

Wireless Communications

- Transmission Media

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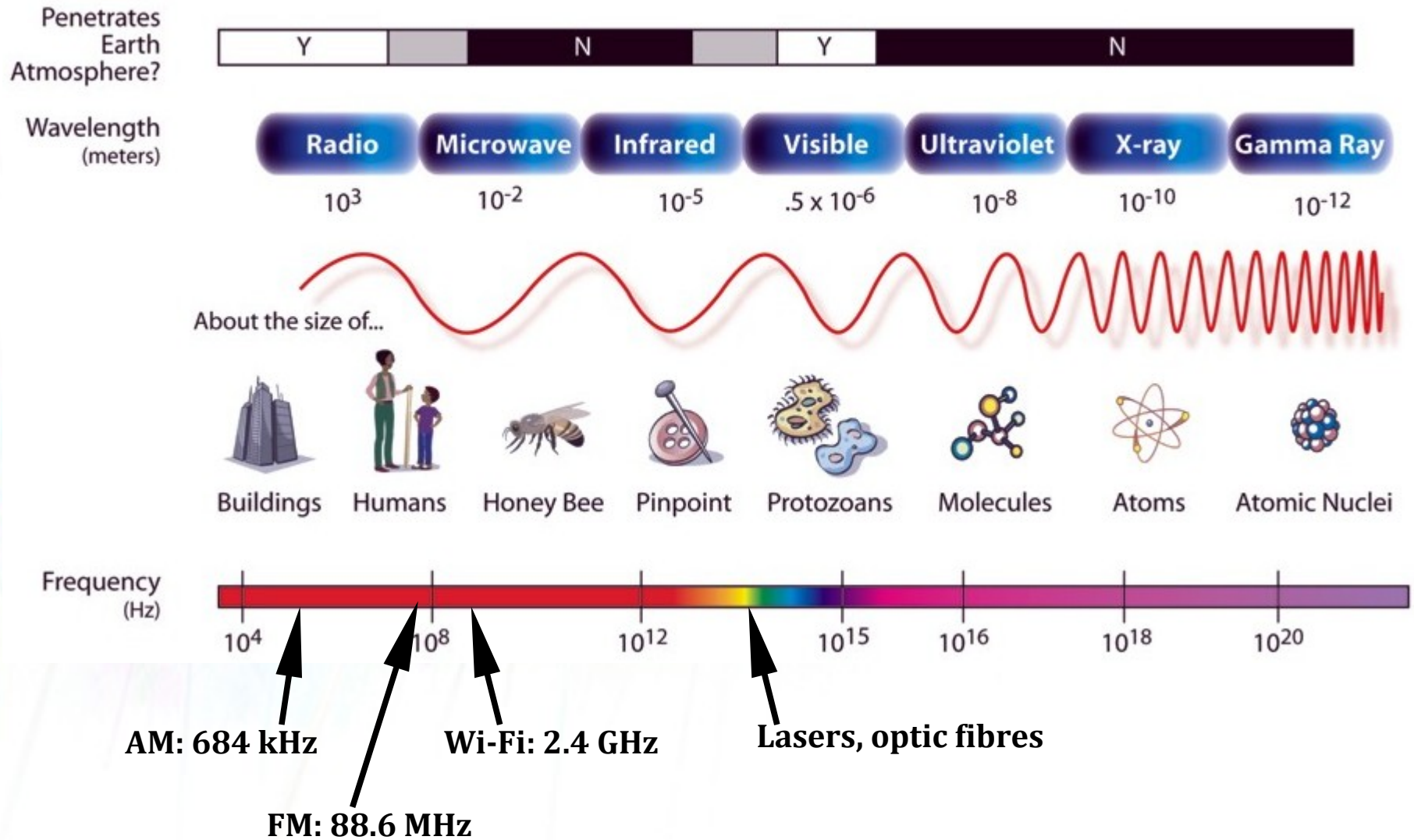
Overview

- Media:
 - Guided – wire or fibre
 - Unguided - wireless
- Transmission characteristics and quality determined by:
 - Signal
 - Medium
- For guided, the medium is more important
- For unguided, the bandwidth provided by the antenna is more important

Design Issues

- Key communication objectives are:
 - ❑ High data rate
 - ❑ Low error rate
 - ❑ Long distance
 - ❑ Bandwidth economy: Trade-off
 - Want larger BW for higher data rates: $C \propto B$
 - But limited by economy: Larger BW is costly e.g. Coaxial vs TP
- Transmission impairments
 - ❑ Attenuation: Twisted Pair > Cable > Fibre (best)
 - ❑ Interference:
Worse with unguided... (the medium is **shared!**)
- Number of receivers
 - ❑ In multi-point links of guided media:
More connected receivers introduce more attenuation

