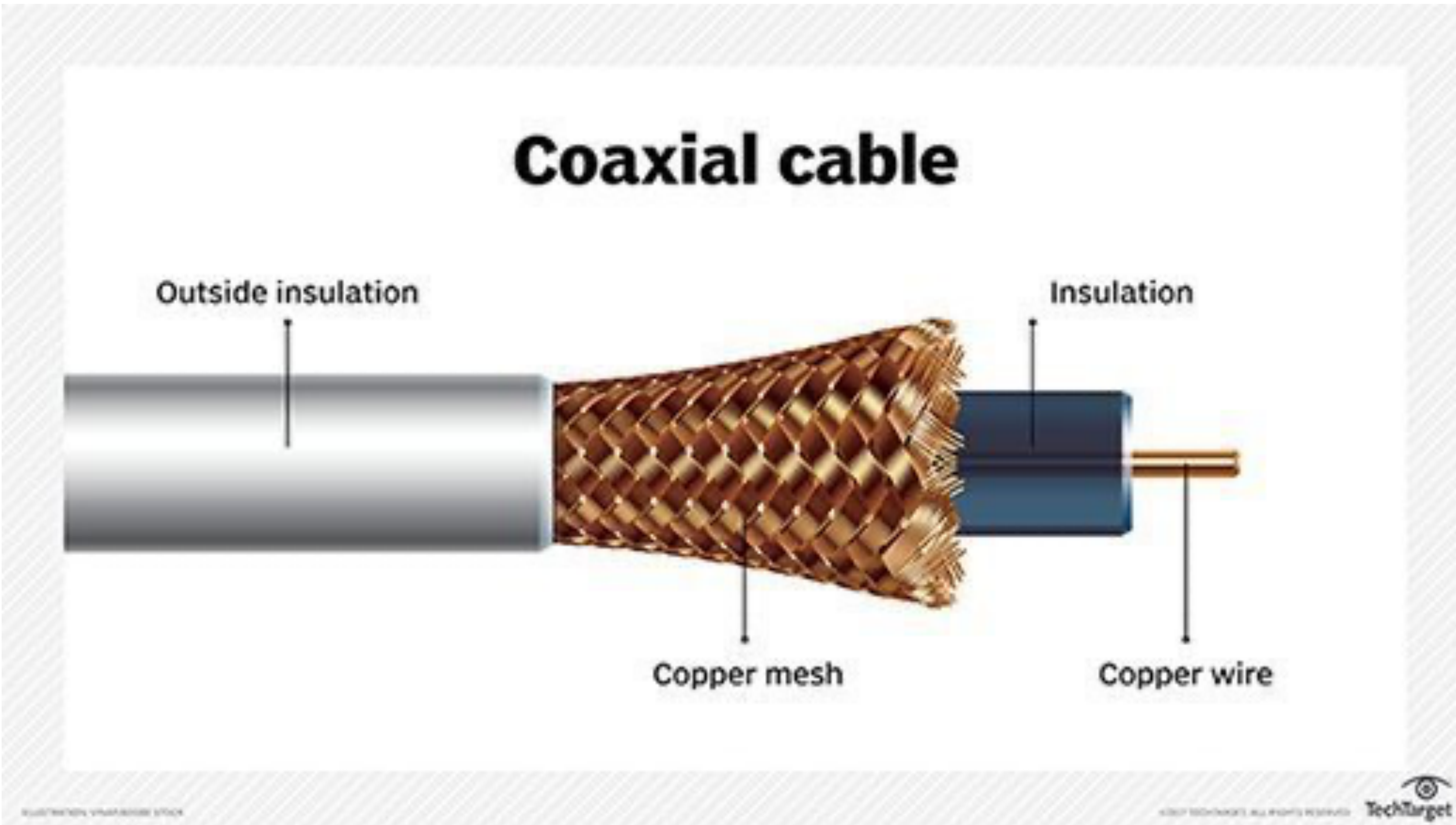
Twisted Pair

- 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



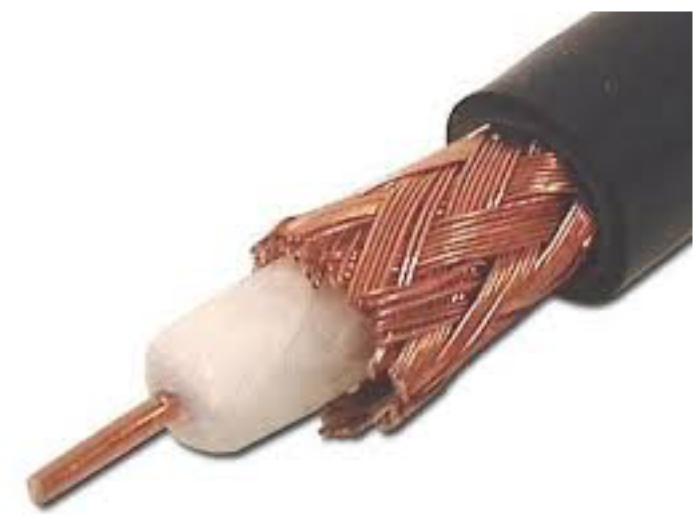
Cat 5 UTP with four twisted pairs

Coaxial Cables



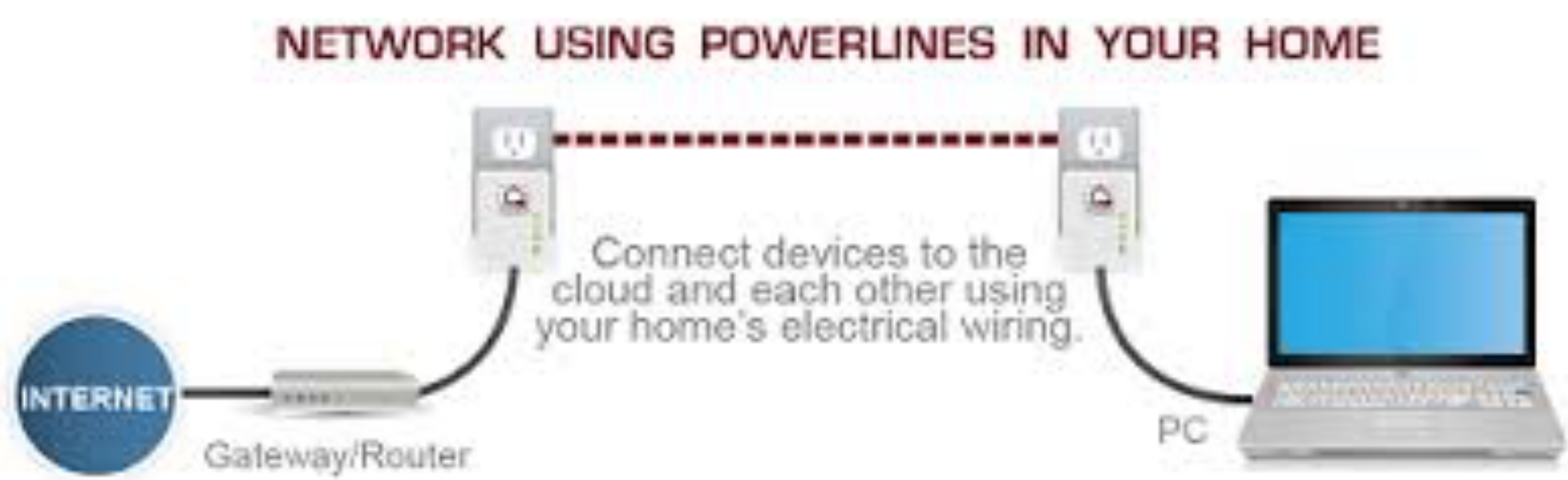
Coaxial Cable

- 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

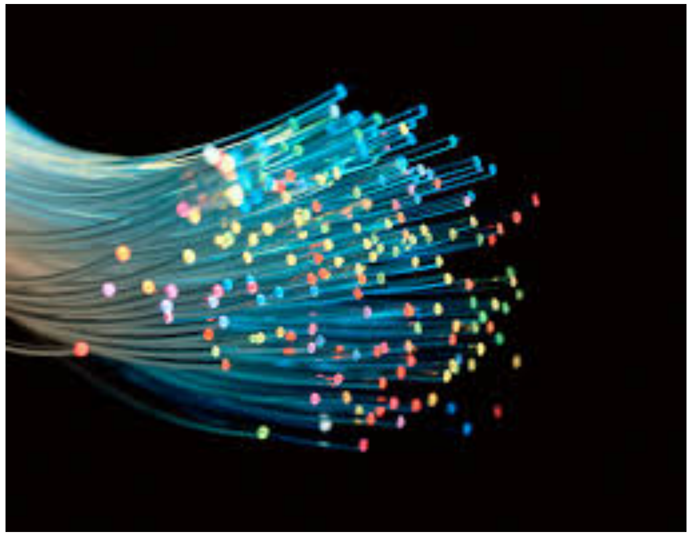


Home Electrical Wiring

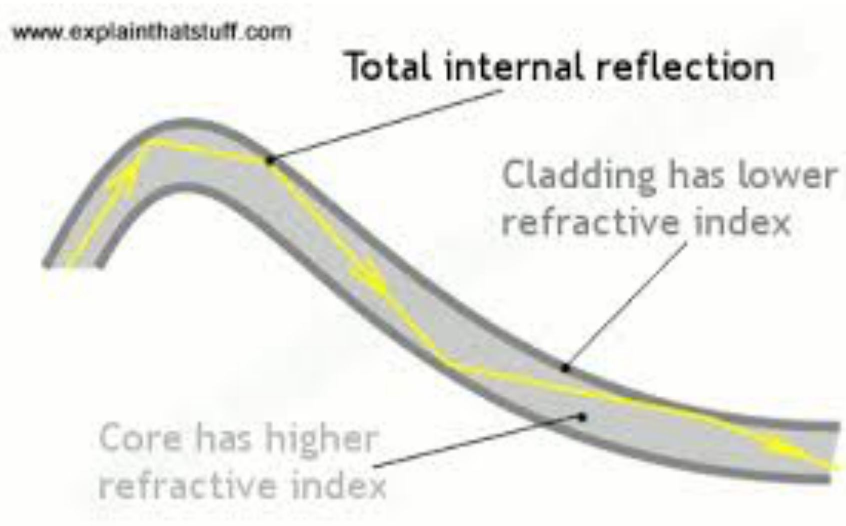
- Use the power electrical wiring in a house
  - Superimpose high frequency signal
