Réseaux sans fil

Introduction

Master Technologies de l'Internet

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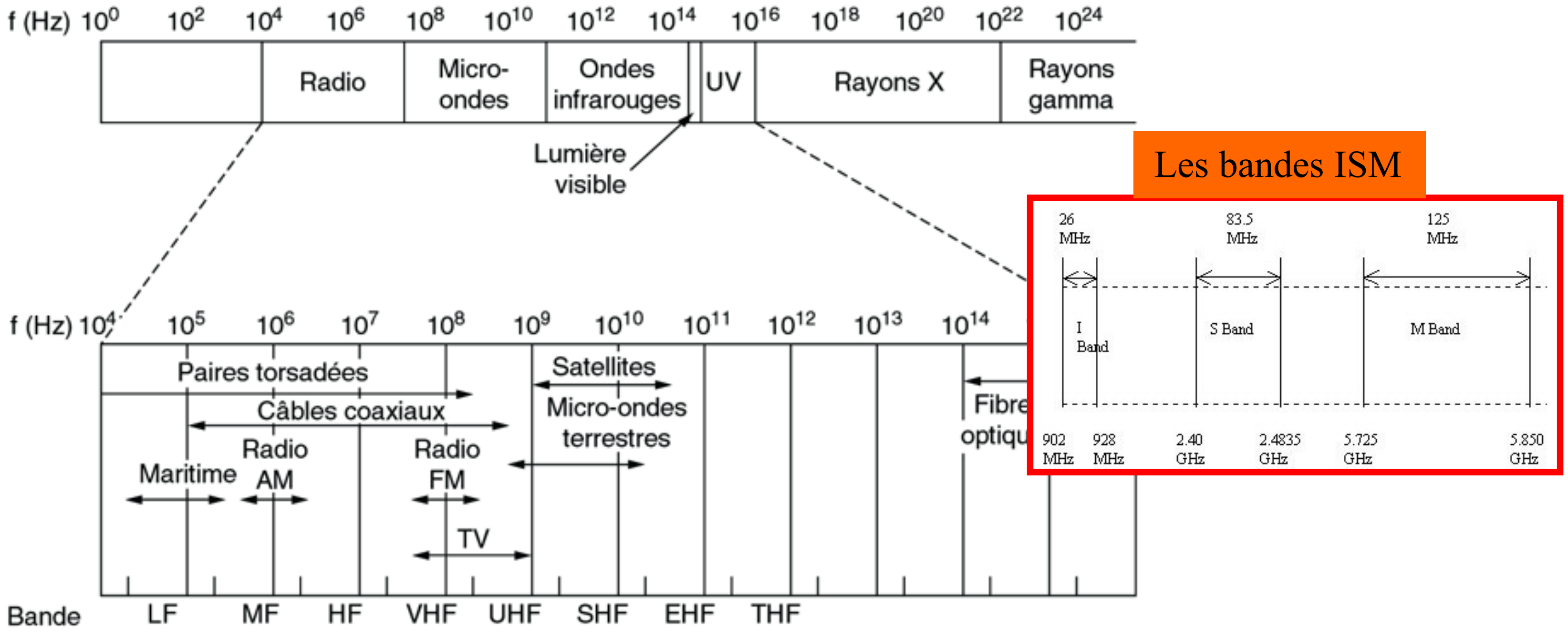
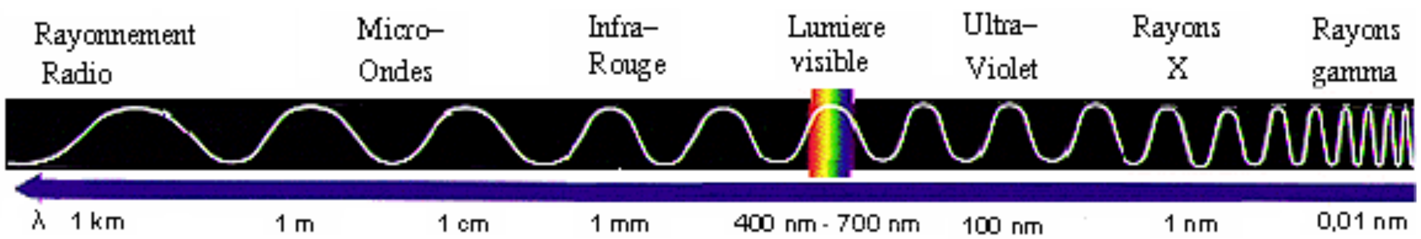
Le spectre électromagnétique





INFO

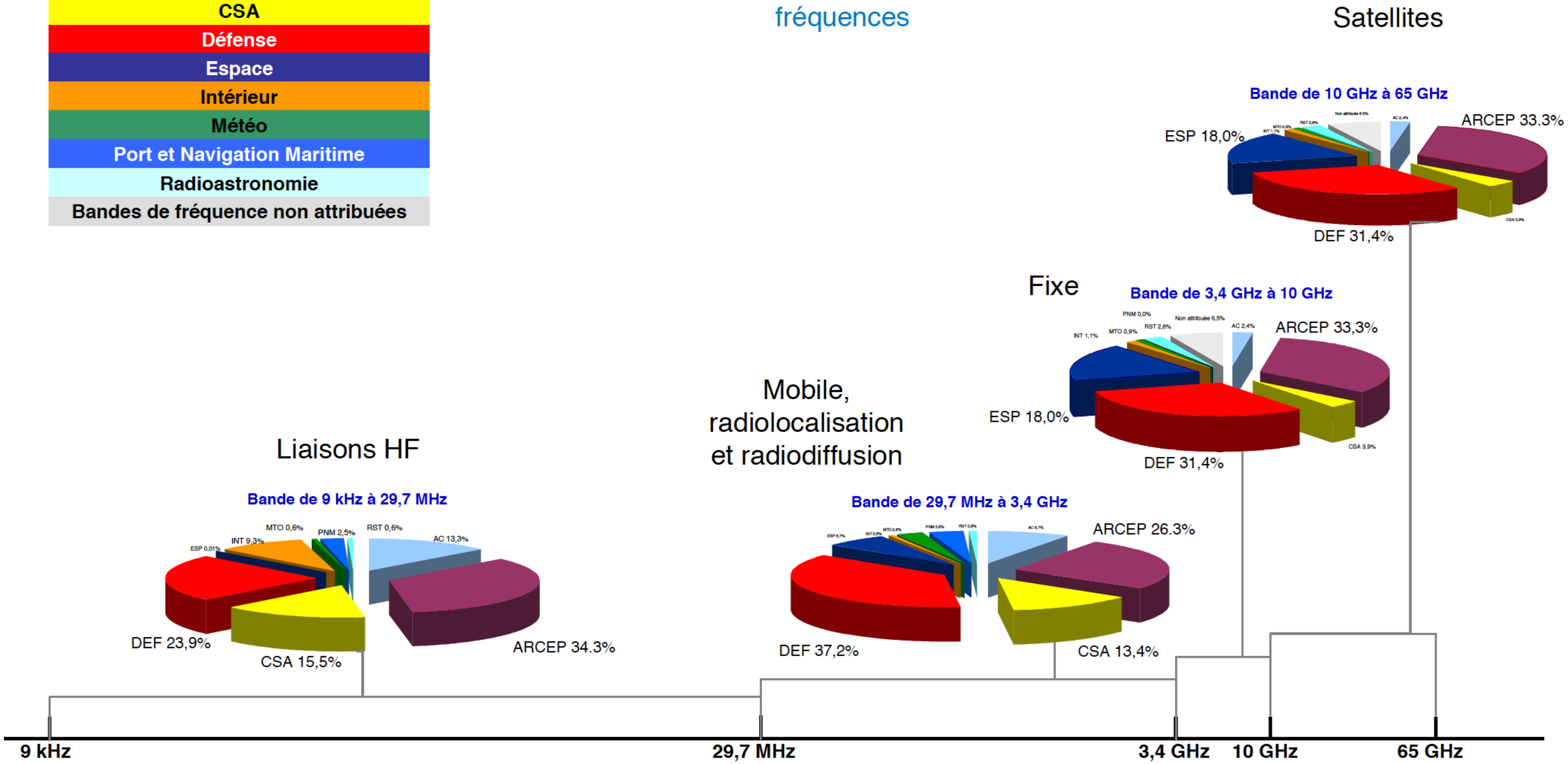
Agence nationale des fréquences (www.afnr.fr)