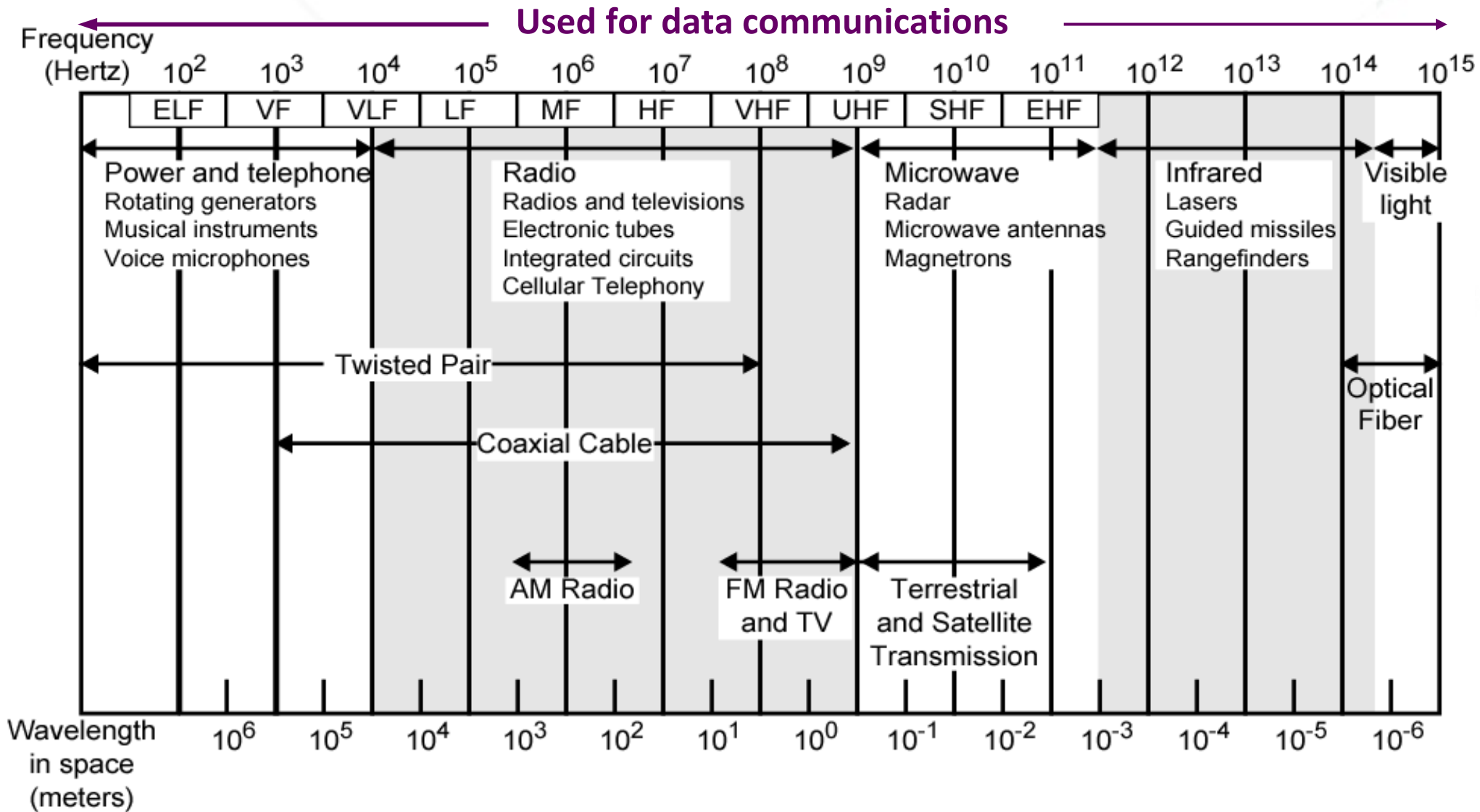
The Electromagnetic Spectrum



SI Units Prefixes 10^{-24} to 10^{+24}

yotta: Y	$10^{24} = 1,000,000,000,000,000,000,000,000$
zetta: Z	$10^{21} = 1,000,000,000,000,000,000,000$
exa: E	$10^{18} = 1,000,000,000,000,000,000$
peta: P	$10^{15} = 1,000,000,000,000,000$
tera: T	$10^{12} = 1,000,000,000,000$
giga: G	$10^9 = 1,000,000,000$
mega: M	$10^6 = 1,000,000$
kilo: k	$10^3 = 1,000$
hecto: h	$10^2 = 100$
deka: da	$10^1 = 10$
deci: d	$10^{-1} = 0.1$
centi: c	$10^{-2} = 0.01$
milli: m	$10^{-3} = 0.001$
micro: μ	$10^{-6} = 0.000001$
nano: n	$10^{-9} = 0.000000001$
pico: p	$10^{-12} = 0.000000000001$
femto: f	$10^{-15} = 0.000000000000001$
atto: a	$10^{-18} = 0.000000000000000001$
zepto: z	$10^{-21} = 0.000000000000000000001$
yocto: y	$10^{-24} = 0.000000000000000000000001$

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

Wireless Transmission

- Free-space is the transmission medium
- Need **efficient radiators**, called **antennas**
 - ❑ Signal fed from transmission line (wireline) and radiated it into free-space (wireless)
- Popular applications
 - ❑ Radio & TV broadcast
 - ❑ Cellular Communications
 - ❑ Microwave Links
 - ❑ Wireless Networks

