

# Frequency, Range and type of Wireless Communication

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# Radio Frequency

Designation	Frequency	Wavelength
<b>ELF</b> extremely low frequency	3Hz to 30Hz	100'000km to 10'000 km
<b>SLF</b> superlow frequency	30Hz to 300Hz	10'000km to 1'000km
<b>ULF</b> ultralow frequency	300Hz to 3000Hz	1'000km to 100km
<b>VLF</b> very low frequency	3kHz to 30kHz	100km to 10km
<b>LF</b> low frequency	30kHz to 300kHz	10km to 1km
<b>MF</b> medium frequency	300kHz to 3000kHz	1km to 100m
<b>HF</b> high frequency	3MHz to 30MHz	100m to 10m
<b>VHF</b> very high frequency	30MHz to 300MHz	10m to 1m
<b>UHF</b> ultrahigh frequency	300MHz to 3000MHz	1m to 10cm
<b>SHF</b> superhigh frequency	3GHz to 30GHz	10cm to 1cm
<b>EHF</b> extremely high frequency	30GHz to 300GHz	1cm to 1mm

Fig.1: Frequency and Wavelength

<b>THF</b>	<b>Tremendously high frequency</b>	<b>300 GHz - 3 THz</b>	<b>1 mm - 0.1 mm (1</b>
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## Penetration - Use

Seawater- Pipeline Inspection Guage/Submarine Communication  
 Seawater - Submarine Communication

Earth- Communication in Mines /

40m in Saltwater - Wireless Telegraph

Kilometer wave - Long Distance Communication

Hectometer wave - AM Radio Broadcasting

Decameter wave - Shortwave radio, aviation communication

- FM radio, Air Traffic Controller, TV Broadcast

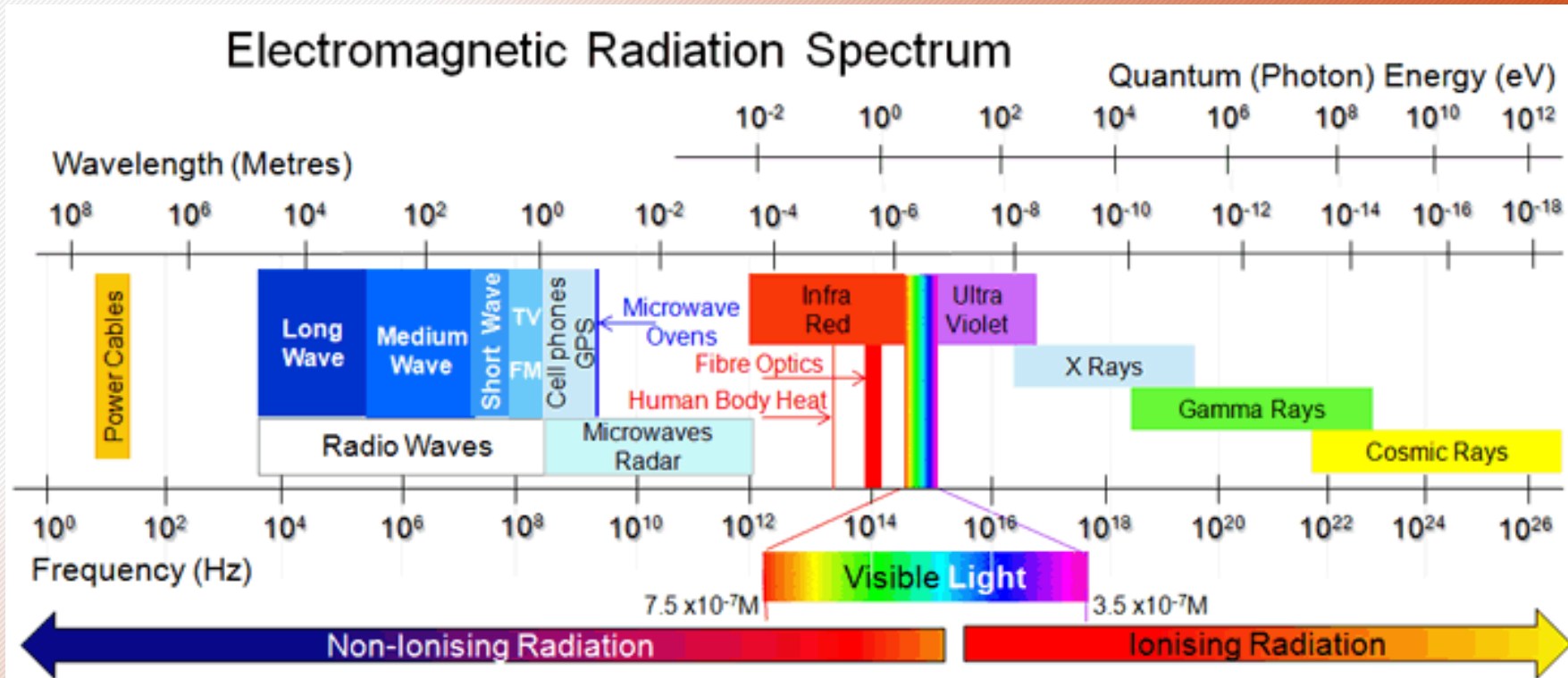
Decimeter wave - GPS, Satellite Comm, Wi-Fi, Bluetooth

Centimeter wave - Microwave radio, Wireless USB, Radar

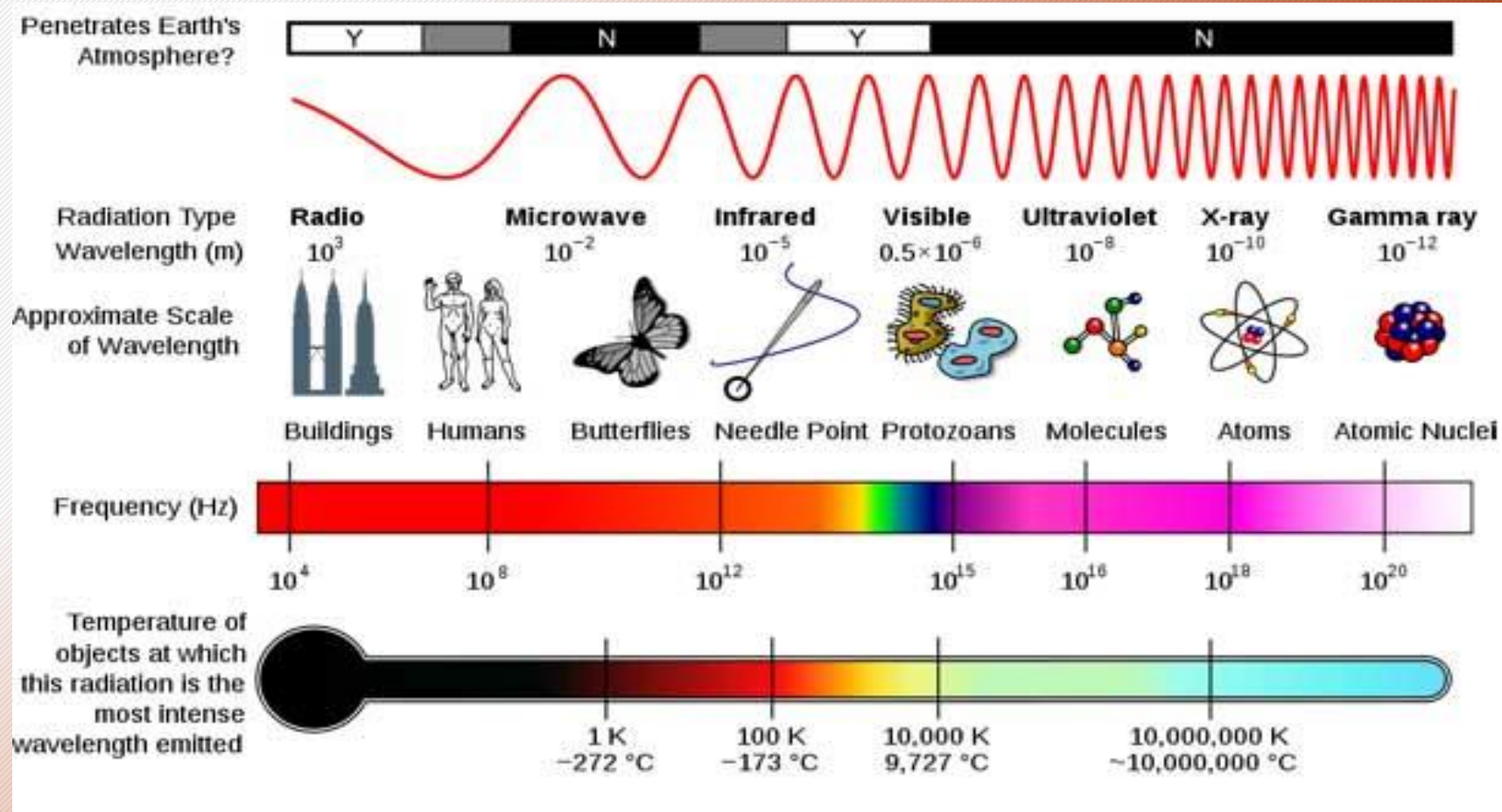
Milimeter wave - Radio Astronomy/5G Mobile phones (Expected)

Radio Wave - Experimental medical imaging to replace X-rays, terahertz computing/communications, remote sensing

