Tishk International University
Science Faculty
IT Department

Wireless Networking

Lecture 1: Radio Propagation

4th Grade -Fall Semester

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Course Name: Wireless Networking
Code/Section: IT 416-A

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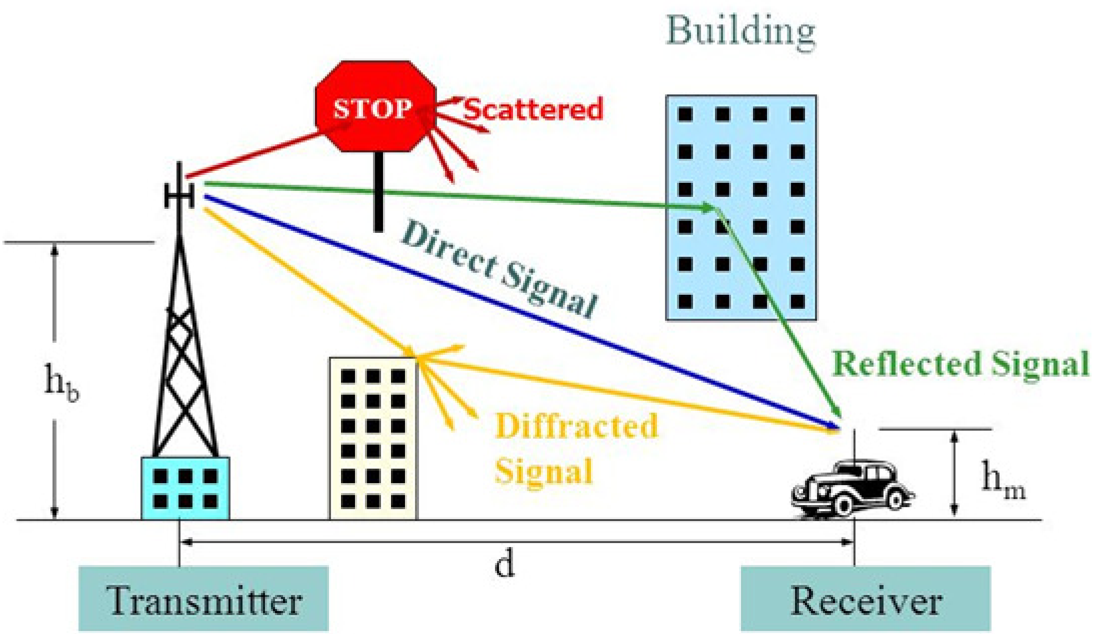
References:

- WIRELESS COMMUNICATIONS Second Edition Andreas F. Molisch, 2011
- Wireless Communication and Networking , Vijay K. Garg.
- Wireless Communications, Andrea Goldsmith, Cambridge University Press.
- Wireless Communications and Networking, Jon Mark, WeihuaZhuang, Prentice Hall.

COURSE CONTENT

#	Topic
1	Radio Propagation
2	Antennas
3	Modulation and Multiple Access Techniques
4	Satellite Systems
5	GSM Networks
6	Wireless LAN

Lecture 1
Radio Propagation



Topics

1. Introduction
2. Definition of Electromagnetic Wave
3. Description of a Waveform
4. The Electromagnetic Spectrum
5. Signal Propagation
6. RF Power Conversion
7. Fresnel Zone
8. Link budget

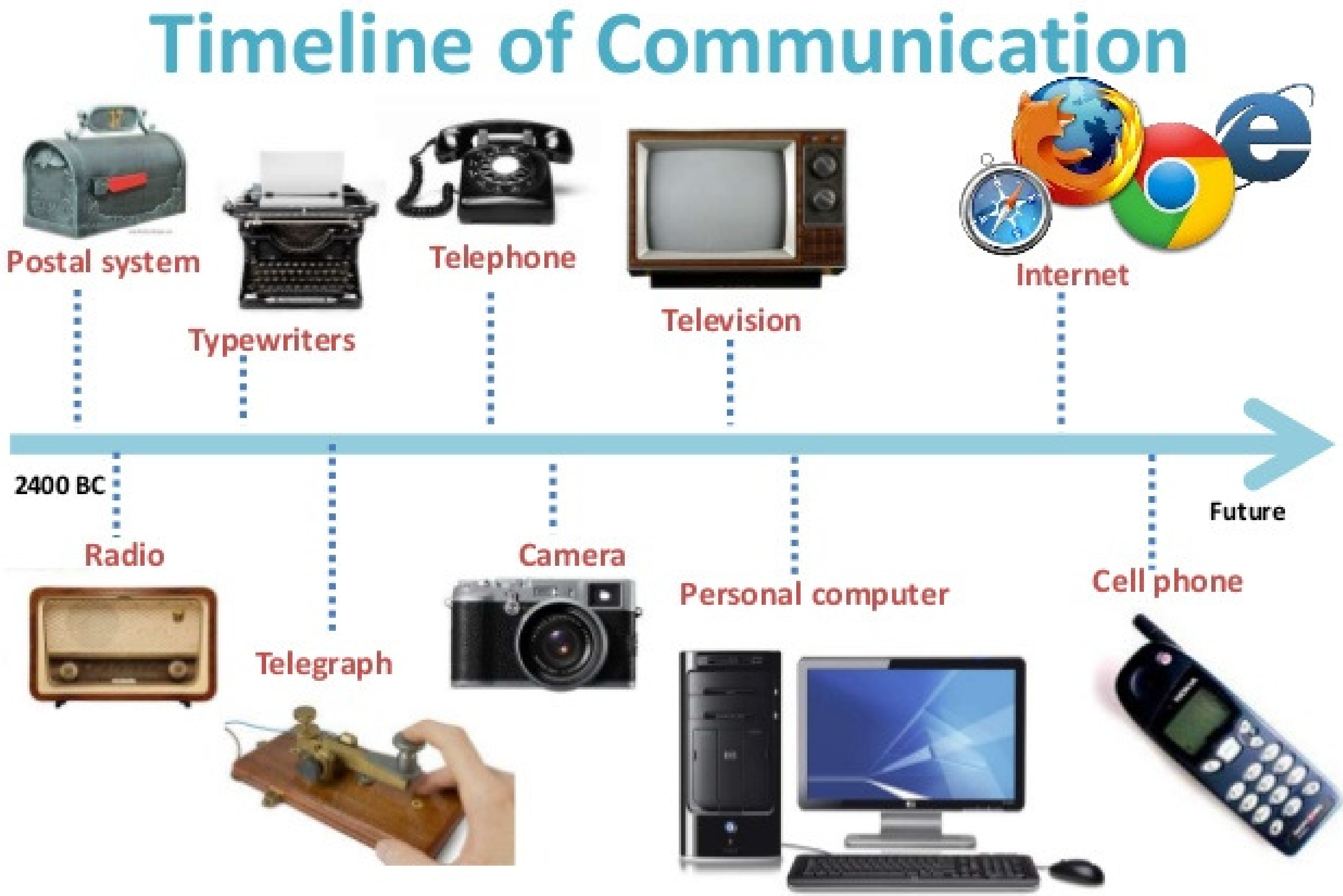
Reasons for Wireless Networks

Wireless communication is needed in areas where:

- wired communication is difficult or impossible.
- Quick deployment
- Low initial cost.
- Information must be broadcast to many locations.

Problems with Wireless Networks

- It is more susceptible to interference, signal loss, noise, and eavesdropping.
- It has lower data rates than wired facilities.
- The Frequency reuse is more difficult.



(not required in the exam)

2. Definition of Electromagnetic Wave

- **RADIO WAVE** is a type of electromagnetic signal designed to carry information through space over relatively long distances..
- Waves are present at all frequencies.
- We can utilize only a small part of this total spectrum to transmit communication signals referred to as the Radio Frequency (RF) spectrum and ranges from about 9 KHz to 300 GHz.