Wireless Transmission Frequency Ranges

- Radio: 30 MHz to 1 GHz
 - Omni-directional
 - Broadcast radio e.g. FM
- Microwaves: 1 GHz to 40 GHz
 - Highly directional beams
 - Point to Point (Terrestrial)
 - Satellite
- Infrared Light: 0.3 THz to 20 THz (below light)
 - Localized communications (confined spaces)

Antennas

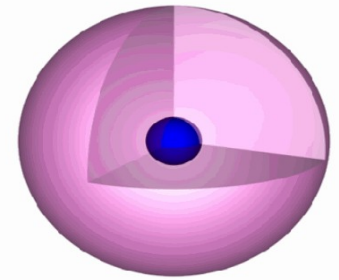
- Electrical conductor (or system of conductors) used to radiate / collect electromagnetic energy into/from surrounding space
- **Transmission**
 - ❑ Radio frequency electrical energy from
 - ❑ Converted into electromagnetic energy
 - ❑ Radiated into surrounding space
- **Reception**
 - ❑ Electromagnetic energy impinging on antenna
 - ❑ Converted to radio frequency electrical energy
 - ❑ Fed to receiver
- Same antenna often used for both Tx and Rx in 2-way communication systems



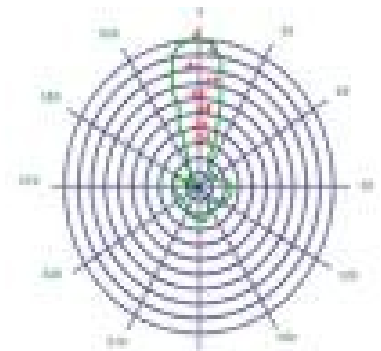
Radiation Pattern

- Power radiated in all directions, but usually not with the same efficiency
- **Isotropic antenna**
 - A hypothetical **point source** in space (Small dimensions relative to λ)
 - Radiates equally in all directions giving a spherical radiation pattern
 - Used as a reference for other antennae
- **Directional Antenna**
 - Concentrates radiation in a given desired direction hence point-to-point, line of sight communications
 - Gives antenna **'gain'** in that direction relative to isotropic for both Tx and Rx
 - **Larger dimensions relative to λ → Greater directivity**