- **Bandes de fréquences** : attribuées aux différents services de radiocommunication par le ***Règlement des radiocommunications*** de **l'Union internationale des télécommunications**, élaboré par les conférences mondiales des radiocommunications.
- **En France, les bandes ainsi attribuées sont réparties entre 9 affectataires (7 administrations et 2 autorités indépendantes)**
  - **AC** Administration de l'aviation civile
  - **DEF** Ministère de la défense
  - **ESP** Espace
  - **INT** Ministère de l'intérieur
  - **MTO** Administration de la météorologie
  - **PNM** Administration des ports et de la navigation maritime (ex phares et balises)
  - **RST** Ministère de l'éducation nationale, de la recherche et de la technologie
  - **CSA** Conseil supérieur de l'audiovisuel
  - **ART** Autorité de régulation des Télécommunications

INFO

Aviation Civile
ARCEP
CSA
Défense
Espace
Intérieur
Météo
Port et Navigation Maritime
Radioastronomie
Bandes de fréquence non attribuées

Répartition des attributions de bandes de fréquences entre affectataires à titre primaire dans les principales gammes de fréquences

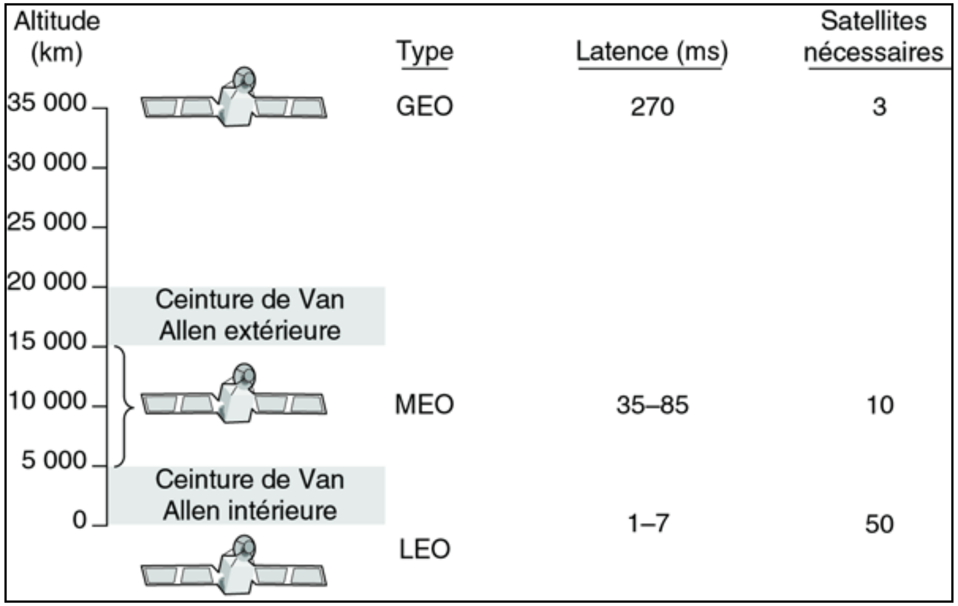


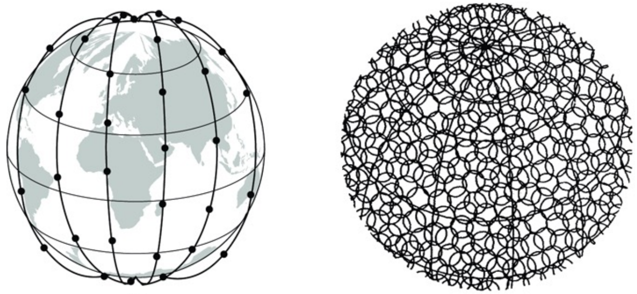
Wireless networks: WiFi

Wireless networks: 2G/3G/4G/5G/6G/...

Wireless networks: Bluetooth

Wireless networks: Satellites

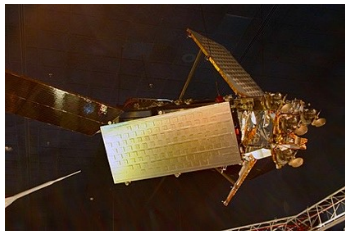


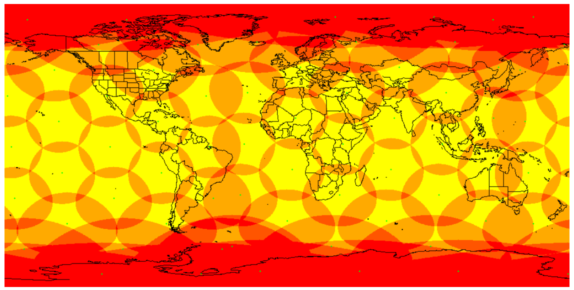


(a) (b)