- An Electromagnetic wave is the propagation of electrical energy caused by oscillating electric fields inducing oscillating magnetic fields, which then induce further oscillating electric fields, which then induce further oscillating magnetic fields, and so on.

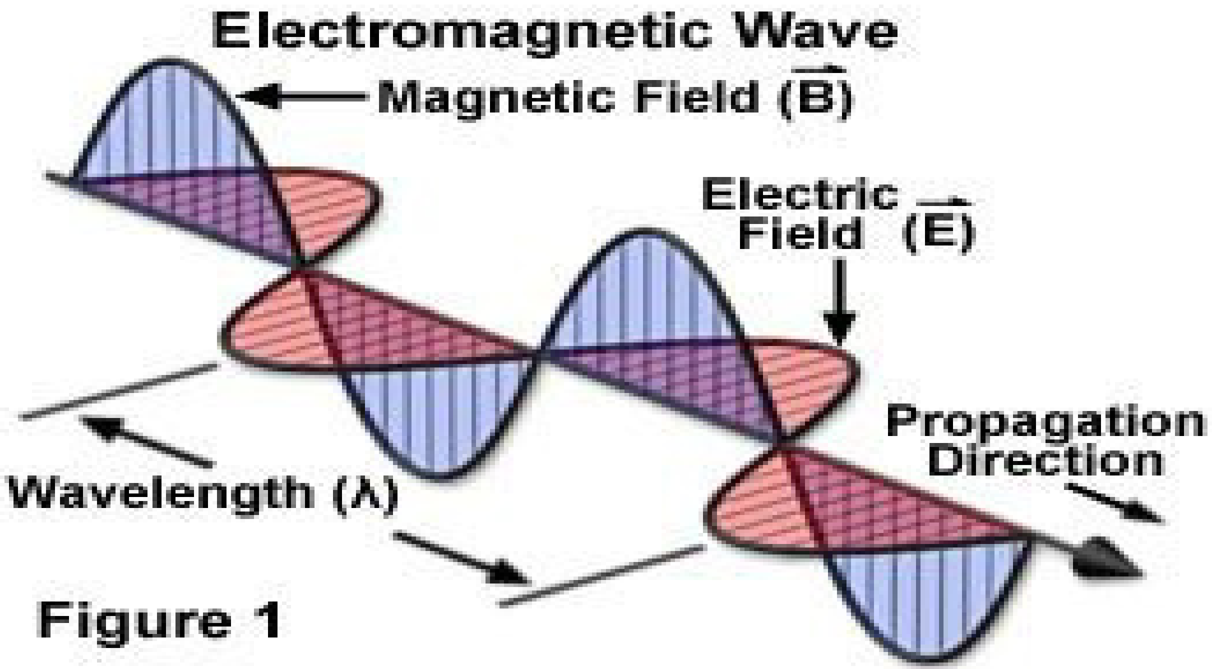
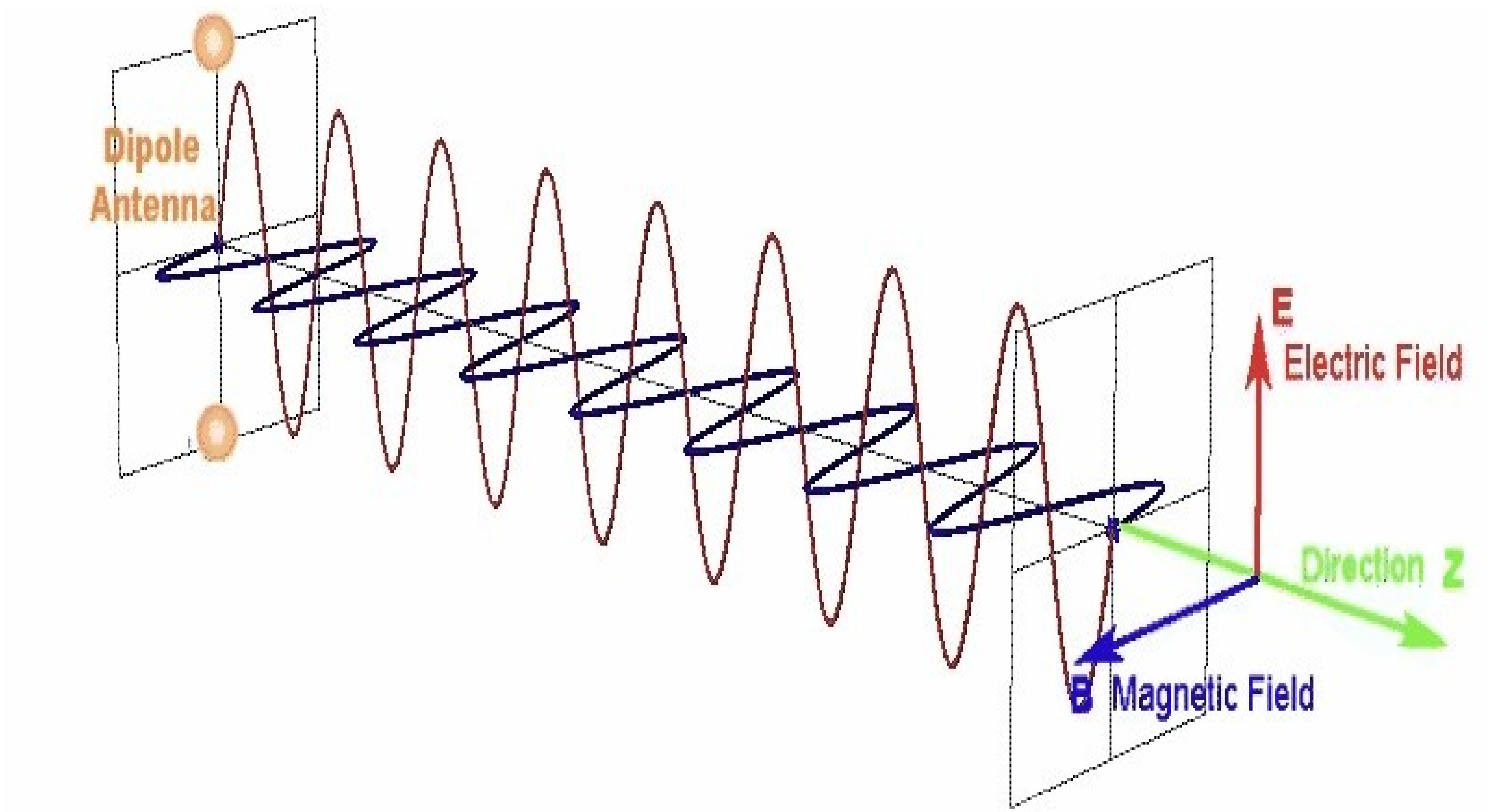
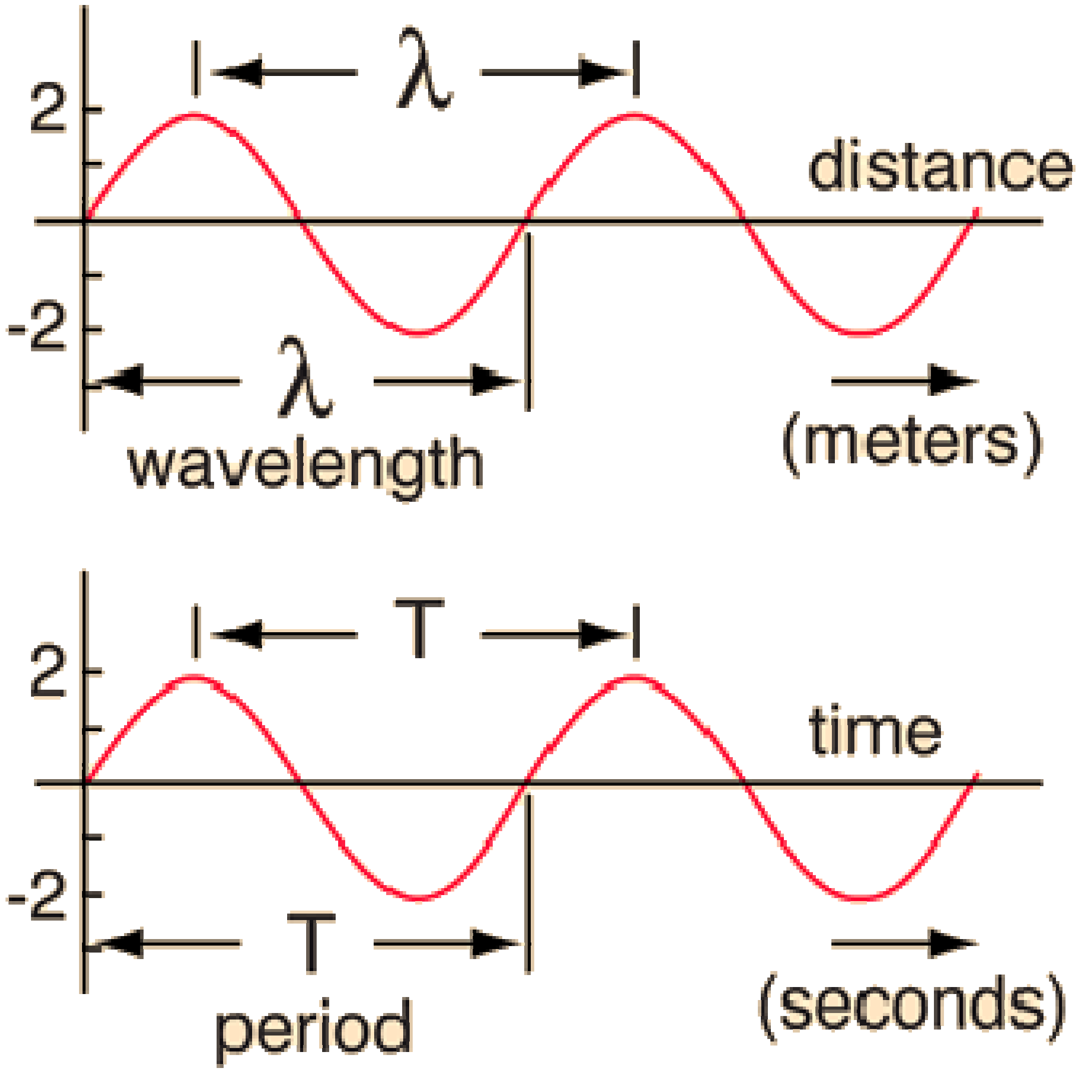


