Frequency, Range and type of Wireless Communication

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Radio Frequency

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

Fig.1: Frequency and Wavelength

THF	Tremendously high frequency	300 GHz – 3 THz	1 mm – 0.1 mm (1

Penitration - 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

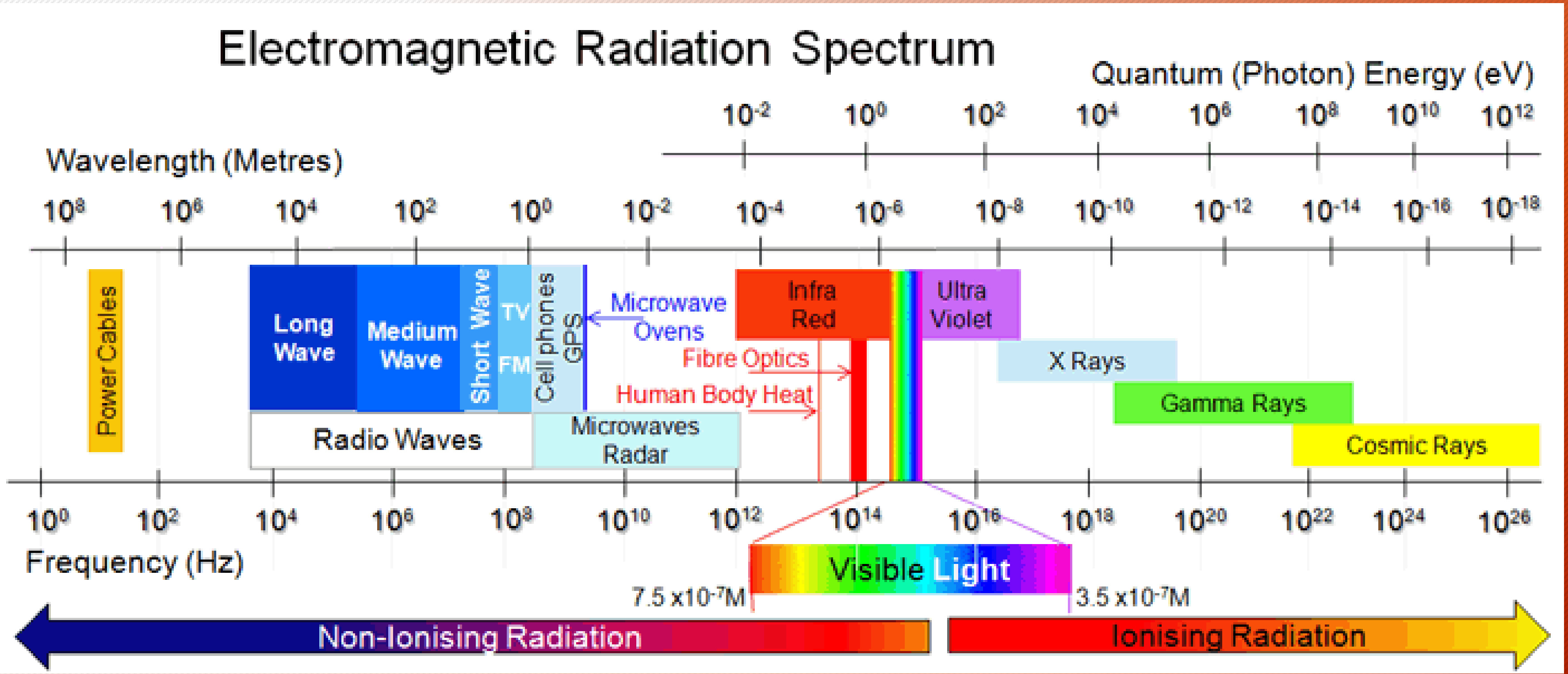
Decimeter wave - GPS, Satellite Comm, Wi-Fi, Bluetooth

Centimeter wave - Microwave radio, Wireless USB, Radar

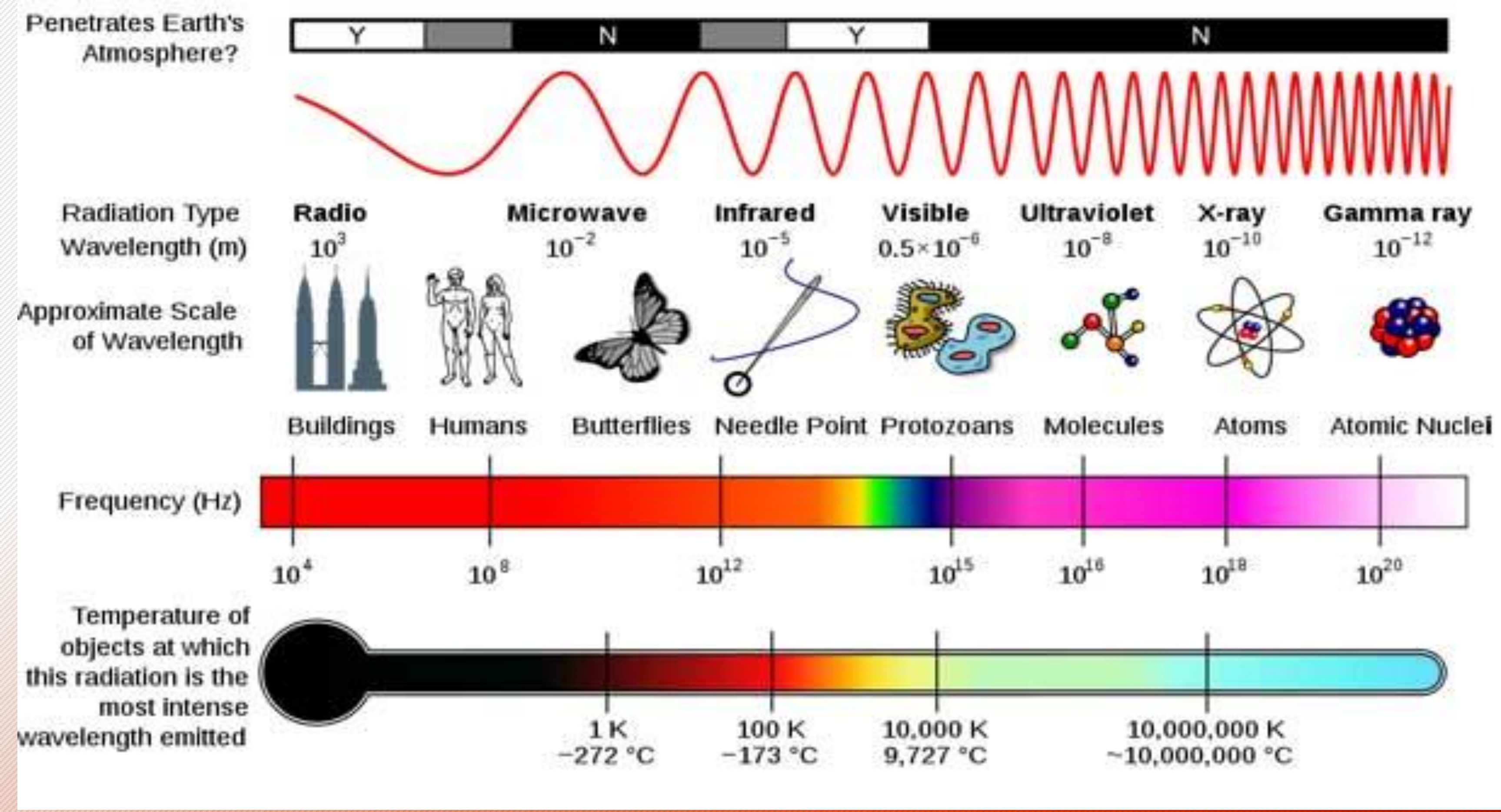
Milimeter wave - Radio Astronomy/5G Mobile phones (Expected)