  - Suffers from bad attenuation and noise
  - Can be used for $\geq$ 100 Mbps



Fiber Optics

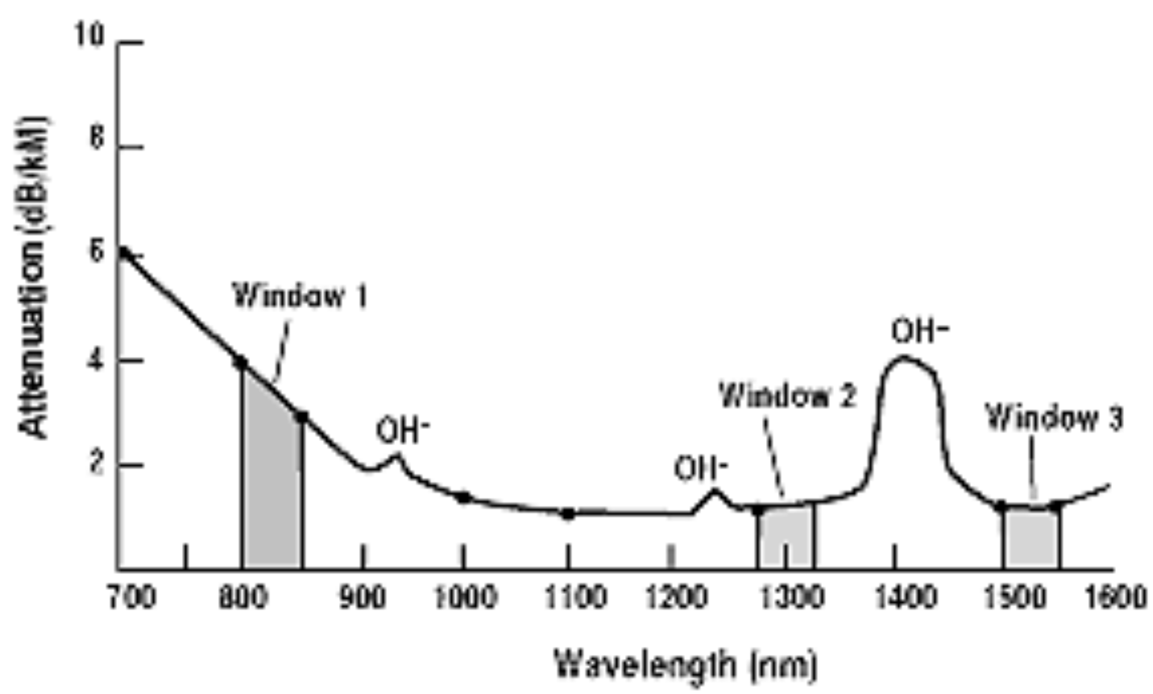


- Use glass for propagation of light
  - Diameter about 50 microns ($50 \times 10^{-6} m$)
  - Protected by cladding and jacket
  - Several strands bundled in a sheath
- Light sources are
  - LED
  - Semiconductor laser (high data rate, long distance)



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

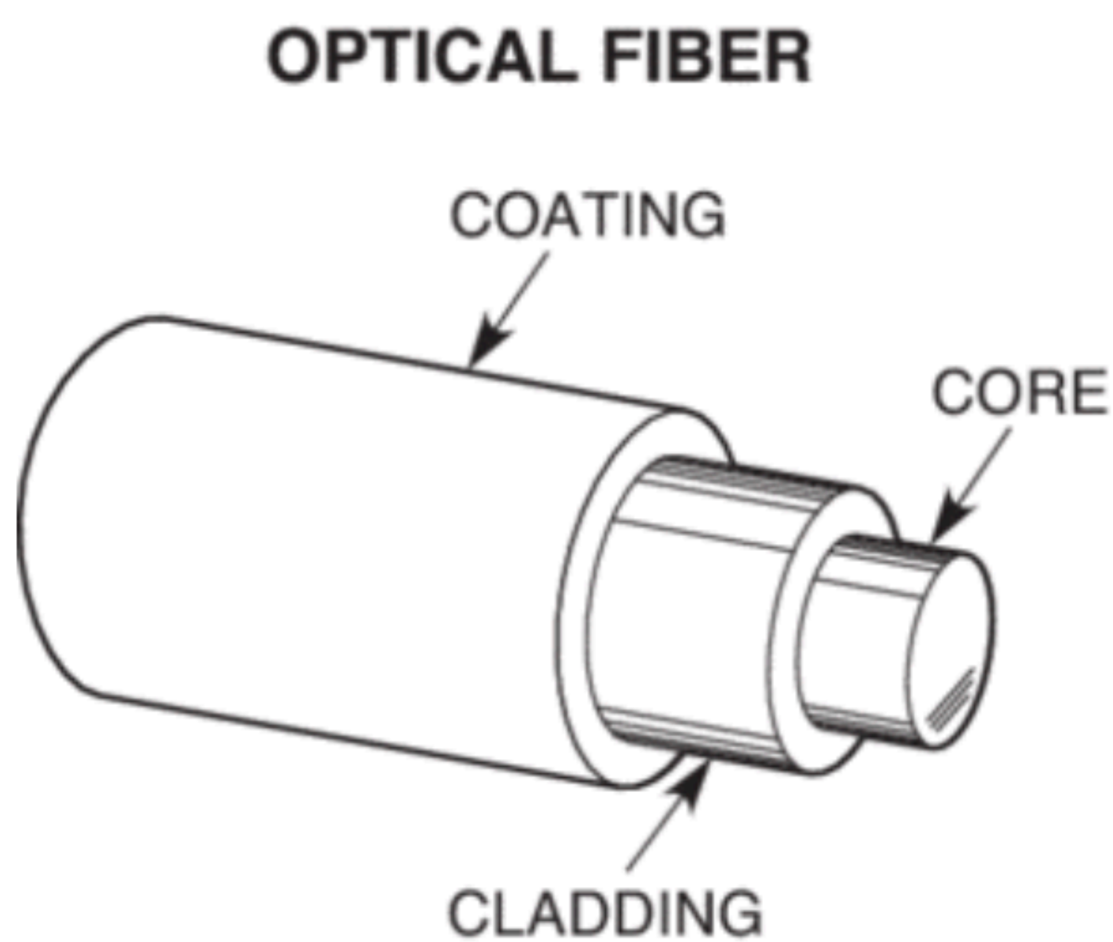


Figure 1. Cross section view of an optical fiber.