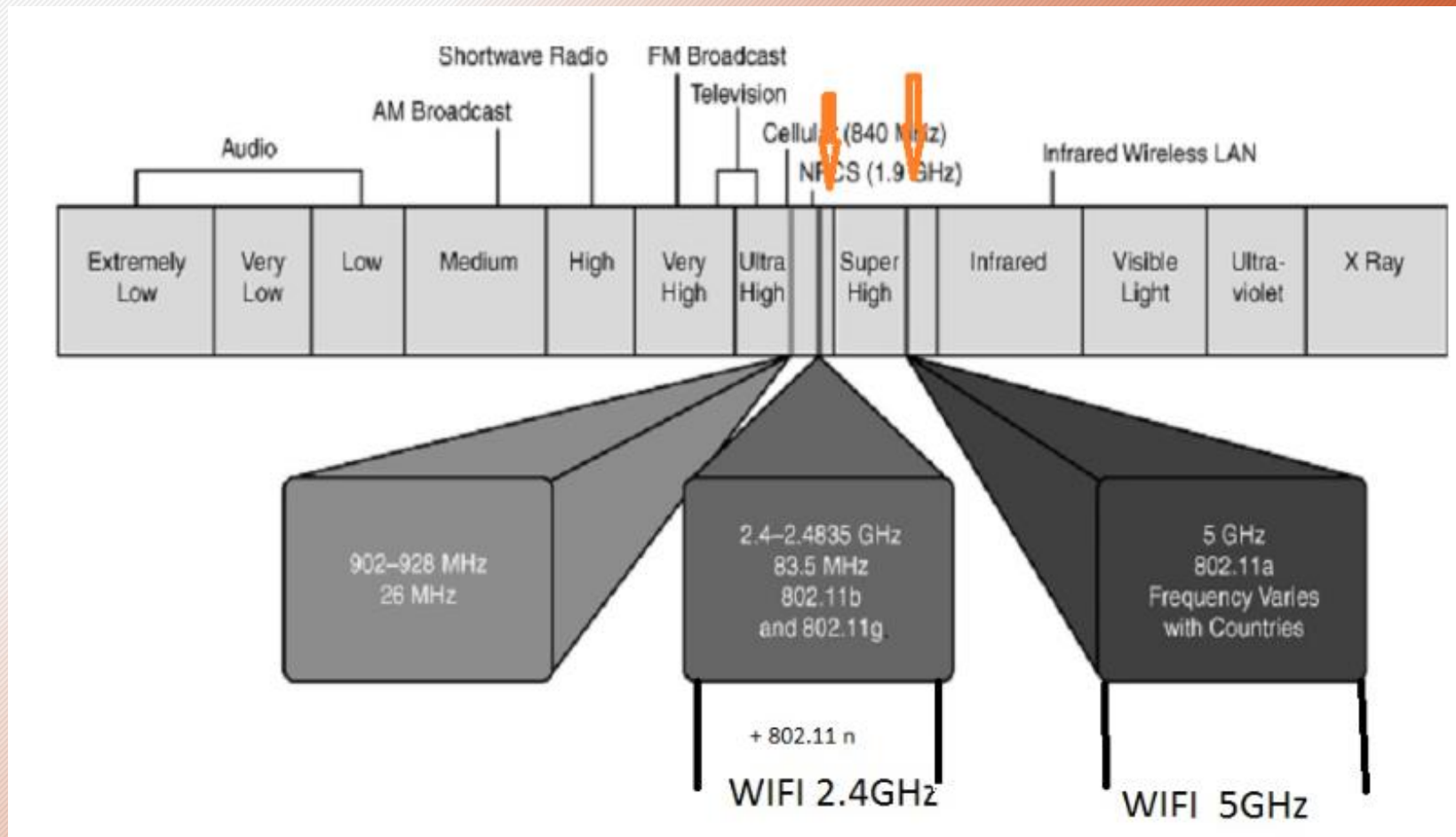
# Electromagnetic Radiation Spectrum



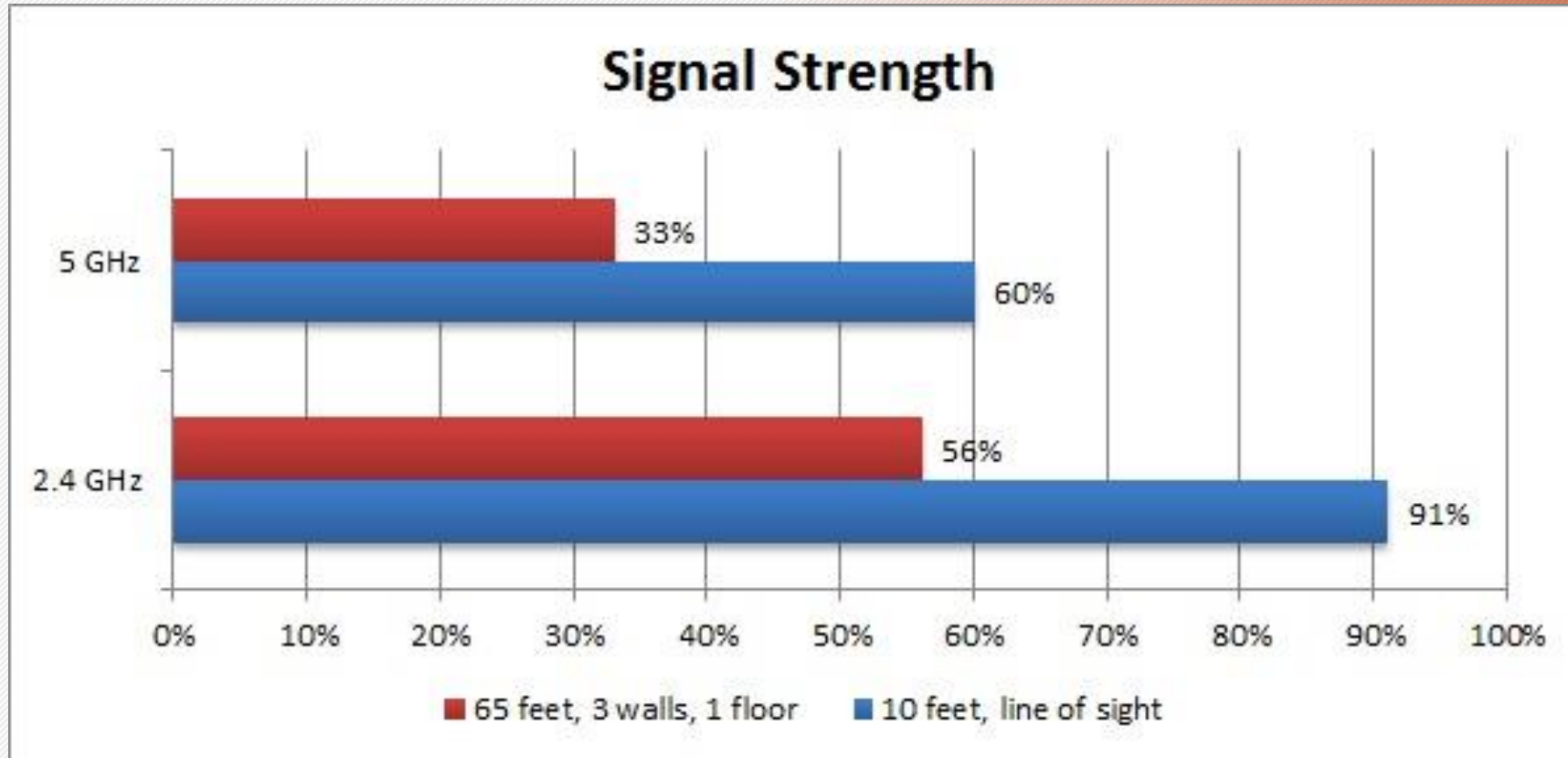
# Frequency and Approximate Scale of Wavelength



# Location of 802.11 Spectrum



# 2.4 GHz and 5 GHz Signal Strength



$$\text{Free Space Path Loss} = \left( \frac{4 \pi d}{\lambda} \right)^2$$

or

$$\text{Free Space Path Loss} = \left( \frac{4 \pi d f}{c} \right)^2$$

$$\lambda := \frac{c}{f} \quad \text{Range(PL)} := \frac{\lambda}{4 \cdot \pi} \cdot 10^{\frac{\text{PL}}{20}}$$

Equation 1-1: Free Space Range

# Towards THz Communications

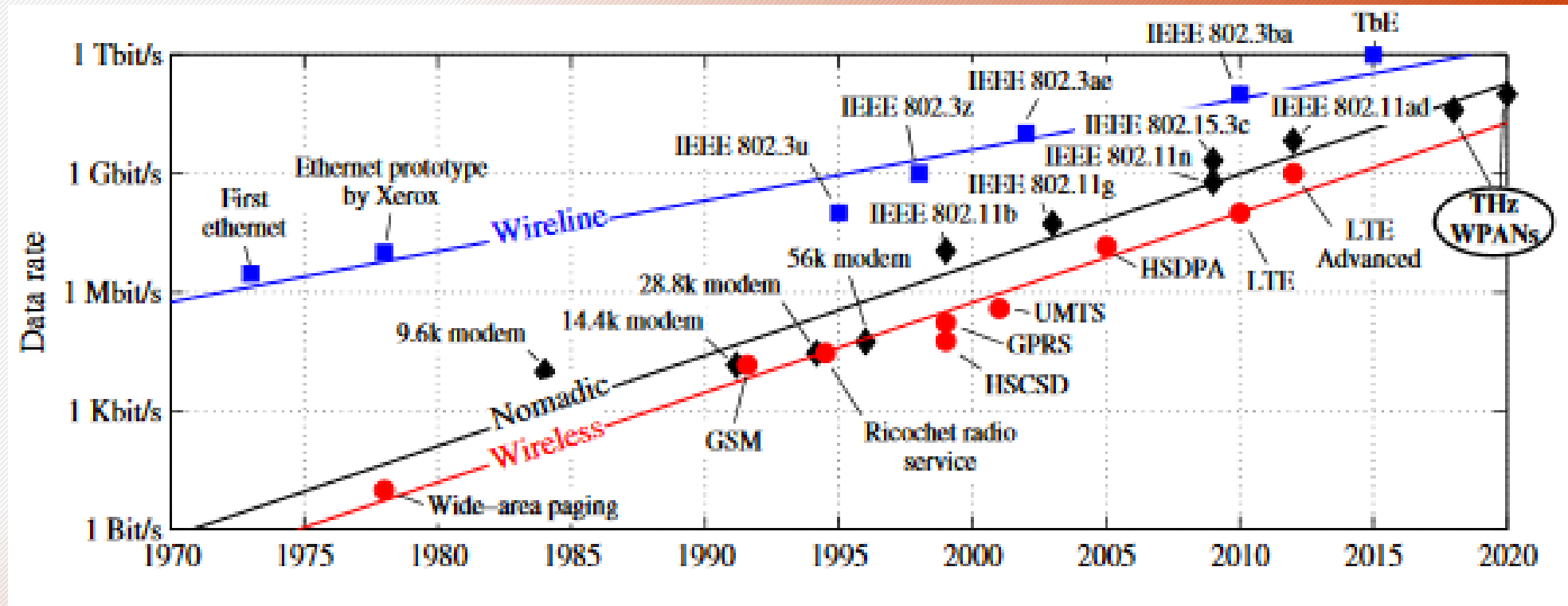
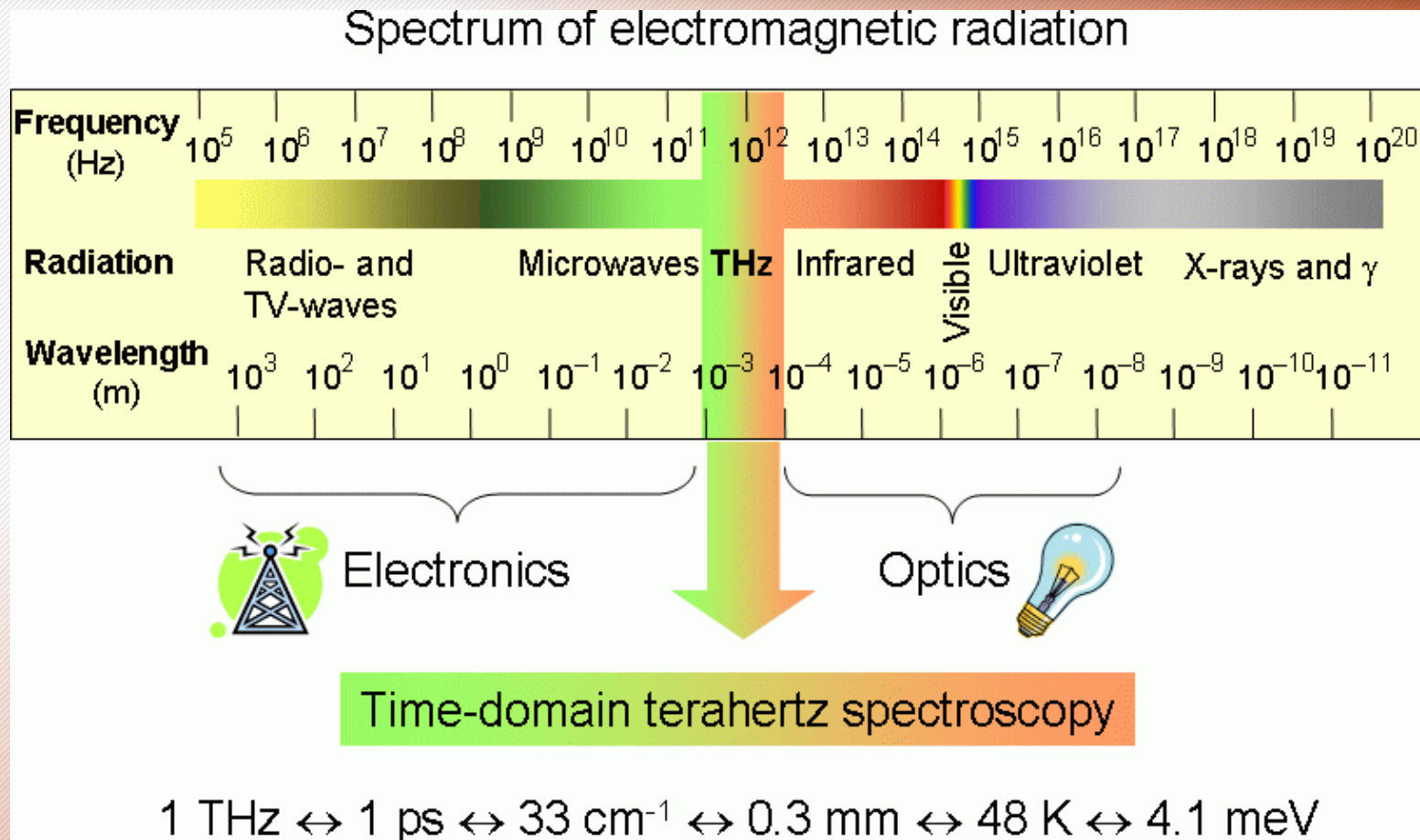


