Wave Propagation

Training materials for wireless trainers

The Abdus Salam
International Centre
for Theoretical Physics

United Nations
Educational, Scientific and
Cultural Organization

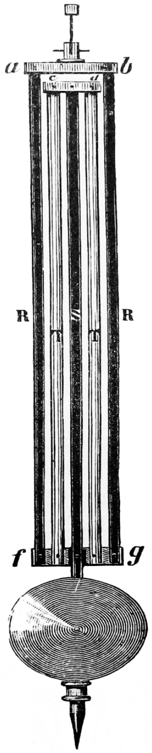
Goals

- Understand why we use wireless, and how it fits into your existing network
- Realize the limits of what wireless can achieve
- See some examples of how wireless has been used to build real-world networks

Goals

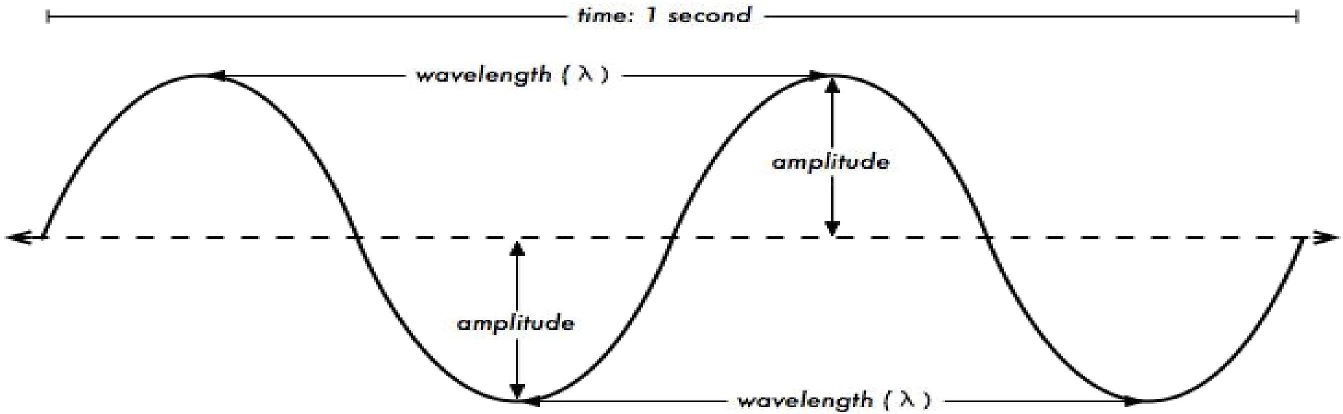
- to introduce the fundamental concepts related to electromagnetic waves (frequency, amplitude, speed, wavelength, polarization, phase)
- to show where WiFi is placed, within the broader range of frequencies used in telecommunications
- to give an understanding of behavior of radio waves as they move through space (absorption, reflection, diffraction, refraction, interference)
- to introduce the concept of the Fresnel zone

What is a Wave?



Electromagnetic Waves

- Characteristic wavelength, frequency, and amplitude
- No need for a carrier medium
- Examples: light, X- rays and radio waves



SI symbols

atto	10^{-18}	1/1000000000000000000	a
femto	10^{-15}	1/1000000000000000	f
pico	10^{-12}	1/1000000000000	p
nano	10^{-9}	1/1000000000	n
micro	10^{-6}	1/1000000	μ
milli	10^{-3}	1/1000	m
centi	10^{-2}	1/100	c
kilo	10^{3}	1000	k
mega	10^{6}	1000000	M
giga	10^{9}	1000000000	G
tera	10^{12}	1000000000000	T
peta	10^{15}	1000000000000000	P
exa	10^{18}	1000000000000000000	E

Wavelength and Frequency

$$\lambda = c/f$$

c = speed (meters / second)
f = frequency (cycles per second, or Hz)
λ = wavelength (meters)

If a wave on water travels at one meter per second, and it oscillates five times per second, then each wave will be twenty centimeters long:

c=1 meter/second, f = 5 cycles/second
λ = 1 / 5 meters
λ = 0.2 meters = 20 cm

Wavelength and Frequency

Since the speed of light is approximately 3×10^8 m/s, we can calculate the wavelength for a given frequency.

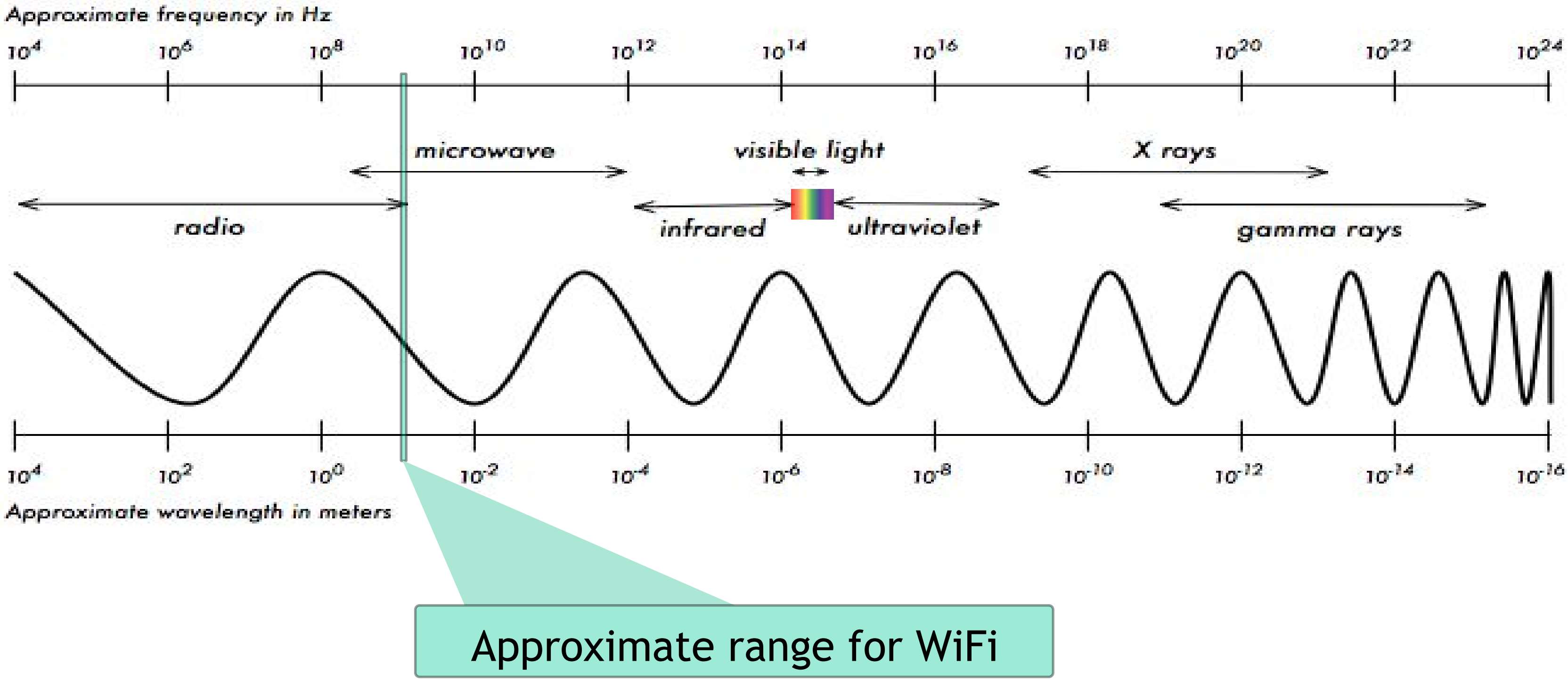
Let us take the example of the frequency of 802.11b/g wireless networking, which is:

f = 2.4 GHz
= 2,400,000,000 cycles / second

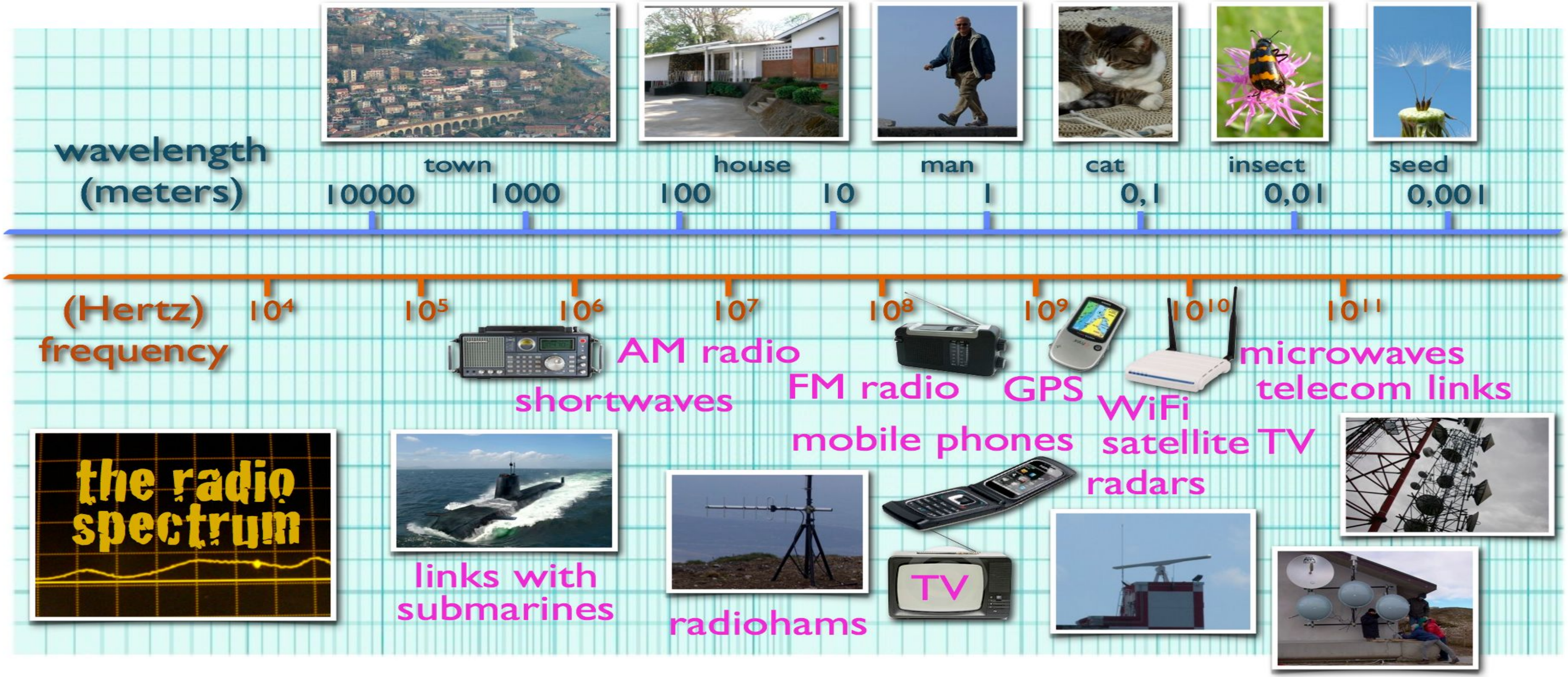
wavelength (λ) = c / f
$$= 3 * 10^8 \text{ m/s} / 2.4 * 10^9 \text{ s}^{-1}$$
$$= 1.25 * 10^{-1} \text{ m}$$
= 12.5 cm

Therefore, the wavelength of 802.11b/g WiFi is about ***12.5 cm***.