Figure 1

Electromagnetic Wave Animation



3. Description of a Waveform



Description of a Waveform - continued

A **cycle** is the smallest portion of a waveform that, if repeated, would represent the entire waveform.

Waveforms can be described as having the following properties:

a = Amplitude

The measurement of a waveform above a center reference.With EM waves this is usually measured in volts or watts.

v = Velocity of Propagation

The velocity of propagation of a wave is the velocity that a wave travels through a medium, and is usually measured in meters per second.

τ = Period

The period of a wave is the time it takes for one cycle to pass a fixed point and is usually measured in seconds. It is designated by the Greek letter tau (τ).

Description of a Waveform - continued

λ = Wavelength

The wavelength of a wave is the distance that the wave will propagate in one cycle and is usually measured in meters and designated by the Greek letter lambda (λ).

f **= Frequency**

The frequency of a wave is the rate at which individual cycles pass a given point and is usually measured in cycles per second or Hertz (Hz), named after Heinrich Hertz, who discovered EM waves.

All of these properties except amplitude are related by the following formula: $f = 1/\tau = v/\lambda$

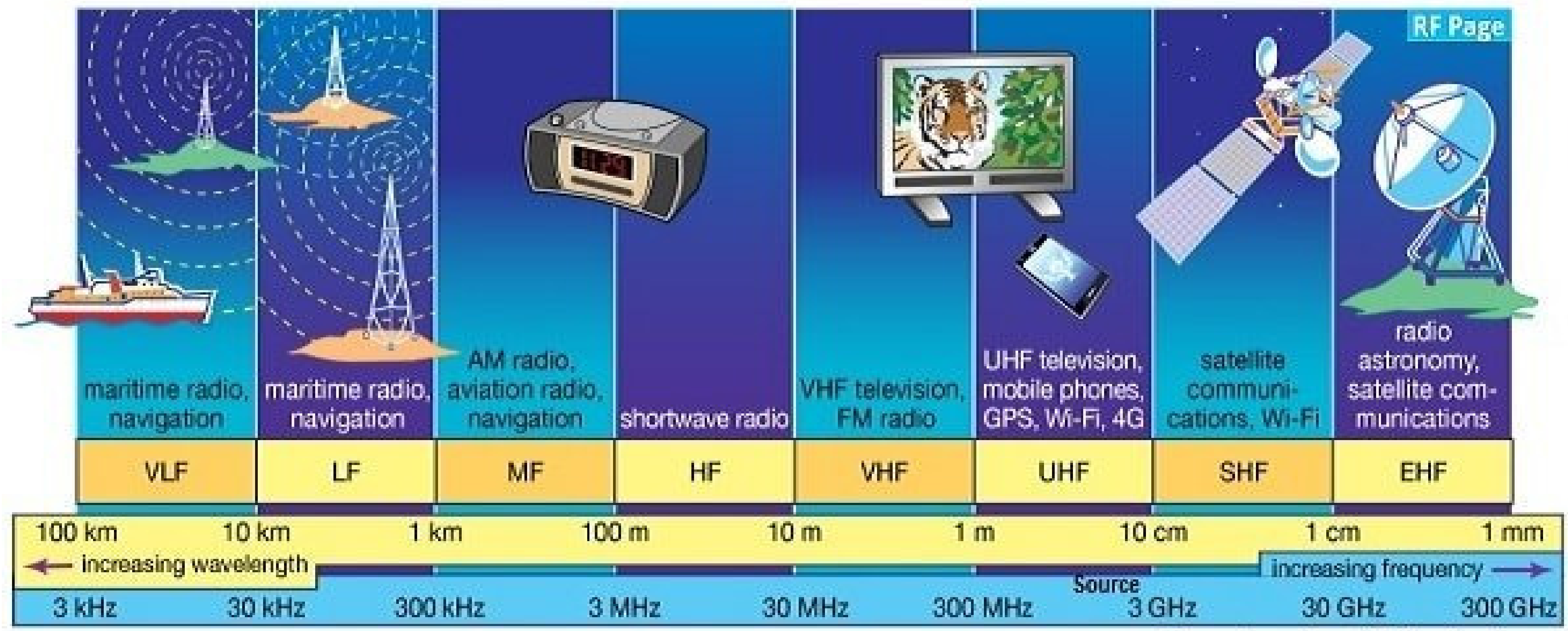
The velocity of propagation for EM waves is is equal to the speed of light (3 × 10^8 m/s).

Substituting this constant for velocity yields the following:

$f = (3 \times 10^8 \text{ m/s}) / \lambda$

4. The Electromagnetic Spectrum

- The EM spectrum is the ENTIRE range of EM waves in order of increasing frequency and decreasing wavelength.
- As you go from left → right, the wavelengths get smaller and the frequencies get higher. This is an inverse relationship between wave length and frequency.



Source: Encyclopaedia Britannica, Inc.

Frequency Bands with Usage
(not required in the Exam)

Types of EM Waves

Radio Waves: Have the longest wavelengths and the lowest frequencies; wavelengths range from 1000s m to .001 m.