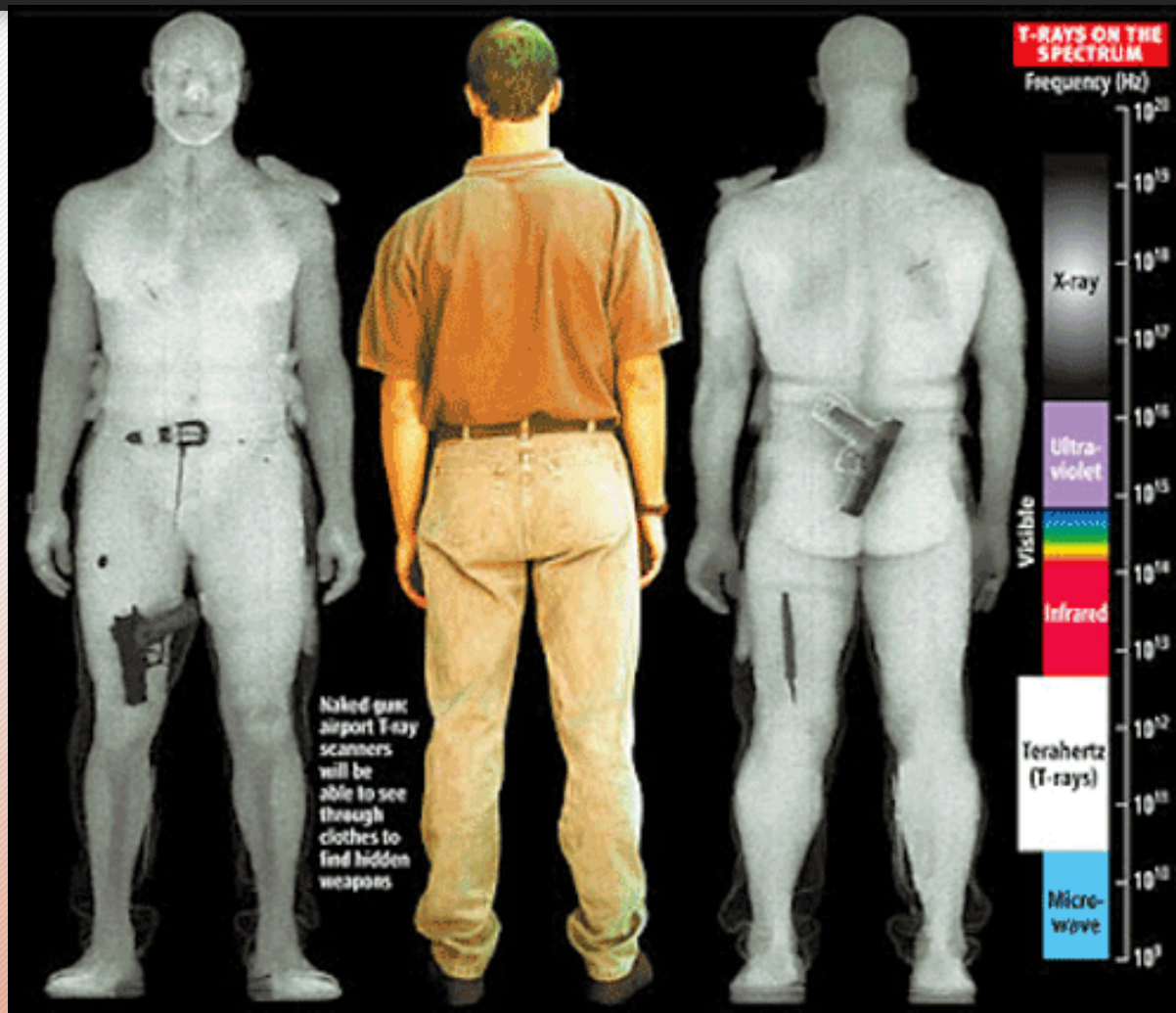
Fig.2: Development of data rates in wireline, nomadic and wireless systems

# Time-domain Terahertz Spectroscopy

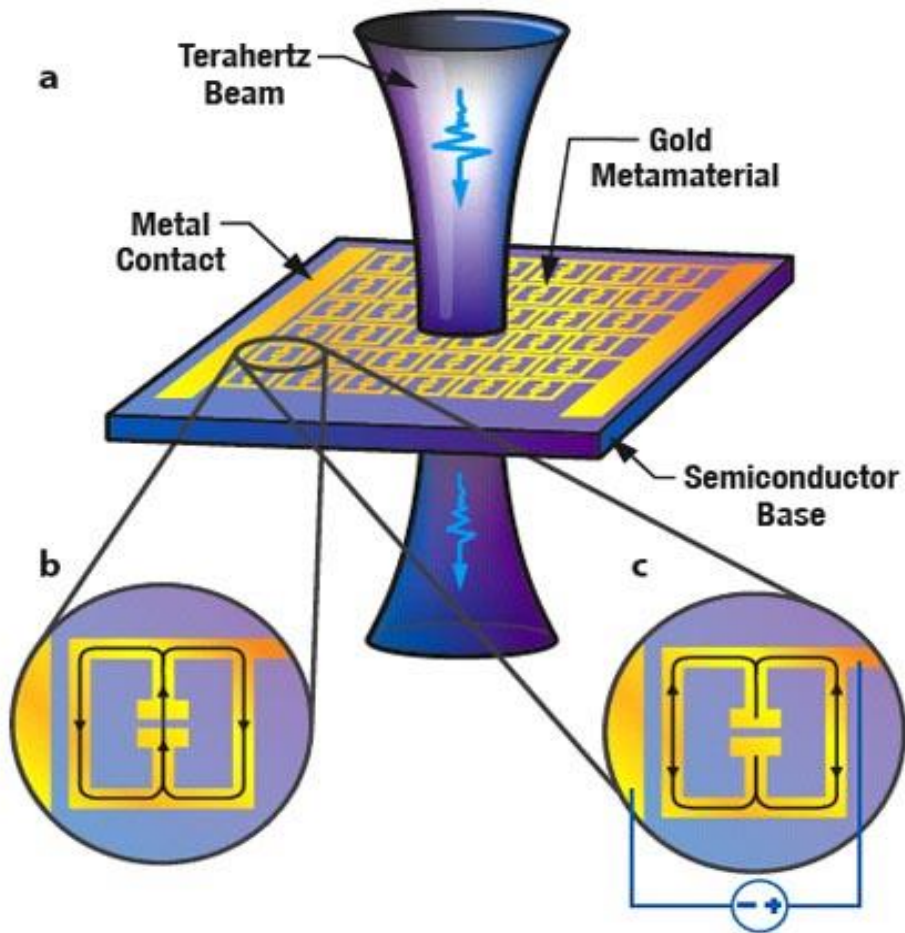




# T-Rays on the Spectrum



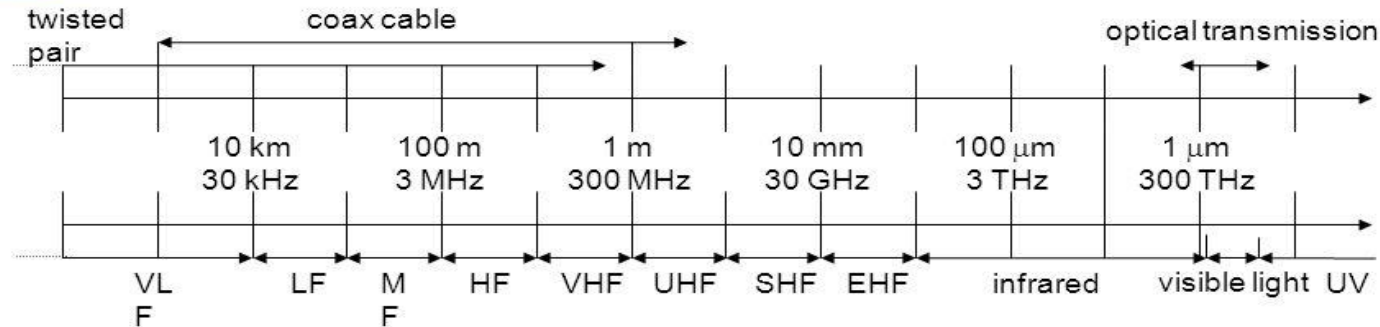
# T-ray metamaterial semiconductor modulator



- C-DOT-rays shine through the modulator.
- With no voltage applied, electrons can flow across the gap in the gold structure. The electrons absorb a few T-rays as they flow easily around the two loops.
- Applying voltage prevents electrons from crossing the gap. But they absorb far more T-rays as they slosh back and forth between the upper and lower halves of the structure. Fewer T-rays pass through the device.