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

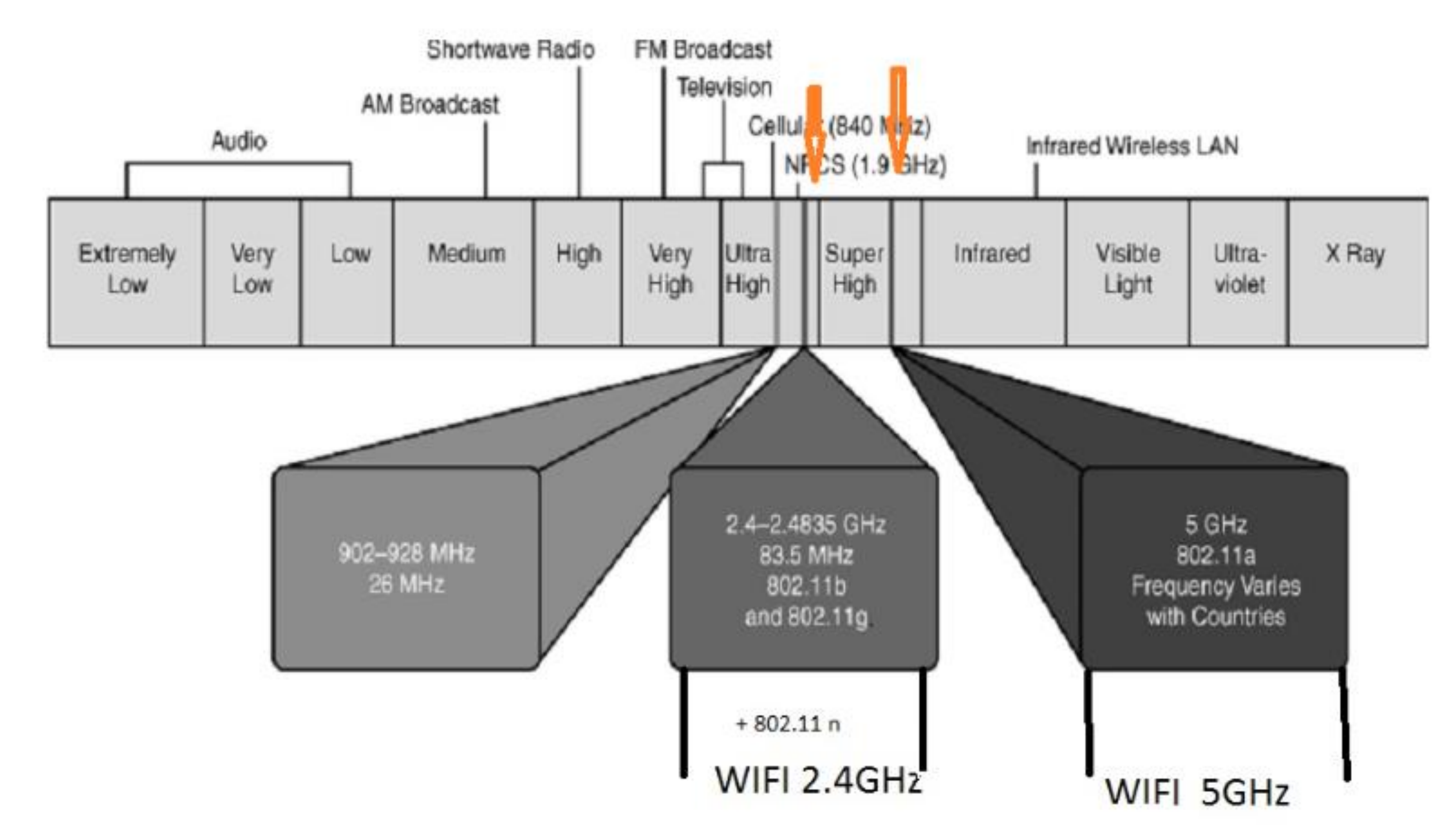
Electromagnetic Radiation Spectrum



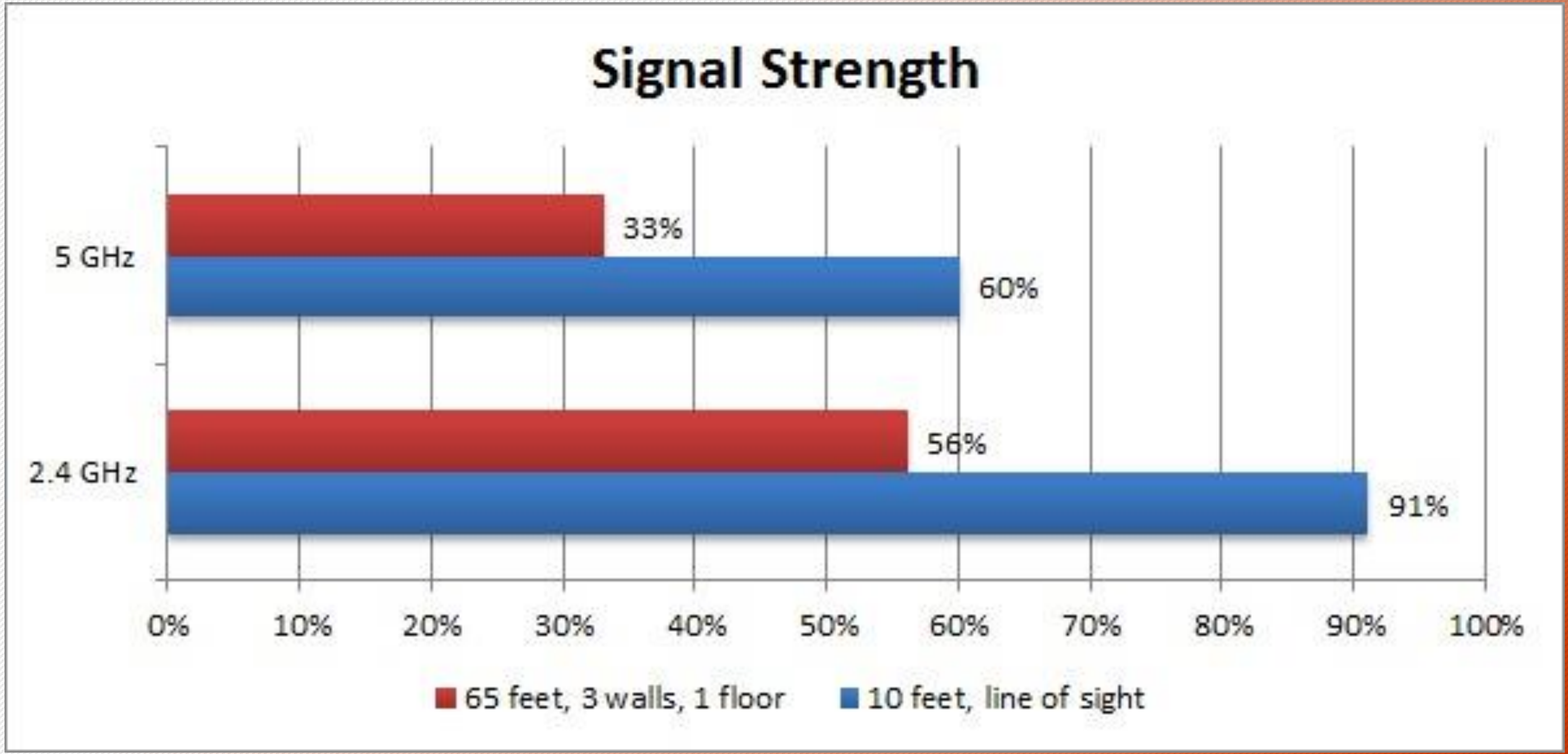
Frequency and Approximate Scale of Wavelength



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

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

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

Equation 1-1: Free Space Range

Towards THz Communications

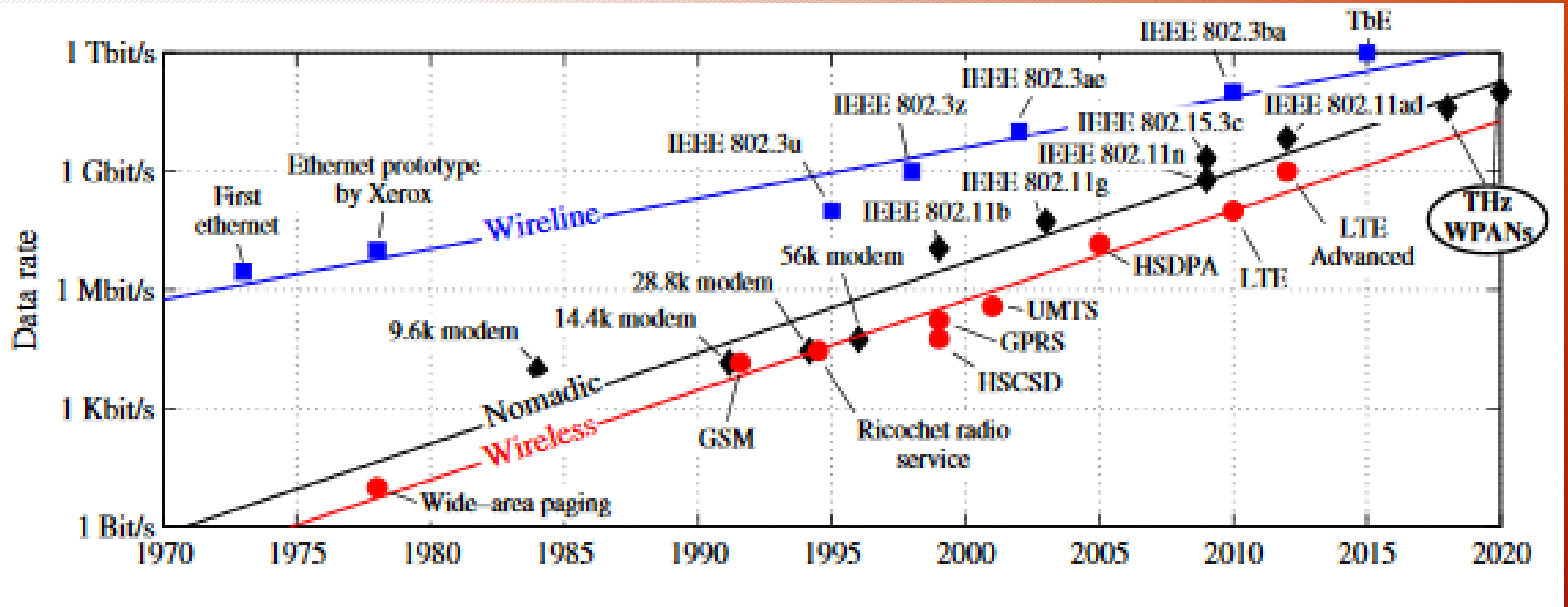
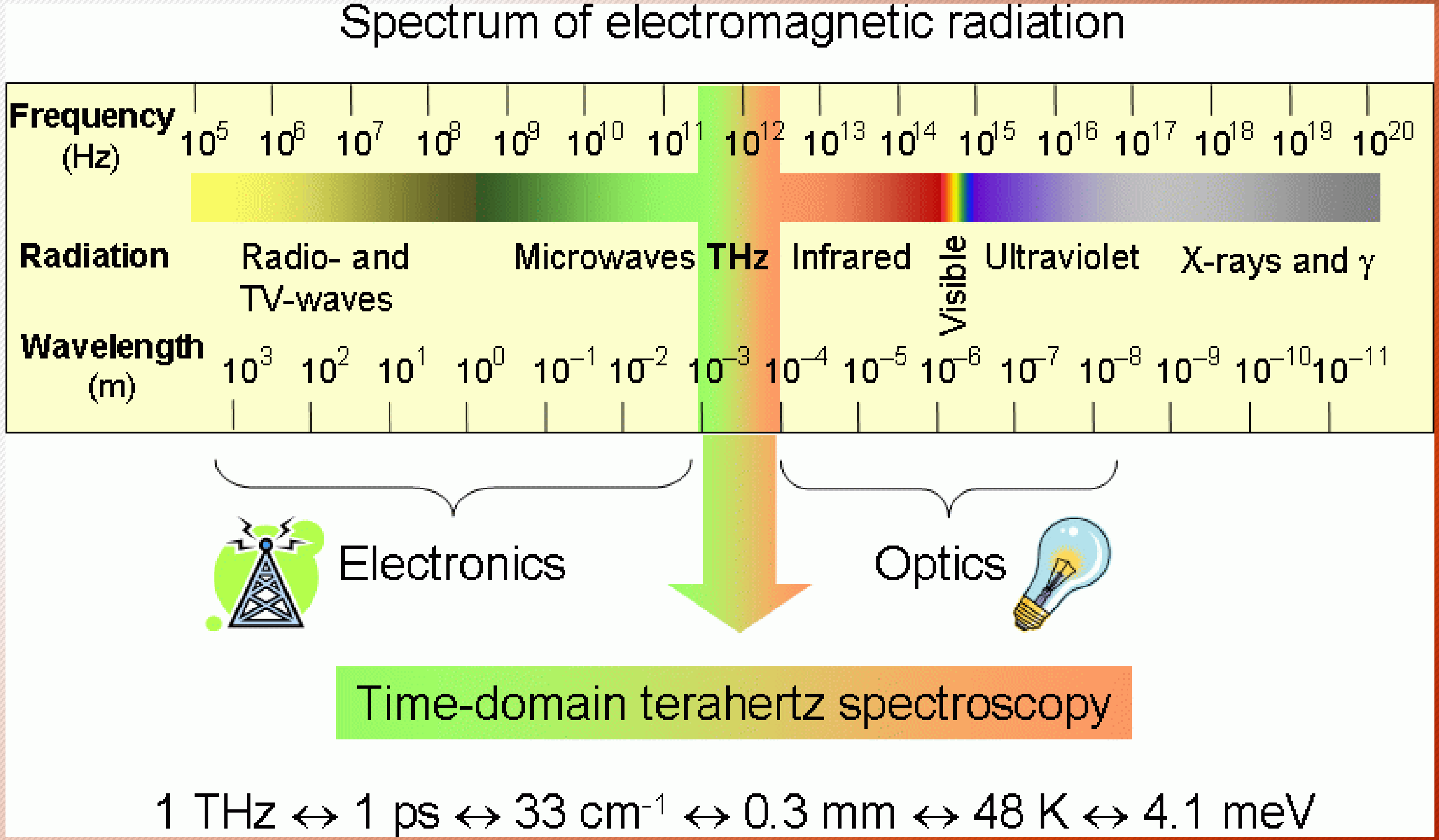
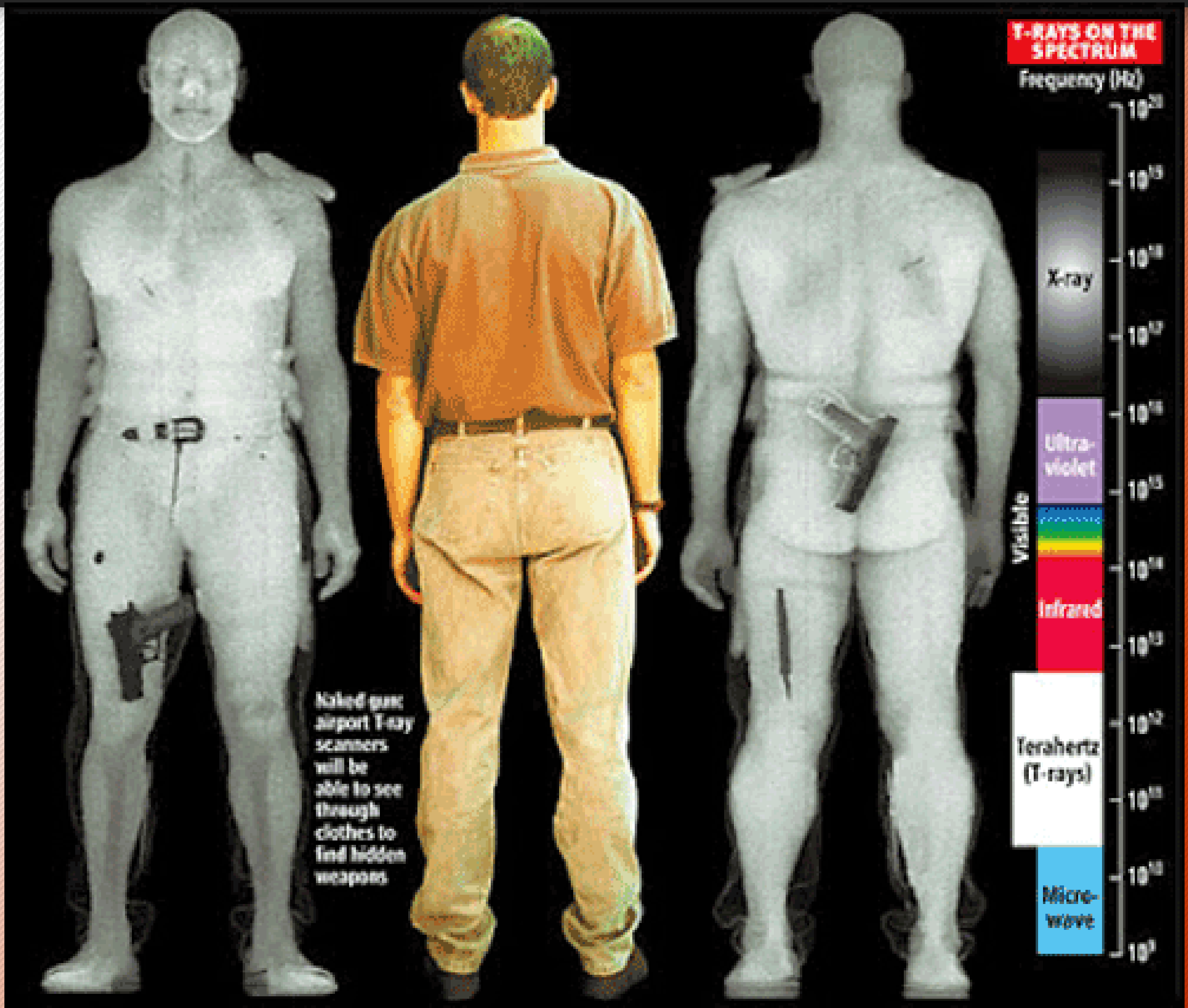