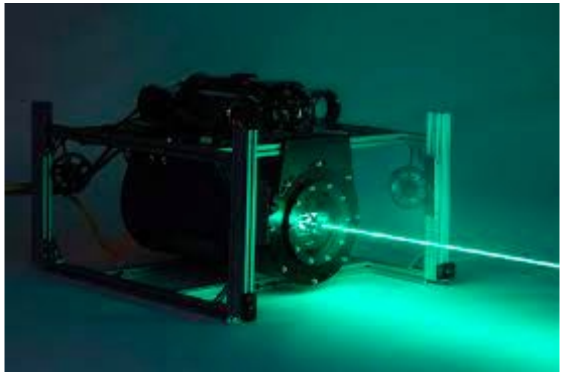
Iridium, 66 satellites

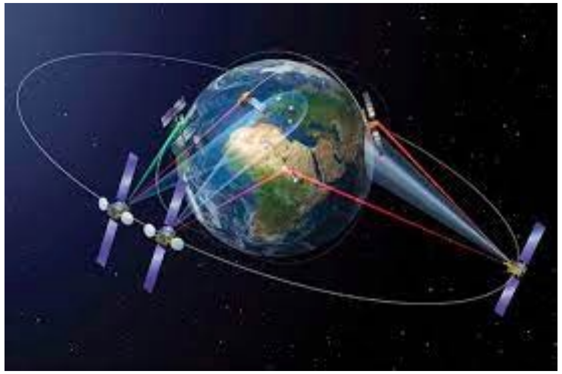
Initially 77

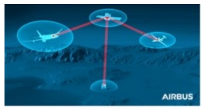




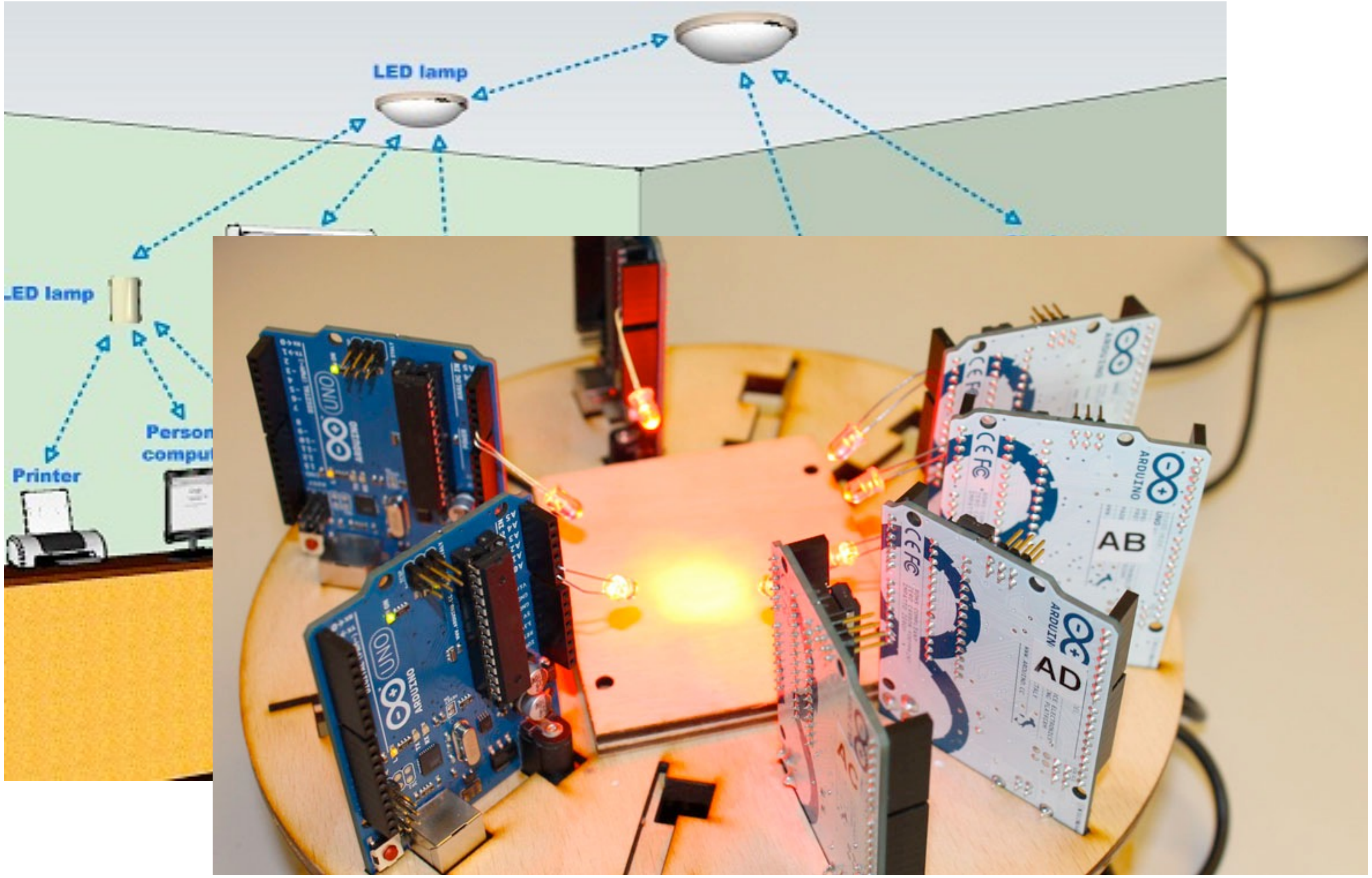
Wireless networks: Laser/Optical





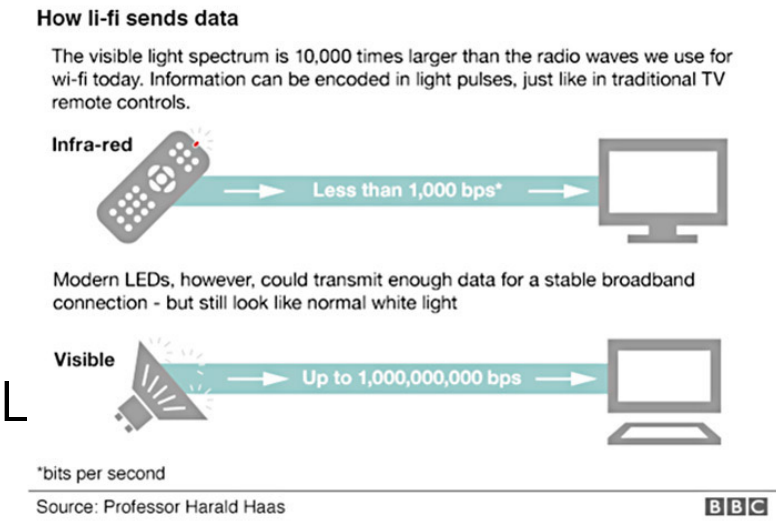


Wireless networks: Visible Light

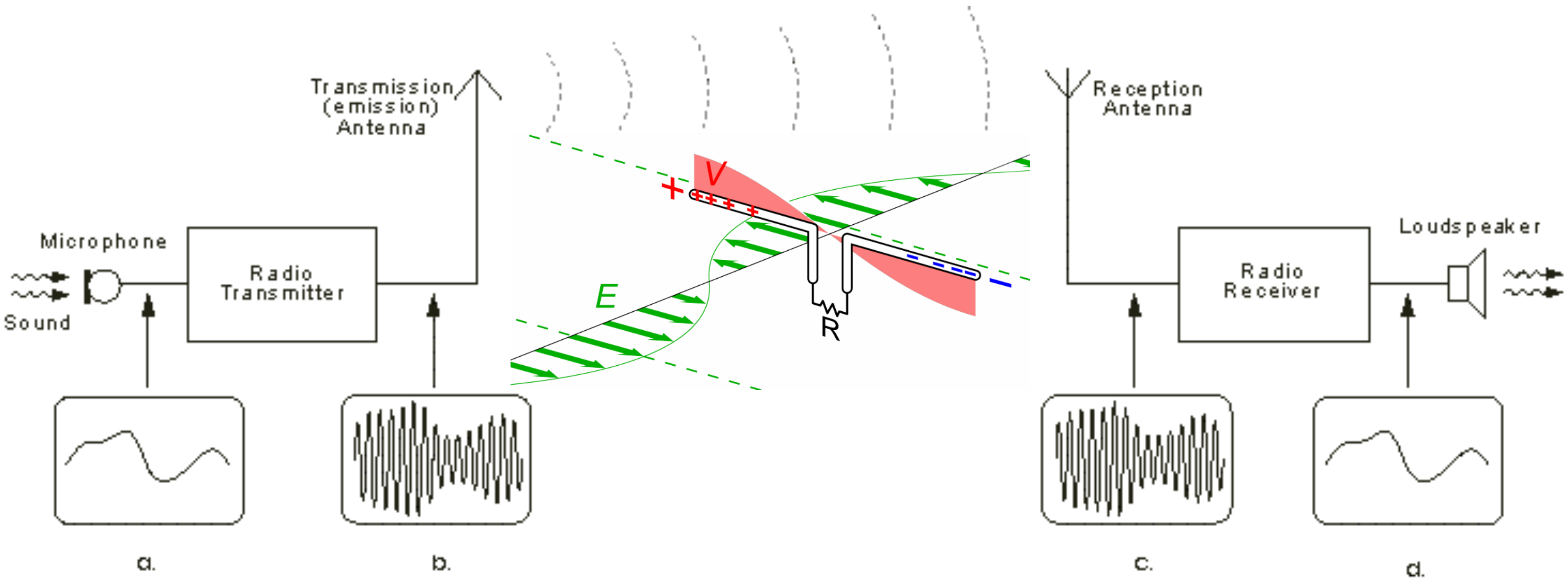


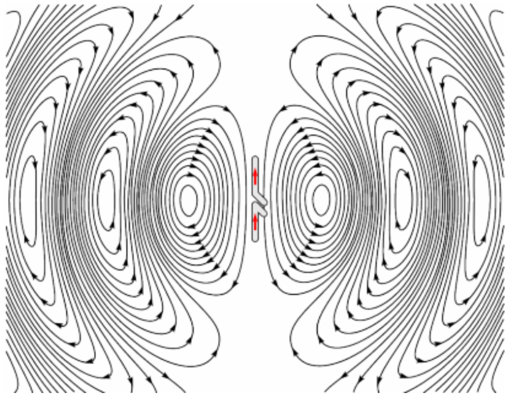
Visible Light Communications, con't

- High throughput is "easy"
- Bi-directionality is still an issue
- VR is a perfect application for VL