# Communication Frequencies

## Communication Frequencies



Frequency and wave length:

$$\lambda = c/f$$

wave length  $\lambda$ , speed of light  $c \cong 3 \times 10^8 \text{m/s}$ , frequency  $f$

# Comparison of conventional and THz communication channels

	2.4 GHz, 5 GHz	60 GHz	300 GHz
Path loss at 10 m	$\approx 60$ dB	$\approx 88$ dB	$\approx 101$ dB
Output powers	Limited by regulations $\approx 22$ dBm	Limited by technology and regulations; typically $\approx 10$ dBm	Currently limited by technology $\ll 10$ dBm
Antennas	Omnidirectional ( $\approx 3$ dBi)	Medium directivities (15...25 dBi)	High directivities (20...40 dBi)
Bandwidths	40 MHz	$\approx 2$ GHz	10...100 GHz
Data rates	600 Mbit/s	$\approx 4$ Gbit/s	100 Gbit/s and beyond

# Why Actual Range May Not Equal Stated Range???

# RF Power And dBm

- RF power is expressed in db with milliwatt i.e., dBm

## dBm to mW conversion:

- $P(\text{dBm}) = 10 \cdot \log_{10}(P(\text{mW}))$
- $P(\text{mW}) = 10^{(P(\text{dBm})/10)}$

# Path Loss

- Path loss = transmit power - receiver sensitivity + gains - losses
- Received power = transmit power + gains - losses
- Maximum path loss = transmit power - receiver sensitivity + gains - losses - fade margin

## RF Propagation Basic loss formula

Propagation Loss

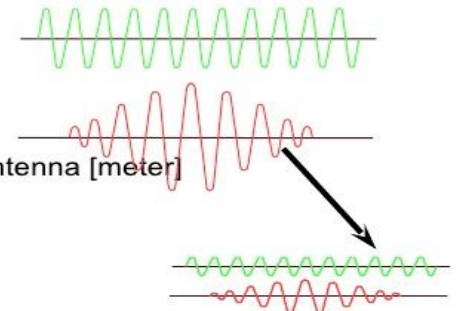
$$P_R = P_T * G * \left(\frac{\lambda}{4\pi d}\right)^2$$

d = distance between Tx and Rx antenna [meter]

P<sub>T</sub> = transmit power [mW]

P<sub>R</sub> = receive power [mW]

G = antennae gain



**P<sub>r</sub> ~ 1/f<sup>2</sup> \* D<sup>2</sup> which means 2X Frequency = 1/4 Power**  
**2 X Distance = 1/4 Power**

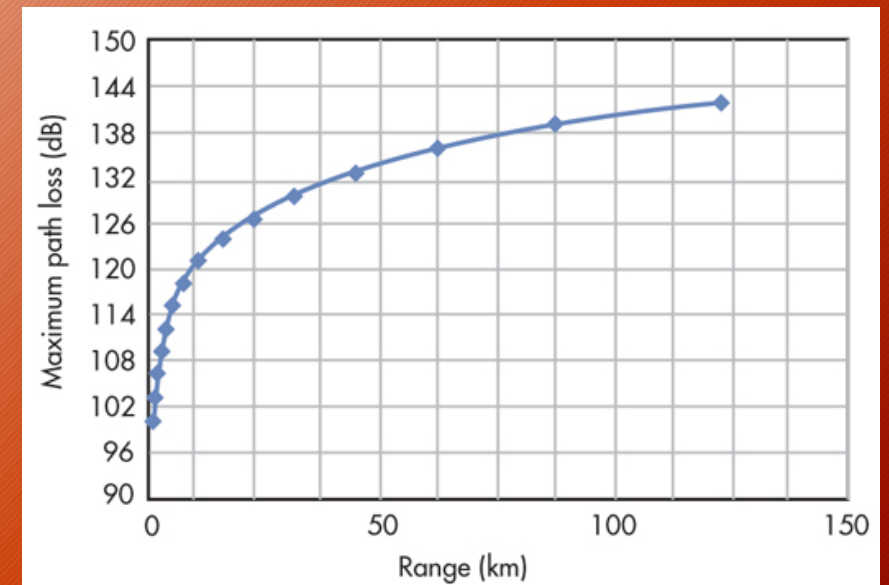
# Range

- Once the maximum path loss has been found, you can find the range from the formula:
- Distance (km) =  $10^{(\text{maximum path loss} - 32.44 - 20\log(f))/20}$

## Factors effecting the range:

- 1) Antenna gain
- 2) Antenna height
- 3) Interference

The relationship between the maximum path loss and range at a frequency of 2.45 GHz.



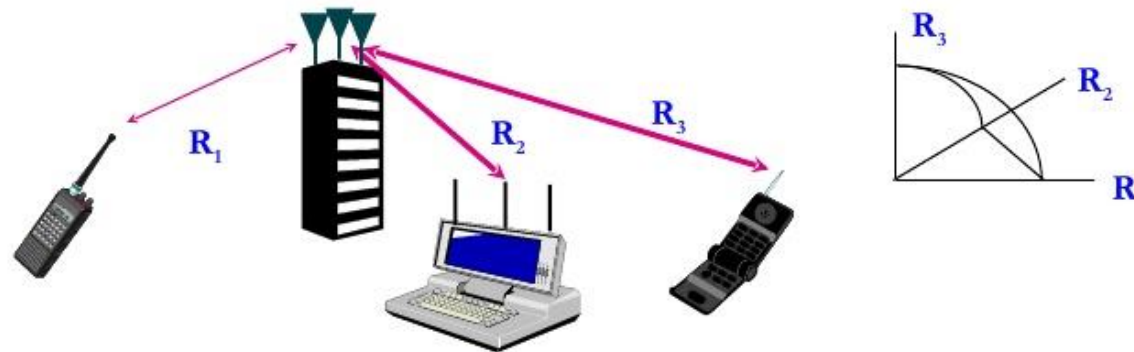
The curve shows the relationship between the link budget or maximum path loss in dBm and estimated range in kilometers.



# Wireless Channel Capacity

## Wireless Channel Capacity *Fundamental Limit on Data Rates*

Capacity: The set of simultaneously achievable rates  $\{R_1, \dots, R_n\}$



- Main drivers of channel capacity
  - Bandwidth and power
  - Statistics of the channel
  - Channel knowledge and how it is used
  - Number of antennas at TX and RX

# AWGN channel (single-antenna, point-to-point scenario)

## Additive White Gaussian Noise

If the average received power is  $\bar{P}$  [W] and the noise power spectral density is  $N_0$  [W/Hz], the AWGN channel capacity is

$$C_{\text{AWGN}} = W \log_2 \left( 1 + \frac{\bar{P}}{N_0 W} \right) \text{ [bits/s]},$$

where  $\frac{\bar{P}}{N_0 W}$  is the received signal-to-noise ratio (SNR). This result is known as the Shannon–Hartley theorem.<sup>[6]</sup>

# Shannon-Hartley Theorem

## Channel Capacity

Theoretical limit on the speed of information transmission is given by Shannon-Hartley theorem:

$$C = B \log_2 \left( 1 + \frac{S}{N} \right).$$

Here:

$C$  — maximal theoretical channel capacity (bits/sec);

$B$  — bandwidth (hertz);

$S$  — signal power (watts);

$N$  — noise power (watts).

In case of wideband signal:

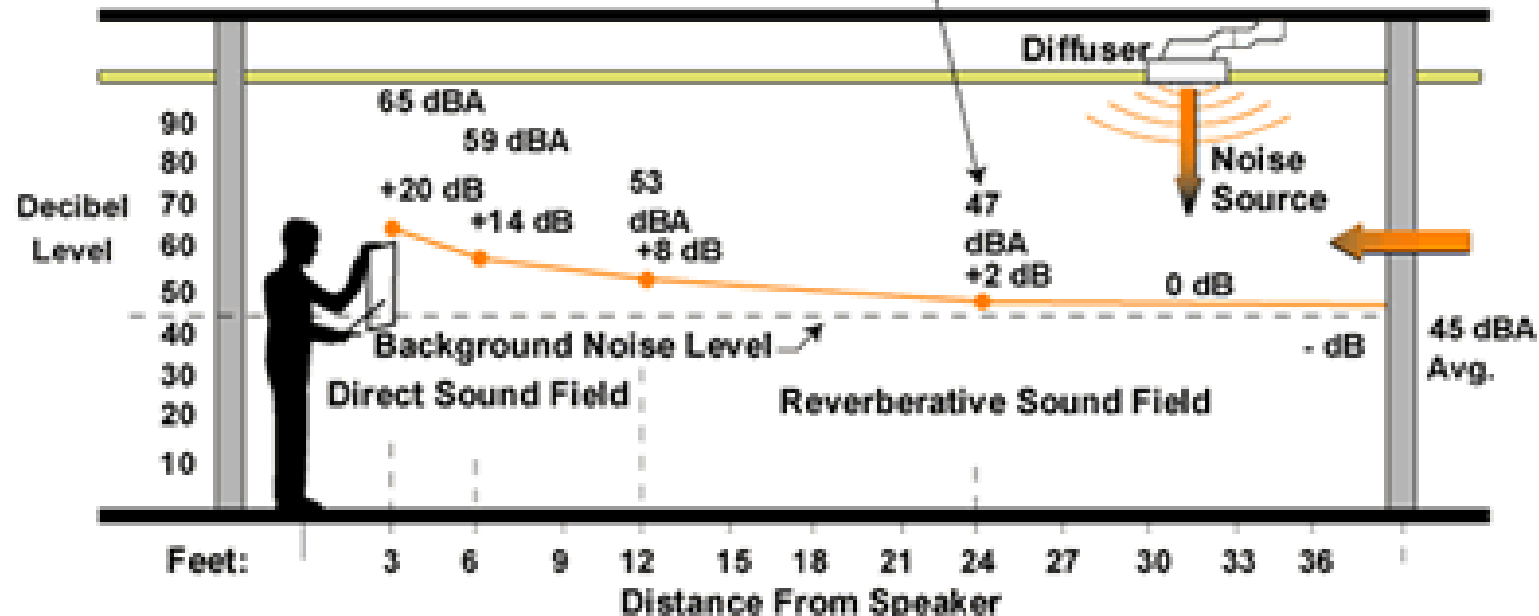
$$C = \int_{f_{min}}^{f_{max}} \log_2 \left( 1 + \frac{S(f)}{N(f)} \right) df.$$