Fig.2: Development of data rates in wireline, nomadic and wireless systems

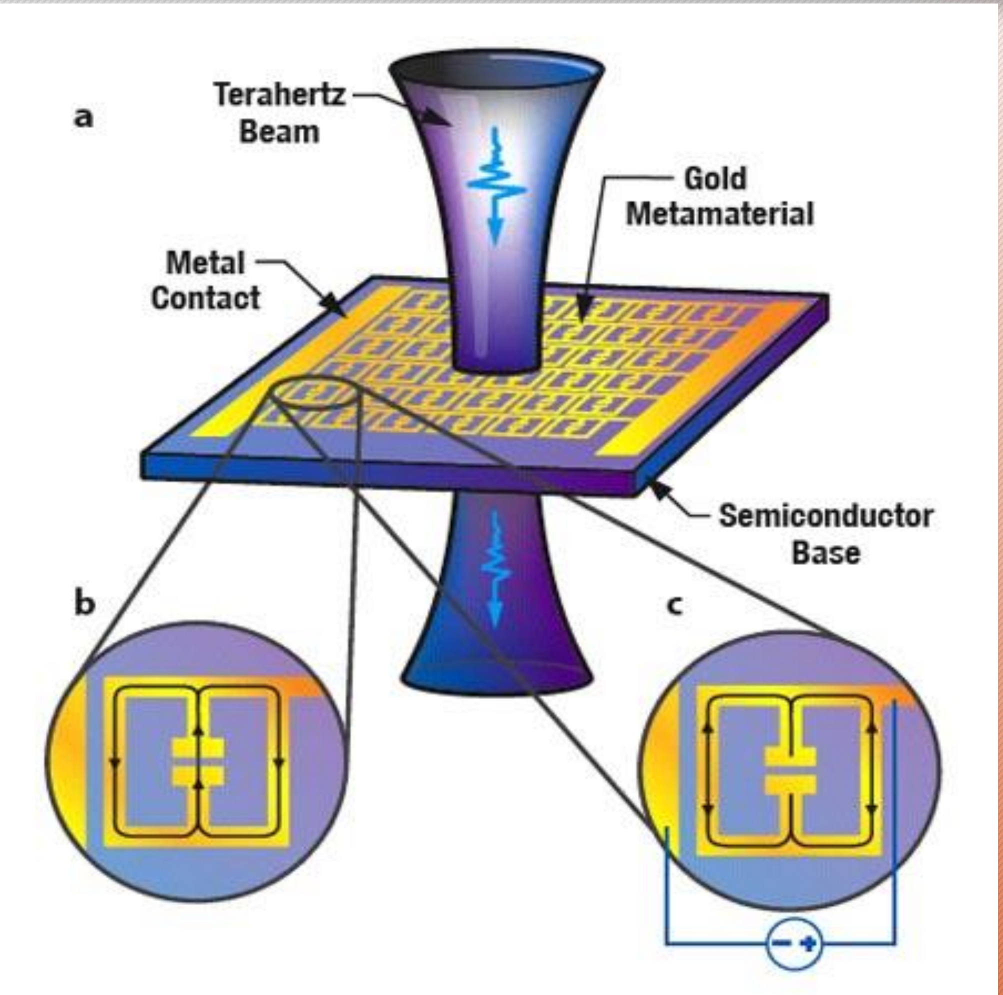
Time-domain Terahertz Spectroscopy



T-Rays on the Spectrum

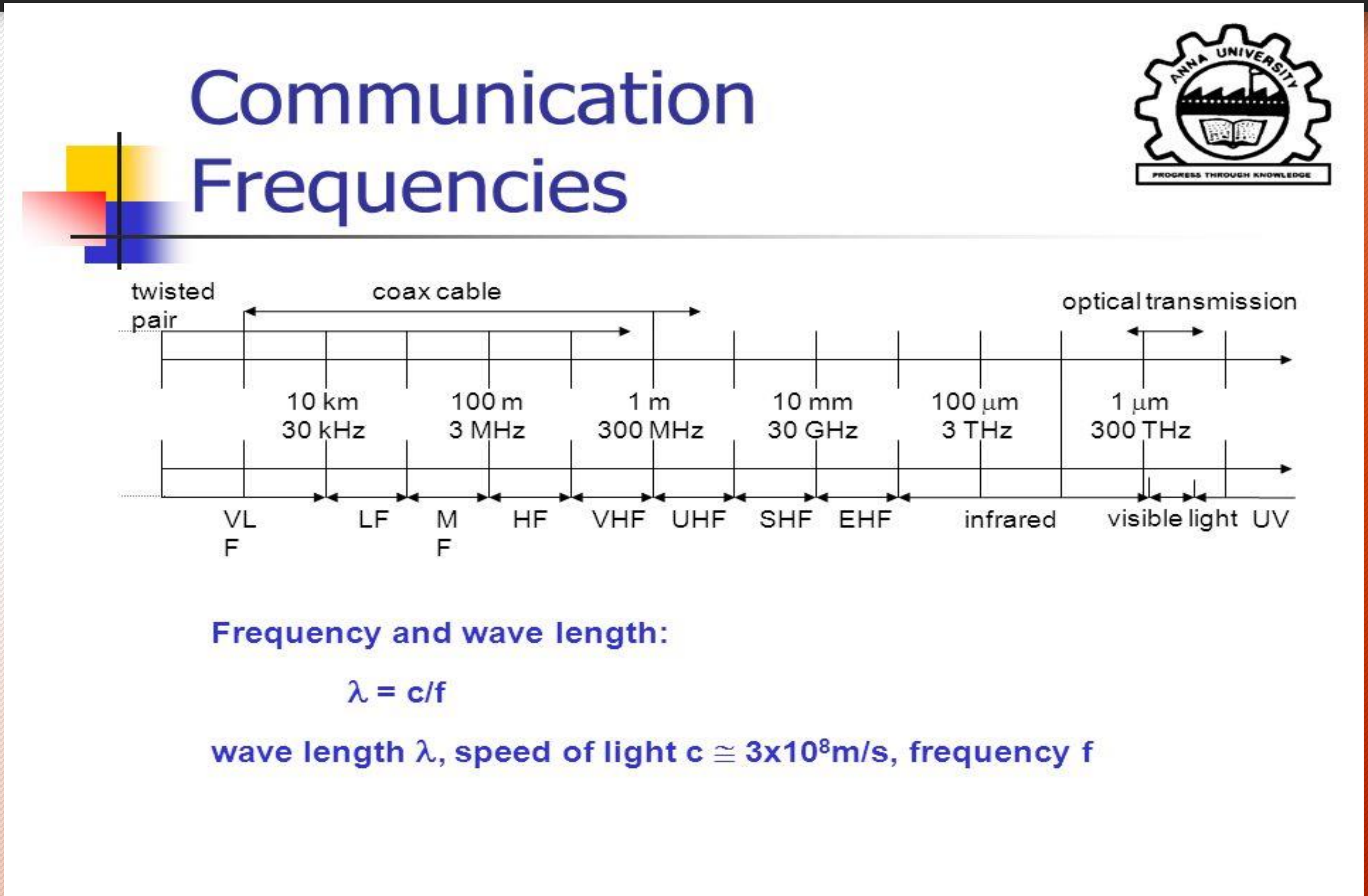


T-ray metamaterial semiconductor modulator



a) C-DOT-rays shine through the modulator.
b) 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.
c) 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



Comparison of conventional and THz communication channels

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

Why Actual Range May Not Equal Stated Range???