Used in: Wireless Communication (will be explained further).

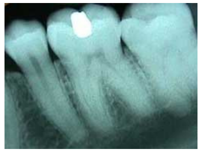
Infrared waves (heat): Have a shorter wavelength, from .001 m to 700 nm, and therefore, a higher frequency.

- Used for finding people in the dark and in TV remote control devices

Visible light: Wavelengths range from 700 nm (red light) to 30 nm (violet light) with frequencies higher than infrared waves.

Ultraviolet Light: Wavelengths range from 400 nm to 10 nm; the frequency (and therefore the energy) is high enough with UV rays to penetrate living cells and cause them damage.

Types of EM Waves



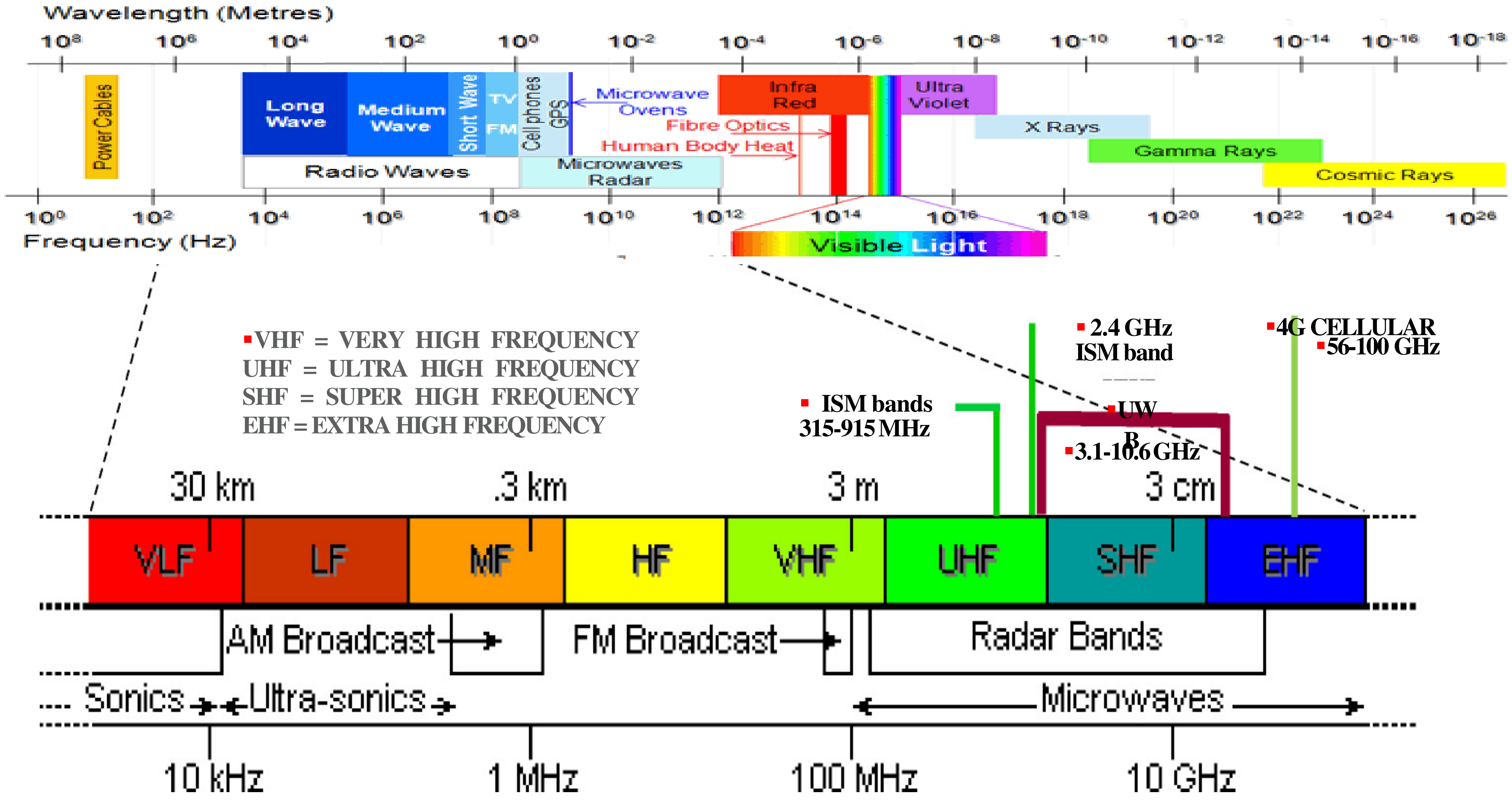
X-Rays: Wavelengths from 10 nm to .001 nm. These rays have enough energy to penetrate deep into tissues and cause damage to cells; are stopped by dense materials, such as bone.

- Used to look at solid structures, such as bones and bridges.

Gamma Rays: Carry the most energy and have the shortest wavelengths, less than one trillionth of a meter (10-12).

- Gamma rays are released by nuclear reactions in nuclear power plants, by nuclear bombs, and by naturally occurring elements on Earth.
- Sometimes used in the treatment of cancers.

Radio Frequencies Spectrum



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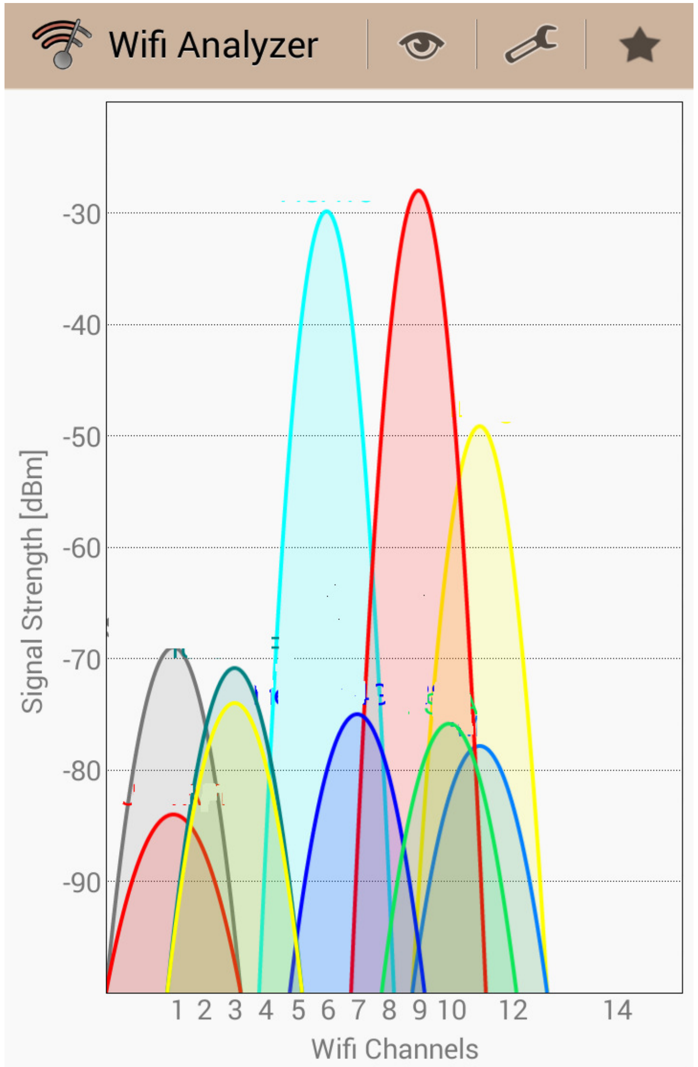
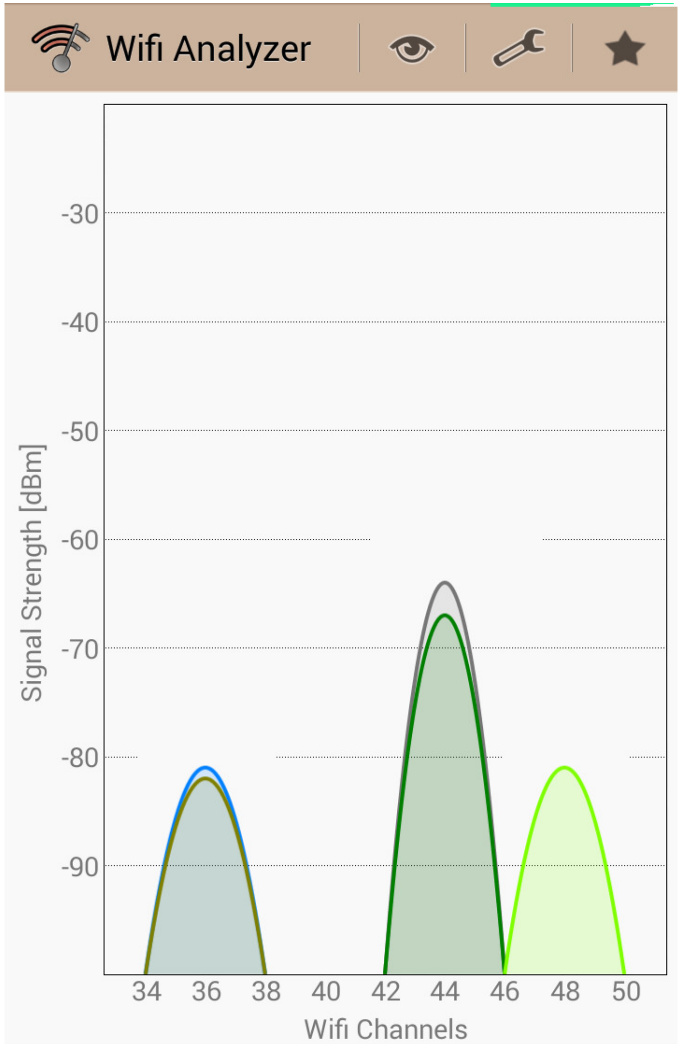
Practical Spectrum Analyzer – WiFi Analyzer App