Fiber Optics

- Attenuation depends on frequency

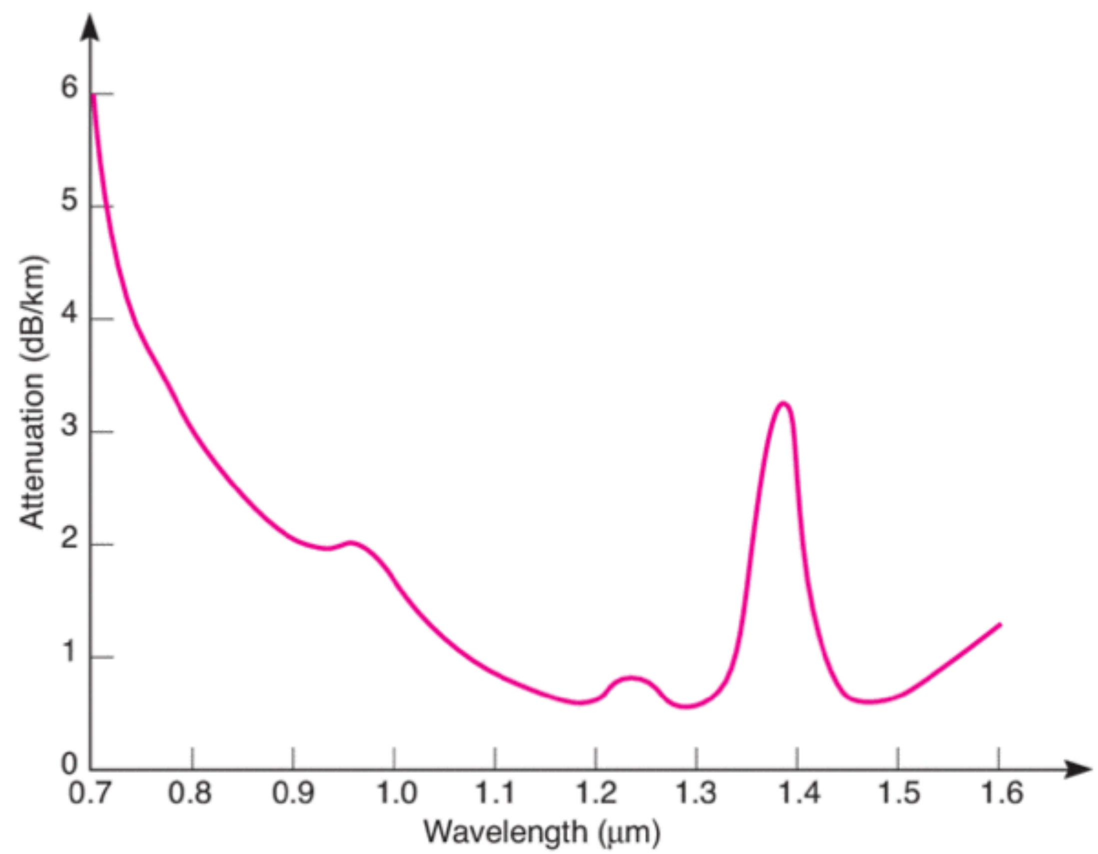


Figure 5. Typical spectral attenuation in silica.

Fiber Optics

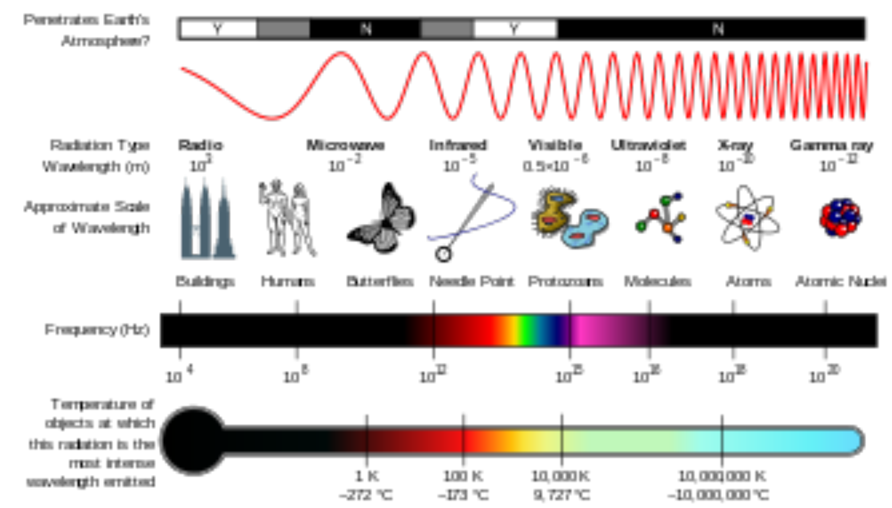
- Attenuation is very low (repeaters every 50 km)
- Not subject to power surges or electro-magnetic interference
- Resistent to corrosion

Wireless Transmission

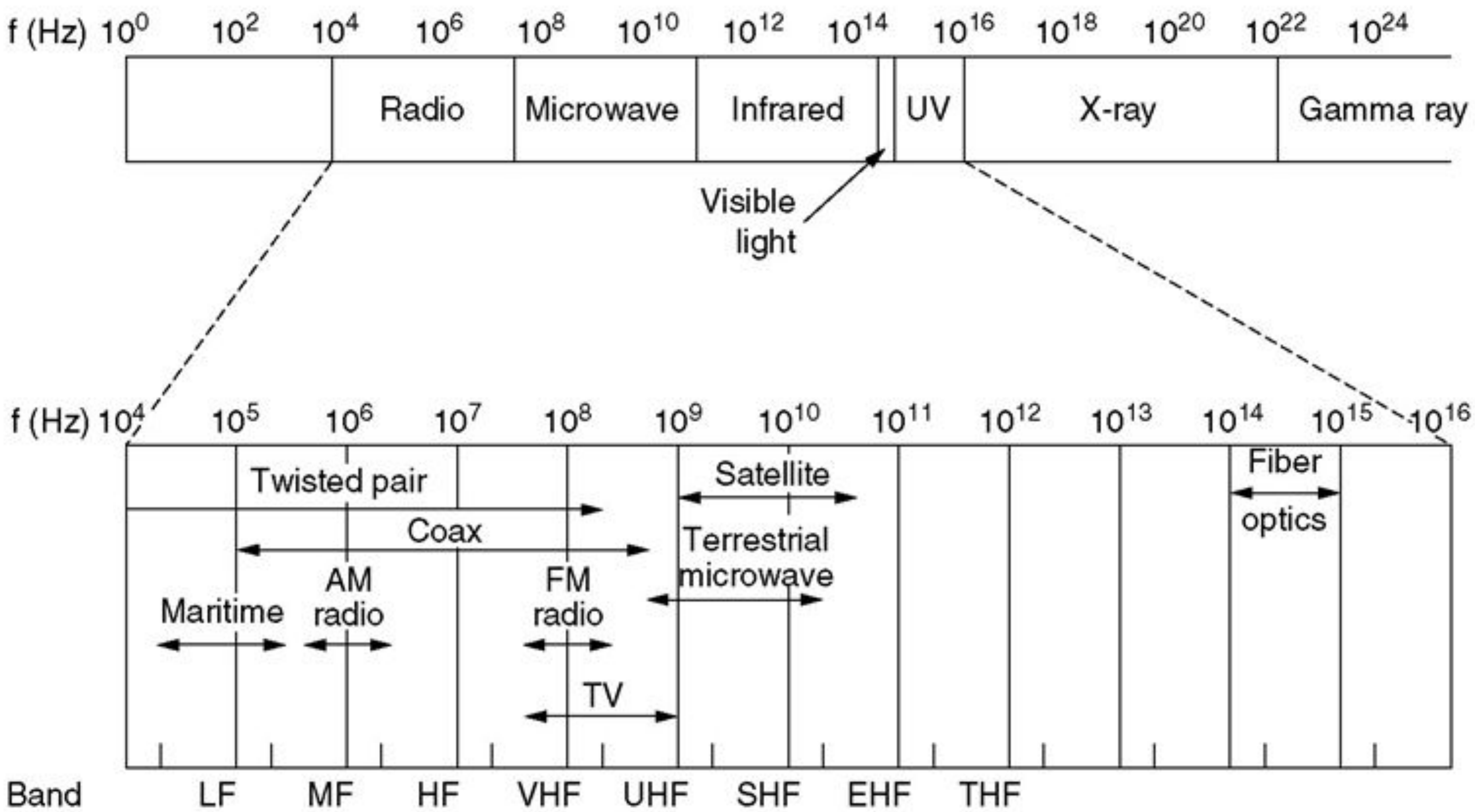
- Attenuation through spread and absorption
  - Spread: attenuation proportional to square of the distance
- Very susceptible to noise
  - Radio spectrum is strictly controlled
- Different interactions with earth, atmosphere depending on the frequency