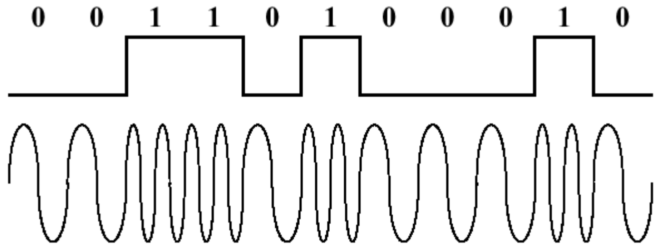


Wireless radio transmission basics





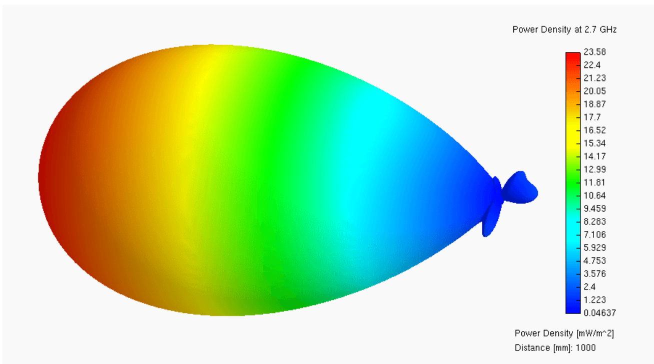
datal modulation



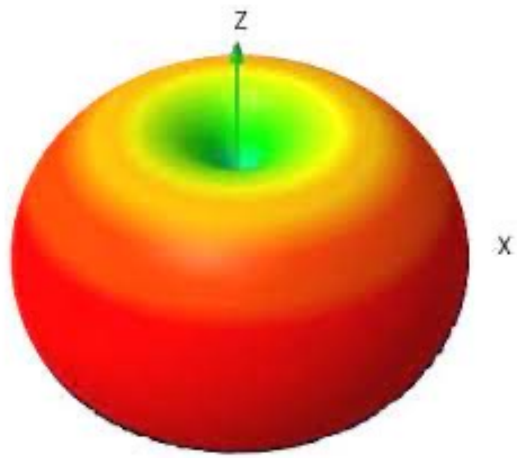
(b) Frequency-shift keying

Antenna types

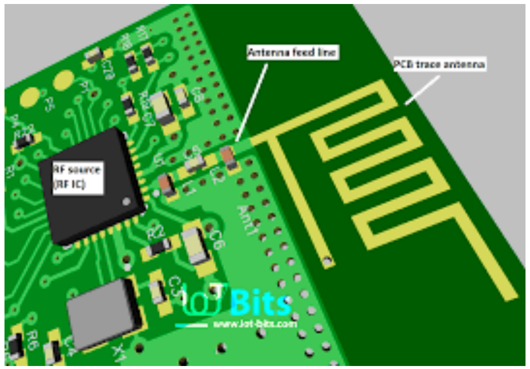
Omni-directional antennas

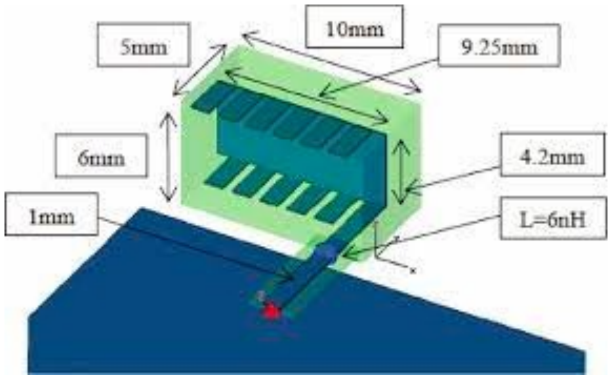


Directional antenna



PCB, patch, ceramic,…





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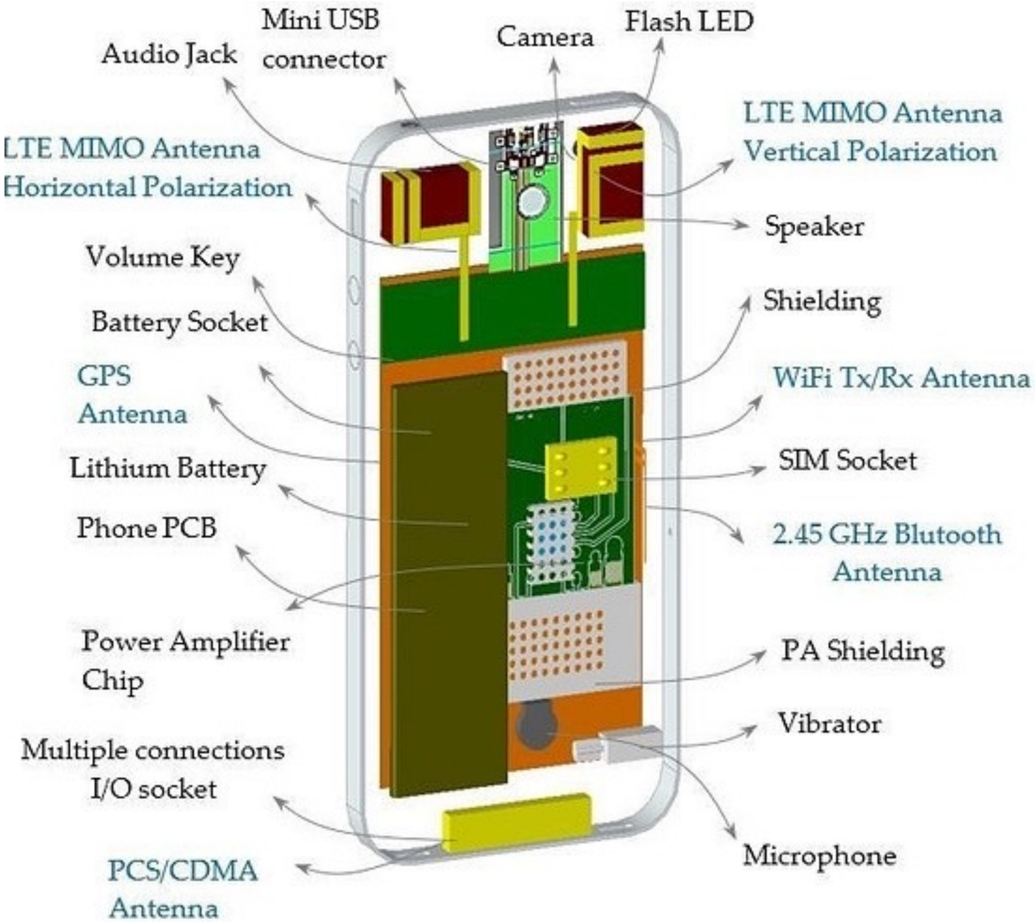
Antennas in a smartphones!



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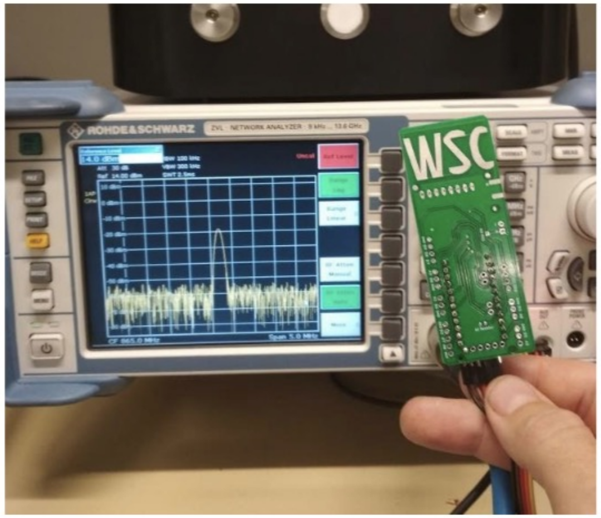
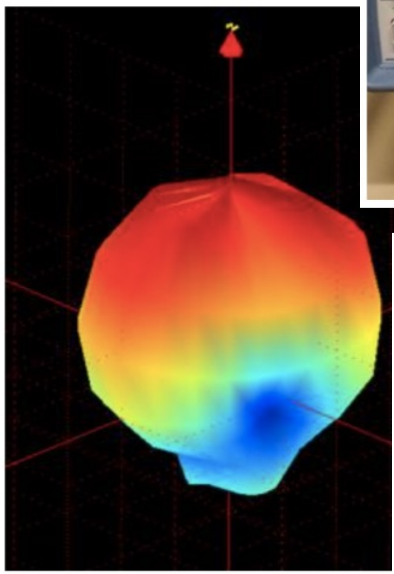
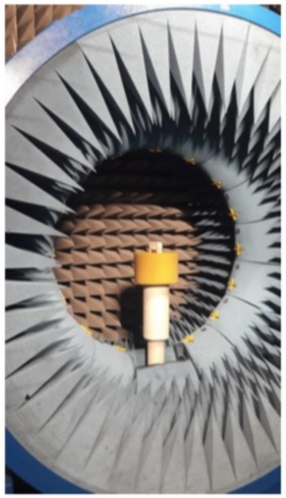
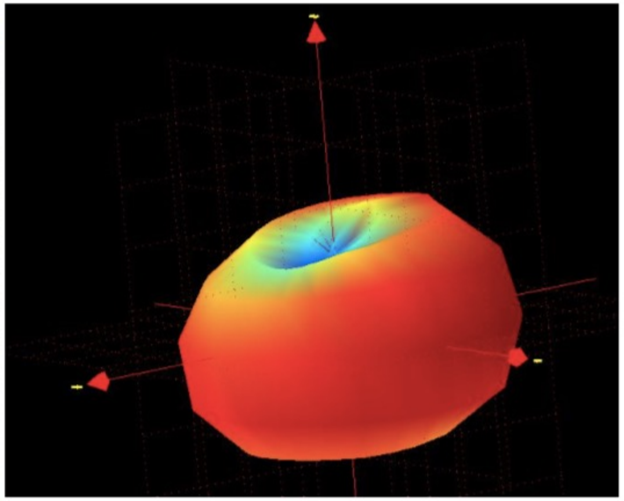
Testing antennas