Radiation Patterns



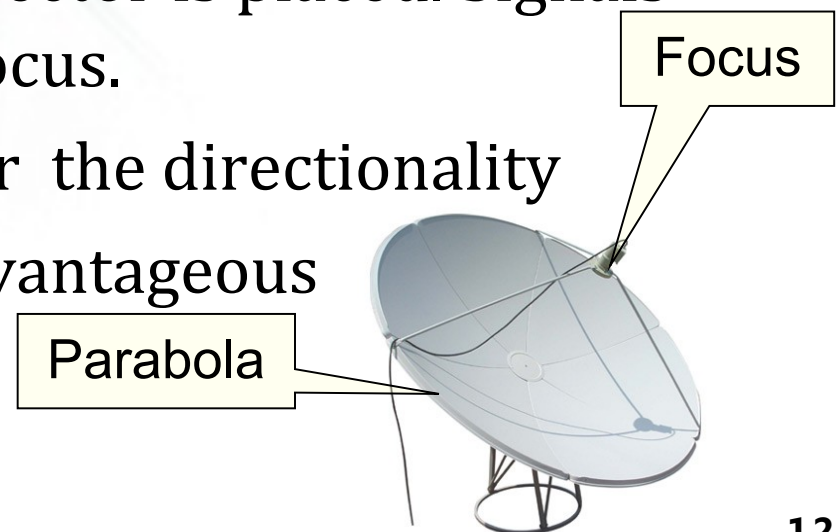
Isotropic



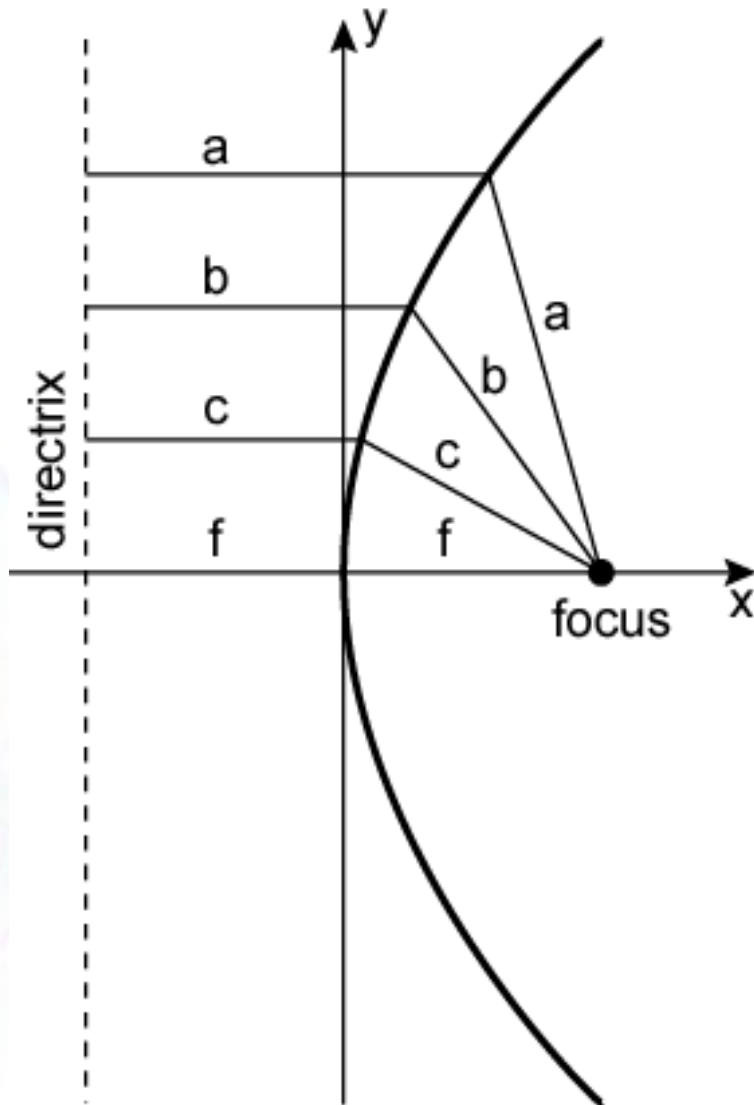
Directional

Parabolic Reflective Antenna

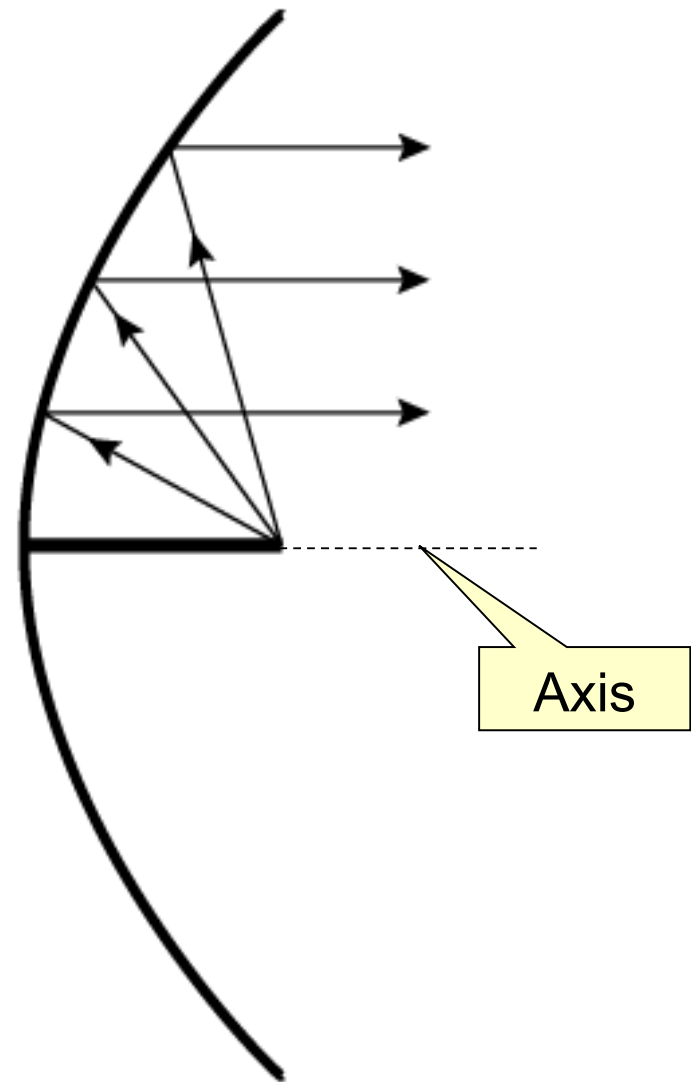
- Used for terrestrial and satellite microwave
- Source placed at the focal point will produce waves that get reflected from parabola *parallel* to the parabola axis
 - Creates a (theoretically) parallel beam of light/sound/radio that does not spread (disperse) in space
 - In practice, some divergence (dispersion) occurs, because source at **focus has a finite size** (not exactly a point!)
- On reception, only signal from the axis direction is concentrated at focus, where detector is placed. Signals from other directions miss the focus.
- The larger the antenna the better the directionality
→so, using Higher frequency is advantageous



Parabolic Reflective Antenna



(a) Parabola



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

Parabolic Antenna Gain, G

- A measure of antenna directionality
- Power output of the antenna in a particular direction **compared to** that produced by a perfect isotropic antenna
- Can be expressed in decibels (dB, dBi) (i = relative to isotropic)
- Increased power radiated in one direction causes less power radiated in another direction (Total power is fixed)
- Effective area A_e :
 - ❑ Related to **size** and **shape** of antenna
 - ❑ Determines the antenna gain G