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 serious of very short pulses in a wide band



The Electromagnetic Spectrum

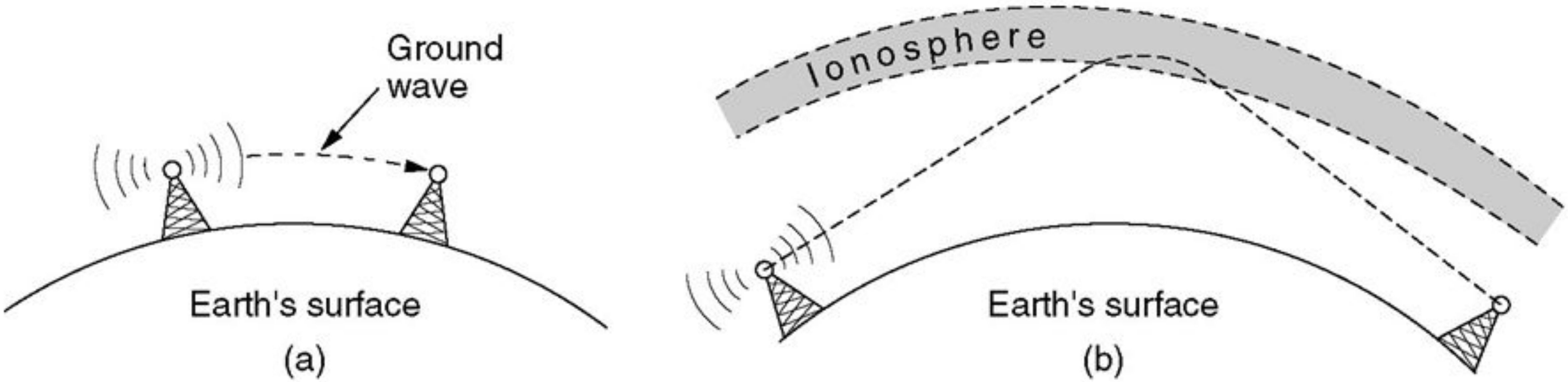


The electromagnetic spectrum and its uses for communication.

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 <u>square</u> of the distance