Electromagnetic Spectrum



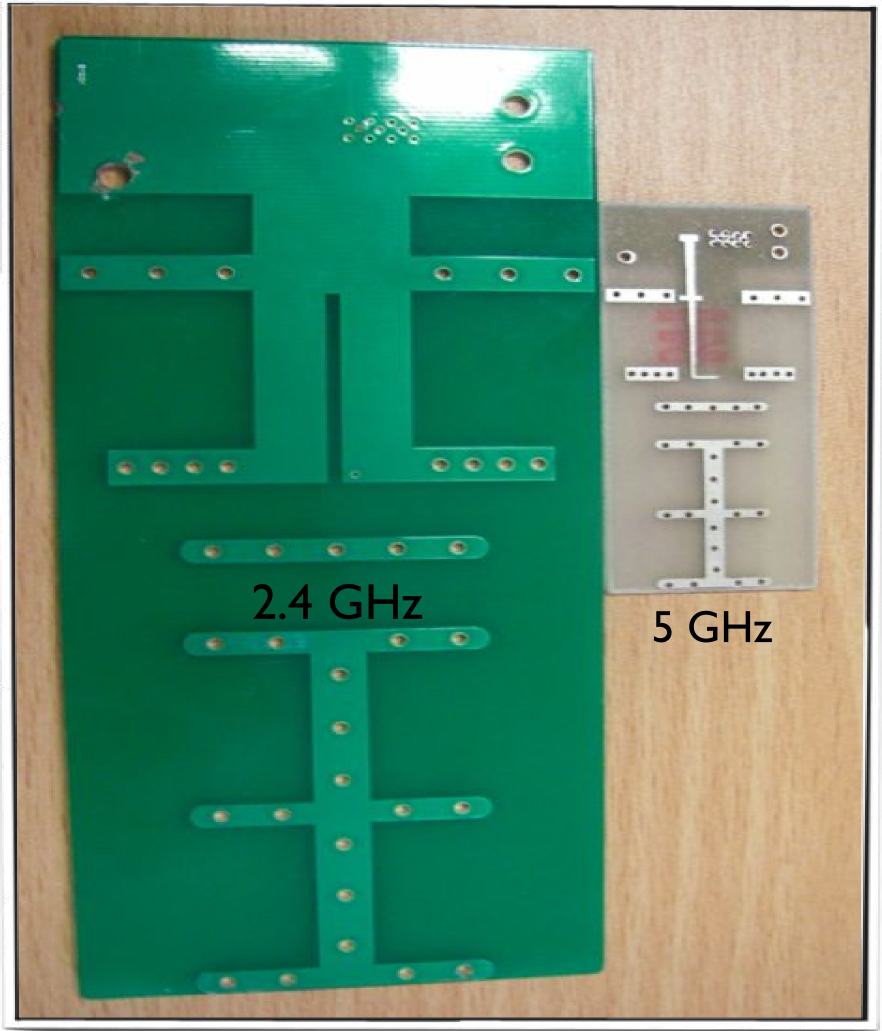
Perspective



Unlicensed bands

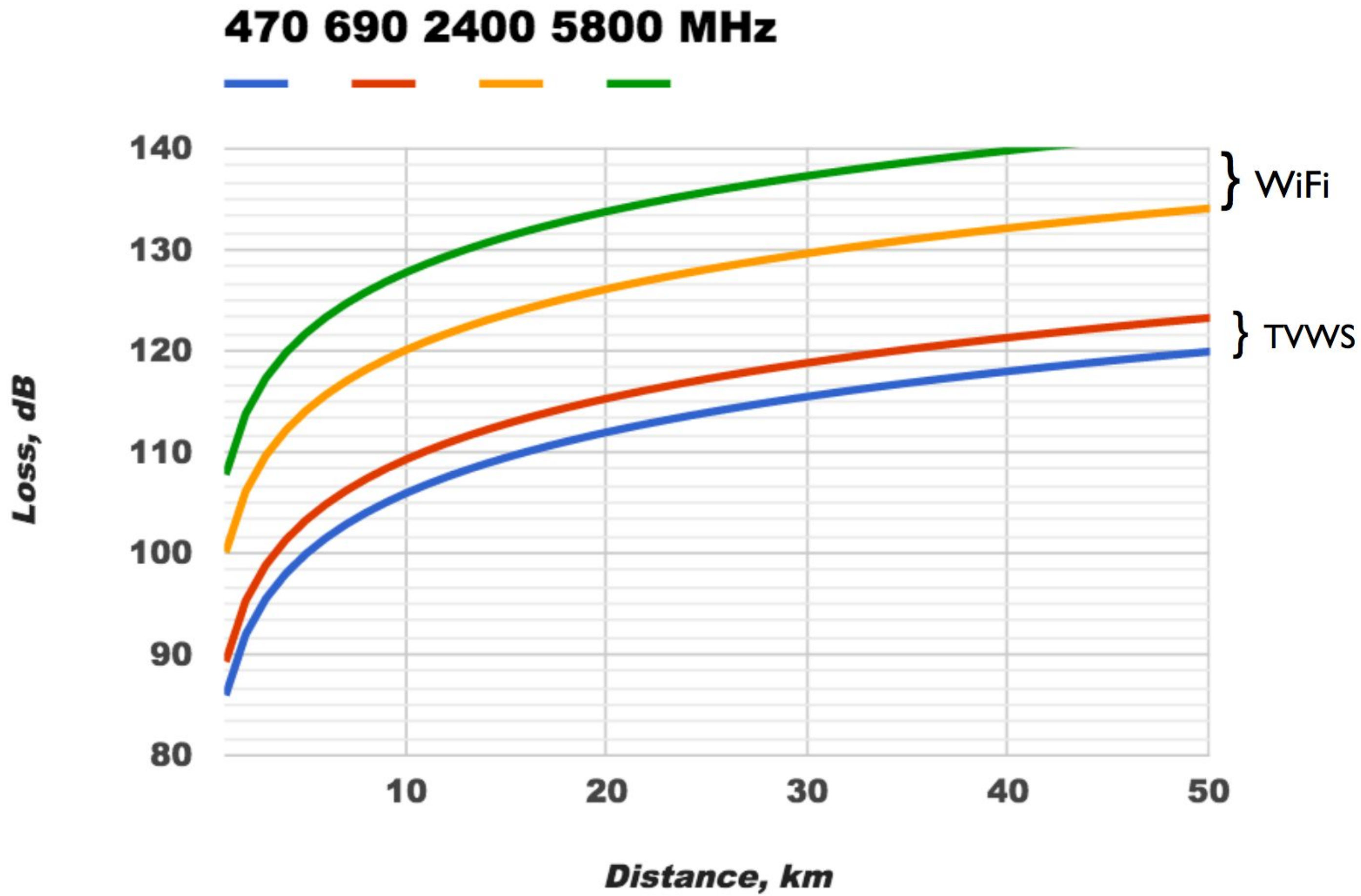
- There are some frequency bands that can be used without the need for the end user to apply for the license, these are the so called “unlicensed bands”, although often the license has been awarded to the manufacturer of the equipment.
- ISM (Industrial, Scientific and Medical) bands are meant to be used for purposes other than telecommunications, but they are also been used nowadays for WiFi and many other devices.
- WiFi success has prompted the designation of other “lightly licensed” bands for telecommunications applications.
- SRDs (Short Range Devices) are very low power radios that can be operated without a licence in ISM and other special bands.