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

Antenna Gain, G

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

- An isotropic antenna has a gain $G = 1$ (0 dBi)
- i.e. $A_e = \frac{\lambda^2}{4\pi}$ ($\approx 0.1 \text{ cm}^2$ at 30 GHz - a 'Point Source')
- A parabolic antenna has:

$$A = \text{Actual Area} = \pi r^2$$

$$A_e = 0.56 A$$

- Substituting we get:

$$G = \frac{4\pi (0.56 A)}{\lambda^2} \approx \frac{7 A}{\lambda^2}$$

- Gain in dBi = $10 \log G$
- **Important:** Gains apply to *both* Tx and Rx antennas

Propagation Attenuation

- As signal propagates in space, its power drops with distance according to the **inverse square law**

$$P_d \propto \frac{1}{d'^2}$$

d' = distance in λ 's

While with a guided medium, signal drops **exponentially with** distance... giving larger attenuation and lower repeater spacing

i.e. loss in signal power over distance travelled, d

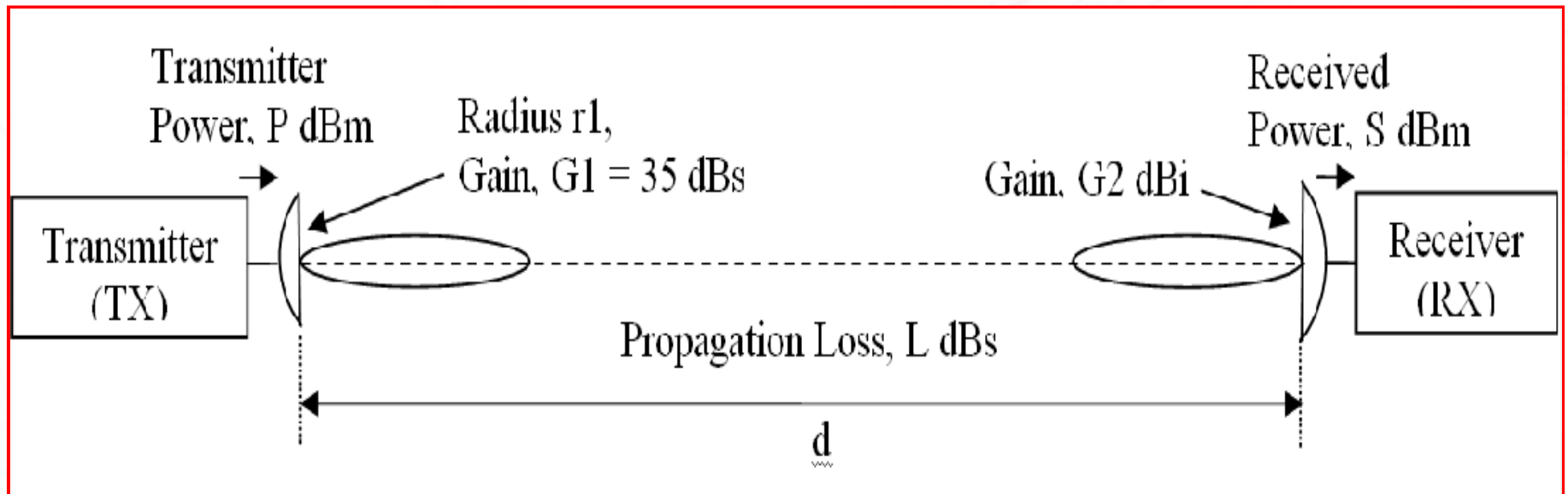
$$L = \frac{P_t}{P_r} = \frac{(4\pi d)^2}{\lambda^2} = \frac{(4\pi f d)^2}{c^2}$$

$$L_{dB} = 10 \log L$$

- Show that L increases by 6 dBs for every doubling of distance d .
- For guided medium, corresponding attenuation = αd dBs, α in dBs/km

A disadvantage for operating at higher frequency?

Microwave Link Calculations



$$\text{TX-RX Net attenuation } A \text{ dBs} = L - G_1 - G_2$$

$$S \text{ dBm} = P \text{ dBm} - A \text{ dBs}$$

Terrestrial Microwave

- Parabolic dish
- Focused beam (with antenna gain)
- Line of sight requirement:
 - ❑ Beam should not be obstructed
 - ❑ **Curvature of earth** limits maximum range
 - ❑ Use relays to increase range (multi-hop link)
 - ❑ Link performance **sensitive to antenna alignment**
- Applications:
 - ❑ Long haul telecommunications
Many voice/data channels over long distances between large cities, through intermediate **relays. Competes with coaxial cable and fibre**
 - ❑ Short wireless links between buildings:
 - CCTV links
 - Wireless links between LANs in close-by buildings
 - ❑ Cellular Telephony