2.4 GHz

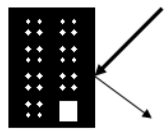


5 GHz

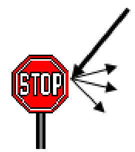
5. Signal Propagation

In a radio system, The path between the transmit and the receive antennas has obstacles (including hills, forests, buildings etc). Here we look at key channel properties that it is important to understand.

- 1) Reflection occurs when a radio wave hits a smooth surface that is much greater than a wavelength and effectively bounces off.
- 2) Diffraction (or shadowing) occurs when the path between the transmitter and receiver is blocked by a dense object that is much greater than a wavelength, forming secondary waves behind the obstruction.
- 3) Scattering occurs when a radio wave hits either a rough surface or a surface with dimensions of a wavelength or less, causing reflected energy to scatter.


reflection

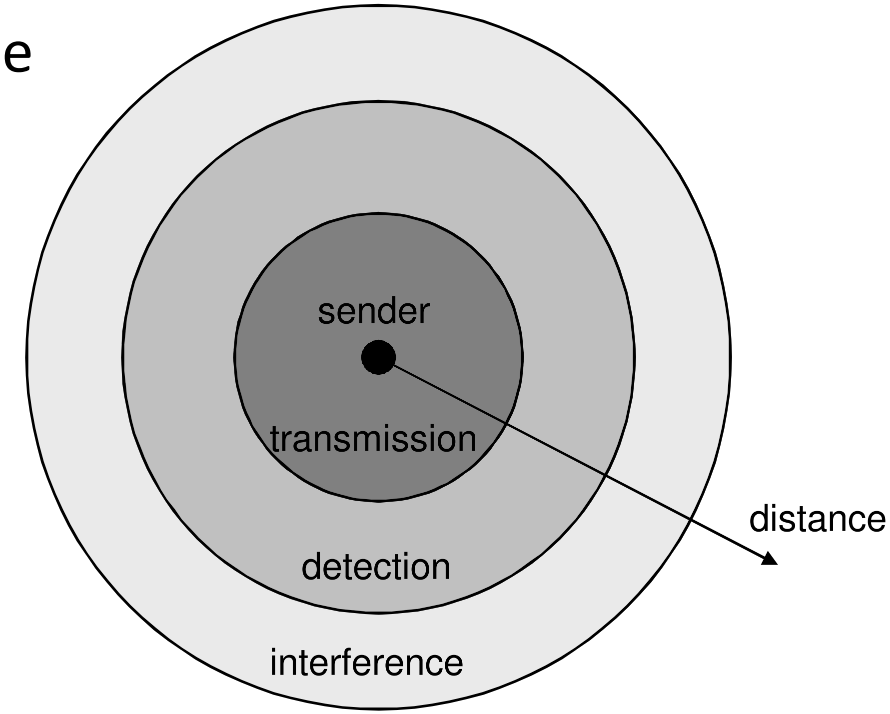

diffraction



scattering

Signal propagation ranges

- Transmission range
  - communication possible
  - low error rate
- Detection range
  - detection of the signal possible
  - no communication possible
- Interference range
  - signal may not be detected
  - signal adds to the background noise



Attenuation

- Strength of signal falls off with distance over transmission medium
- Attenuation factors for wireless media:
  - Received signal must have sufficient strength so that circuitry in the receiver can interpret the signal
  - Signal must maintain a level sufficiently higher than noise to be received without error
  - Attenuation is greater at higher frequencies, causing distortion

6. RF Power Conversion

- **Power, strength of a signal (absolute)**
  - **dBm or dB(mW)** (decibel milliwatt, power ratio) — absolute power in decibels relative to 1 mW.

The conversion between Power in mW and Power in dBm can be done by

$$P_{dBm} = 10 * \ log_{10}(P_{mW})$$

$$P_{mW} = 10^{\left(\frac{P_{dBm}}{10}\right)}$$

-30 dBm = 1 micro W

0 dBm = 1mW

20 dBm = 100mW

30 dBm = 1W

Typical Practical Radio Power in dBm Values

dBm level	Power	Notes
80 dBm	100 kW	Typical transmission power of FM radio station with 30-40 miles range
60 dBm	1 kW	Typical combined radiated RF power of microwave oven elements
36 dBm	4 W	Typical maximum output power for a Citizens' band radio station (27 MHz) in many countries
30 dBm	1 W	Typical RF leakage from a microwave oven - Maximum output power for DCS 1800 MHz mobile phone
27 dBm	500 mW	Typical cellular phone transmission power
20 dBm	100 mW	Bluetooth Class 1 radio, 100 m range (maximum output power from unlicensed FM transmitter). Typical wireless router transmission power.
18 dBm	70mW	Maximum output power of a Typical WLAN card
4 dBm	2.5 mW	Bluetooth Class 2 radio, 10 m range
0 dBm	1.0 mW	Bluetooth standard (Class 3) radio, 1 m range
−10 dBm	100 μW	Typical max received signal power (−10 to −30 dBm) of a wireless network
−70 dBm	100 pW	Typical range of Wireless received signal power over a network
−127.5 dBm	0.178 fW	Typical received signal power from a GPS satellite

Example of Signal Attenuation in Different Material (not required in the Exam)

Partition dependent losses at 2.4 GHz.