WiFi frequencies and wavelengths



Standard	Frequency	Wavelength
802.11 b/g/n	2.4 GHz	12.5 cm
802.11 a/n	5.x GHz	5 to 6 cm

Free Space Loss Versus distance for different bands



Behavior of radio waves

There are a few simple rules of thumb that can prove extremely useful when making first plans for a wireless network:

- The ***longer*** the wavelength, the further it goes
- The ***longer*** the wavelength, the better it travels through and around things
- The ***shorter*** the wavelength, the more data it can transport

All of these rules, simplified as they may be, are rather easy to understand by example.

Traveling radio waves

Radio waves do not move in a strictly straight line. On their way from “point A” to “point B”, waves may be subject to:

- Absorption
- Reflection
- Diffraction
- Refraction

Absorption

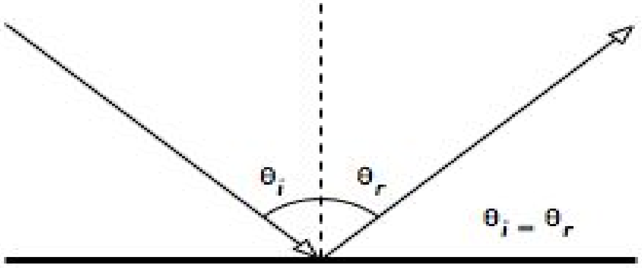
When electromagnetic waves go through some material, they generally get weakened or dampened.

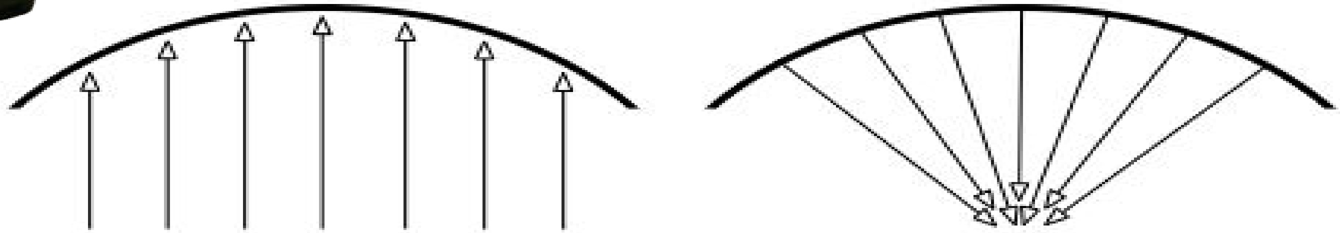
Materials that absorb energy include:

- ***Metal***. Electrons can move freely in metals, and are readily able to swing and thus absorb the energy of a passing wave.
- ***Water*** molecules jostle around in the presence of radio waves, thus absorbing some energy.
- ***Trees*** and ***wood*** absorb radio energy proportionally to the amount of water contained in them.
- ***Humans*** are mostly water: we absorb radio energy quite well!

Reflection

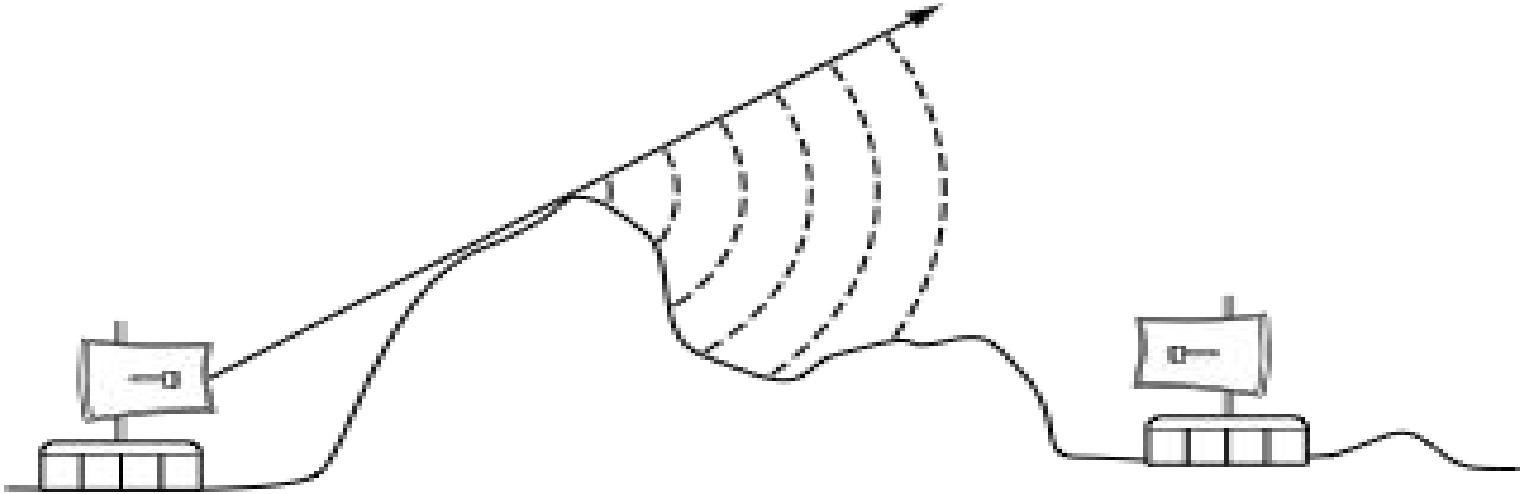
The rules for reflection are quite simple: the angle at which a wave hits a surface is the same angle at which it gets deflected. **Metal** and **water** are excellent reflectors of radio waves.