# Signal to Noise Ratio

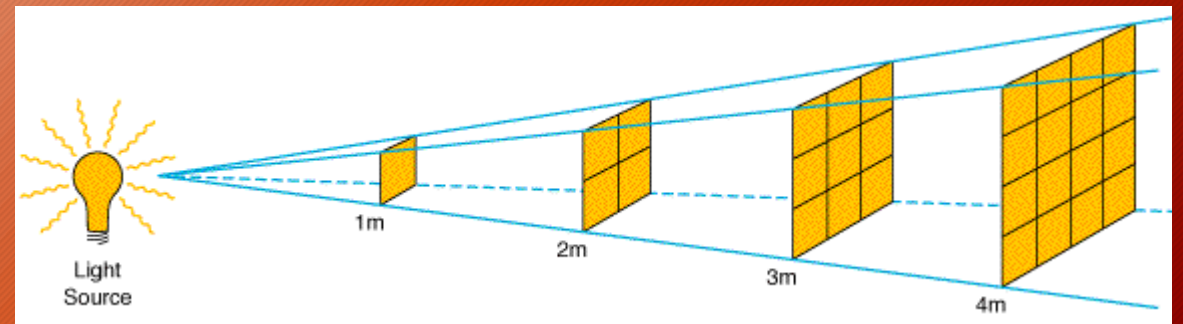
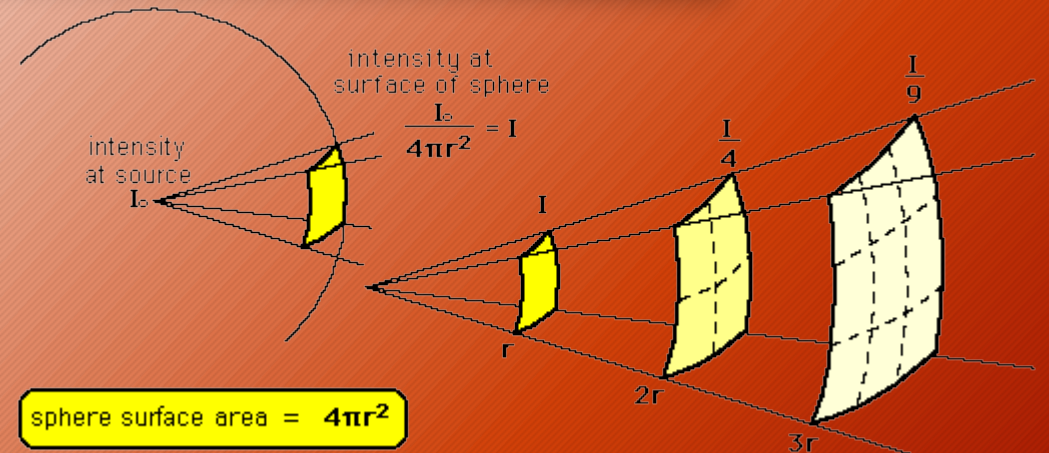
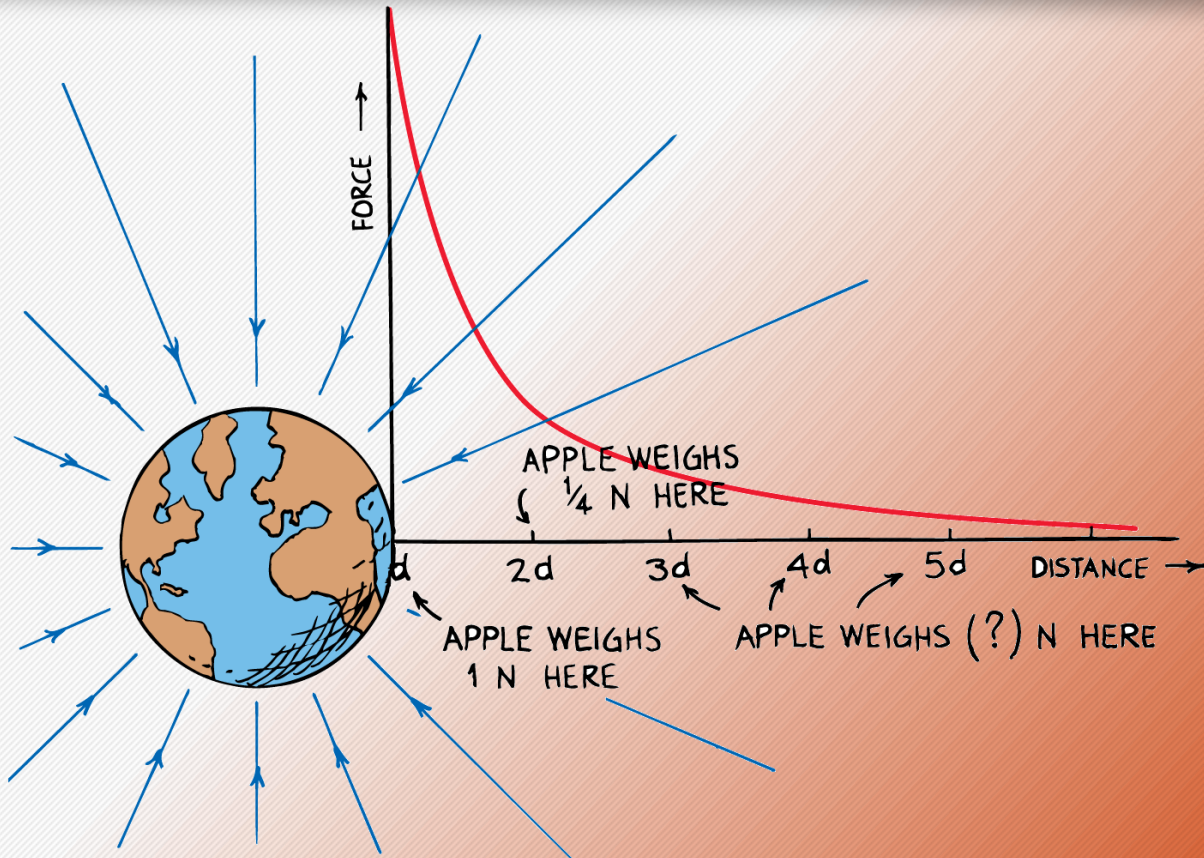
## SIGNAL-TO-NOISE RATIO (SNR)

The sound level at the listener's ear, above the background noise level.

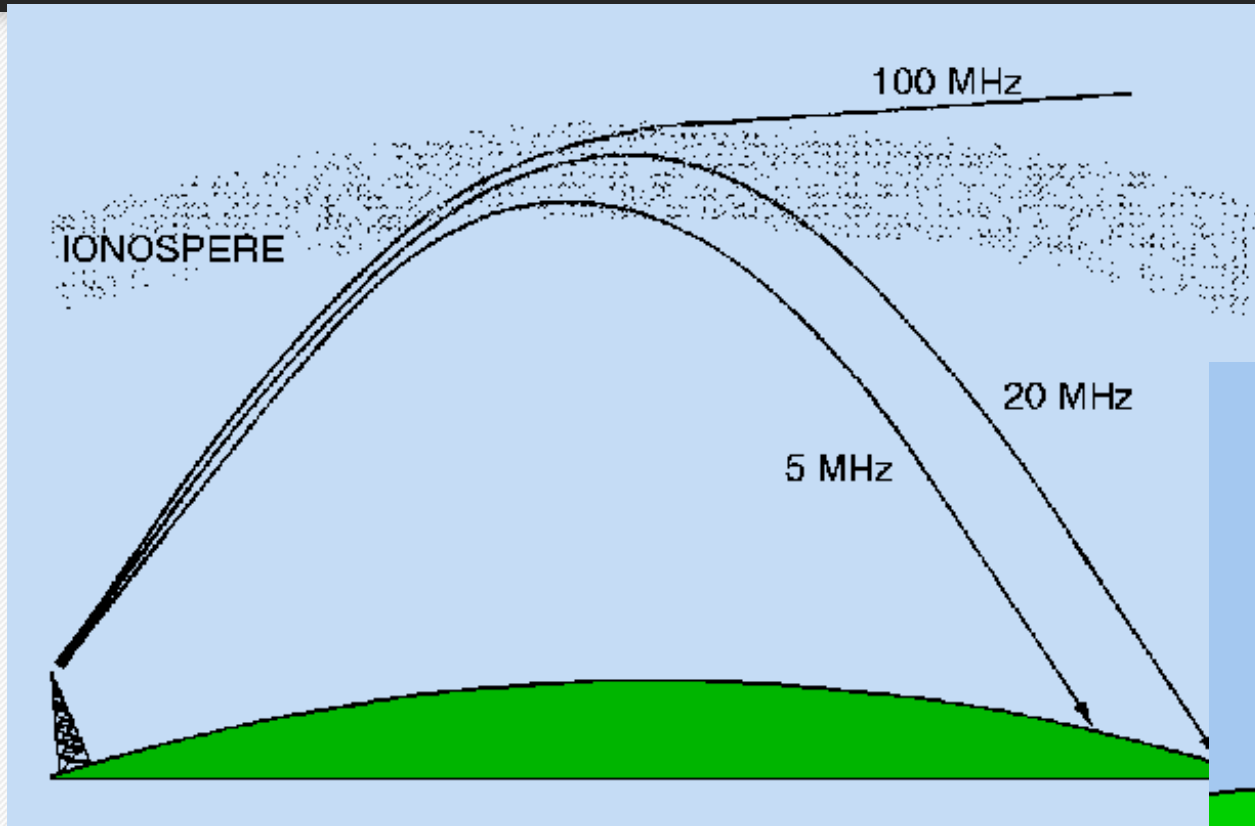
If the Signal at listener's ear is 47 decibels and the background Noise level is 45 decibels, the S/NR = +2 dB.