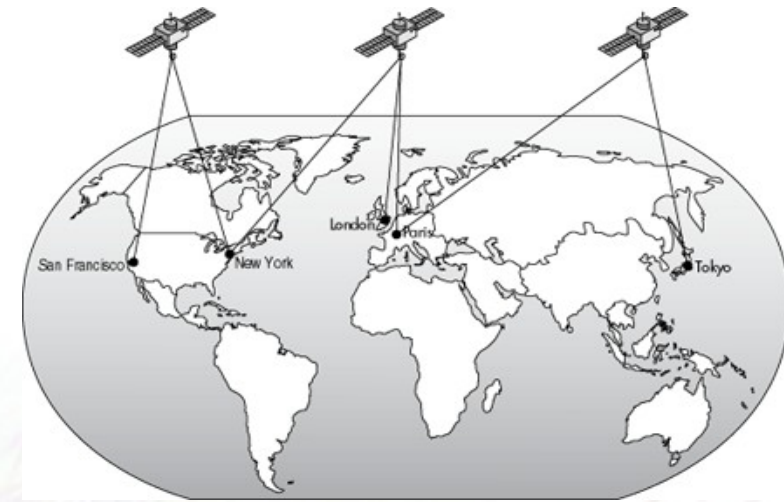


Terrestrial Microwave: Transmission Properties

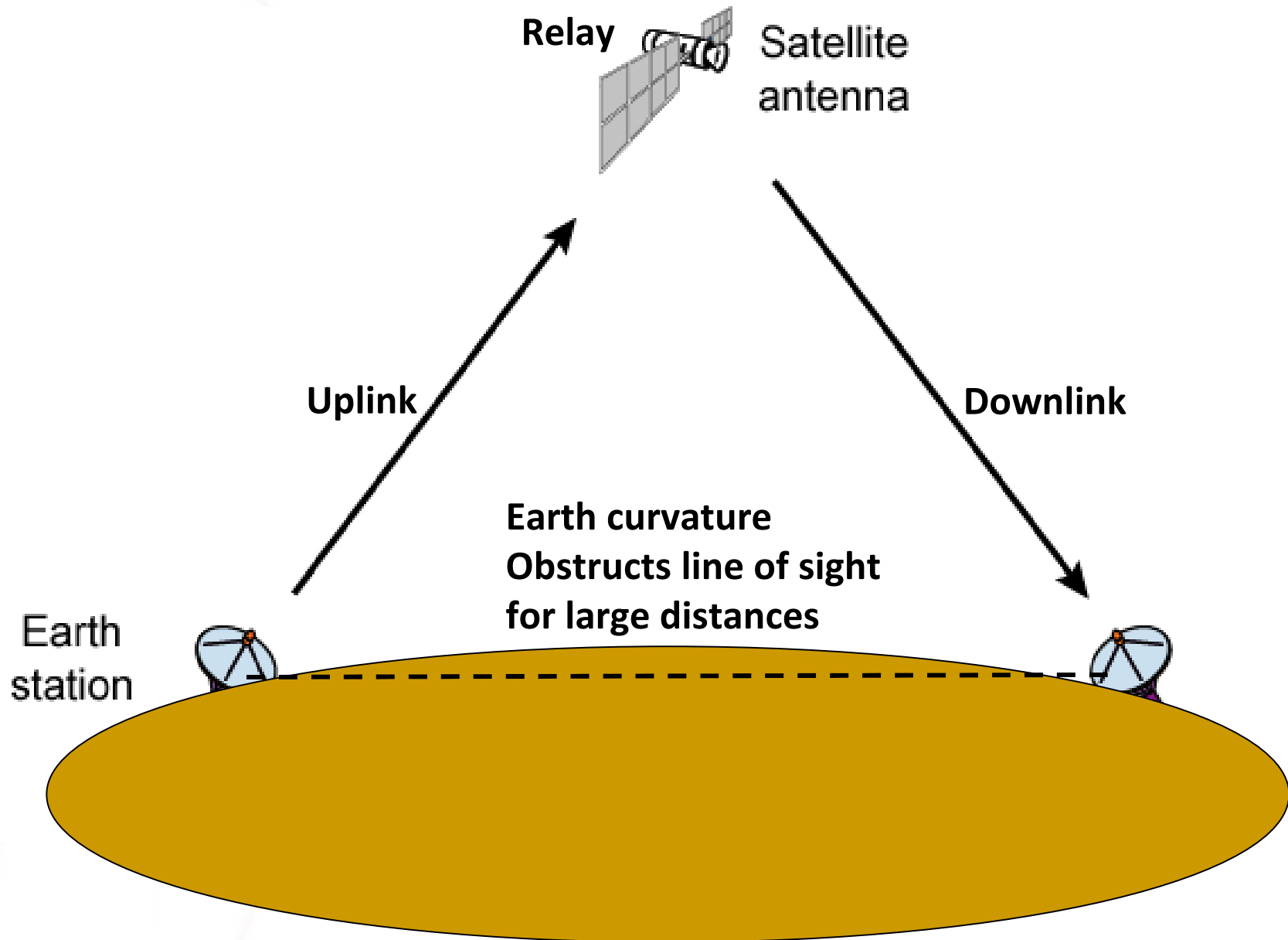
- Operating Frequency range: 1 - 40 GHz
- Higher frequency advantages:
 - Larger bandwidth, B implies higher data rate
 - Smaller λ implies smaller (lighter hence cheaper) antenna for a required antenna gain.
- But higher frequency implies larger attenuation due propagation and absorption by rain. So,
 - Long-haul links (long distances) operate at lower frequencies (4-6 GHz, 11 GHz) to avoid large attenuation
 - Short links between close-by buildings operate at higher frequencies e.g. 22 GHz. (Attenuation is not a big problem for the short distances, smaller antenna size)