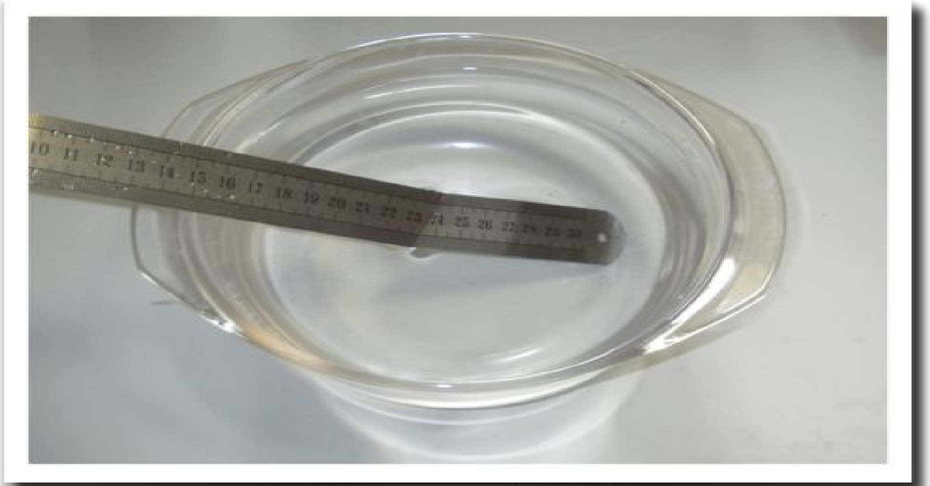
Diffraction

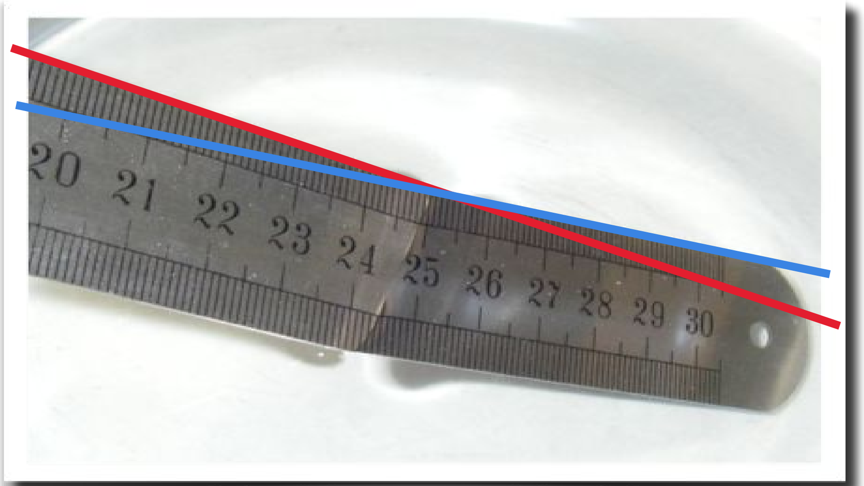
Because of the effect of diffraction, waves will “bend” around corners or through an opening in a barrier.



Refraction

Refraction is the apparent "bending" of waves when they meet a material with different characteristics. When a wave moves from one medium to another, it changes speed and direction upon entering the new medium.





Other important wave properties

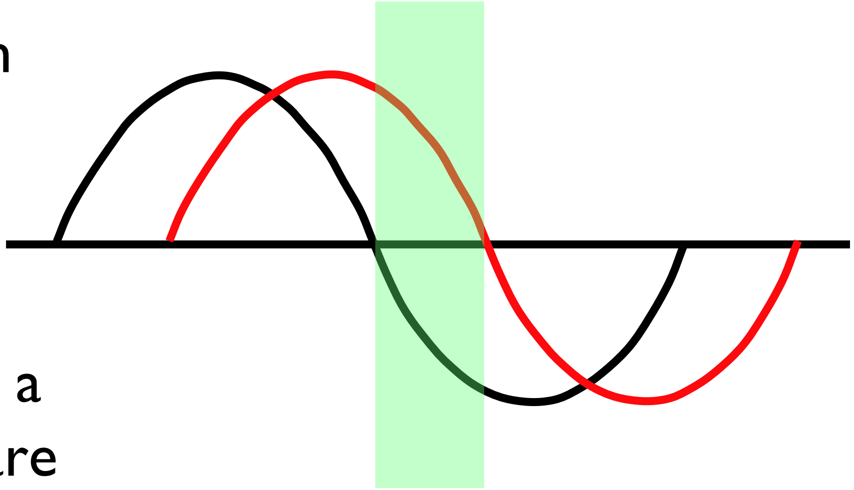
These properties are also important to consider when using electromagnetic waves for communications.

- Phase
- Polarization
- Fresnel Zone

Phase

The **phase** of a wave is the fraction of a cycle that the wave is offset from a reference point. It is a relative measurement that can be express in different ways (radians, cycles, degrees, percentage).