RF Power And dBm

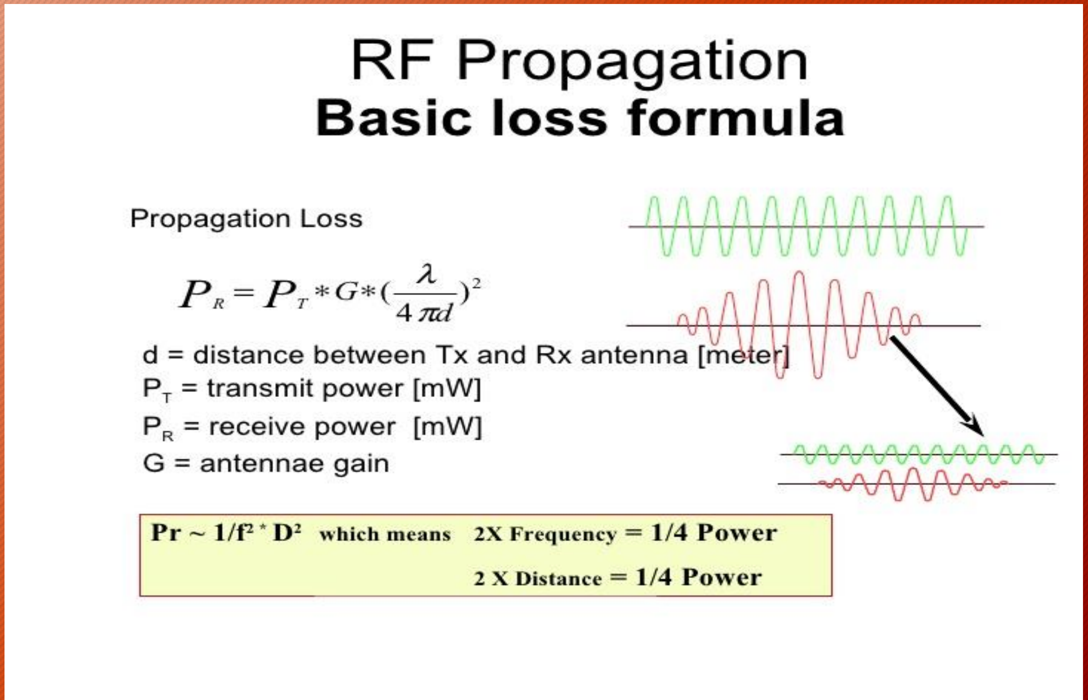
- RF power is expressed in db with milliwatt i.e., dBm

dBm to mW convertion:

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

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



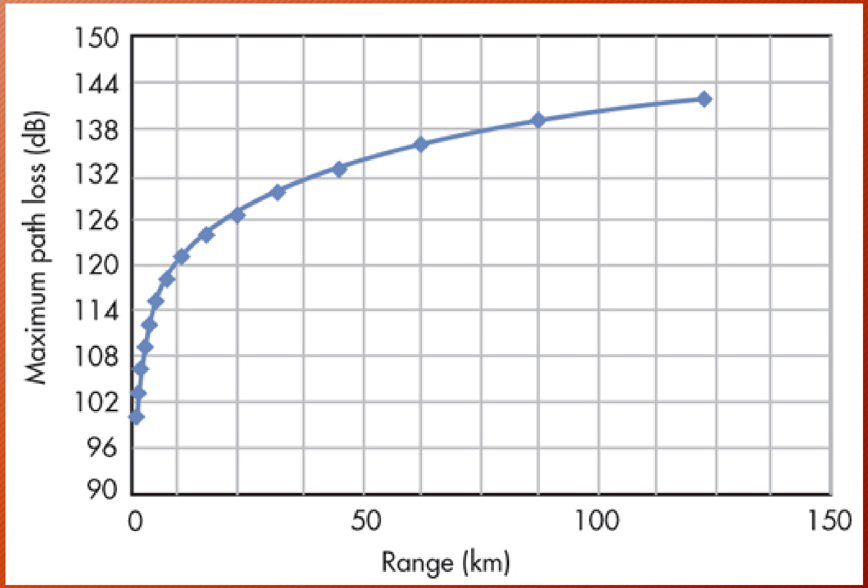
Range

- 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.



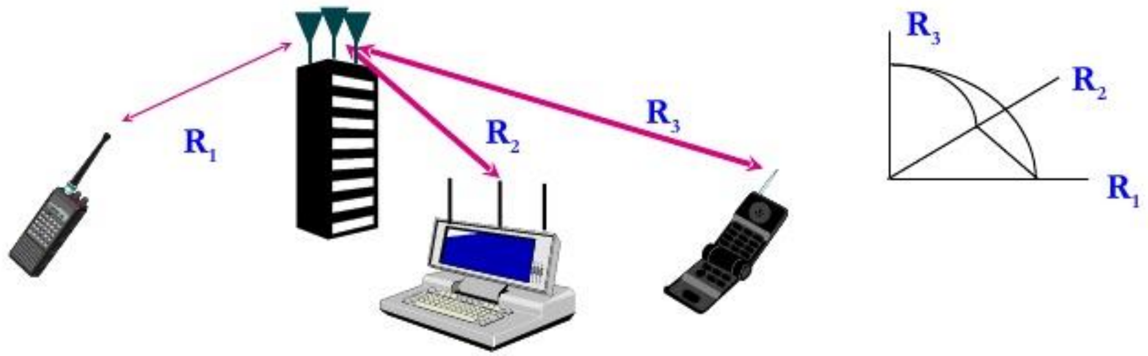
The curve shows the relationship between the link budget or maximum path loss in dBm and estimated range in kilometers.

Wireless Channel Capacity

Wireless Channel Capacity

Fundamental Limit on Data Rates

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



- 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.[6]

Shannon-Hartley Theorem

Channel Capacity

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

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

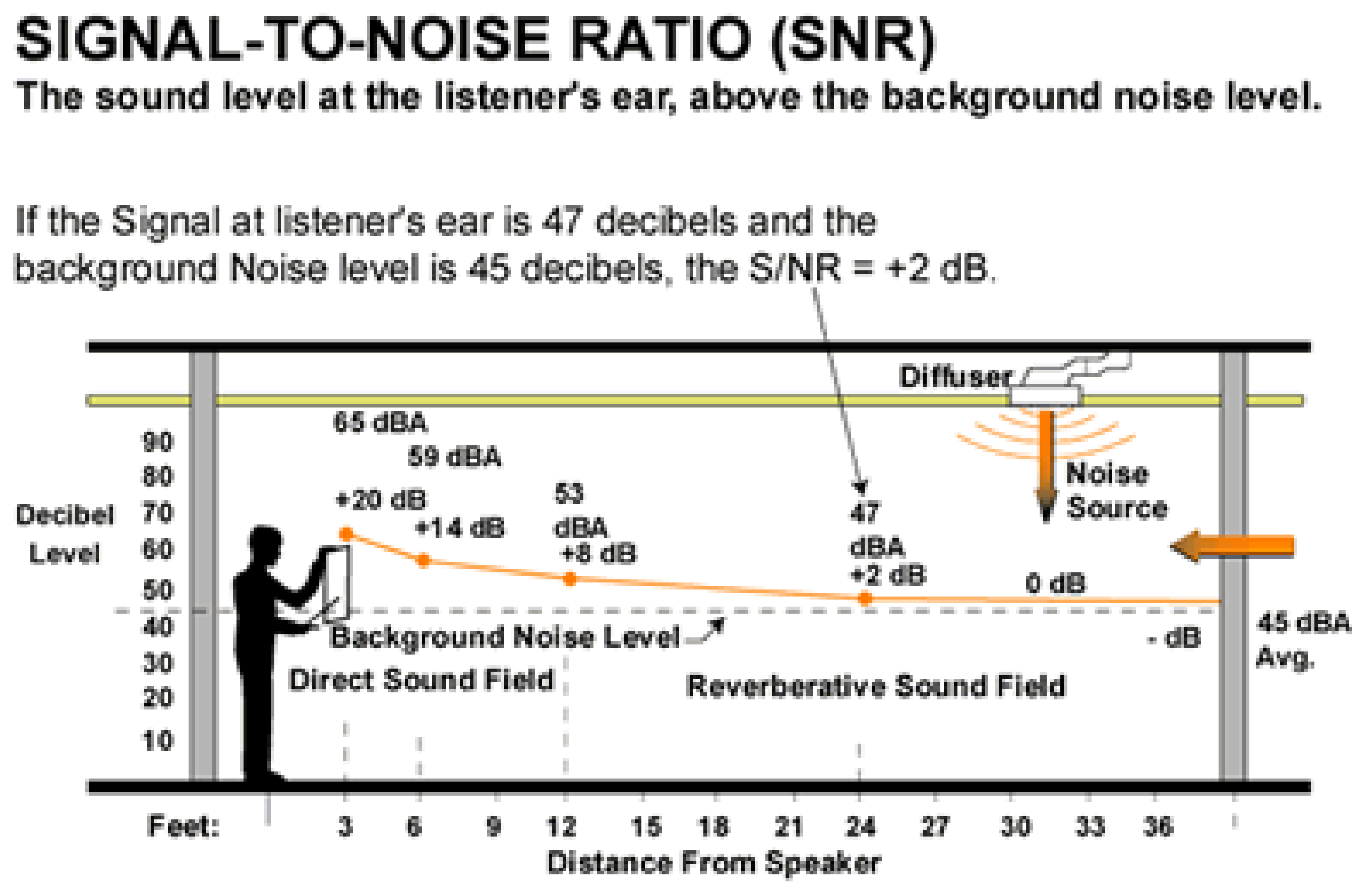
Here:

- C — maximal theoretical channel capacity (bits/sec);
- B — bandwidth (hertz);
- S — signal power (watts);
- N — noise power (watts).

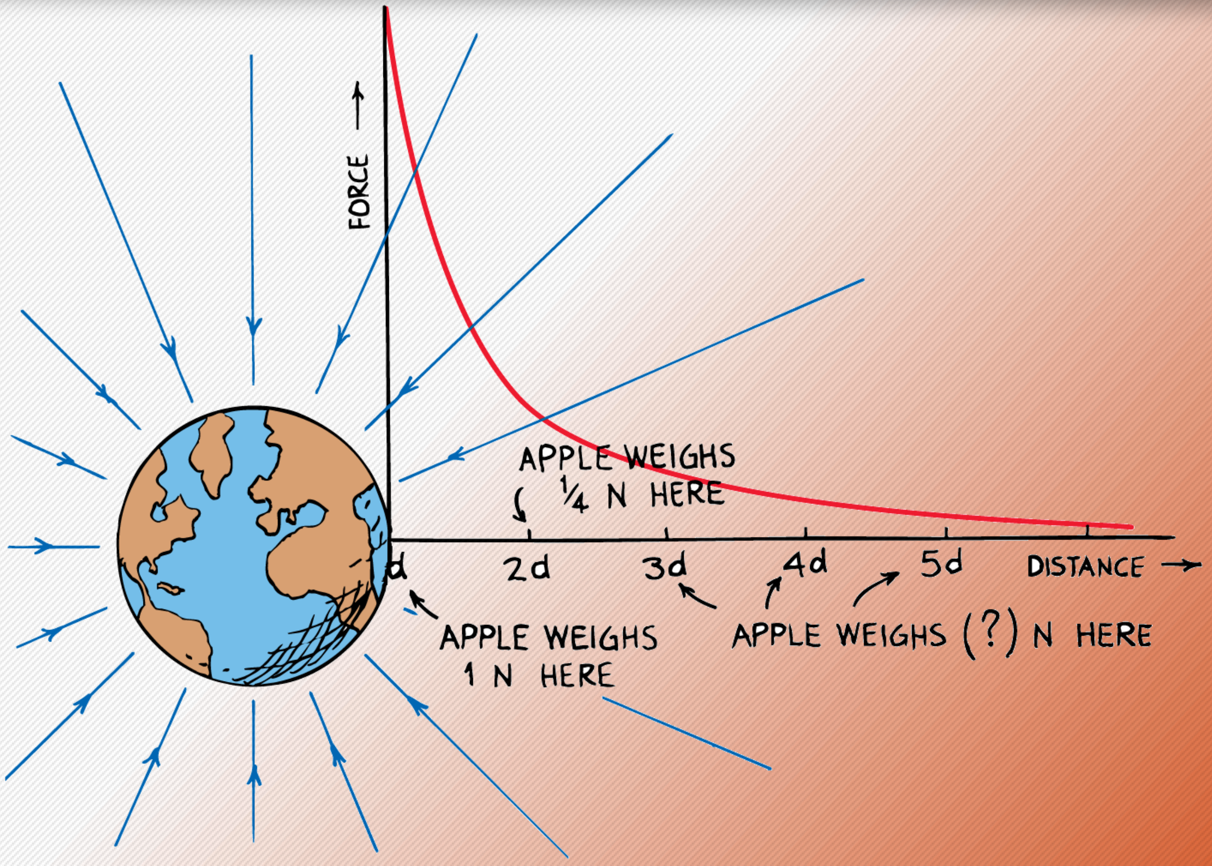
In case of wideband signal:

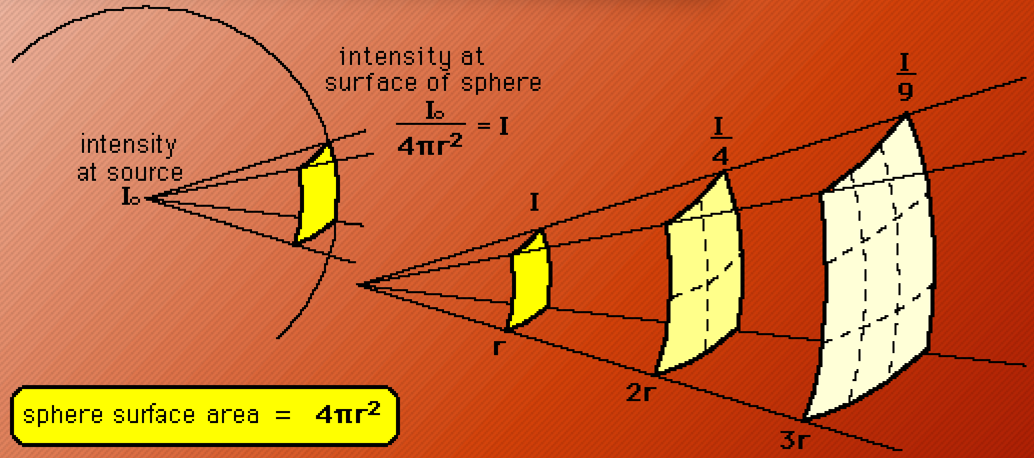
$$C = \int_{f_{min}}^{f_{max}} \log_2\left(1+\frac{S(f)}{N(f)}\right)df\,.$$