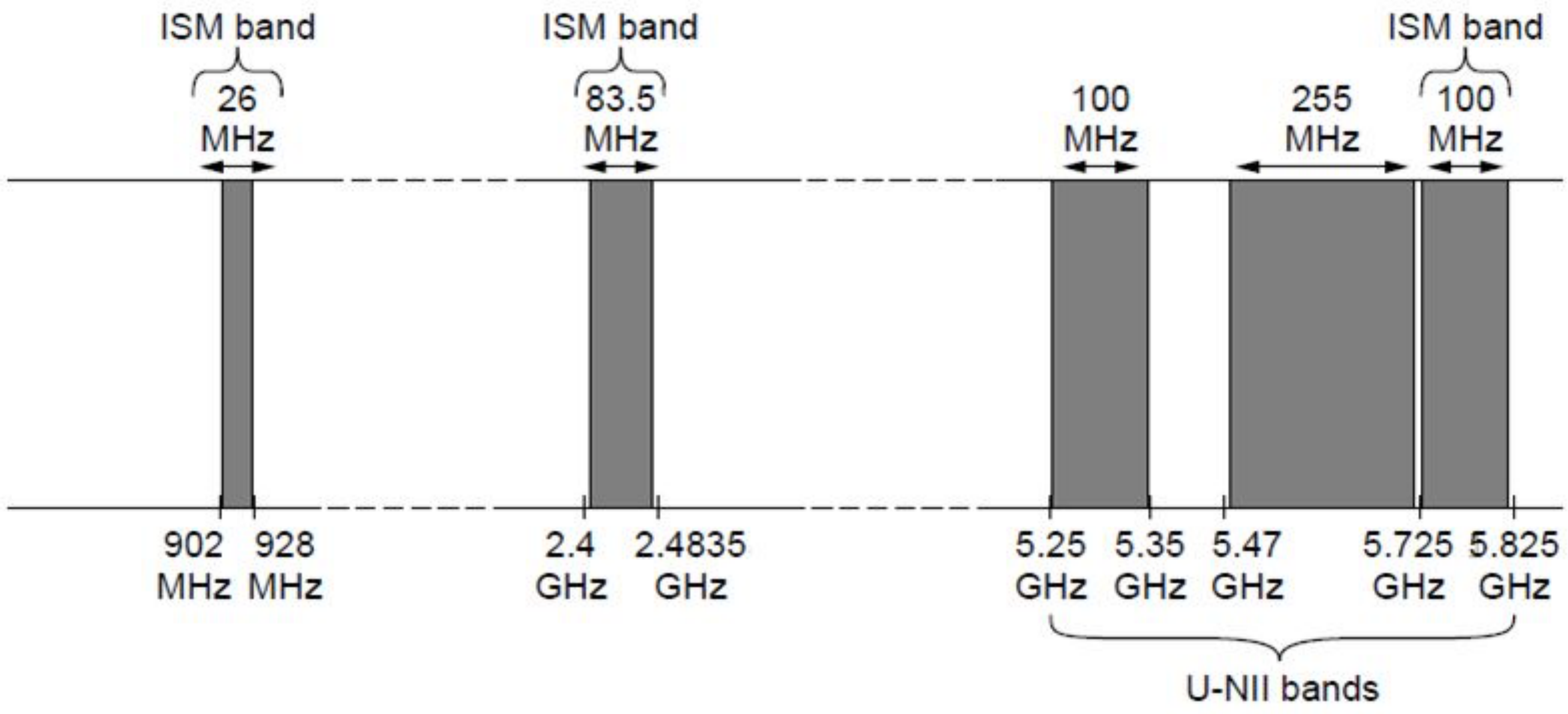
Radio Transmission



(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

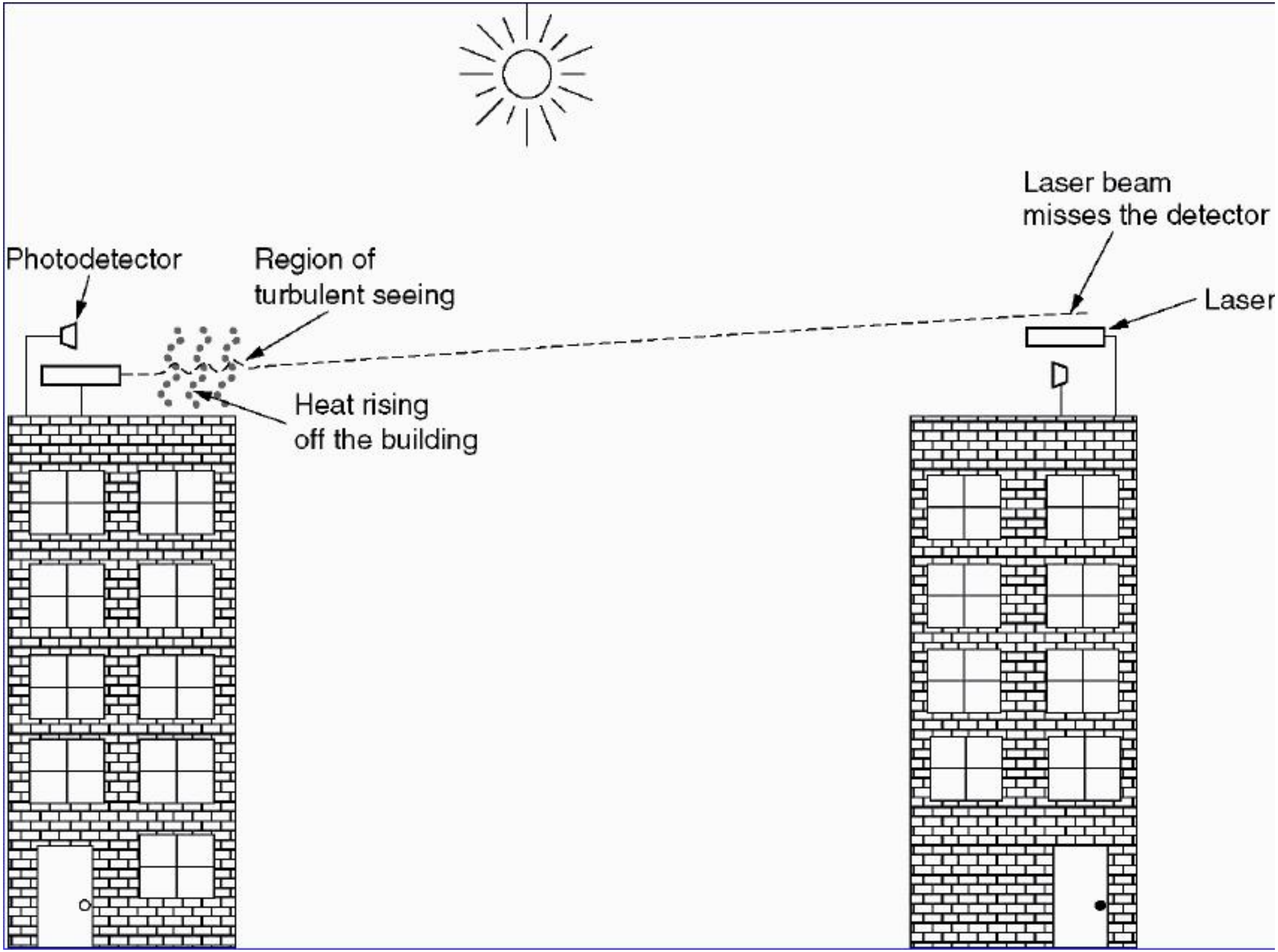
- MCI: Built a system of microwave towers
- Sprint: Owned by Southern Pacific Railroad with lots of stretched our real estate: Used fiber optics