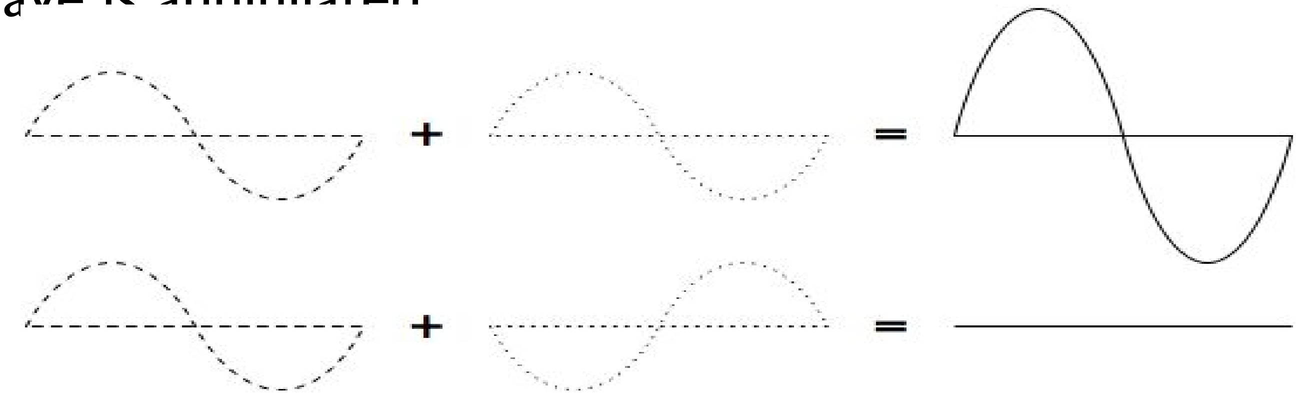
Two waves that have the same frequency and different phases have a **phase difference**, and the waves are said to be out of phase with each other.



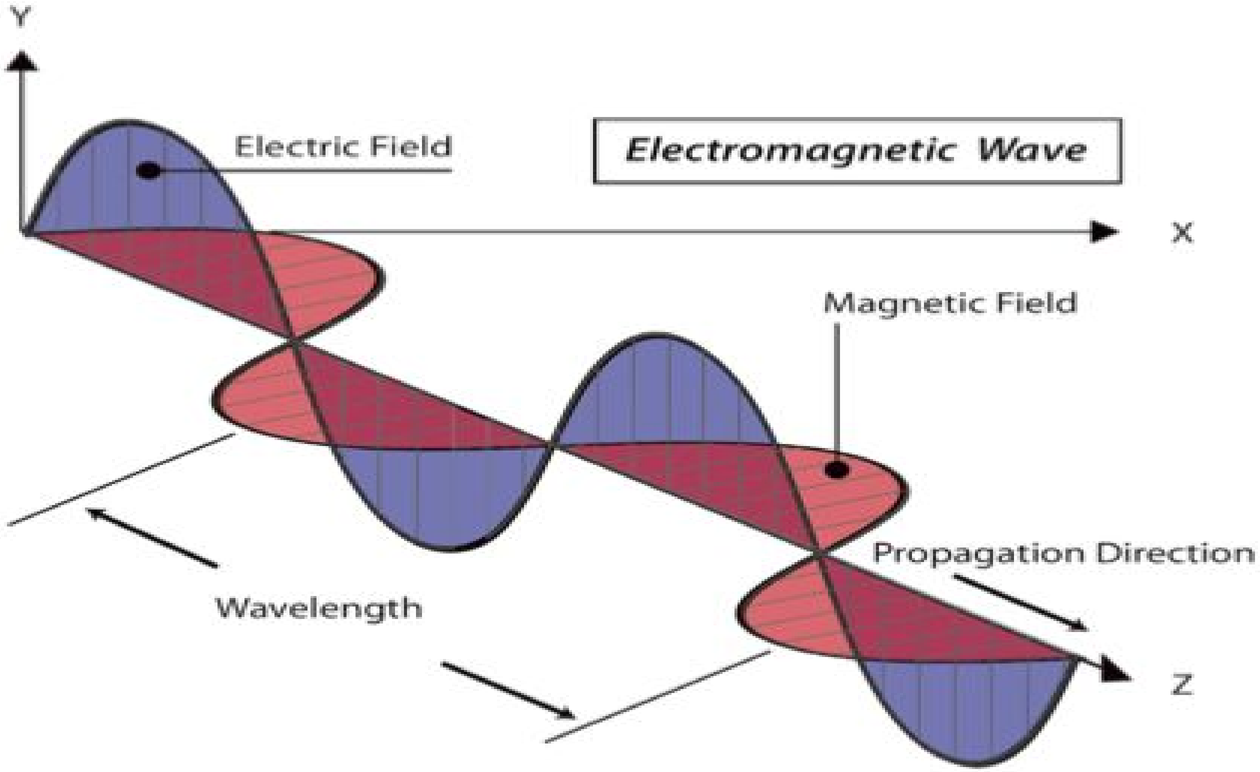
Interference

When two waves of the same frequency, amplitude and **phase** meet, the result is ***constructive interference***: the amplitude doubles.