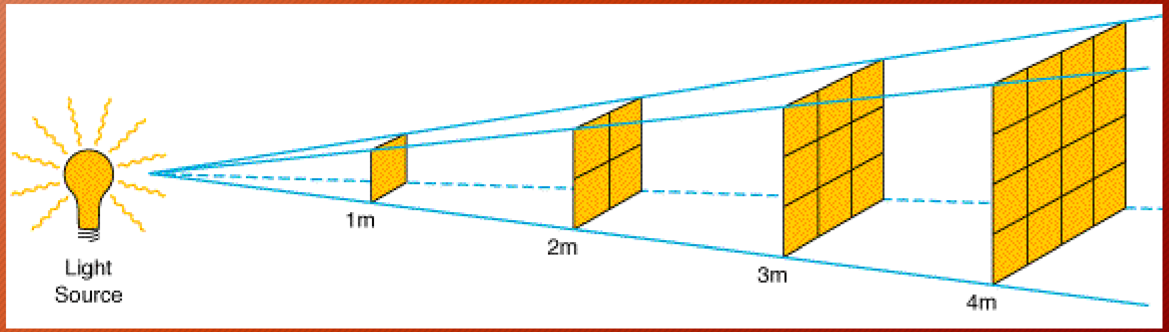
Signal to Noise Ratio



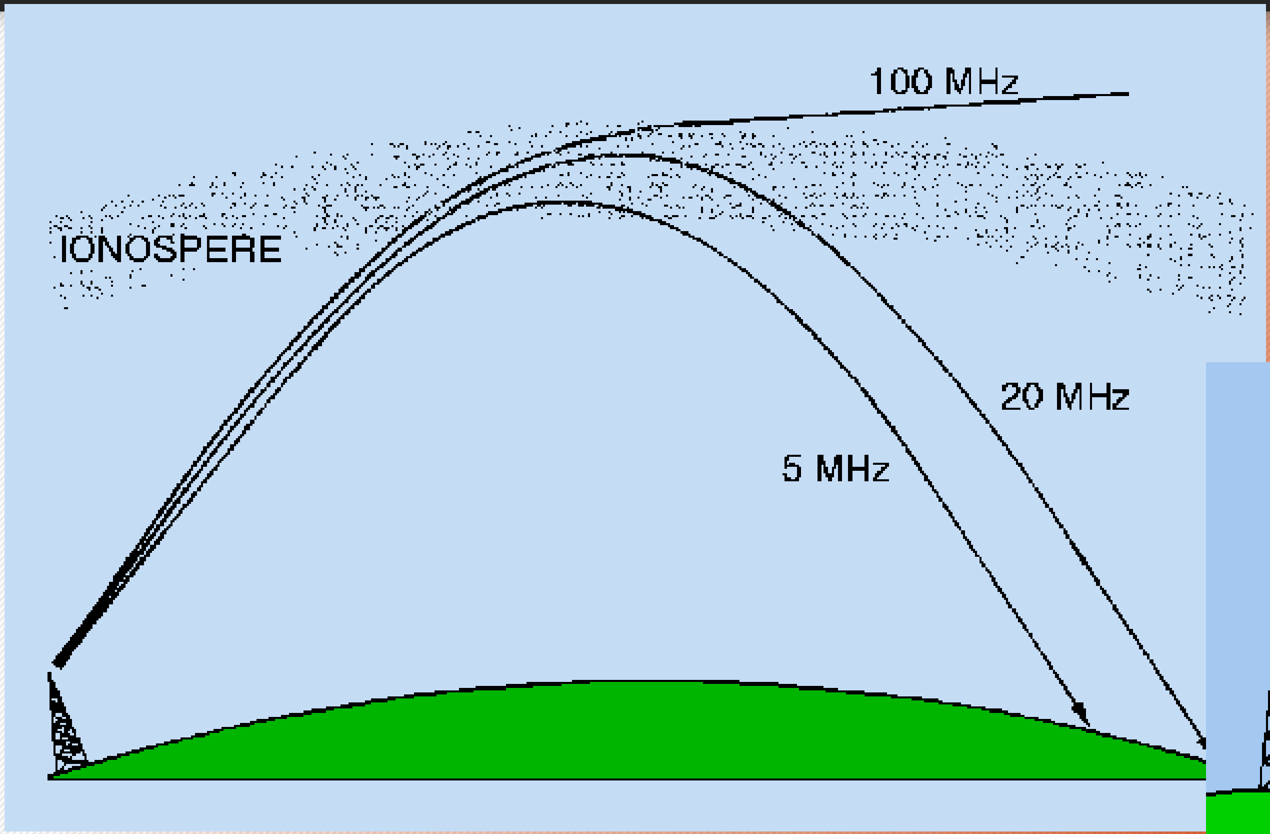
Power of transmitted signals



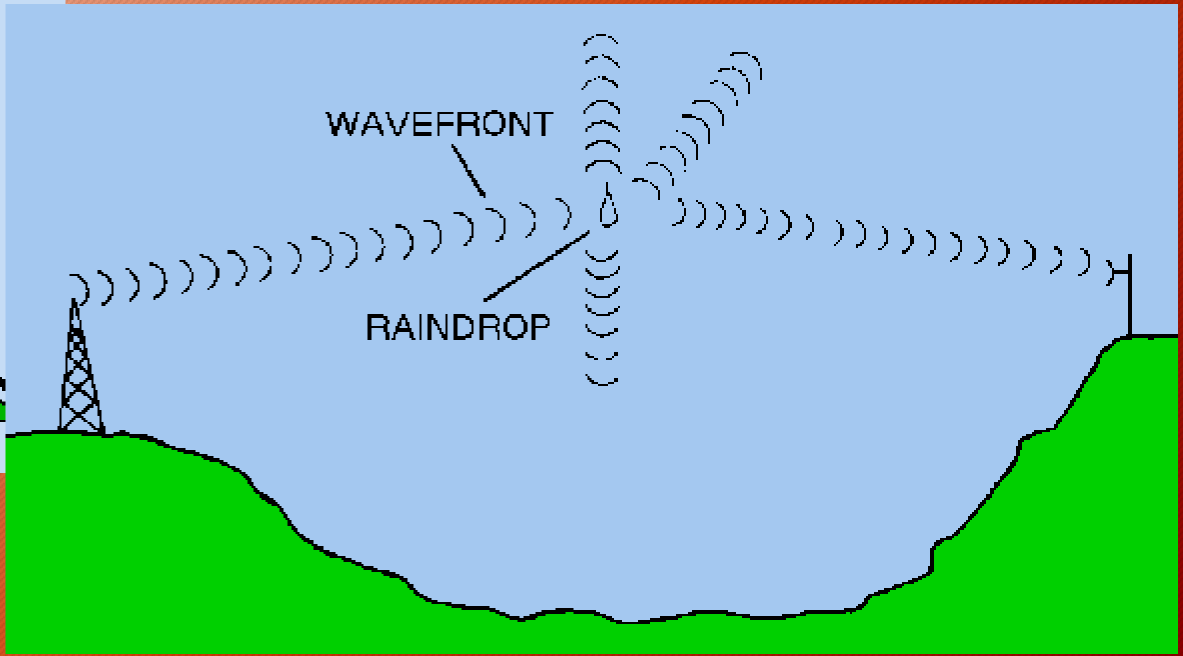




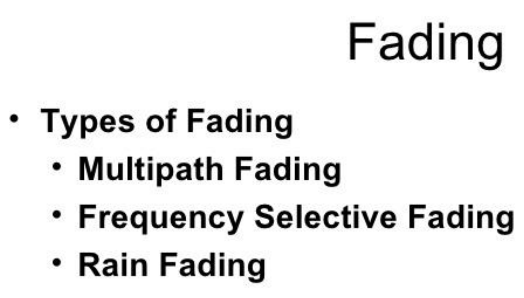
Wave fades with distnace

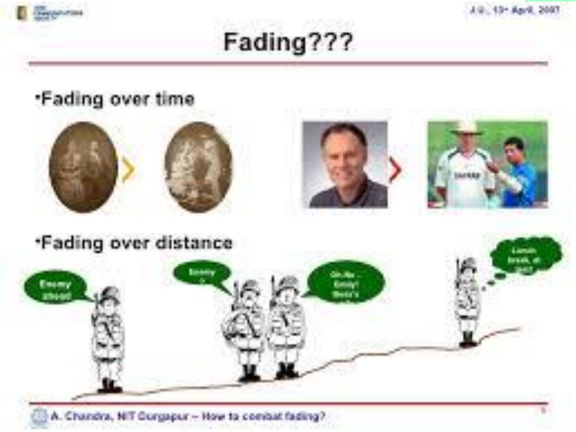


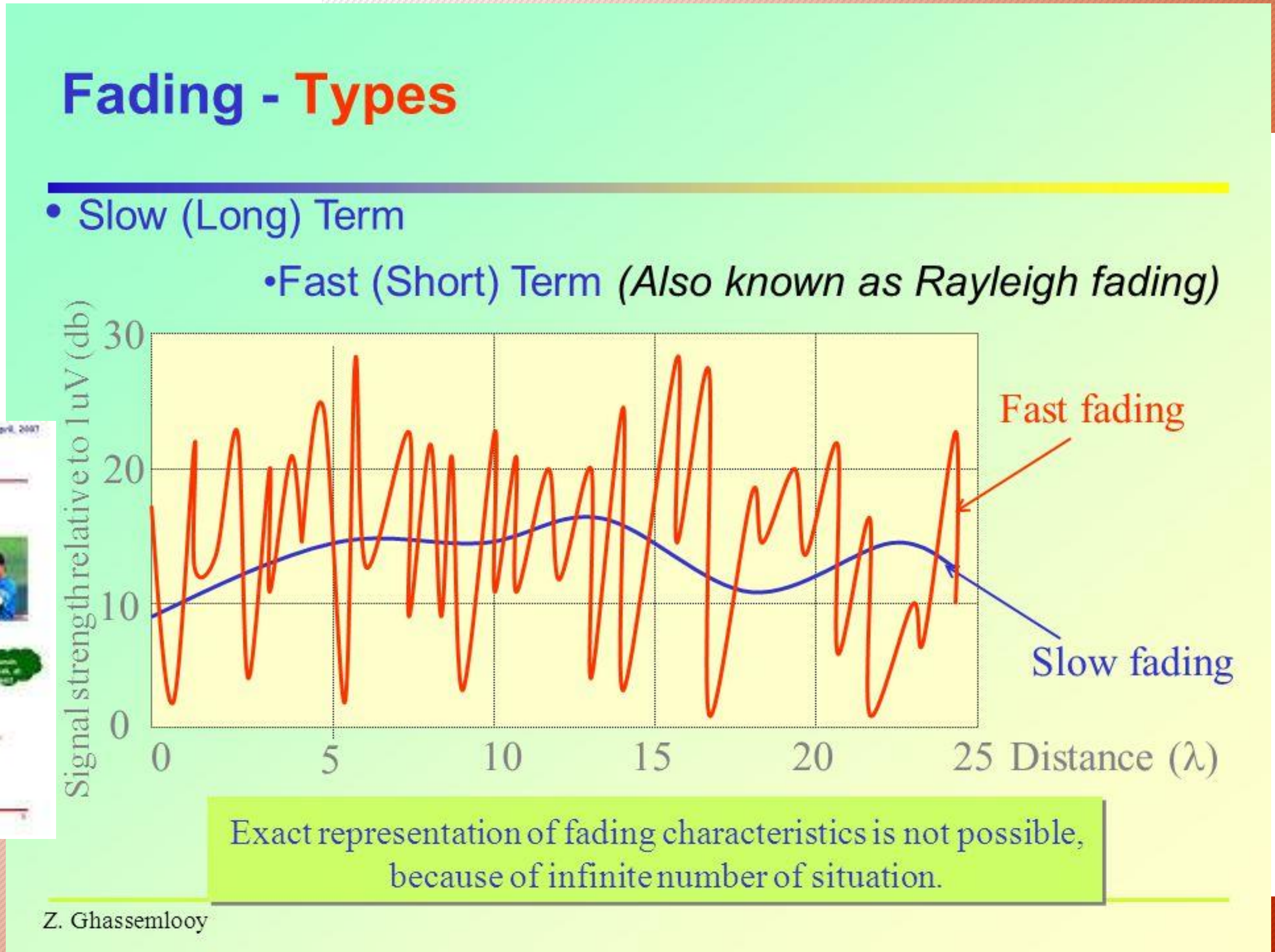
Wave Defraction

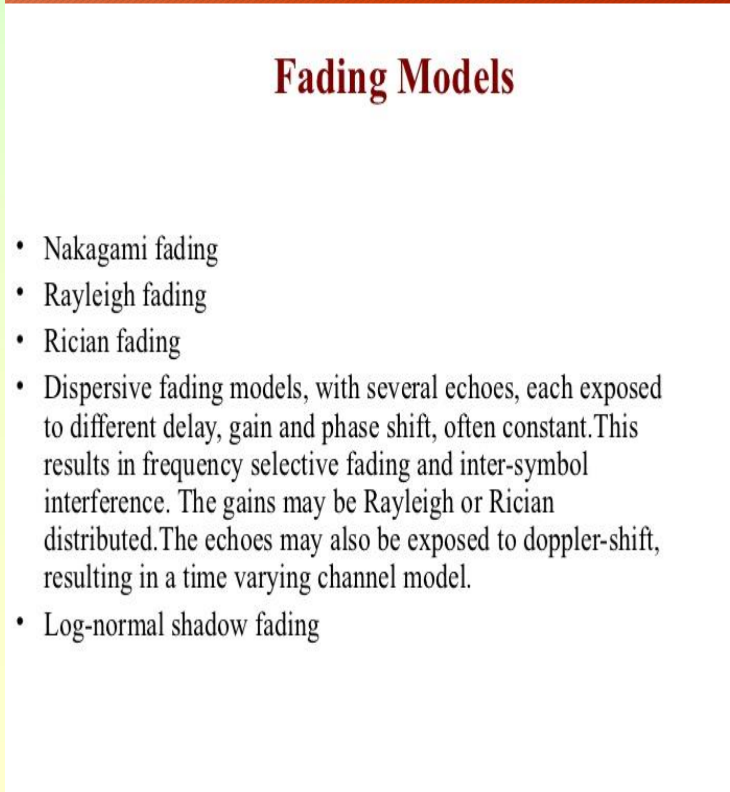


Wave fading types

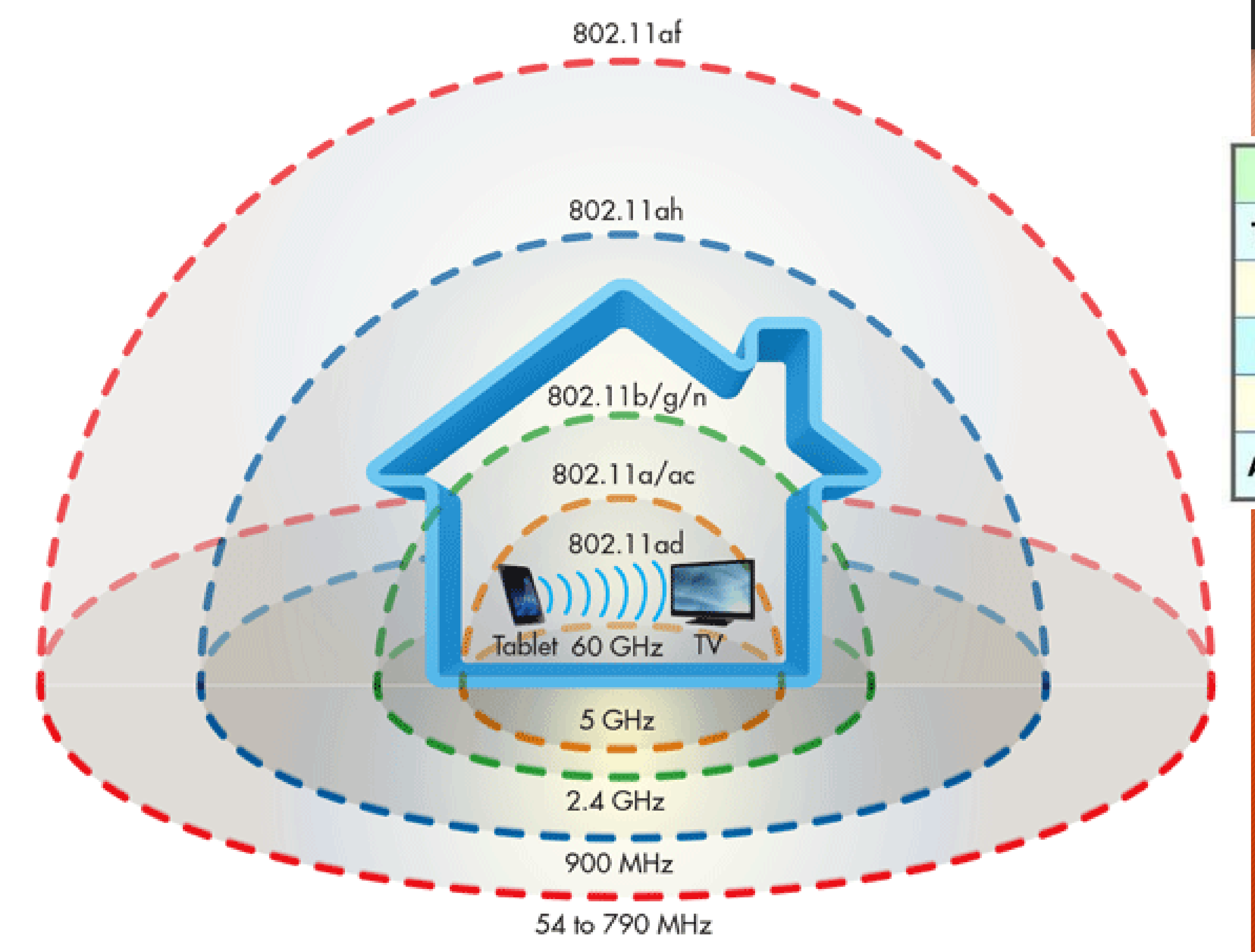






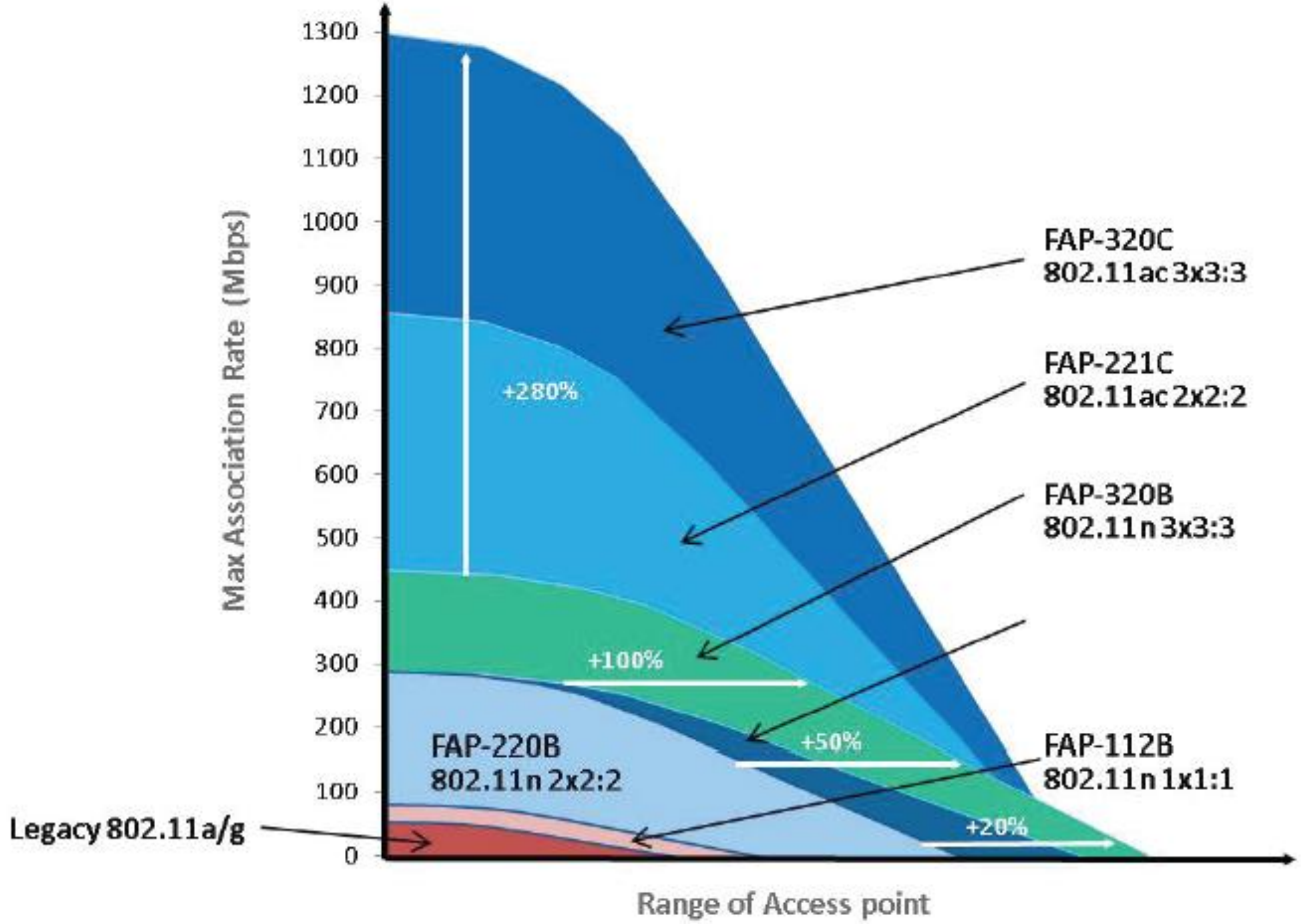


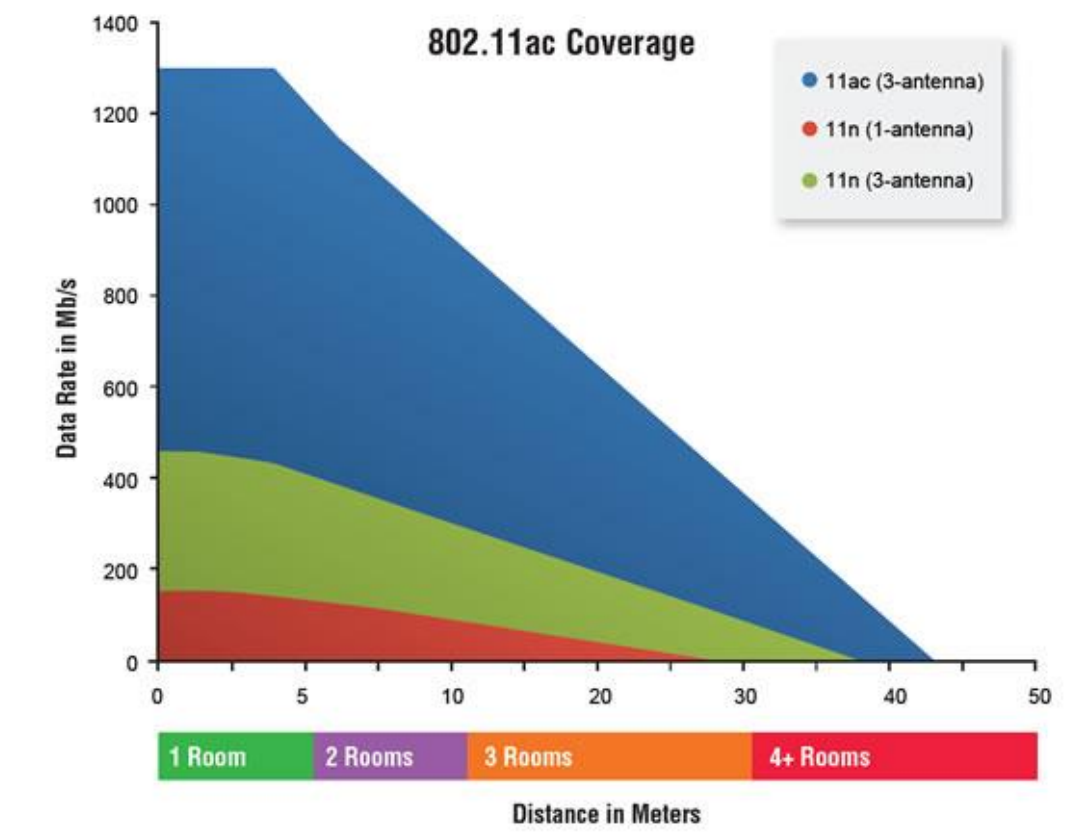
Range vs Rate



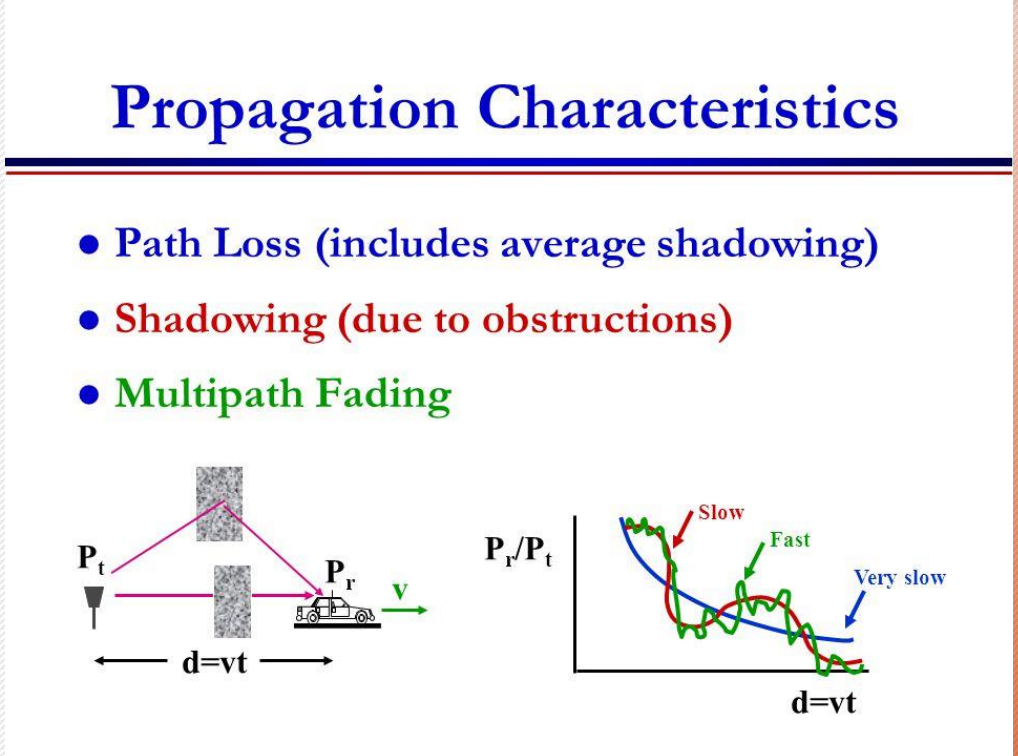
	802.11n	802.11ac	802.11ad