Signal attenuation through	Loss (dB)
Window in brick wall	2
Metal frame, glass wall in building	6
Office wall	6
Metal door in office wall	6
Cinder wall	4
Metal door in brick wall	12.4
Brick wall next to metal door	3

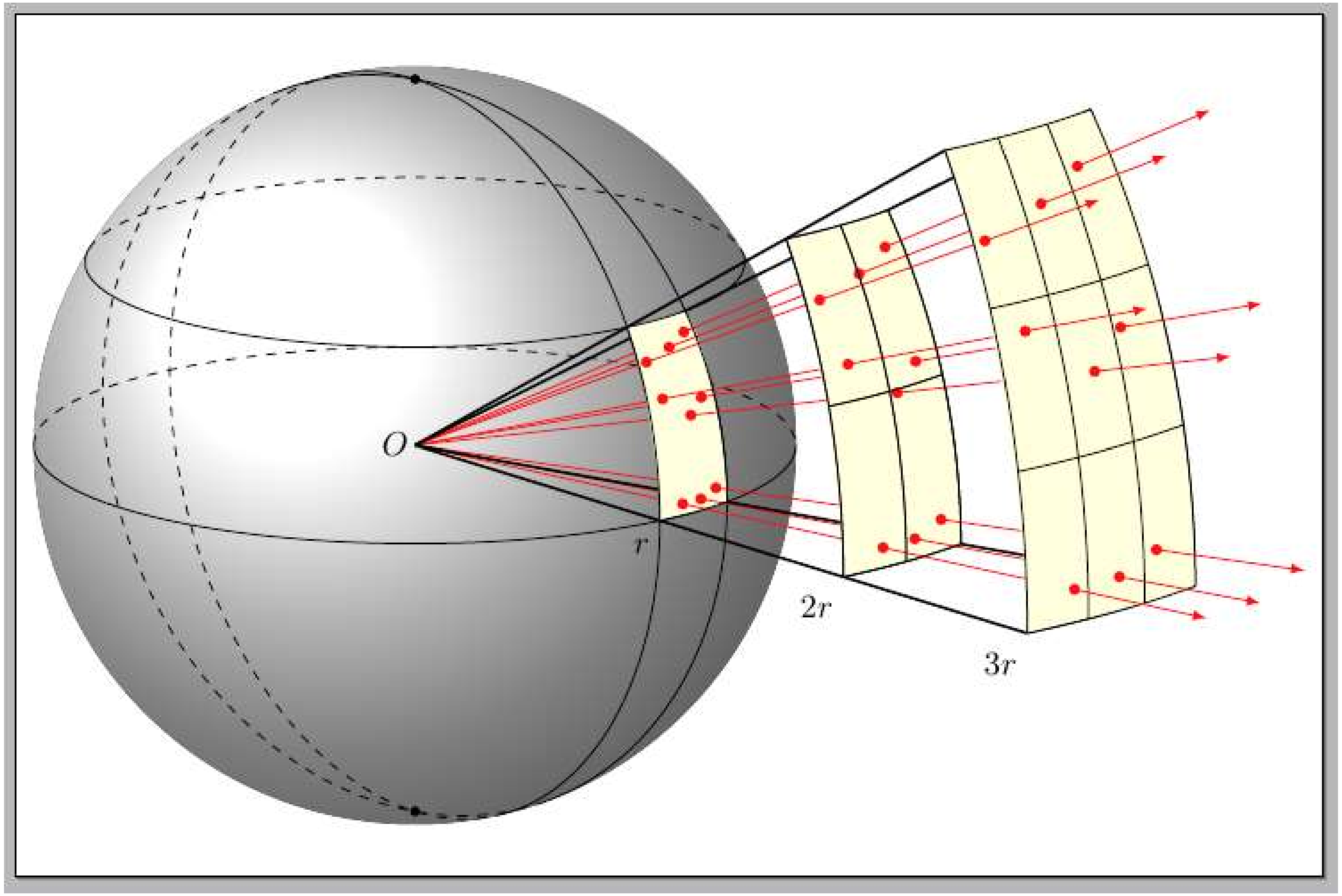
Decibel version of free space path loss equation

- Most RF comparisons and measurements are performed in decibels. This gives an easy and consistent method to compare the signal levels present at various points. Accordingly it is very convenient to express the free space path loss formula, FSPL, in terms of decibels.

$$L_{fs} = 92.45 + 20 \cdot \log(d \cdot f)$$

d = distance in kilometers f = frequency in GHz

▪Free Space Path Loss Diagram

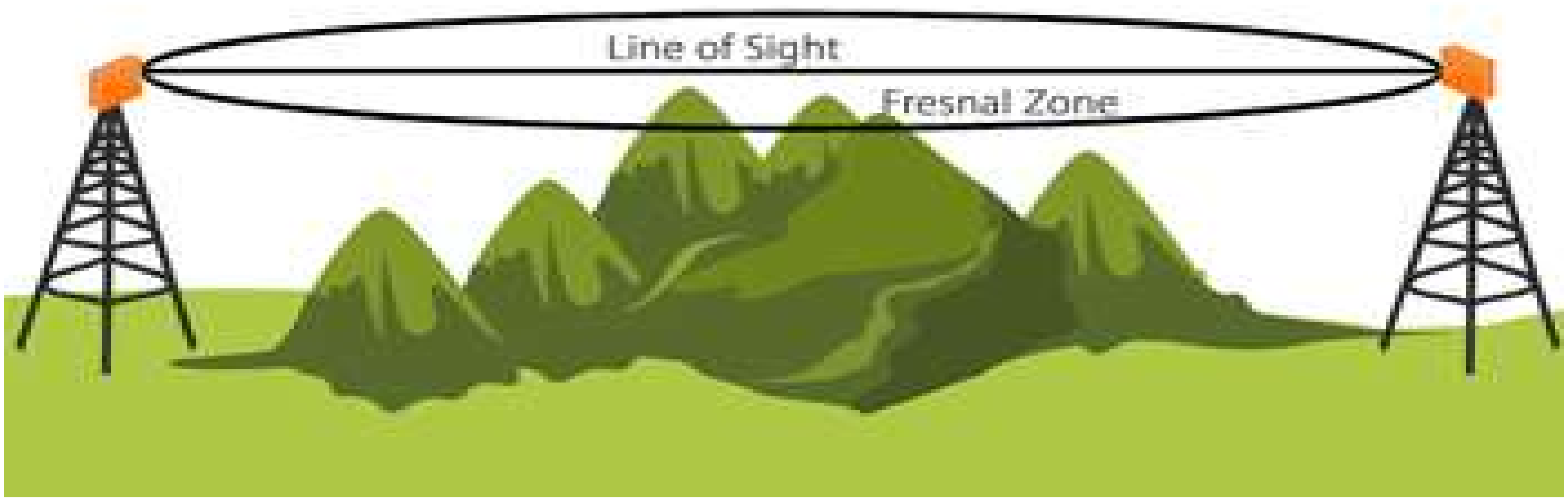


7. Fresnel Zone

- The Fresnel Zone is a volume around the Line of Sight (LOS) that must be clear of any obstacle for the maximum power to reach the receiving antenna.

- Objects in the Fresnel Zone as trees, hilltops and buildings can considerably attenuate the received signal, even when there is an unobstructed line between the TX and RX.