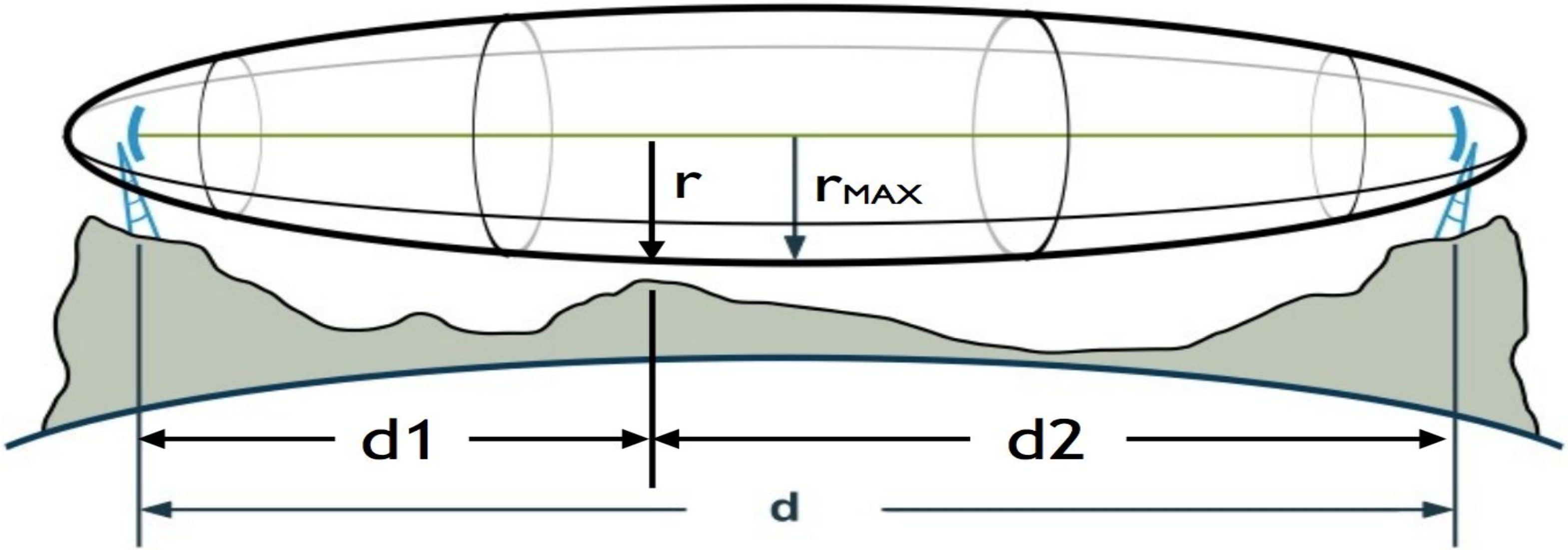
When two waves of the same frequency and amplitude and **opposite phase** meet, the result is ***destructive interference***: the wave is annihilated.



Polarization



Line of Sight and Fresnel Zones



$$r = \mathrm{sqrt}(\lambda * d1 * d2 / d)$$

$$r_{MAX} = 1/2 * \mathrm{sqrt}(\lambda * d)$$

where all the dimensions are in meters

Optical and Radio LOS

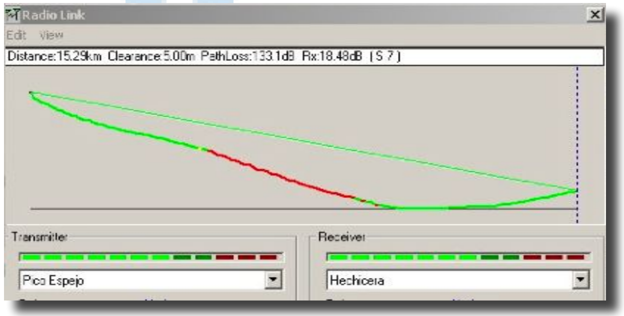
- Optical signals also occupy a Fresnel zone, but since the wavelength is so small (around 10-6 m), we don't notice it.

- Therefore, clearance of optical LOS does not guarantee the clearance of RADIO LOS.

- The lower the frequency, the bigger the Fresnel zone; but the diffraction effects are also more significant, so lower radio frequencies can reach the receiver even if there is No Line of Sight.

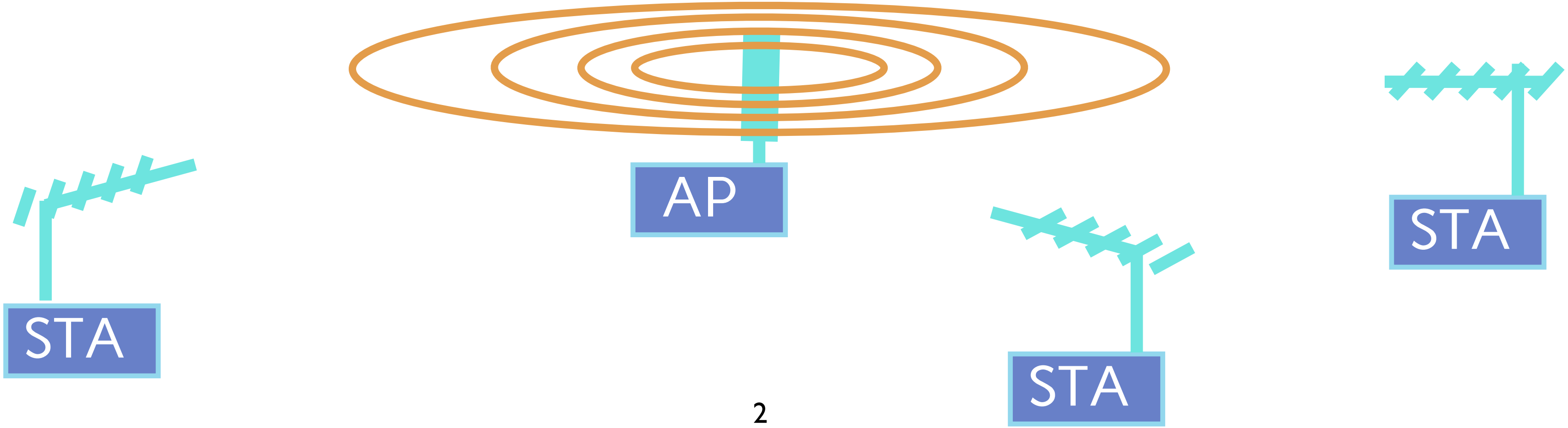
Low-cost wireless: examples

- Wireless MANs:
  - for private institutions/companies:
  - Point-to-Multipoint
  - Point-to-Point (larger distance, fewer coexistence problems)
  - line-of-sight, security issues
  - radio link planning and design



Low-cost wireless: P2MP MANs

- Point-to-Multipoint
- Star topology, one AP, many stations
- Omnidirectional antenna for AP
- Directional antennas for stations



Low-cost wireless: planning

- Distance, obstacles, power budget
- Site survey, antenna installation
- Detect and mitigate interference
- Powering and protection
- Grounding and bonding
- Security (theft/vandalism)
- Network Layer (TCP/IP)

It is possible to build a very inexpensive long distance radio link with off–the–shelf devices and low cost antennas, but good planning is needed!