Throughput	600 Mbps	3.2 Gbps	Up to 7 Gbps
Coverage	Home, 70 m	Home, 30 m	Room, <5m
Freq. Band	2.4/5 GHz	5 GHz	2.4/5/60 GHz
Antennas	4 x 4 MIMO	8 x 8 MIMO	>10 x 10 MIMO
Applications	Data, Video	Video	Uncompressed Video

Range vs Rate cont...





Propagation Characteristics



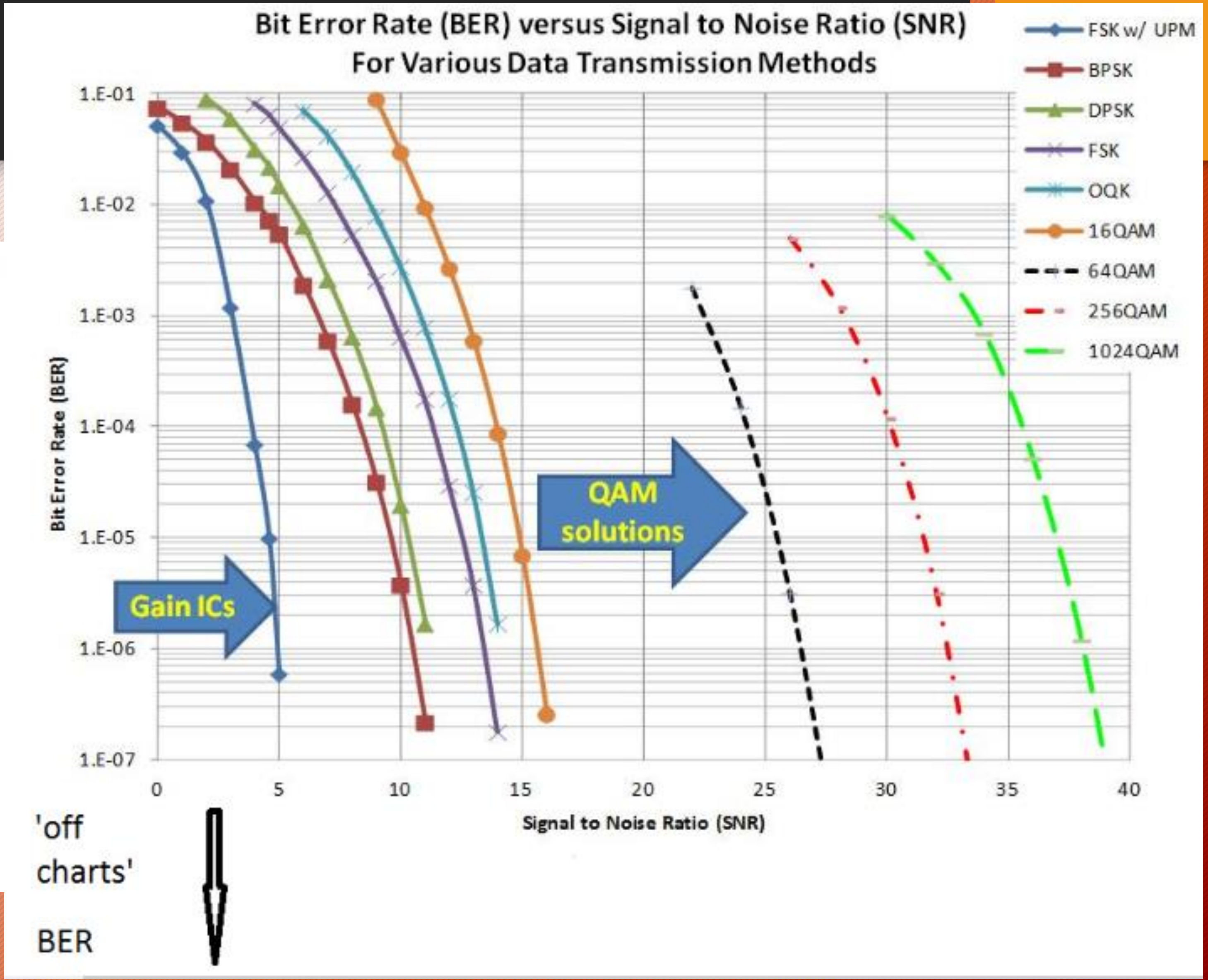
BER vs SNR

Bit error rate (BER) = Bit error probability = Pb

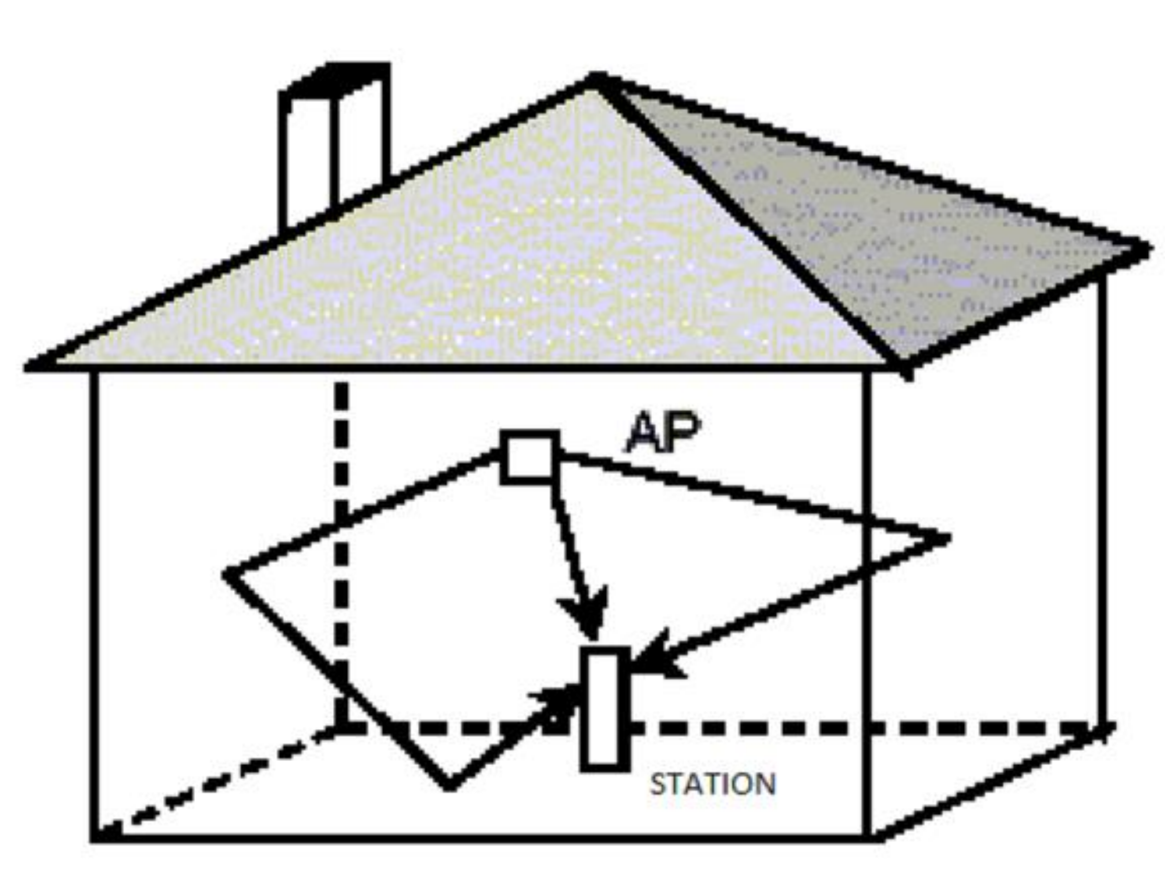
$$
\begin{aligned}
P\{\text{single bit error}\} &= p \\
P\{\text{no error in single bit}\} &= (1-p) \\
P\{\text{no error in 8 bits}\} &= (1-p)^8 \\
P\{\text{unseen error in 8 bits}\} &= 1-(1-p)^8 \\
&= 7.9 \times 10^{-4}
\end{aligned}
$$