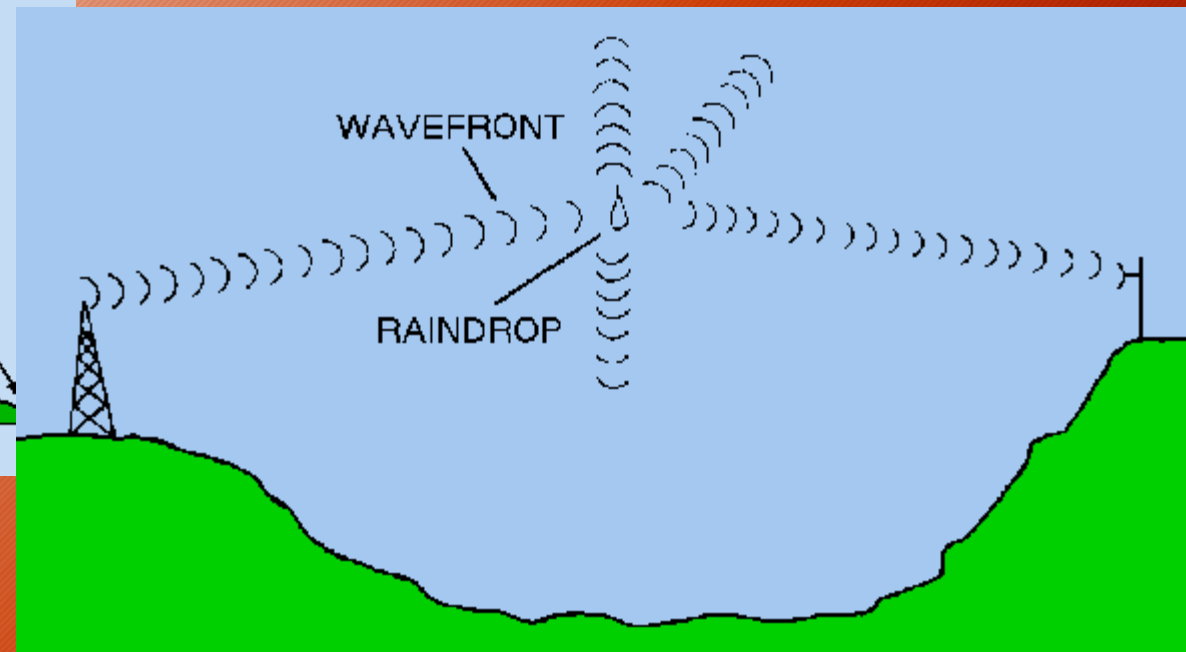
# Power of transmitted signals



# Wave fades with distance



## Wave Diffraction



# Wave fading types

## Fading

- Types of Fading
  - Multipath Fading
  - Frequency Selective Fading
  - Rain Fading

## Fading - Types

- Slow (Long) Term
  - Fast (Short) Term (Also known as Rayleigh fading)

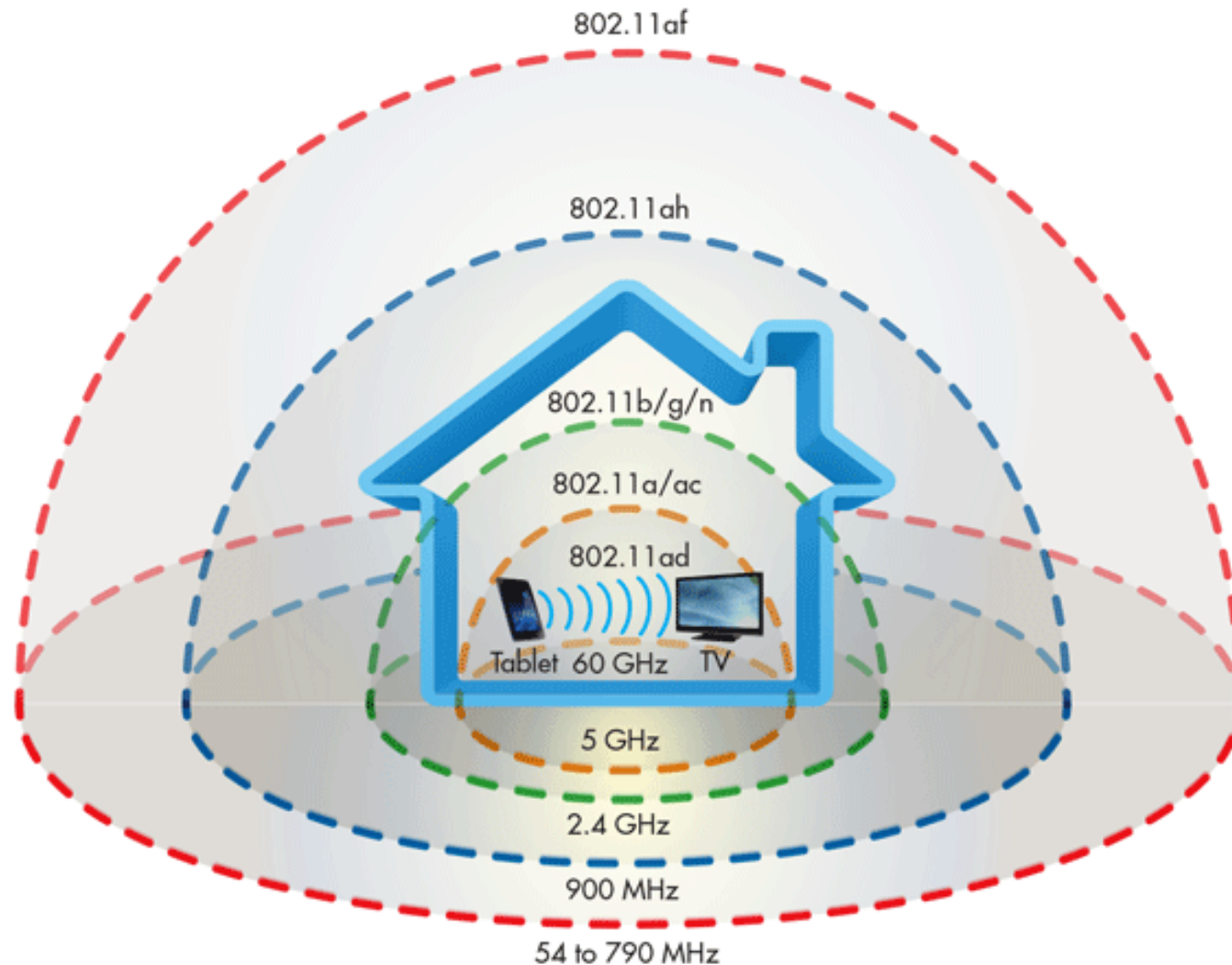


Exact representation of fading characteristics is not possible, because of infinite number of situation.

## Fading Models

- Nakagami fading
- Rayleigh fading
- Rician fading
- Dispersive fading models, with several echoes, each exposed to different delay, gain and phase shift, often constant. This results in frequency selective fading and inter-symbol interference. The gains may be Rayleigh or Rician distributed. The echoes may also be exposed to doppler-shift, resulting in a time varying channel model.
- Log-normal shadow fading

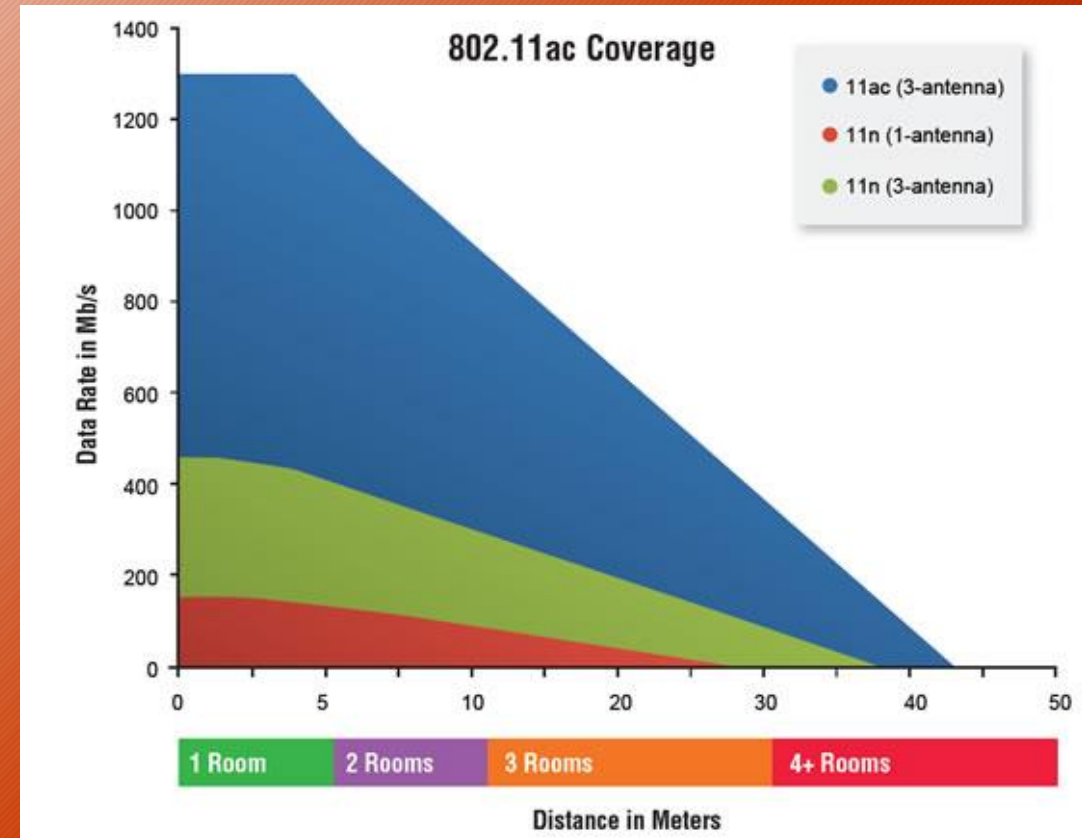
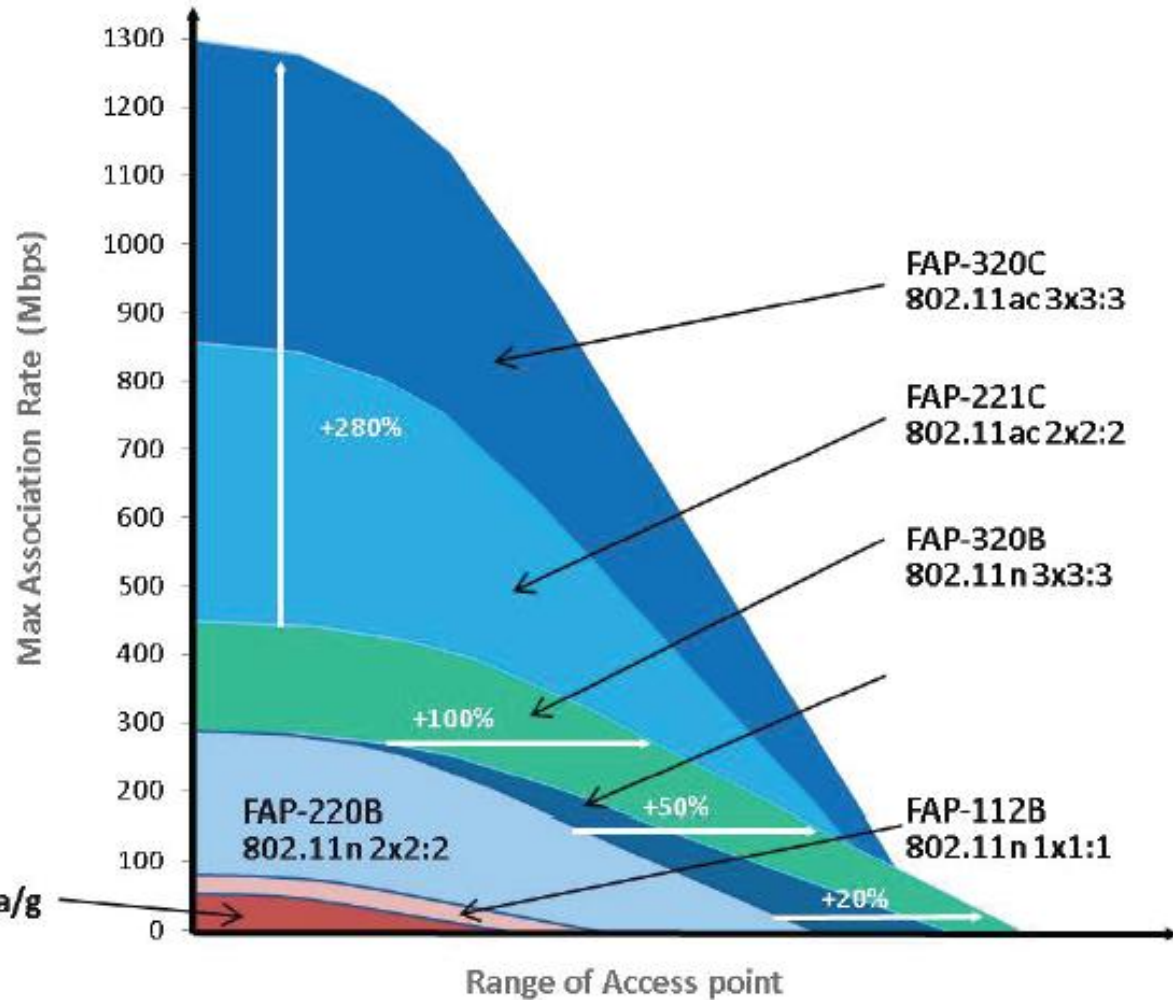
# Range vs Rate