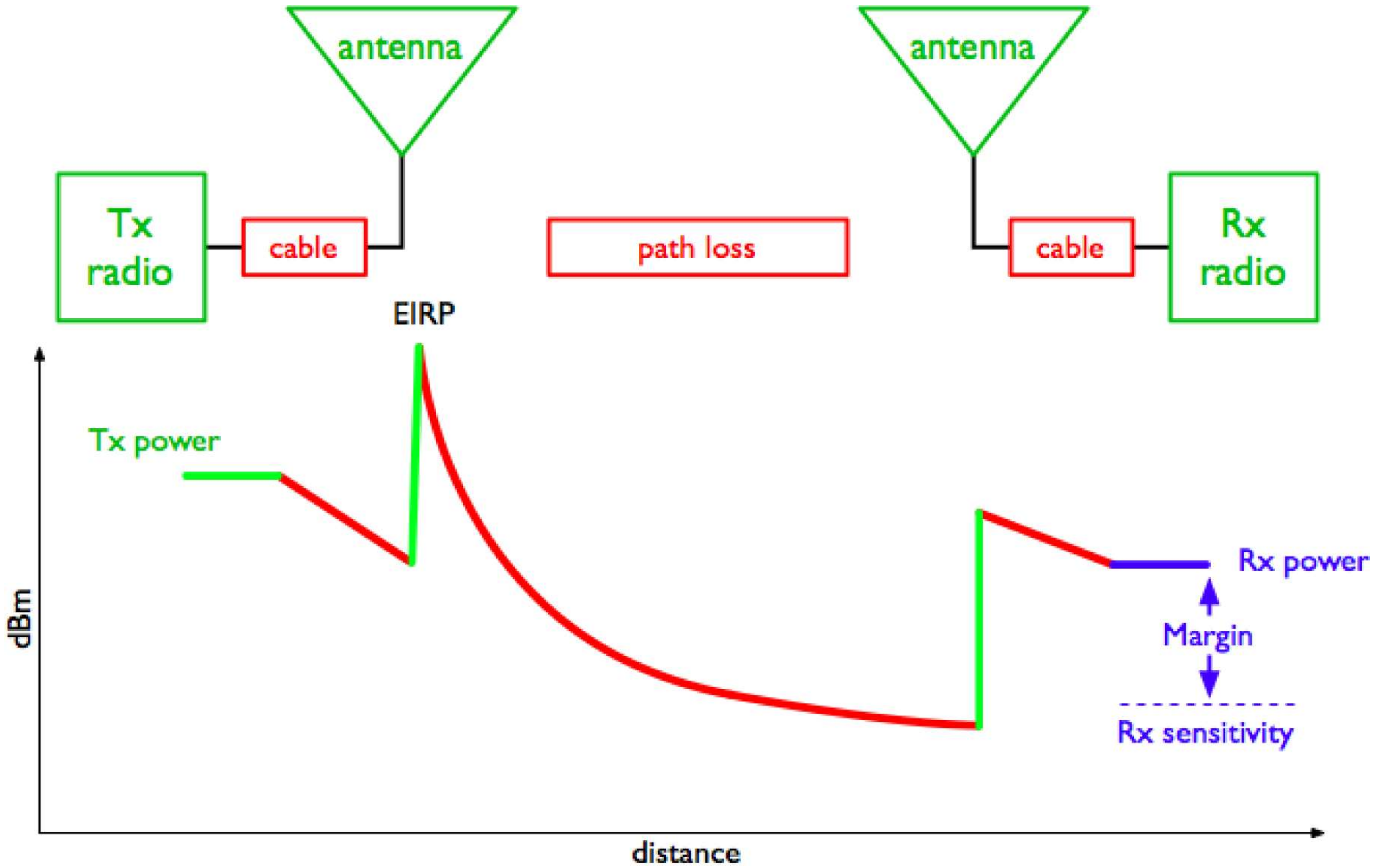
- It is better that no more than 20% blockage of the Fresnel Zone.



8. Link budget

- ***Link budget*** is a way of evaluating the link performance of the link and it is a calculation to decide whether there is enough signal strength to meet the receiver's minimum requirements
- The received power in the wireless link is determined by three factors: ***transmit power***, ***transmitting antenna gain***, ***receiving antenna gain, and Losses (cable loses and Free Space Lose)***
- The difference between the minimum received signal level and the actual received power is called the ***link budget*** or ***link margin***.
- The link margin must be positive, and should be maximized (should be at least 10dB or more for reliable links).

▪ Link Budget calculation



Example of Wireless AP Specifications

SYSTEM INFORMATION	
Processor Specs	Atheros MIPS 4KC, 180MHz
Memory Information	16MB SDRAM, 4MB Flash
Networking Interface	1 X 10/100 BASE-TX (Cat. 5, RJ-45) Ethernet Interface

REGULATORY / COMPLIANCE INFORMATION	
Wireless Approvals	FCC Part 15.247, IC RS210, CE
RoHS Compliance	YES

RADIO OPERATING FREQUENCY 2412-2462 MHz

TX SPECIFICATIONS			
	DataRate	TX Power	Tolerance
802.11b	1Mbps	20 dBm	+/-1dB
	2Mbps	20 dBm	+/-1dB
	5.5Mbps	20 dBm	+/-1dB
	11Mbps	20 dBm	+/-1dB
802.11g OFDM	6Mbps	20 dBm	+/-1dB
	9Mbps	20 dBm	+/-1dB
	12Mbps	20 dBm	+/-1dB
	18Mbps	20 dBm	+/-1dB
	24Mbps	20 dBm	+/-1dB
	36Mbps	18 dBm	+/-1dB
	48Mbps	16 dBm	+/-1dB
	54Mbps	15 dBm	+/-1dB

RX SPECIFICATIONS			
	DataRate	Sensitivity	Tolerance
802.11b	1Mbps	-95 dBm	+/-1dB
	2Mbps	-94 dBm	+/-1dB
	5.5Mbps	-93 dBm	+/-1dB
	11Mbps	-90 dBm	+/-1dB
802.11g OFDM	6Mbps	-92 dBm	+/-1dB
	9Mbps	-91 dBm	+/-1dB
	12Mbps	-89 dBm	+/-1dB
	18Mbps	-88 dBm	+/-1dB
	24Mbps	-84 dBm	+/-1dB
	36Mbps	-81 dBm	+/-1dB
	48Mbps	-75 dBm	+/-1dB
	54Mbps	-72 dBm	+/-1dB

▪Link Budget Calculation Example

Estimate the feasibility of a **5 km** link, with one access point and one client radio.
The access point is connected to an antenna with **10 dBi** gain, with a transmitting power of **20 dBm** and a receive sensitivity of **-89 dBm**.
The client is connected to an antenna with **14 dBi** gain, with a transmitting power of **15 dBm** and a receive sensitivity of **-82 dBm**.
The cables in both systems are short, with a loss of **2dB** at each side at the **2.4 GHz** frequency of operation.

The solution should have two parts:

1) From Access Point to Client Radio
2) From Client Radio to Access Point.