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

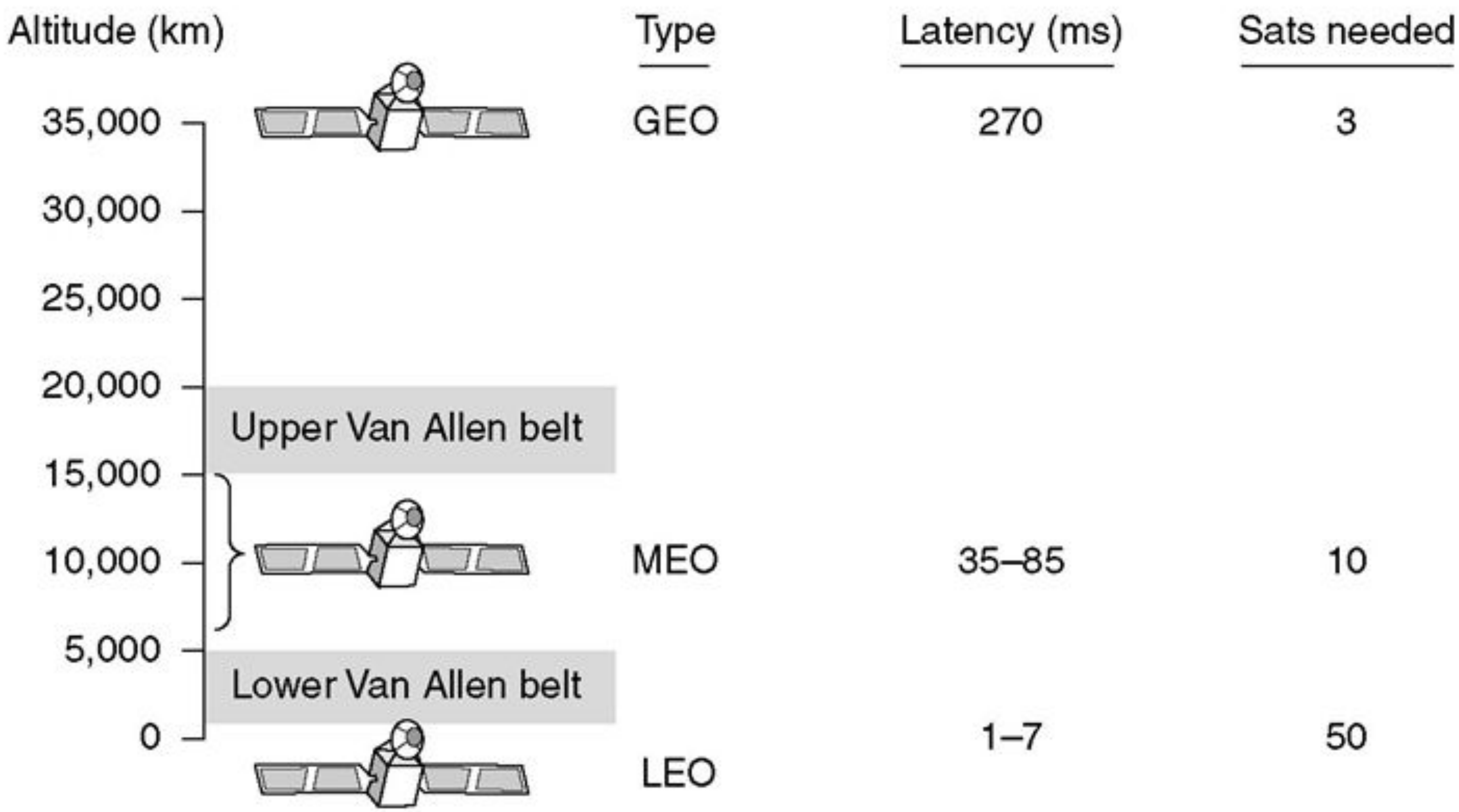


Light transmission with duplex lasers

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

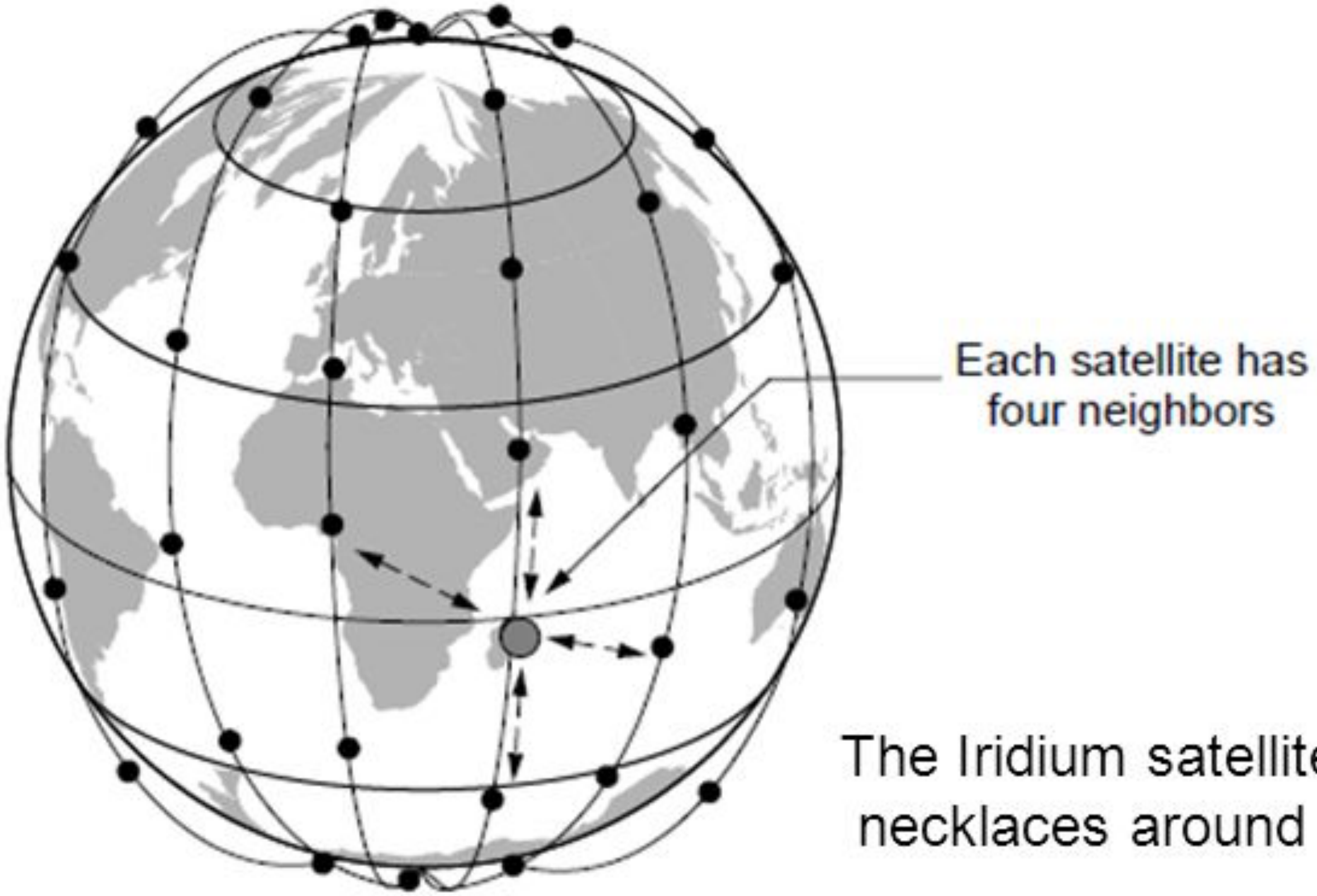
Communication Satellites



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

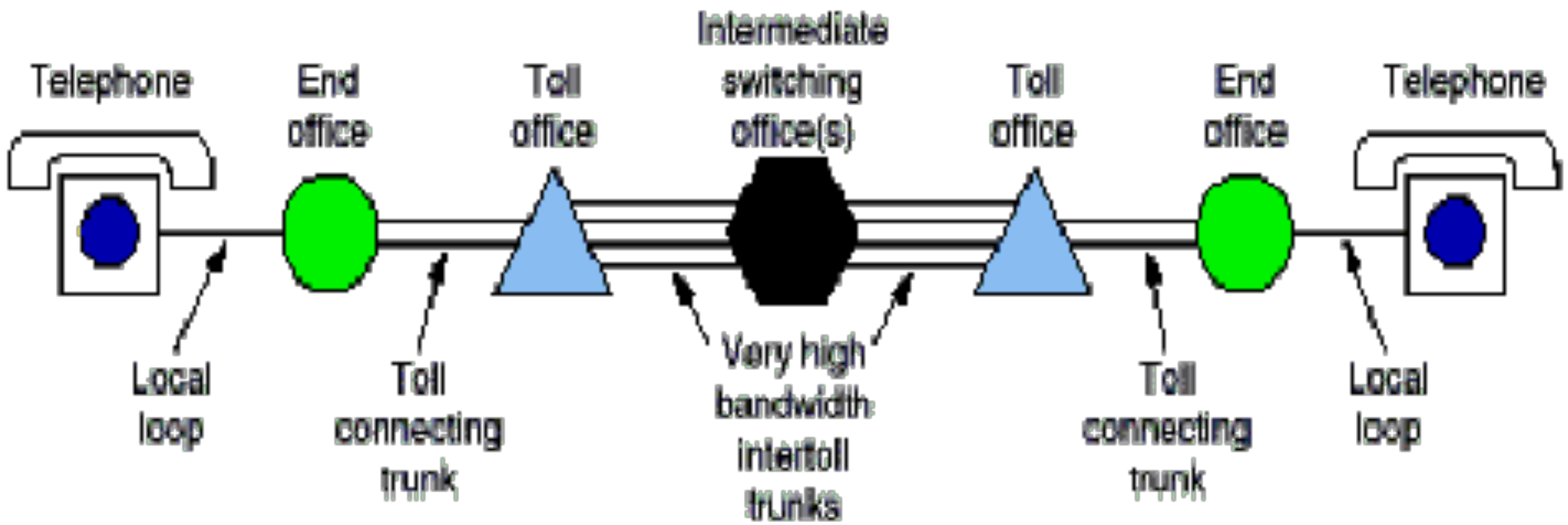
Low-Earth Orbit Satellites

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



The Iridium satellites form six necklaces around the earth.

Public Switched Telephone Network

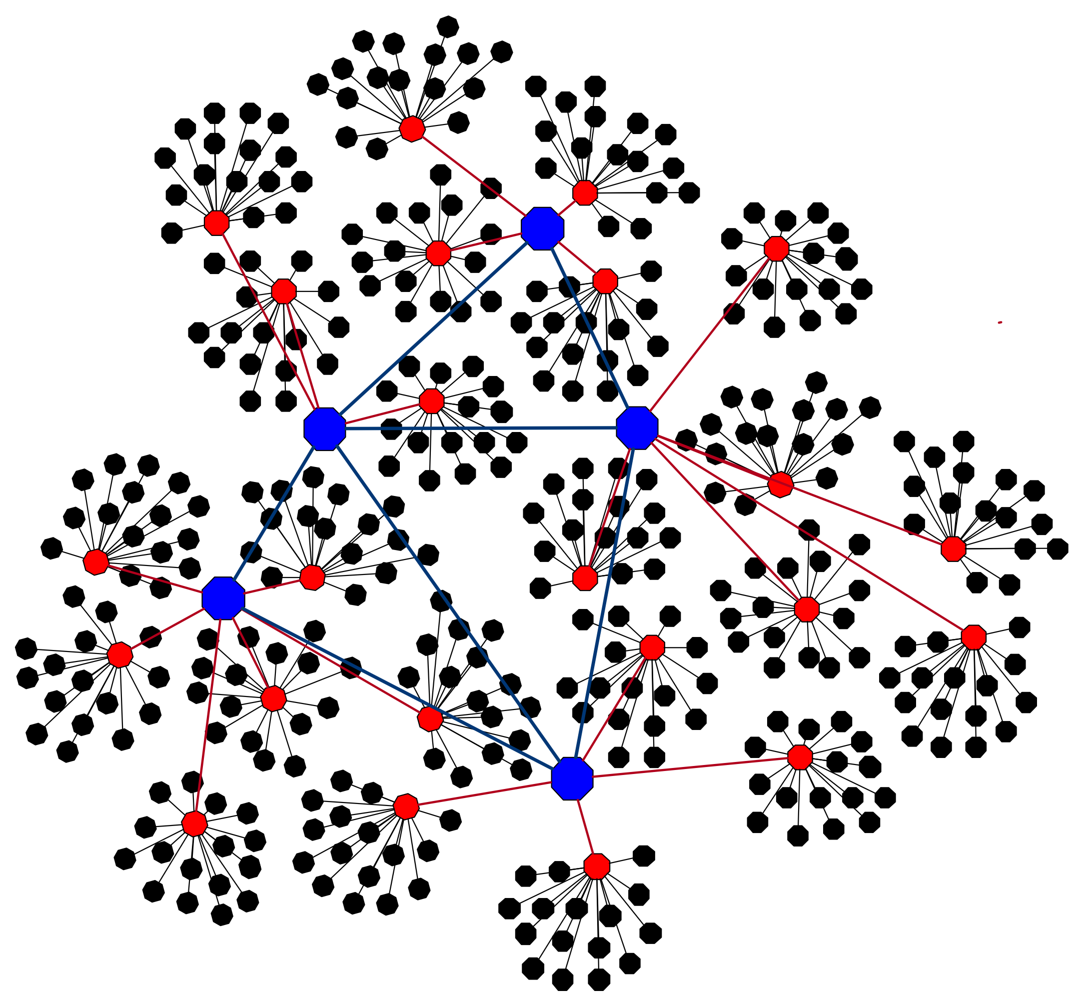

Telephone
End office
Toll office
Intermediate switching office(s)
Toll office
End office
Telephone
Local loop
Toll connecting trunk
Very high bandwidth intertoll trunks
Toll connecting trunk
Local loop