- Source: F. Ferrero, University of Nice



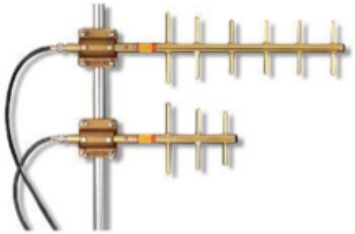






Antenna gain (1)

- Antenna gain
  - Directional antennas FOCUS energy: they DO NOT ADD energy



- Antenna Gain
  - Omni-directional antennas FOCUS energy: they DO NOT ADD energy

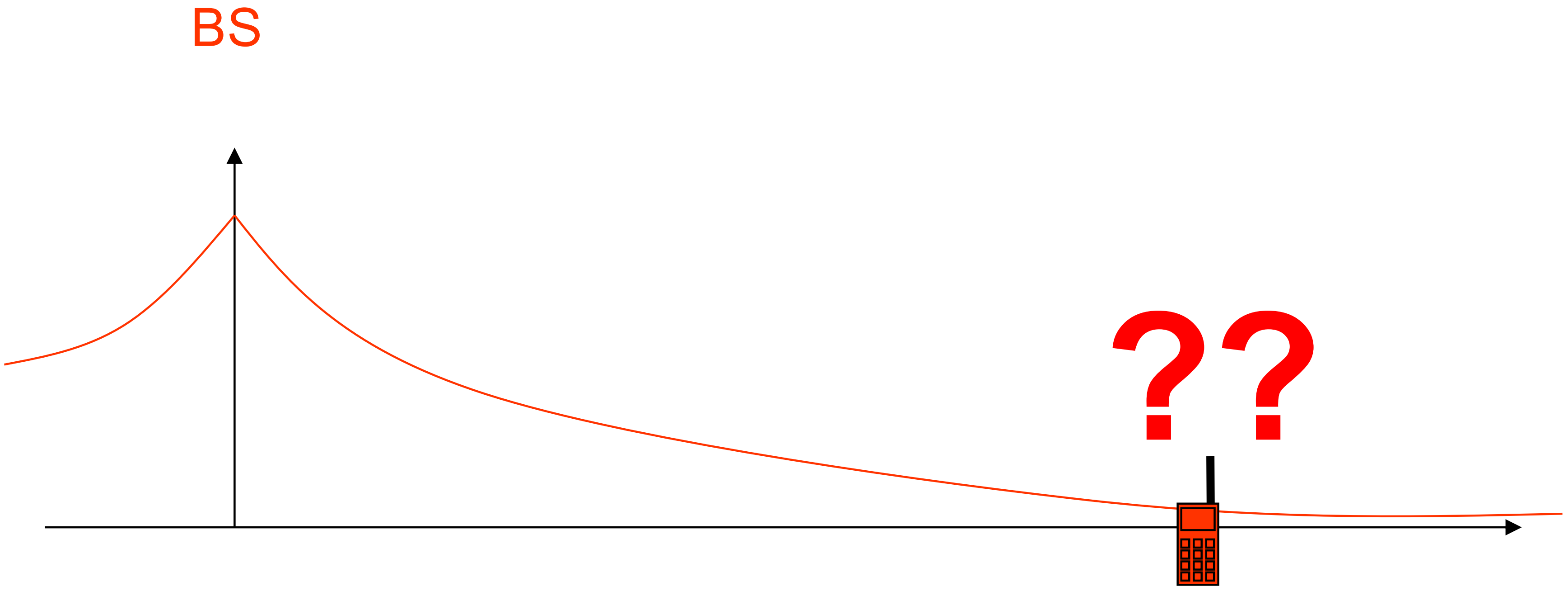
Antenna gain (2)

- Antenna gain and its effective surface

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

- with
  - G = gain
  - A_e= effective surface
  - f = signal frequency
  - c = light speed in space 3.10^8 m/s
  - λ= wave length of the signal=c/f

1st challenge: signal attenuation



Attenuation limits the range!

- Attenuation depends mainly on distance

$$\boxed{P_r = P_e d^{-\alpha}}$$

- with :
  - P_e = transmitted power
  - P_r = received power
  - d = distance between antennas
  - α from 2 to 4

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Attenuation in practice

- For an ideal antenna (theoretic)

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

  - P_e = transmitted power
  - P_r = received power
  - P_e / P_r is high when P_r is small → high attenuation
  - d = distance between antennas
  - c = light speed in space 3.10^8 m/s
  - λ= wave length of the signal=c/f
  - Higher frequencies f means higher attenuation!