Satellite Microwave

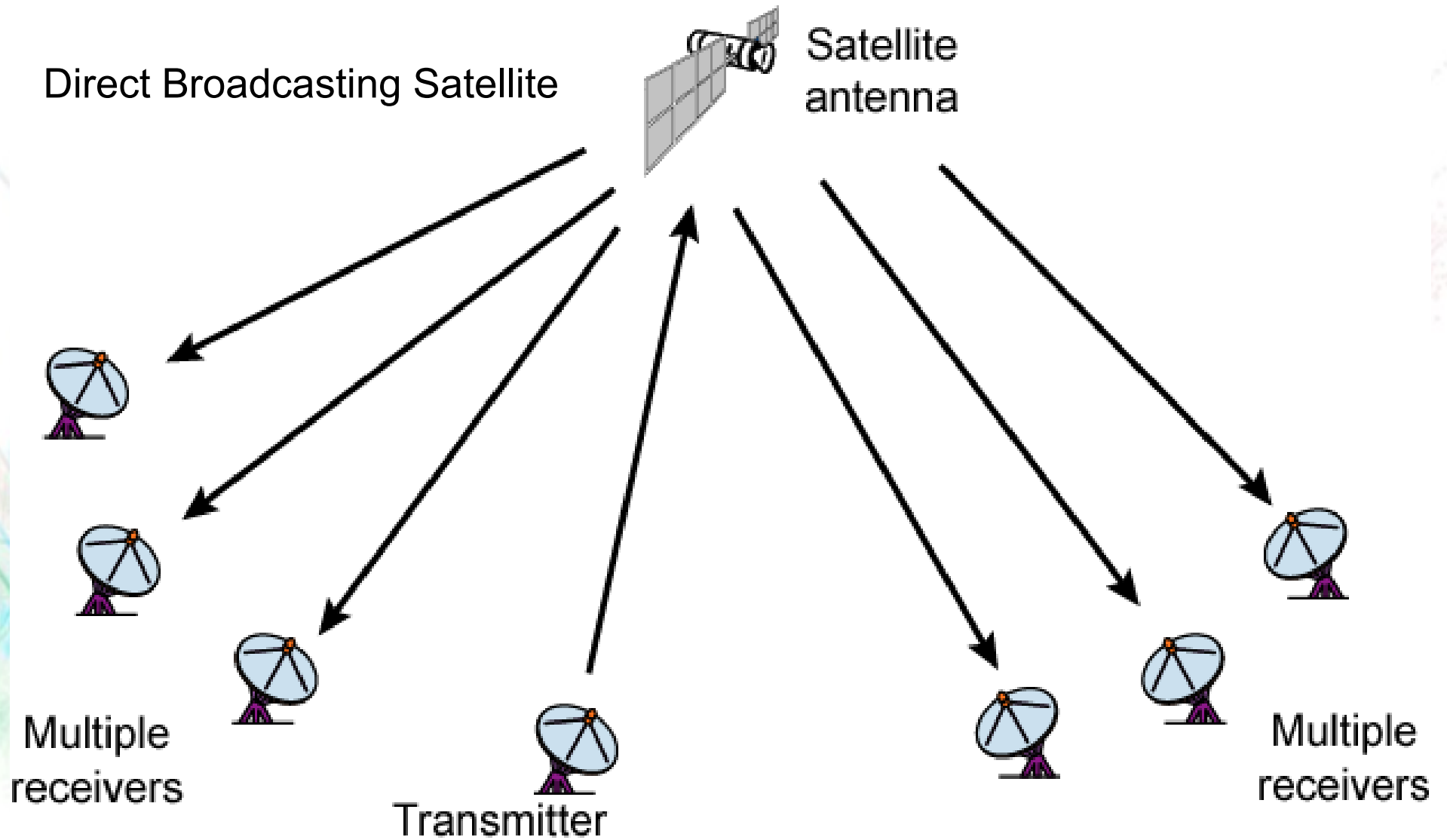
- Satellite acts as a relay station for the link
- Satellite receives on one frequency (uplink), amplifies or repeats signal and re-transmits it on another frequency (downlink)
- Spatial angular separation (e.g. 3°) to avoid interference from neighbouring TXs
- Require a geo-stationary orbit (satellite rotates at the same speed of earth rotation, so appears stationary):
 - Height: 35,784 km (long link, large transmission delays)
- Applications:
 - Television direct broadcasting
 - Long distance telephony
 - Private business networks linking multiple company sites



a. Satellite Point to Point Link



b. Satellite Broadcast Link



Satellite Microwave: Transmission Properties

- 1-10 GHz
- Frequency Trade offs:
 - Lower frequencies: More noise and interference
 - Higher frequencies: Larger rain attenuation, but smaller antennas
- Downlink/Uplink frequencies recently going higher: 4/6 GHz → 12/14 → 20/30 (better receivers becoming available)
- Delay = 0.25 s → noticeable for telephony
- Inherently a **broadcasting** facility