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



Public Telephone System

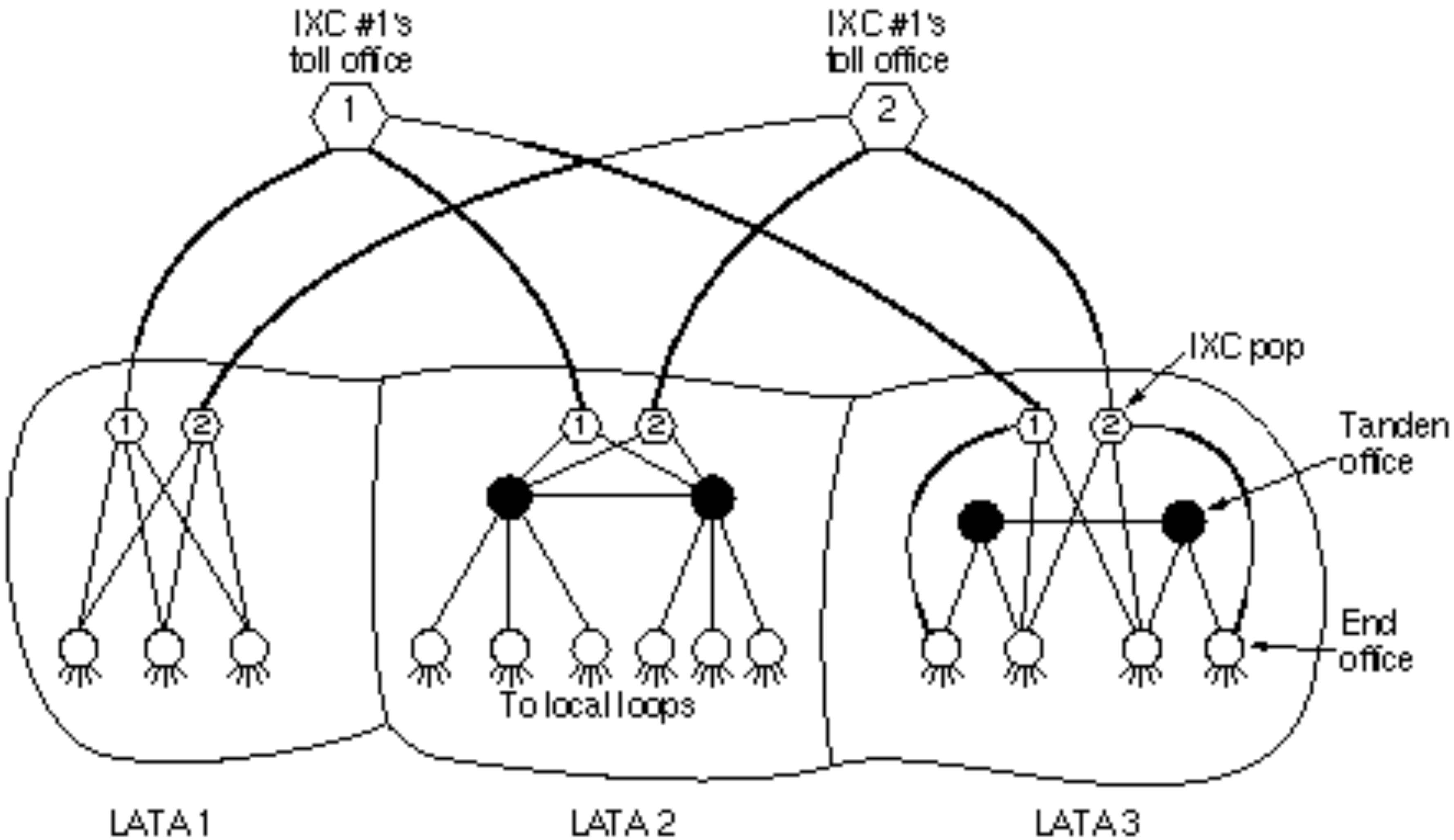
- Each telephone is connected to the *end office* aka local central office
    - Connection is the “local loop” (1-10 km)
    - Local calls are between subscribers attached to the same end office
- Each end office is connected to one or more switching centers, the *toll offices* or *tandem offices* in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

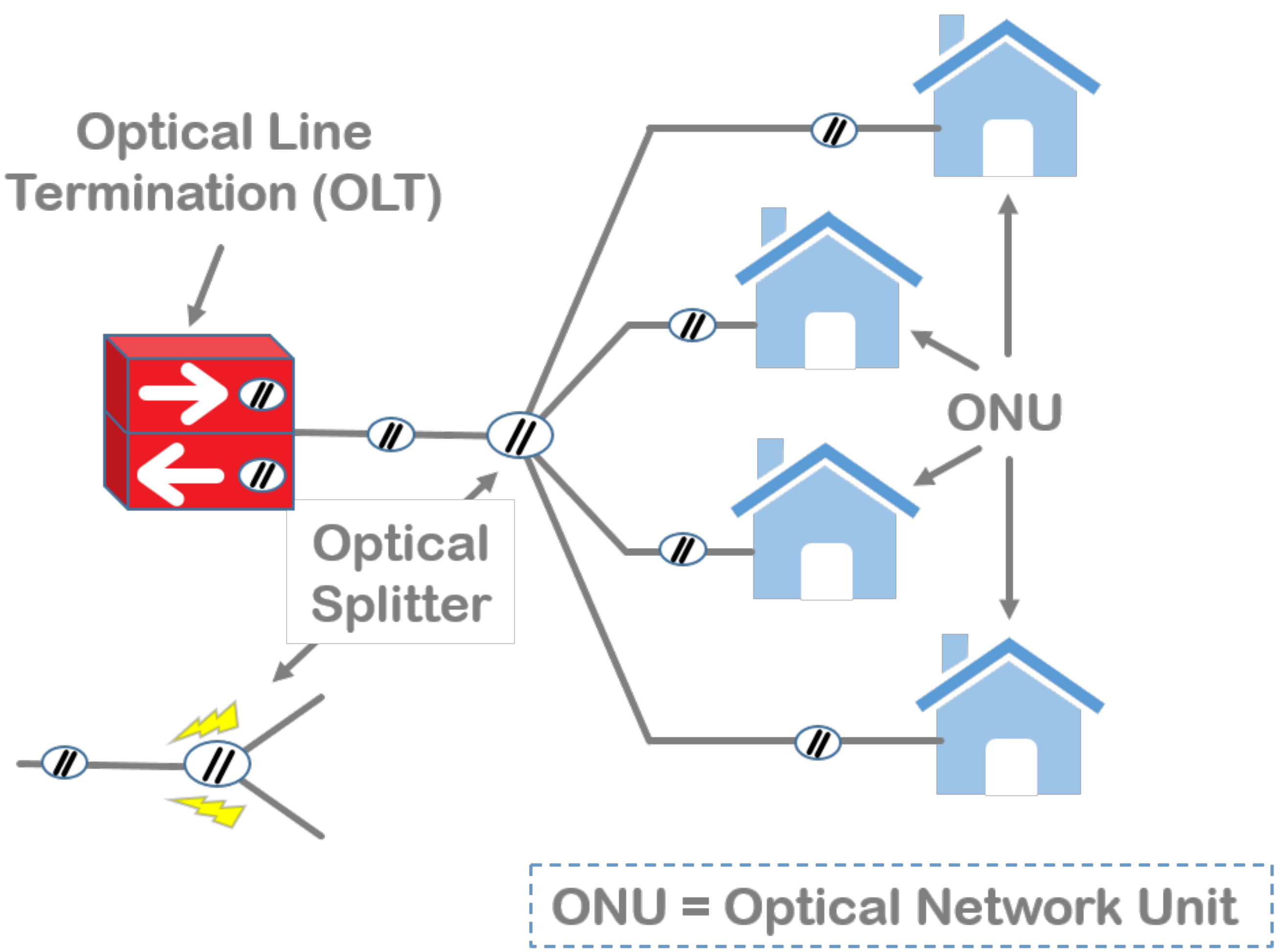


IXC #1's
toll office
1
IXC #1's
toll office
2
IXC pop
Tandem
office
End
office
To local loops
LATA 1
LATA 2
LATA 3