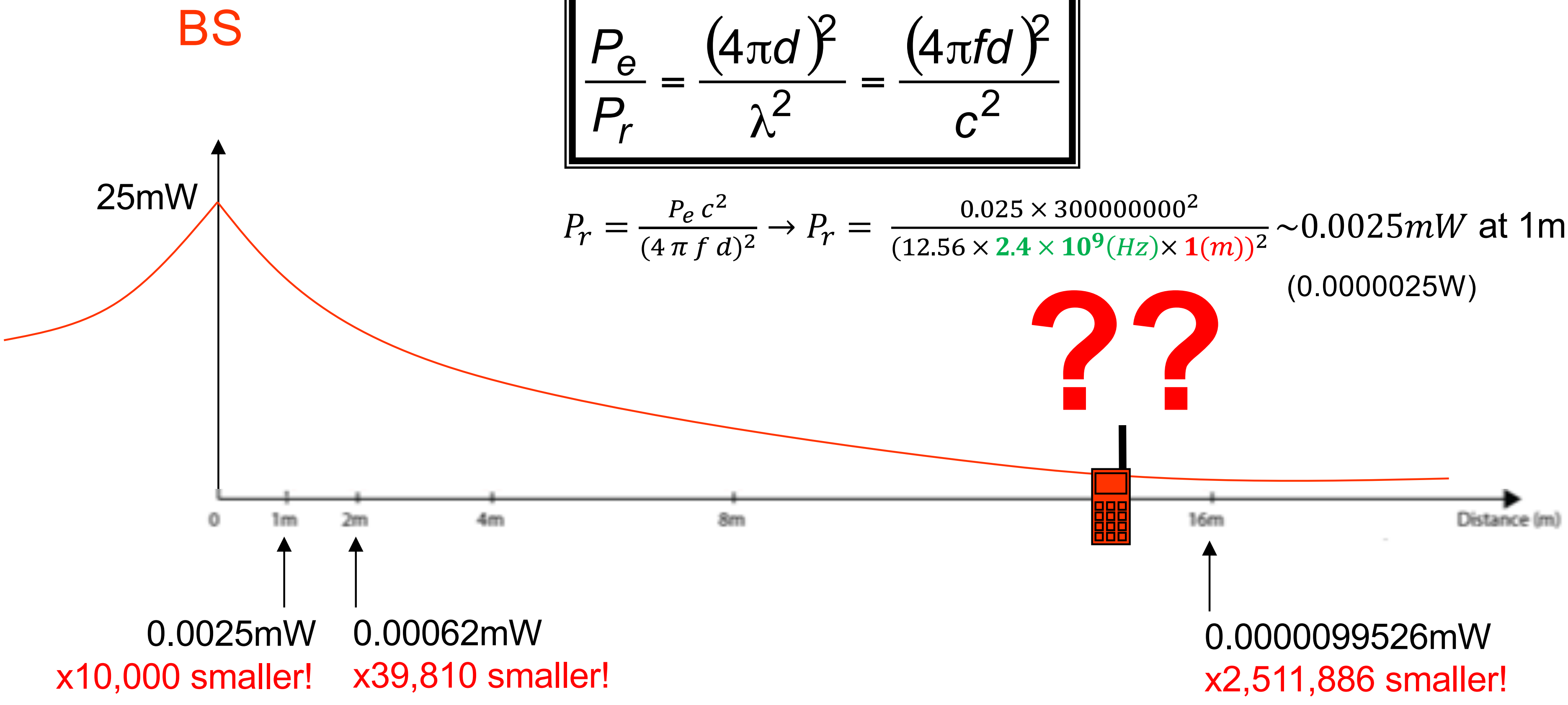
Attenuation, values in watts

- Free Space Path Loss model

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

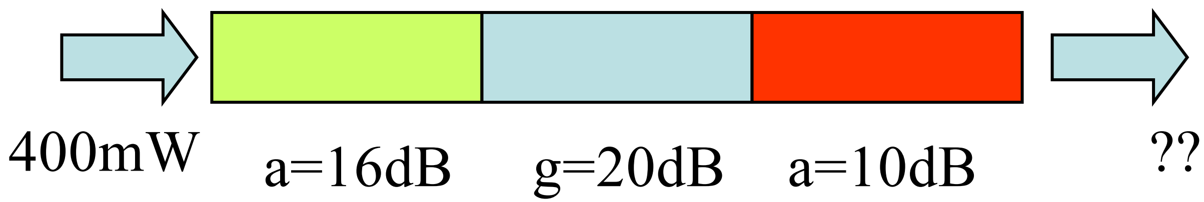
$$P_r = \frac{P_e\, c^2}{(4\,\pi\, f\, d)^2} \rightarrow P_r = \frac{0.025 \times 300000000^2}{(12.56 \times 2.4 \times 10^9 (Hz) \times 1(m))^2} \sim 0.0025 mW \text{ at 1m}$$

(0.0000025W)



Attenuation in decibel (dB)

- Decibel uses logarithmic scale as attenuation values can be very large
- Attenuation in dB: $10\log10(P_e/P_r)$, P_e and P_r in watts
  - So $P_e/P_r = 10^{dB/10}$
  - Difference of 3dB≈half (divided by 2) as $P_e/P_r = 10^{3/10} = 10^{0.3} = 1.99526\ldots$
- ➡Gain = $10\log10(P_r/P_e)$
- We can add various sections with attenuation or gain

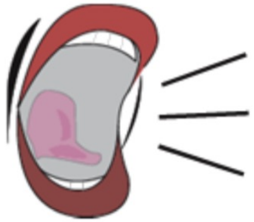


-16dB + 20dB - 10dB = -6dB, so it is an attenuation

$P_e/P_r = 10^{6/10} = 10^{0.6} = 3.98$ ➡ $P_r = P_e/3.98 \approx 100mW$

dB, dBm, …

- Total net output power of transmitter
- Typically measured in dBm or mW



- mW: milliwatts are a measurement of power (1000 mW = 1 Watt).
- dB: decibel is a unit for expressing the ratio of two amounts of signal power equal to 10 times the common logarithm of this ratio. So, a power measurement in dB has to be relative to something.
- dBm: dB(mW) is power relative to 1 milliwatt (mW to dBm = $10\text{Log}_{10}(\text{mW}/1000) + 30$).

  $P(\text{dBm}) = 10 \cdot \log10(P(\text{mW}) / 1\text{mW})$
- dBi: dB(isotropic) is the forward gain of an antenna compared to the hypothetical isotropic antenna, which uniformly distributes energy in all directions.

dBm to mW conversion

P(dBm)=10.$\log_{10}$(P(mW)/1mW)

$$P(mW) = 10^{\frac{P(dBm)}{10}}$$

Ex:

$$P(mW) = 10^{\frac{14dBm}{10}} = 10^{1.4} = 25.118mW$$

dBm	Watts	dBm	Watts	dBm	Watts
0	1.0 mW	16	40 mW	32	1.6 W
1	1.3 mW	17	50 mW	33	2.0 W
2	1.6 mW	18	63 mW	34	2.5 W
3	2.0 mW	19	79 mW	35	3.2 W
4	2.5 mW	20	100 mW	36	4.0 W
5	3.2 mW	21	126 mW	37	5.0 W
6	4 mW	22	158 mW	38	6.3 W
7	5 mW	23	200 mW	39	8.0 W
8	6 mW	24	250 mW	40	10 W
9	8 mW	25	316 mW	41	13 W
10	10 mW	26	398 mW	42	16 W
11	13 mW	27	500 mW	43	20 W
12	16 mW	28	630 mW	44	25 W
13	20 mW	29	800 mW	45	32 W
14	25 mW	30	1.0 W	46	40 W
15	32 mW	31	1.3 W	47	50 W

RF Essentials from Digi

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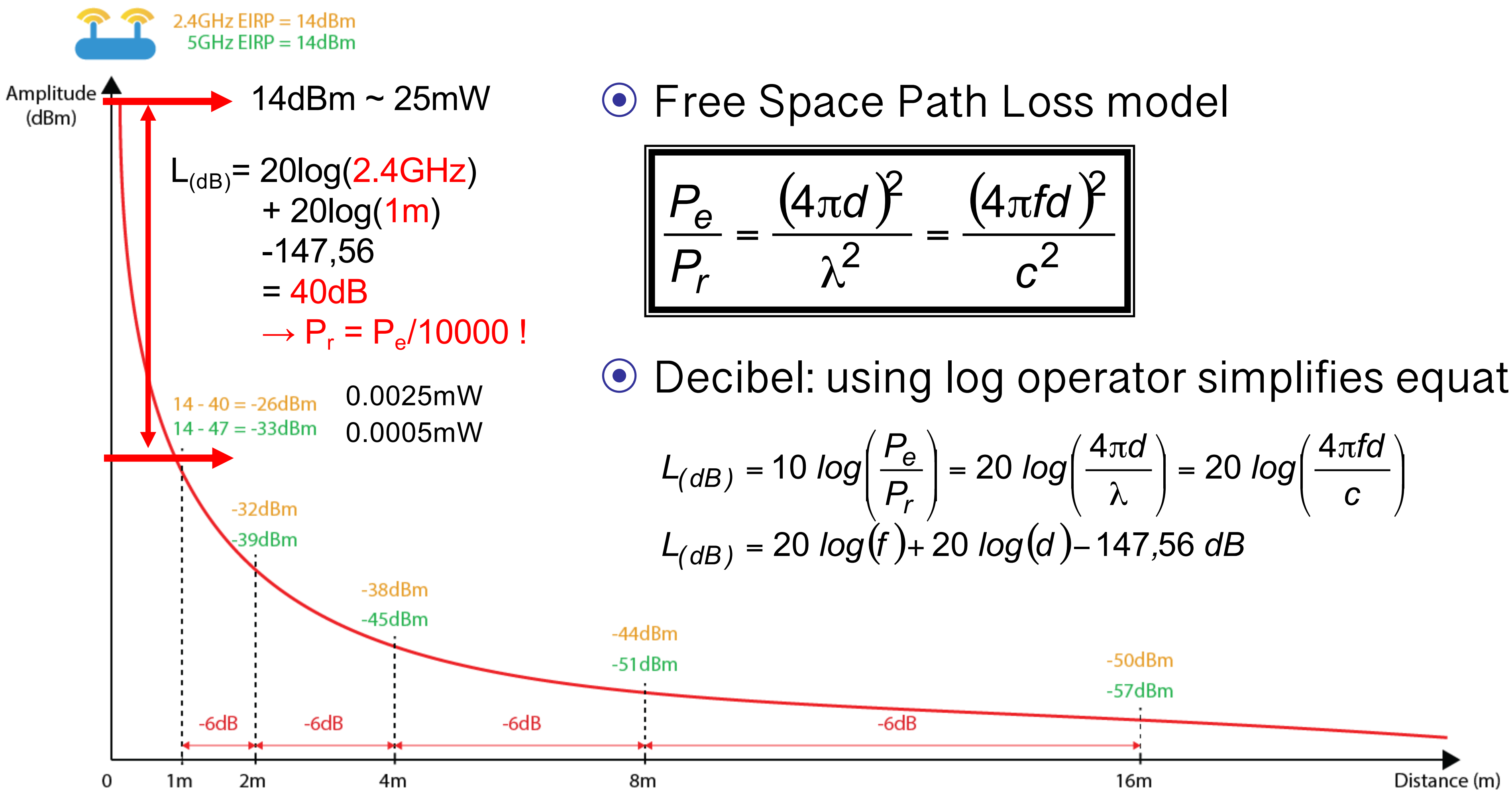
Attenuation, using dBm & dB



$$10^{\frac{-26dBm}{10}} = 10^{-2.6} = 0.0025118mW$$

$$10^{\frac{-32dBm}{10}} = 10^{-3.2} = 0.00063mW$$

- Free Space Path Loss model

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

- Decibel: using log operator simplifies equation

$$L_{(dB)} = 10\ log\left(\frac{P_e}{P_r}\right) = 20\ log\left(\frac{4\pi d}{\lambda}\right) = 20\ log\left(\frac{4\pi f d}{c}\right)$$

$$L_{(dB)} = 20\ log(f) + 20\ log(d) - 147{,}56\ dB$$

Additional advantage of log scale: very large and very small values can be plotted on the same graph