Packet error rate (PER) = Packet error probability for packet length N bits:

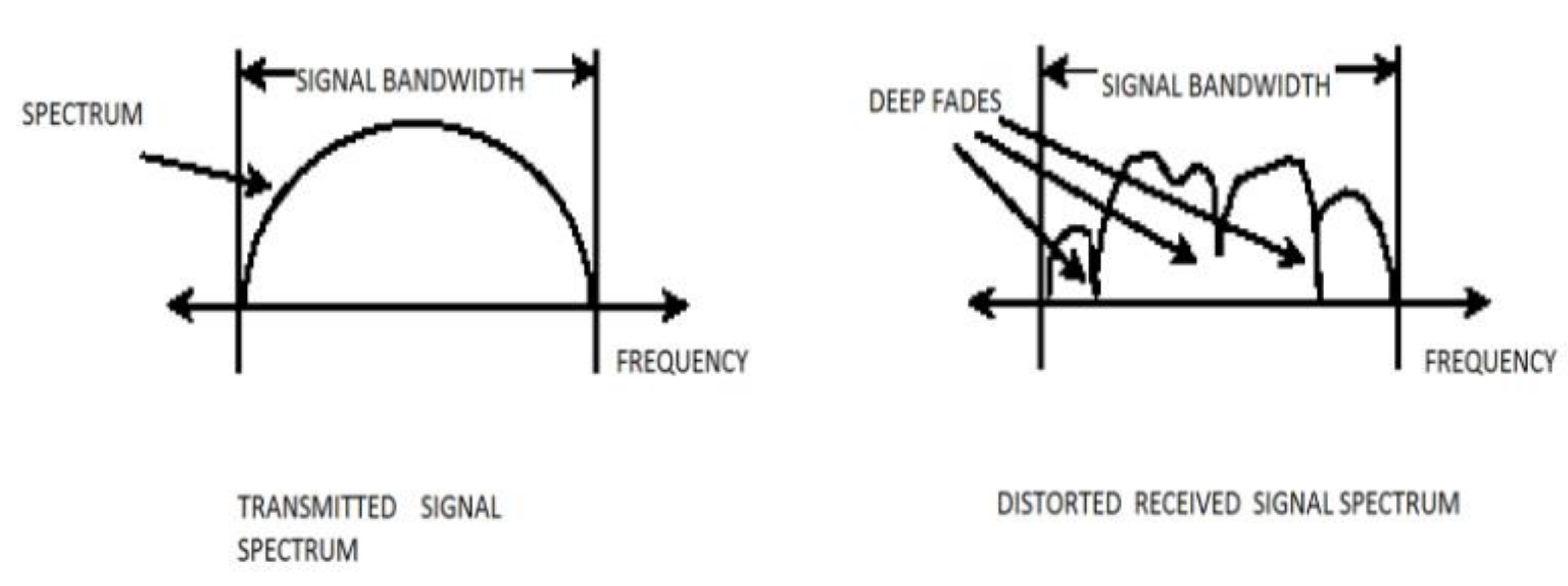
$Pp = 1 - (1-Pb)^N$



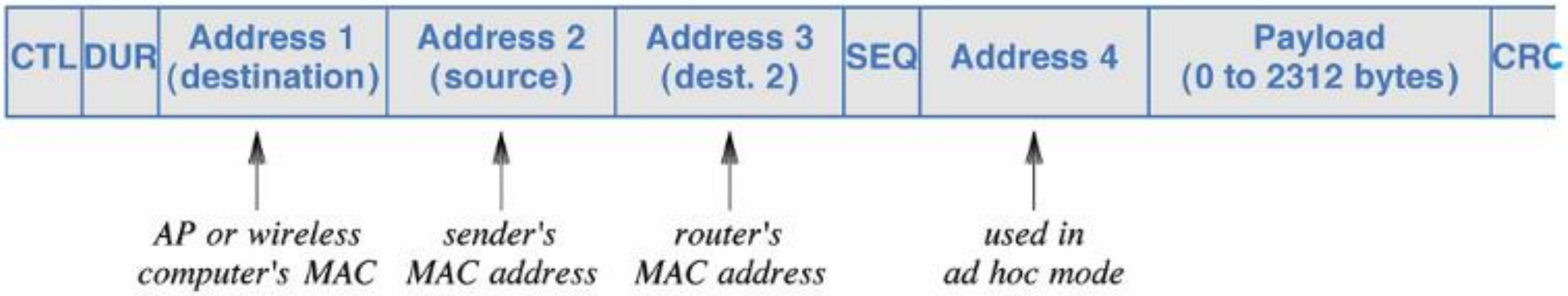
POSSIBLE SIGNAL PATH FROM AP TO USER



WHAT COULD HAPPEN TO SIGNAL ALONG THE WAY TO RECEIVER

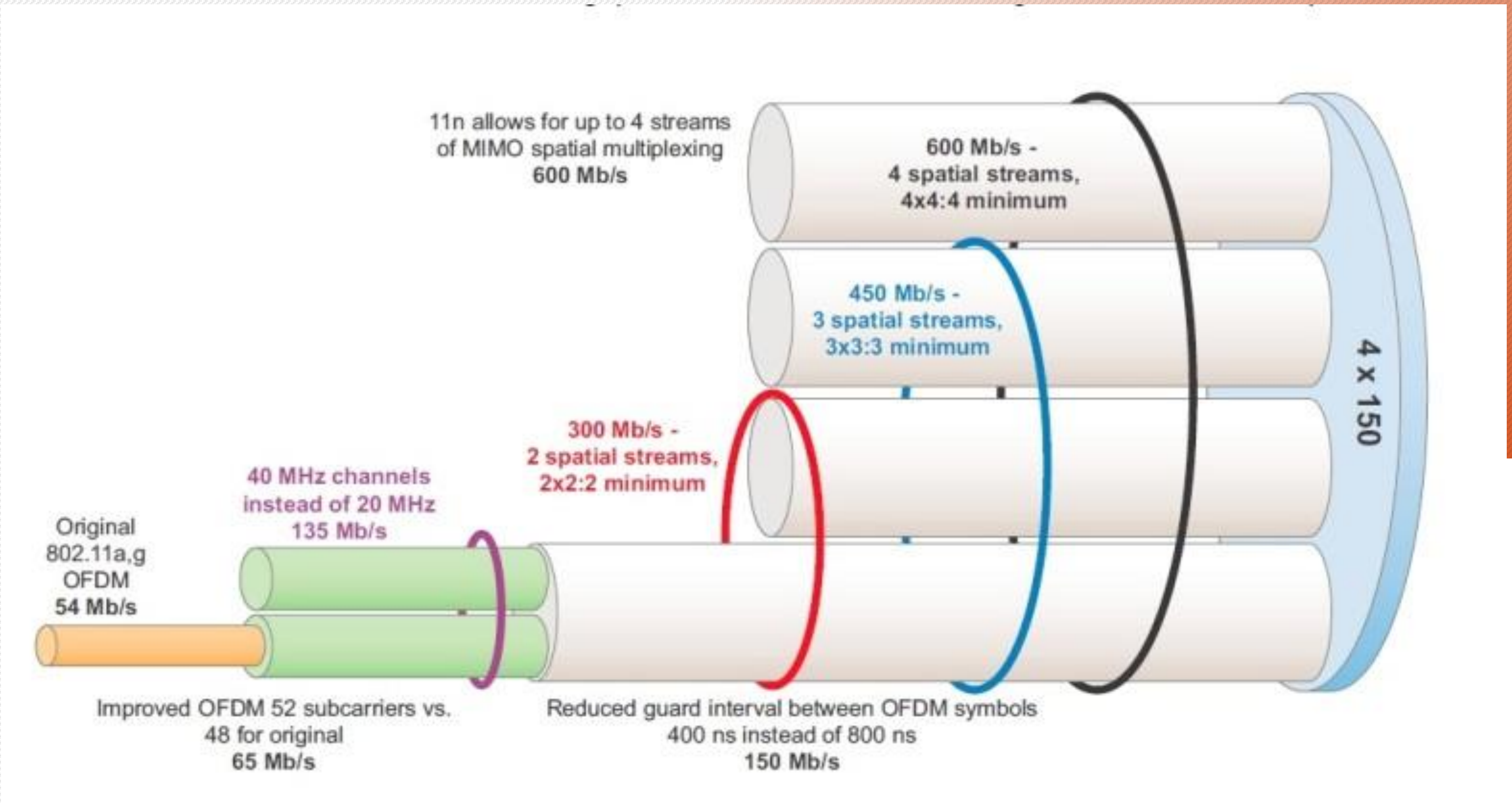


The frame format used with an 802.11 wireless LAN.



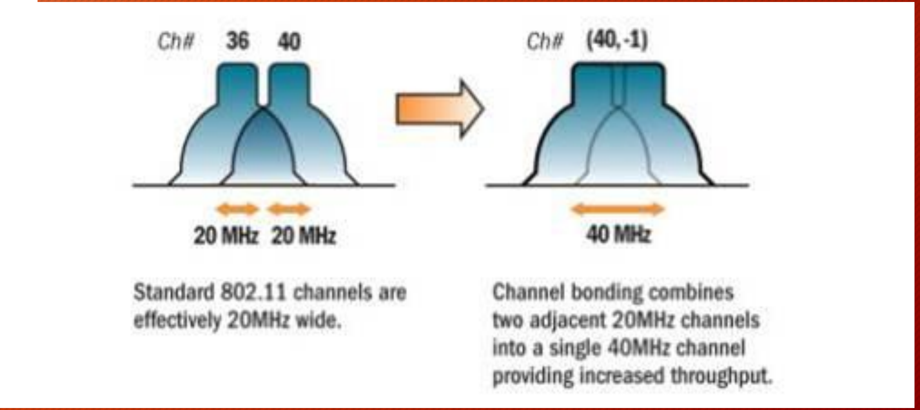
payload is typically fewer than 1500 bytes

Wireless Channel Bonding



Channel Width (columns); Number of Streams (rows)

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



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Questions????

Thank you!