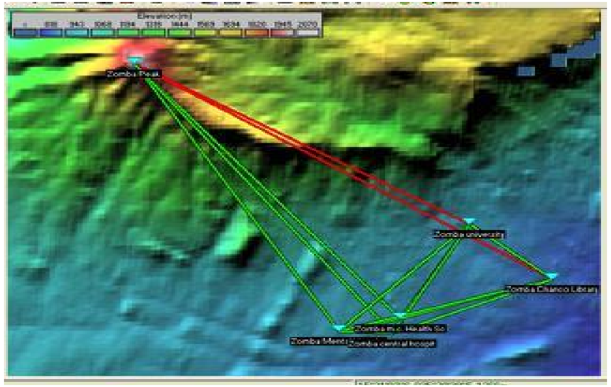
Low-cost wireless: long links

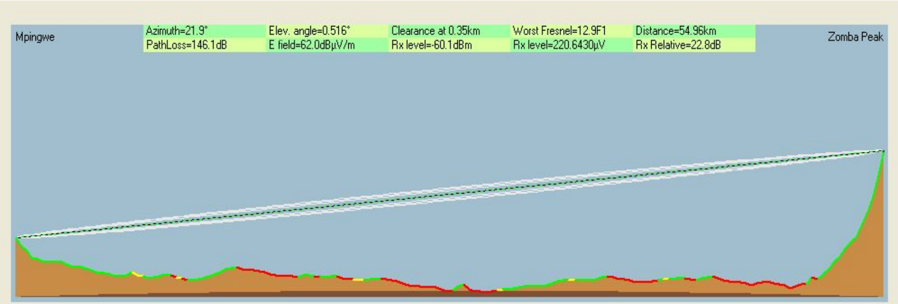
- From our field experiences, what is possible?
  - 2006: (Venezuela, 382 km, World record for WiFi link)
  - 2006-8: Malawi (50+100 km @5GHz, throughput 20 Mbps full duplex, double link for redundancy)
  - 2016: Italy (304 km at 350 Mbps point to point)

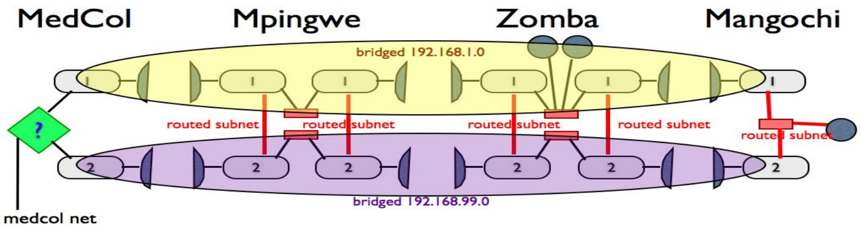
Long link in Malawi

Long link in Malawi: planning

- design the network, plan the survey, setup and test activities

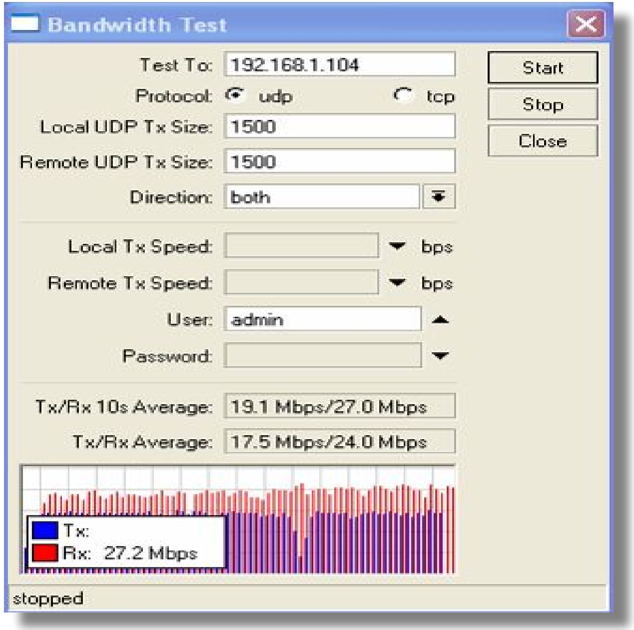


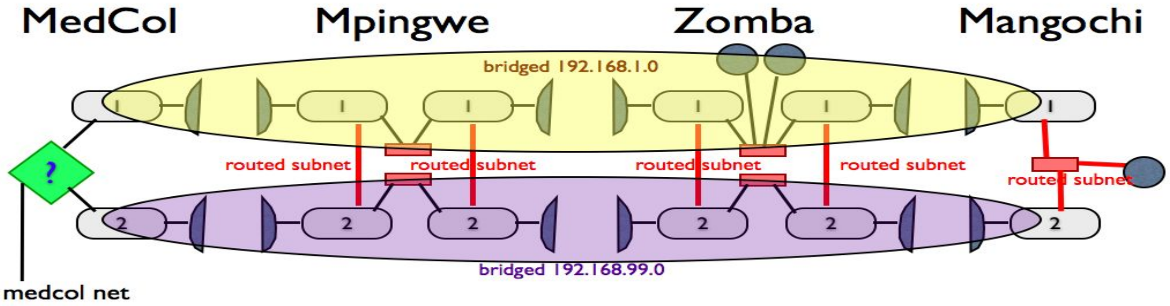




Long link in Malawi: results

- > 20 Mbps full duplex for each link
- Two independent links from Blantyre through Mpingwe, Zomba, and all the way to Mangochi.





Conclusions

- Radio waves have a characteristic wavelength, frequency and amplitude, which affect the way they travel through space.
- WiFi uses a tiny part of the electromagnetic spectrum
- Lower frequencies travel further, but at the expense of throughput.
- Radio waves occupy a volume in space, the Fresnel zone, which should be unobstructed for optimum reception.

Thank you for your attention

For more details about the topics presented in this lecture, please see the book ***Wireless Networking in the Developing World***, available as free download in many languages at:

http://wndw.net