Impact of signal frequency

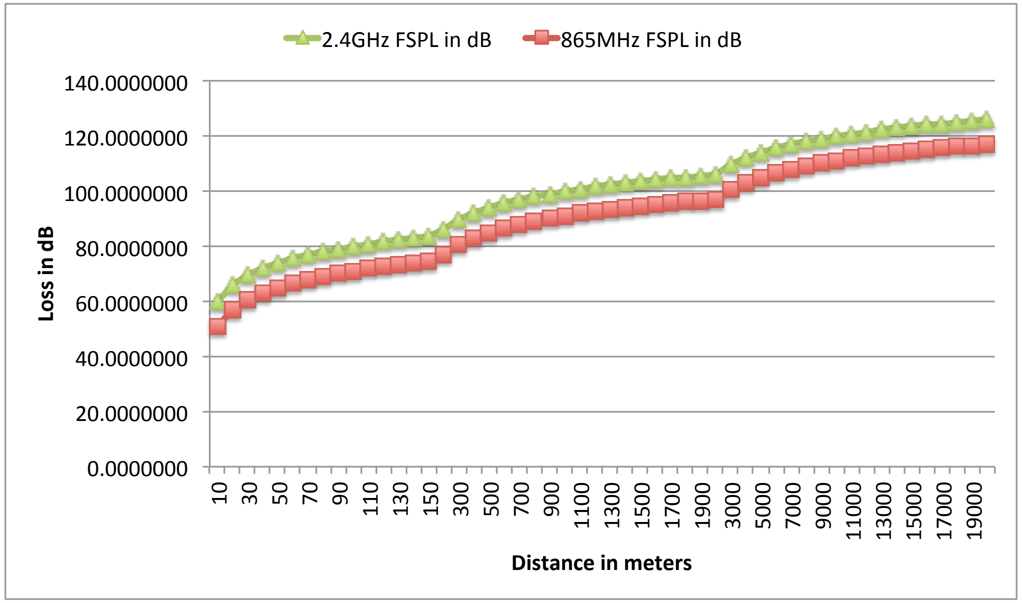
- Free Space Path Loss model

$$\text{FSPL} = \left(\frac{4\pi d}{\lambda}\right)^2 = \left(\frac{4\pi df}{c}\right)^2 \qquad FSPL = \frac{P_t}{P_r} G_t G_r$$

FSPL assume Gt=Gr=1

$$L_{(dB)} = 10\log\left(\frac{P_t}{P_r}\right) = 20\log\left(\frac{4\pi d}{\lambda}\right) = 20\log\left(\frac{4\pi fd}{c}\right)$$

$$L_{(dB)} = 20\log(f) + 20\log(d) - 147{,}55\ dB$$

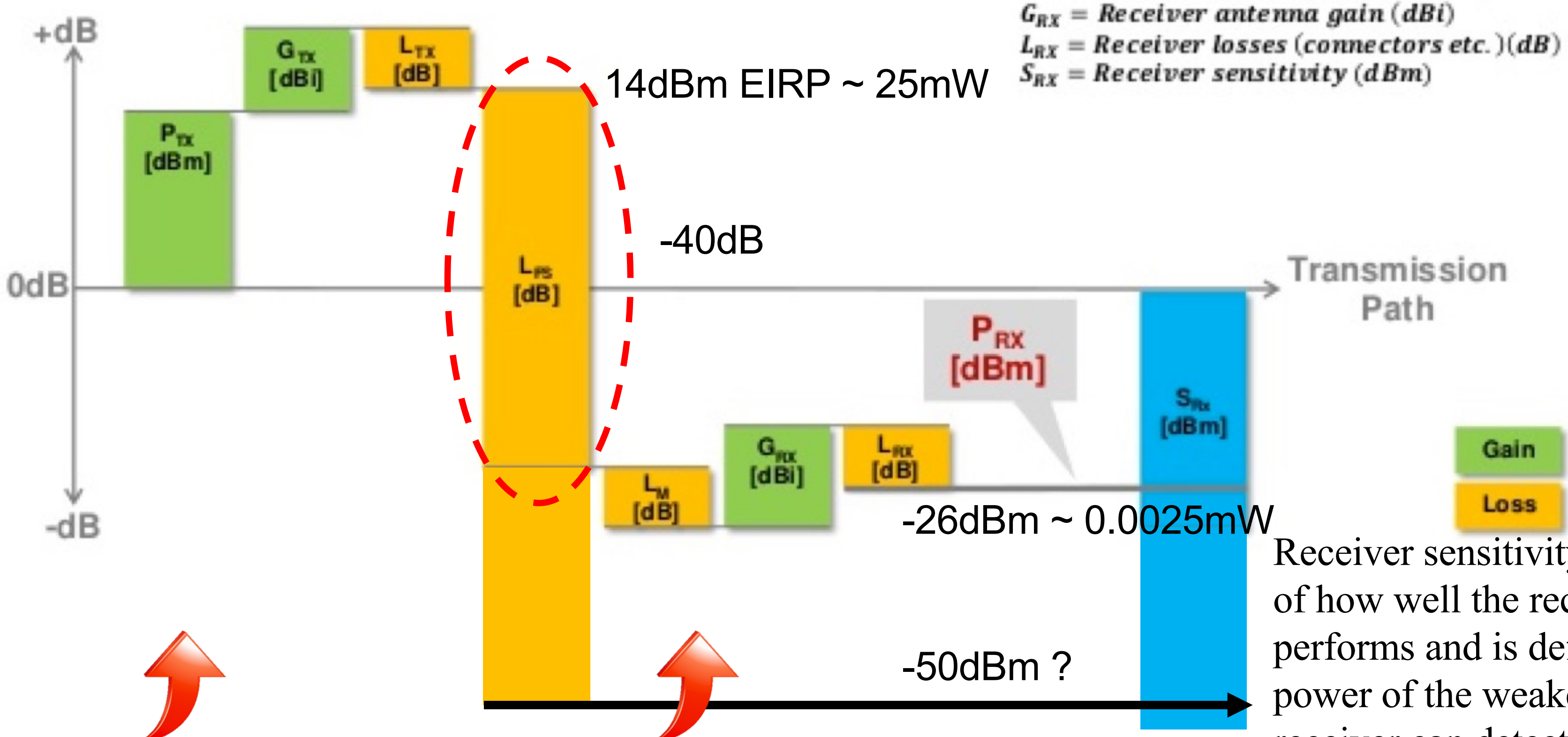


Link budget in wireless system

$$P_{RX} = P_{TX} + G_{TX} - L_{TX} - L_{FS} - L_M + G_{RX} - L_{RX}$$

P_{RX} = Received power (dBm)
P_{TX} = Sender output power (dBm)
G_{TX} = Sender antenna gain (dBi)
L_{TX} = Sender losses (connectors etc.)(dB)
L_{FS} = Free space loss (dB)
L_M = Misc. losses (multipath etc.)(dB)
G_{RX} = Receiver antenna gain (dBi)
L_{RX} = Receiver losses (connectors etc.)(dB)
S_{RX} = Receiver sensitivity (dBm)