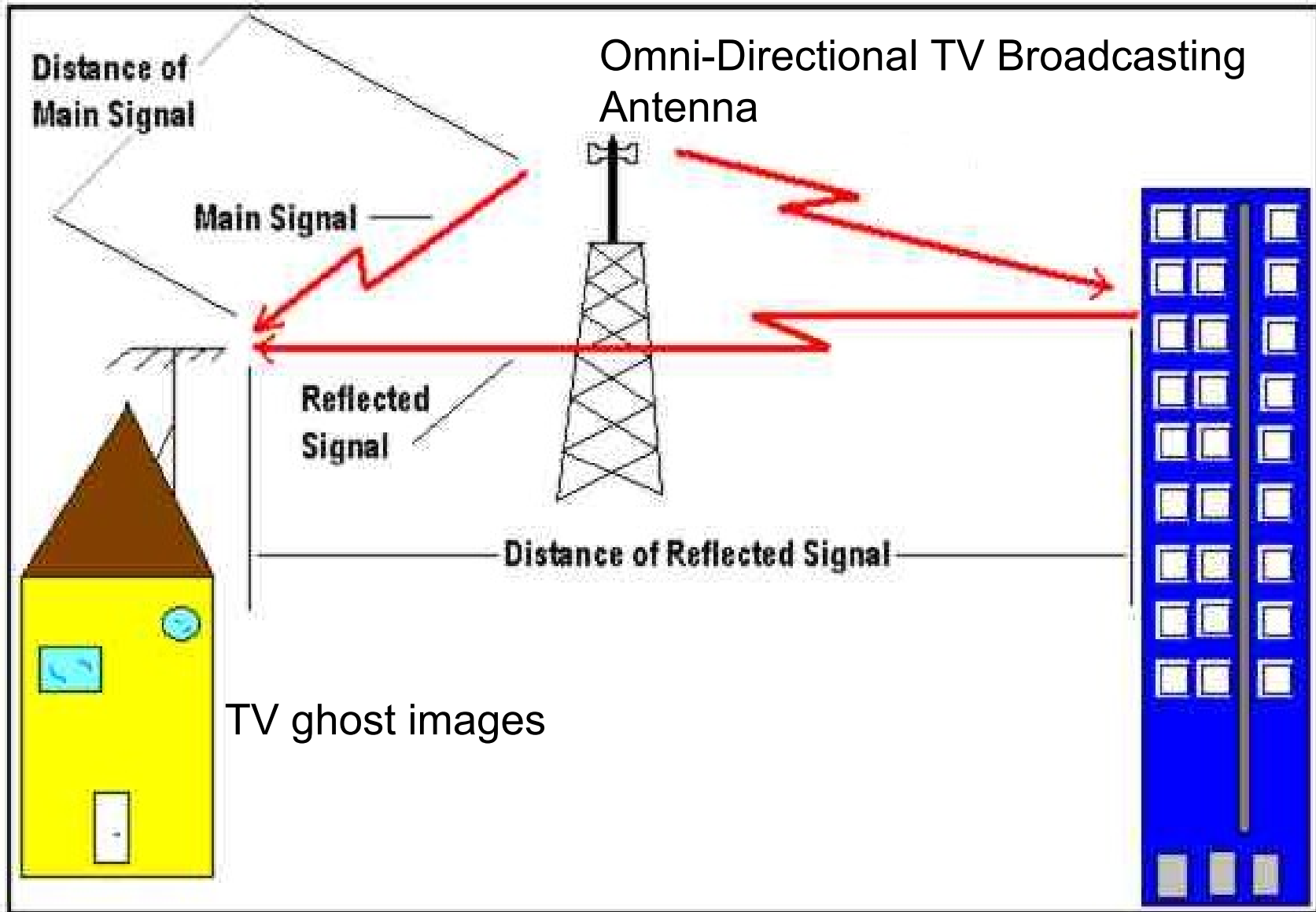
Broadcast Radio: 30 MHz – 1 GHz

- **Omni directional** (no need for antenna directionality horizontally)
 - ❑ No dishes
 - ❑ No line of sight requirement
 - ❑ No antenna alignment requirement/problems
- Applications:
 - ❑ FM radio
 - ❑ UHF and VHF television
- Choice of frequency range:

Reflections from ionosphere < 30 MHz - 1 GHz < Rain
- Propagation attenuation:

Lower than for Microwaves (as λ is larger)
- Problems caused by **omni directionality**: Interference due to multi-path reflections
 - ❑ e.g. TV ghost images

Multi-Path effects of omni-directionality



Infra-red

- Data modulates a non-coherent infra-red light
- Relies on line of sight (or reflections through walls or ceiling)
- Blocked by walls (unlike microwaves)
- No licensing required for frequency allocation
- Applications:
 - ❑ TV remote control
 - ❑ Transfer between mobile devices e.g. notebooks, cellular phones, digital camera, etc.