	802.11n	802.11ac	802.11ad
<b>Throughput</b>	600 Mbps	3.2 Gbps	Up to 7 Gbps
<b>Coverage</b>	Home, 70 m	Home, 30 m	Room, <5m
<b>Freq. Band</b>	2.4/5 GHz	5 GHz	2.4/5/60 GHz
<b>Antennas</b>	4 x 4 MIMO	8 x 8 MIMO	>10 x 10 MIMO
<b>Applications</b>	Data, Video	Video	Uncompressed Video



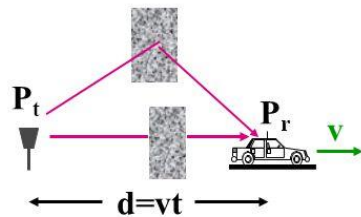
# Range vs Rate cont...



# Propagation Characteristics

## Propagation Characteristics

- Path Loss (includes average shadowing)
- Shadowing (due to obstructions)
- Multipath Fading

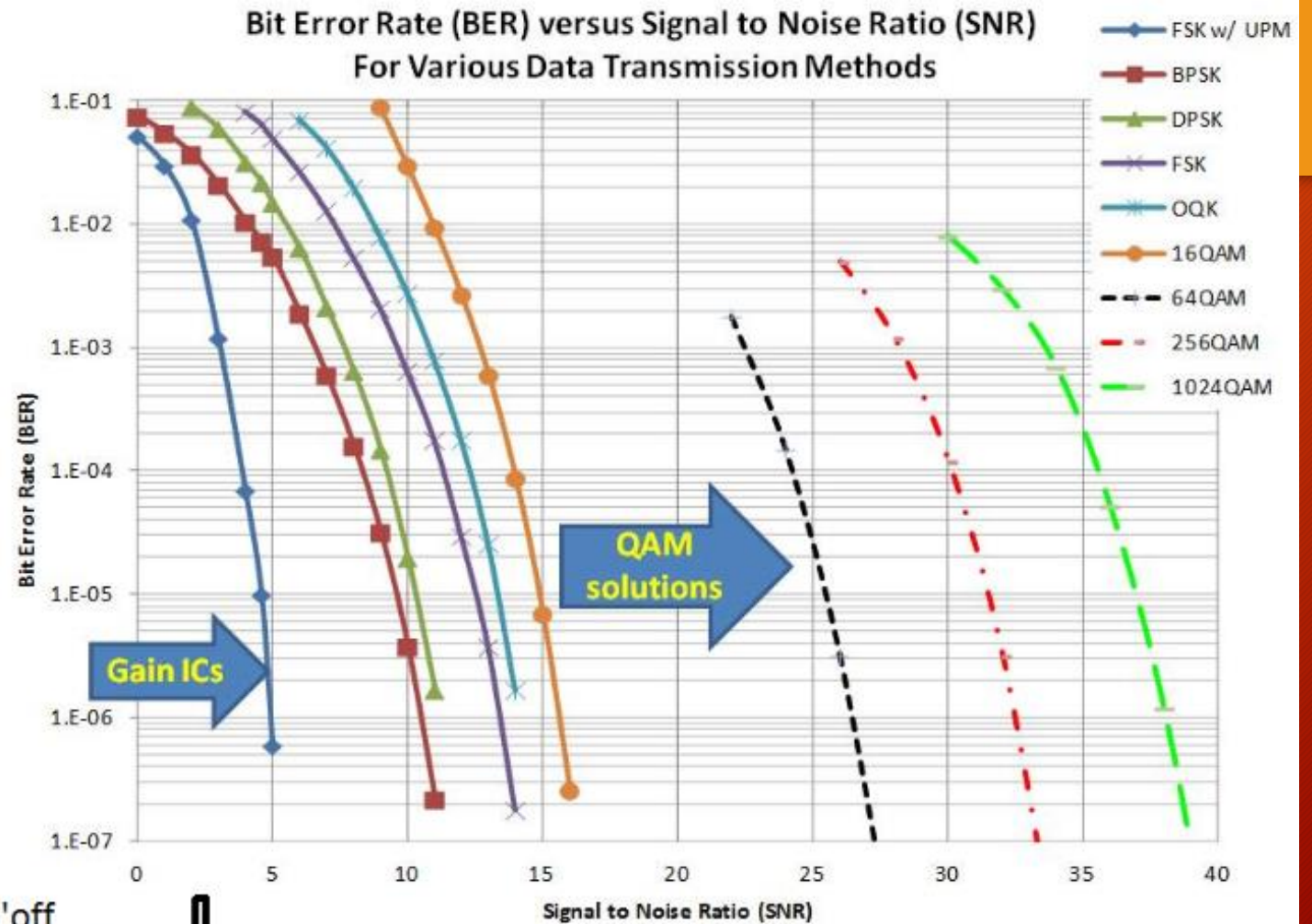


# BER vs SNR

Bit error rate (BER) = Bit error probability =  $P_b$

$$\begin{aligned}
 P\{\text{single bit error}\} &= p \\
 P\{\text{no error in single bit}\} &= (1 - p) \\
 P\{\text{no error in 8 bits}\} &= (1 - p)^8 \\
 P\{\text{unseen error in 8 bits}\} &= 1 - (1 - p)^8 \\
 &= 7.9 \times 10^{-4}
 \end{aligned}$$

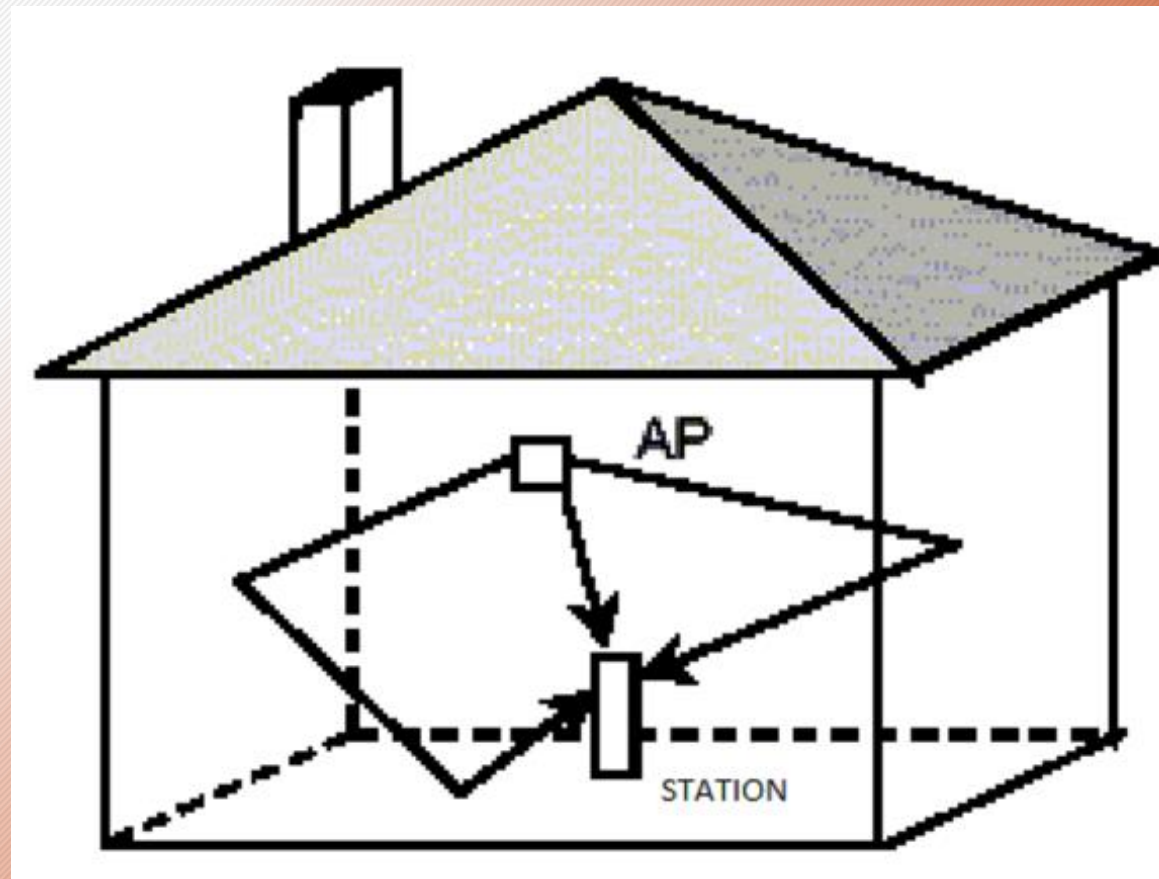
Packet error rate (PER) = Packet error probability for packet length N bits:  
 $P_p = 1 - (1 - P_b)^N$