Adapted from Peter R. Egli, INDIGOO.COM

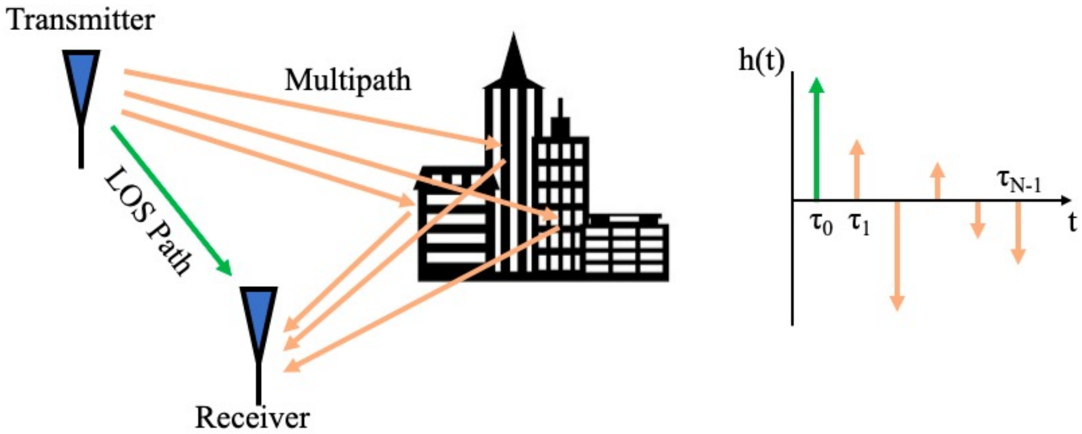


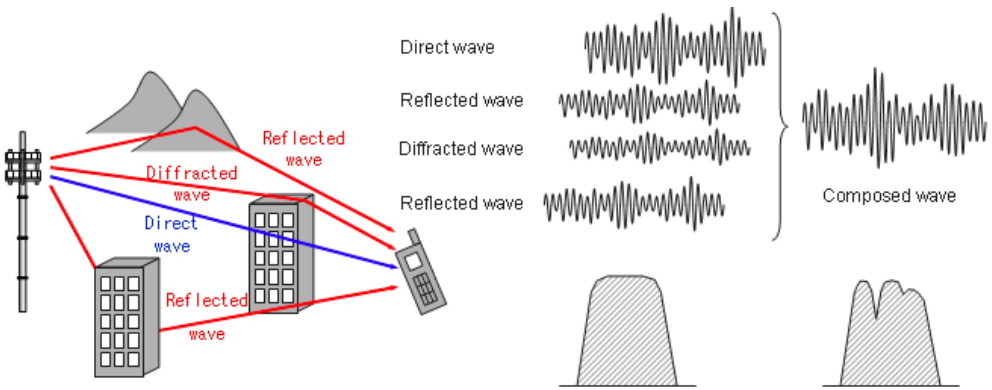
Receiver sensitivity is a measure of how well the receiver performs and is defined as the power of the weakest signal the receiver can detect

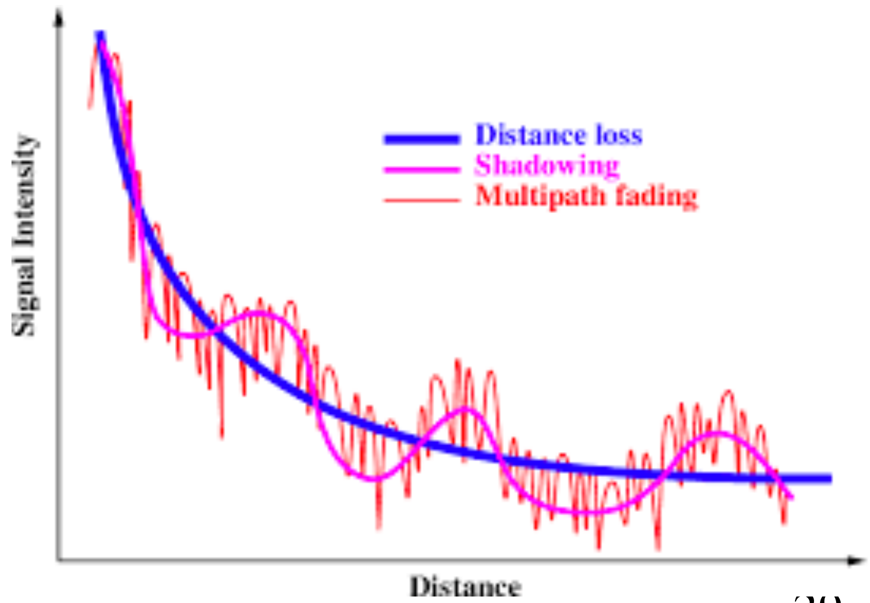
$$L_{(dB)} = 20\log(f) + 20\log(d) - 147{,}56\ dB$$

Shadow fading & Multi-path fading

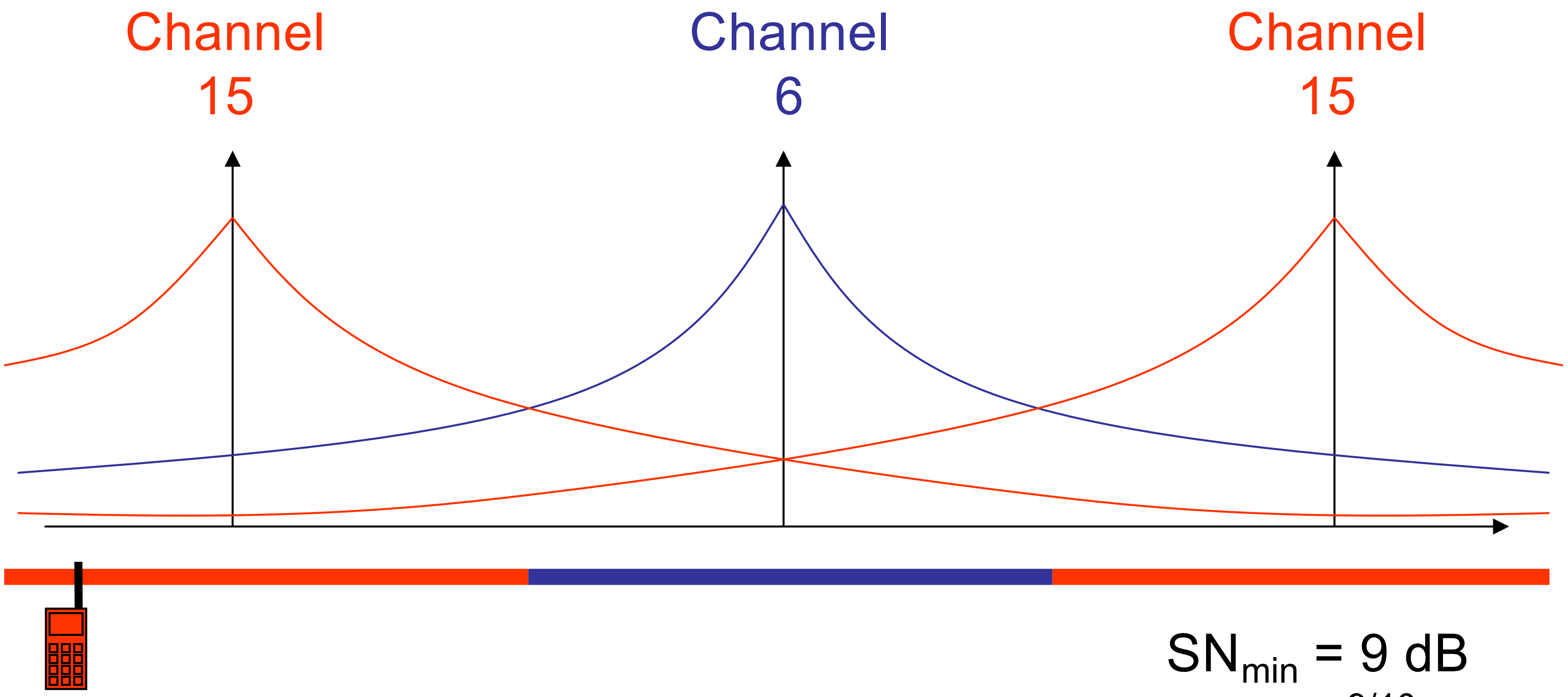
- Things are getting even worse!
- Shadow fading by obstacles
- Multi-path fading
- …







Frequency re-use



SN_{min} = 9 dB

$S/N=10^{9/10}=7.94$

2nd challenge: energy-range dilemma Low-power & long-range radios