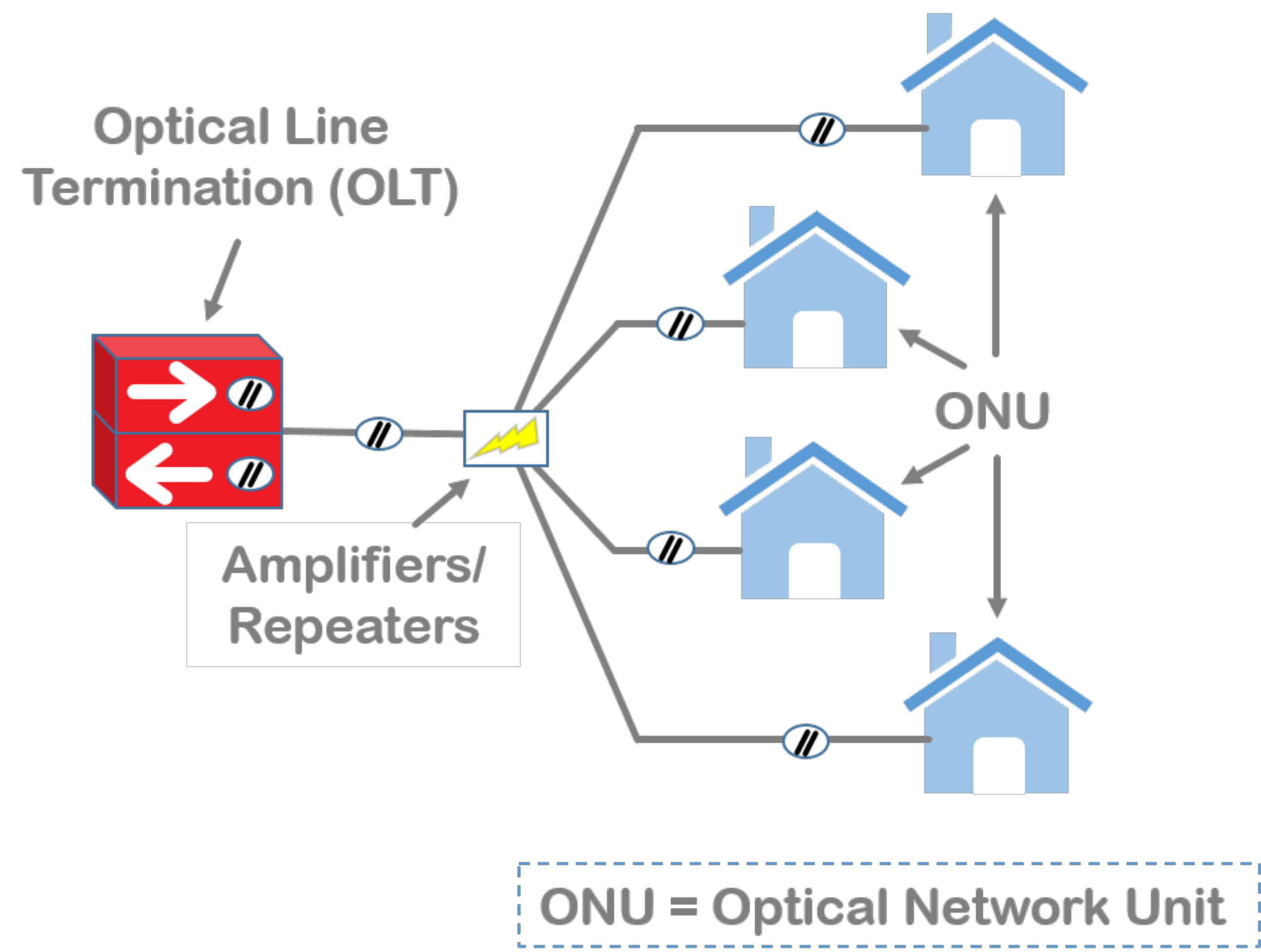
Public Telephone System

- 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



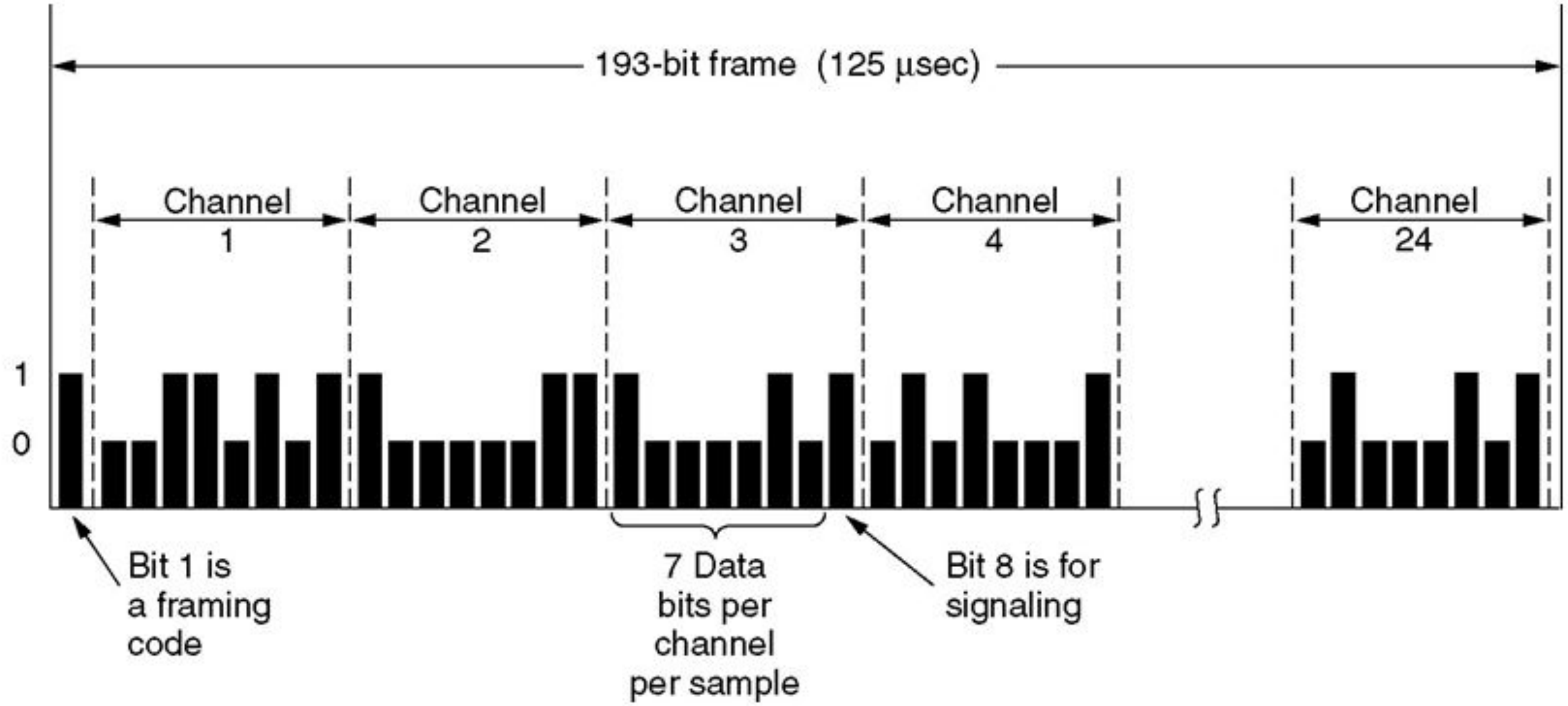
Public Telephone Network

- Trunks
  - Core of telephone network carries digital data
  - Use TDM and FDM multiplexing
  - Voice is digitized
    - End office has a **co**der-**dec**oder
      - Codec samples incoming voice 8000 times per second (1/125μsec)
        - 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 125μsec
- North America and Japan: T1 carrier
  - 24 voice channels multiplexed together
  - Frames consists of 193 b, sent every 125μsec
  - 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