- Solution for link budget calculation Part 1

- Free Space Loss Calculation

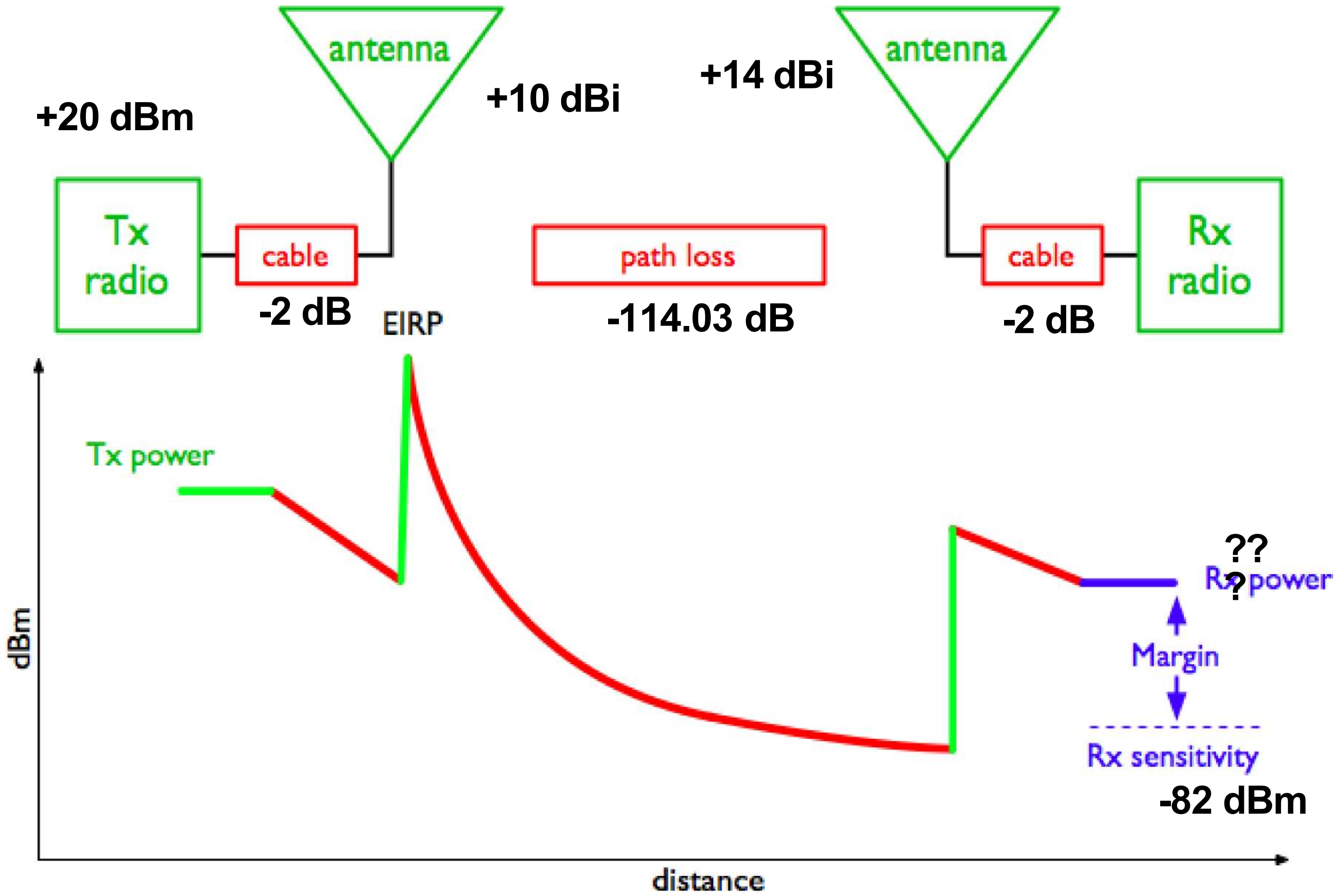
$$FSPL = 92.45 + (20 \log_{10} (d . f))$$

FSPL = path loss in dB
f = frequency in GHz
d = distance in kilometers between antennas

In the example f= 2.4 GHz , d = 5 Km

$$FSPL = 92.45 + 20 \times \log_{10} (5 \times 2.4) = 114.03 \text{ dB}$$

Part -1: AP to Client link



Link budget – Part 1: AP to Client link

+20	dBm (TX Power AP)
- 2	dB (Cable Losses AP)
+ 10	dBi (Antenna Gain AP)
-114.03	dB (free space loss @5 km)
+ 14	dBi (Antenna Gain Client)
- 2	dB (Cable Losses Client)

- 74.03 dBm (expected received signal level)

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\- 82.00 dBm (sensitivity of Client)

\+ 7.97 dB (link margin)

- Solution for link budget calculation Part 2

- Free Space Loss Calculation

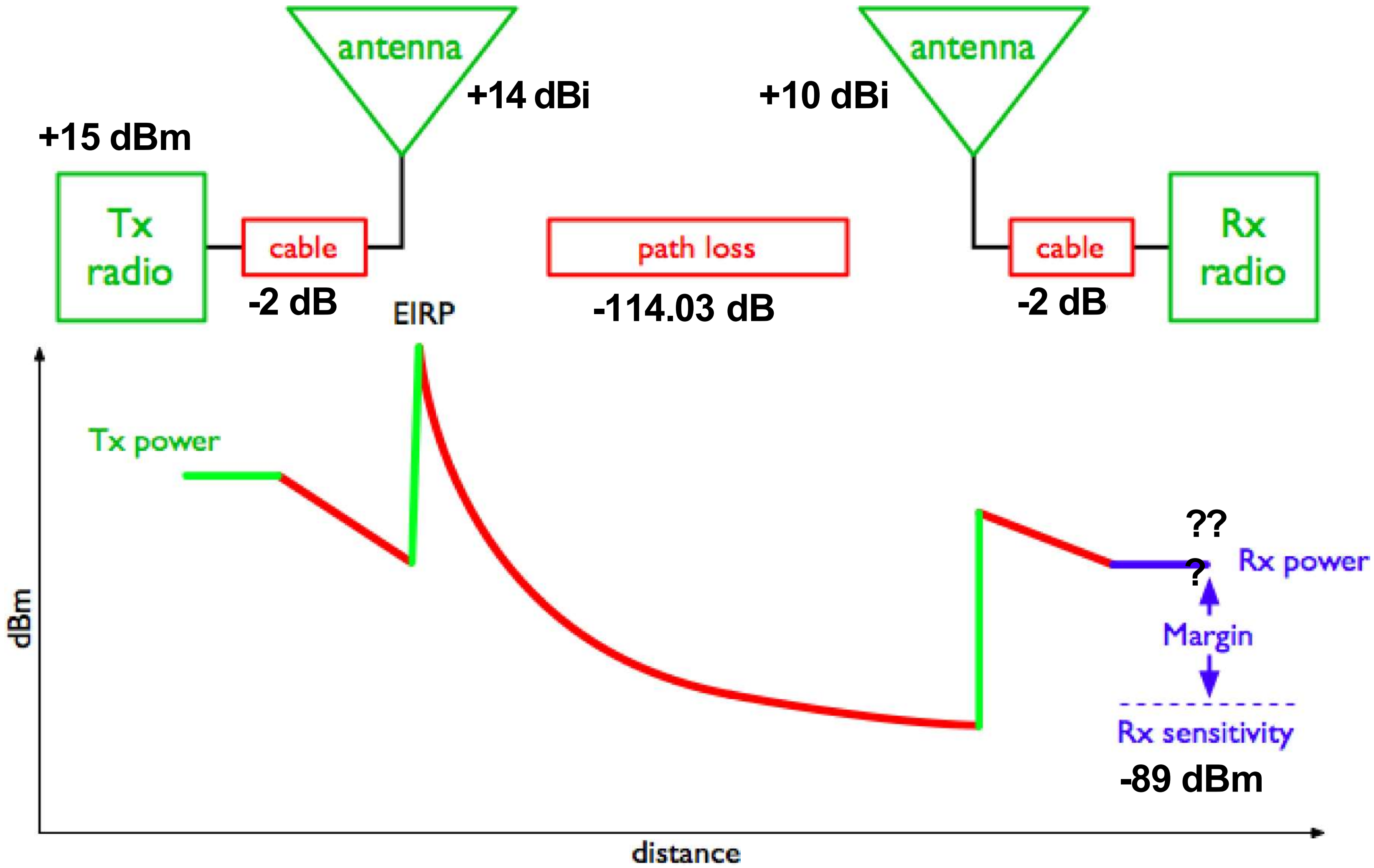
$FSPL = 92.45 + (20 \log_{10} (d \cdot f))$

FSPL = path loss in dB
f = frequency in GHz
d = distance in kilometers between antennas

In the example f= 2.4 GHz , d = 5 Km

$FSPL = 92.45 + 20 \times \log_{10} (5 \times 2.4) = 114.03$ dB

Part 2: Client to AP



Link budget-Part 2: Client to AP link

+15 dBm (TX Power Client)
- 2 dB (Cable Losses Client)
+ 14 dBi (Antenna Gain Client)
-114.03 dB (free space loss @5 km)
+ 10 dBi (Antenna Gain AP)
- 2 dB (Cable Losses AP)

- 79.03 dBm (expected received signal level)

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- 89.00 dBm (sensitivity of AP)

+ 9.97 dB (link margin)