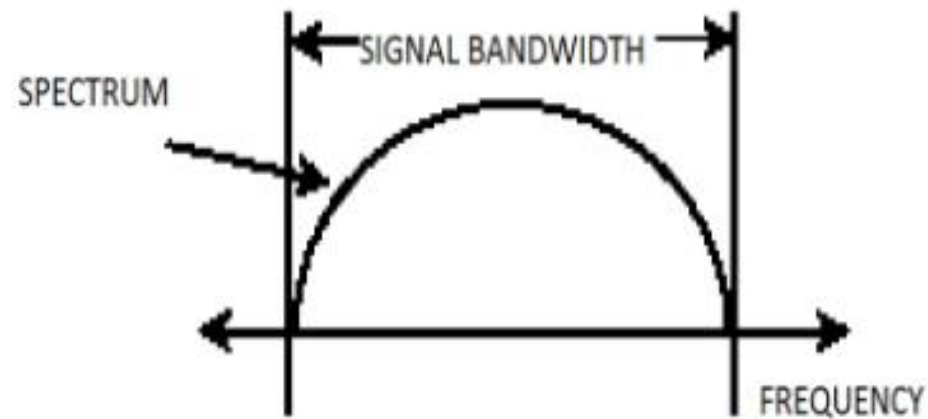
'off charts'  
 BER



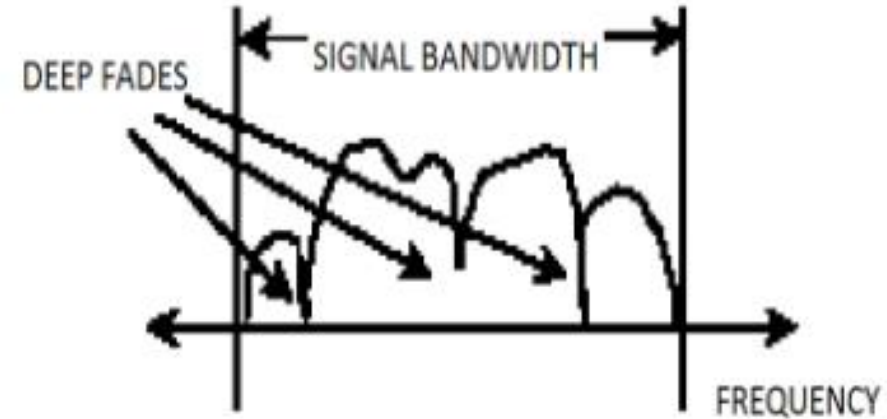
# POSSIBLE SIGNAL PATH FROM AP TO USER



## WHAT COULD HAPPEN TO SIGNAL ALONG THE WAY TO RECEIVER

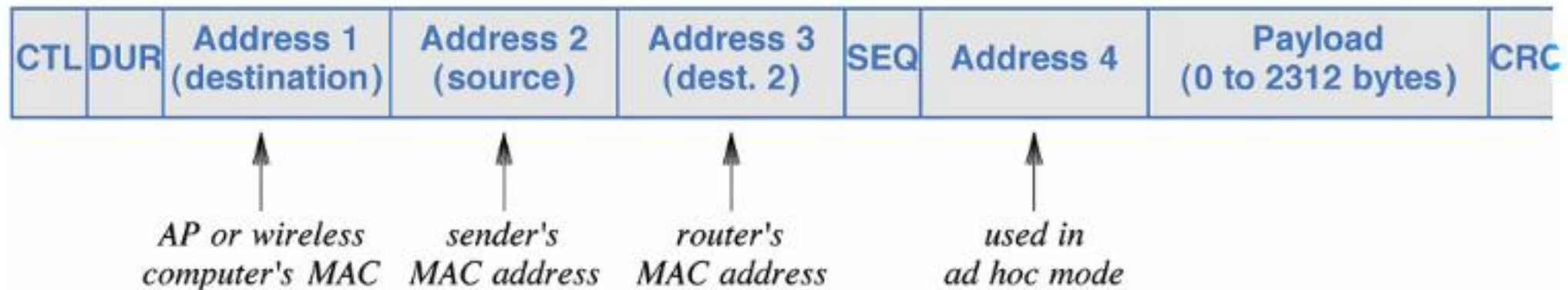


TRANSMITTED SIGNAL  
SPECTRUM



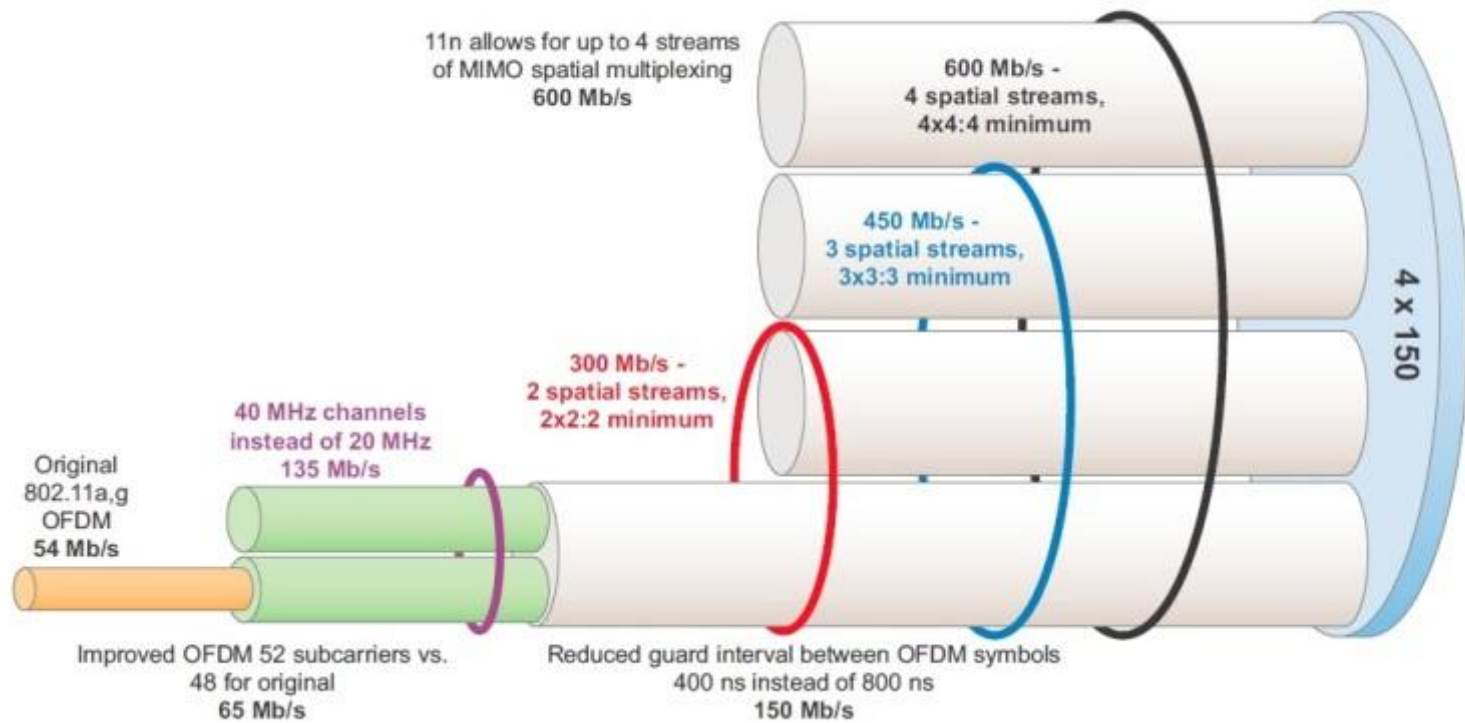
DISTORTED RECEIVED SIGNAL SPECTRUM

## The frame format used with an 802.11 wireless LAN.



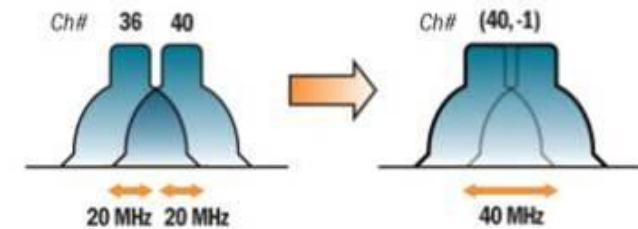
payload is typically fewer than 1500 bytes

# Wireless Channel Bonding



Channel Width

Number of Streams	Bitrate	20 MHz	40 MHz	80 MHz
1 stream	87 Mbps	87 Mbps	200 Mbps	433 Mbps
2 streams	173 Mbps	173 Mbps	400 Mbps	866 Mbps
3 streams	289 Mbps	289 Mbps	600 Mbps	1300 Mbps



Standard 802.11 channels are effectively 20MHz wide.

Channel bonding combines two adjacent 20MHz channels into a single 40MHz channel providing increased throughput.

# References

- <http://www.vlf.it/frequency/bands.html>
- [http://foresight.ifmo.ru/ict/shared/files/201311/1\\_143.pdf](http://foresight.ifmo.ru/ict/shared/files/201311/1_143.pdf)
- <http://www.wirelesscommunication.nl/reference/chaptr05/digimod/awgn.htm>
- [https://en.wikipedia.org/wiki/Shannon\\_capacity\\_of\\_a\\_graph](https://en.wikipedia.org/wiki/Shannon_capacity_of_a_graph)
- [https://en.wikipedia.org/wiki/Channel\\_capacity](https://en.wikipedia.org/wiki/Channel_capacity)
- <http://electronicdesign.com/communications/understanding-wireless-range-calculations>
- [https://en.wikipedia.org/wiki/Radio\\_spectrum](https://en.wikipedia.org/wiki/Radio_spectrum)
- [https://commons.wikimedia.org/wiki/File:T-ray\\_metamaterial\\_semiconductor\\_modulator.jpg](https://commons.wikimedia.org/wiki/File:T-ray_metamaterial_semiconductor_modulator.jpg)
- <http://www.ni.com/tutorial/3541/en/>
- <http://hyperphysics.phy-astr.gsu.edu/hbase/ems2.html>
- <http://www.vlf.it/frequency/bands.html>
- [http://cwi.unik.no/images/e/e7/Frequency\\_Range\\_Communications\\_Raul.pdf](http://cwi.unik.no/images/e/e7/Frequency_Range_Communications_Raul.pdf)
- [https://en.wikipedia.org/wiki/Radio\\_frequency](https://en.wikipedia.org/wiki/Radio_frequency)
- [http://foresight.ifmo.ru/ict/shared/files/201311/1\\_143.pdf](http://foresight.ifmo.ru/ict/shared/files/201311/1_143.pdf)



Questions????

**Thank you!**