IOT Online Course

Fundamentals of IoT

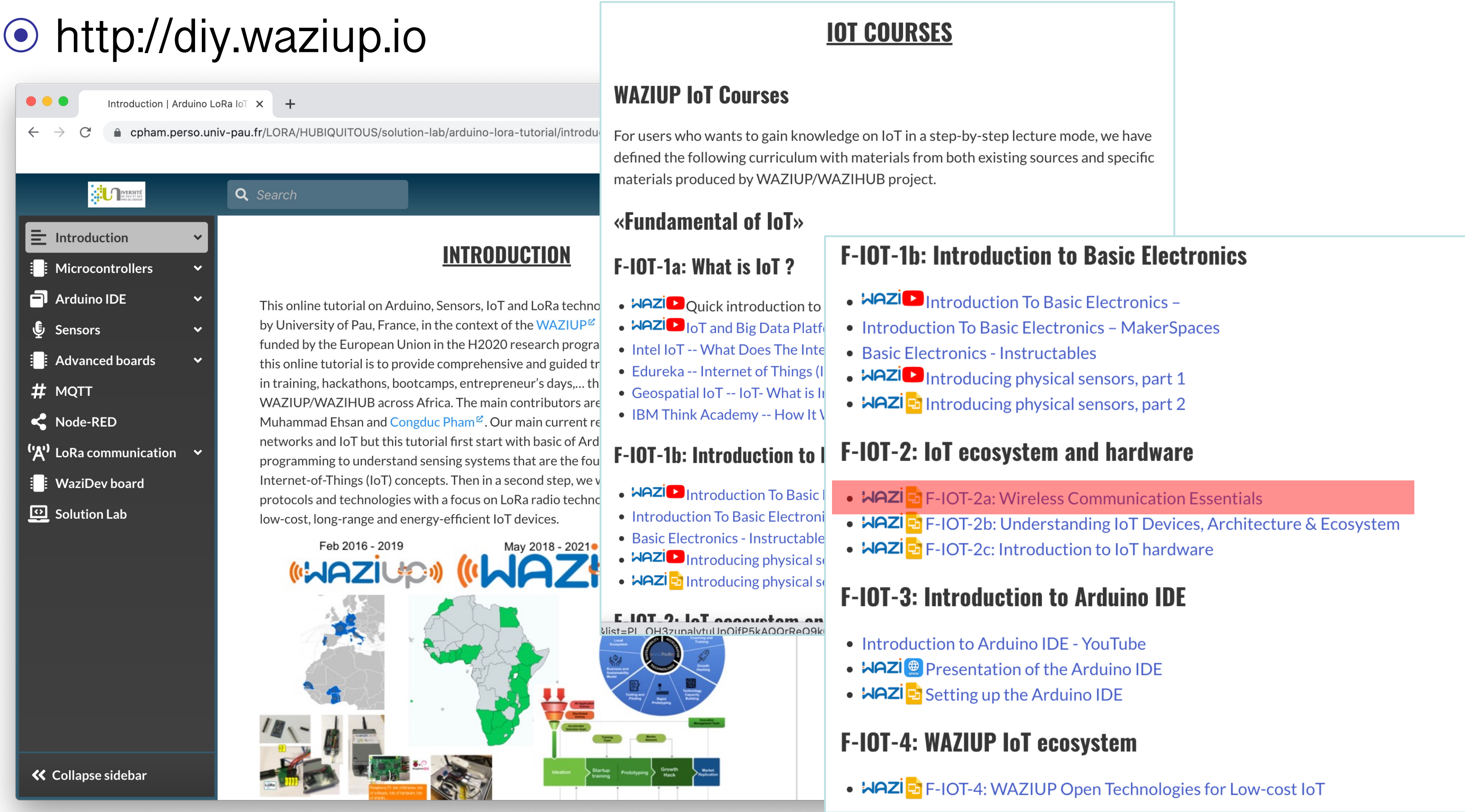
F-IOT-2a: Wireless Communication Essentials

Prof. Congduc Pham
http://www.univ-pau.fr/~cpham
Université de Pau, France

IoT – from idea to reality

IoT Online Course

- http://diy.waziup.io

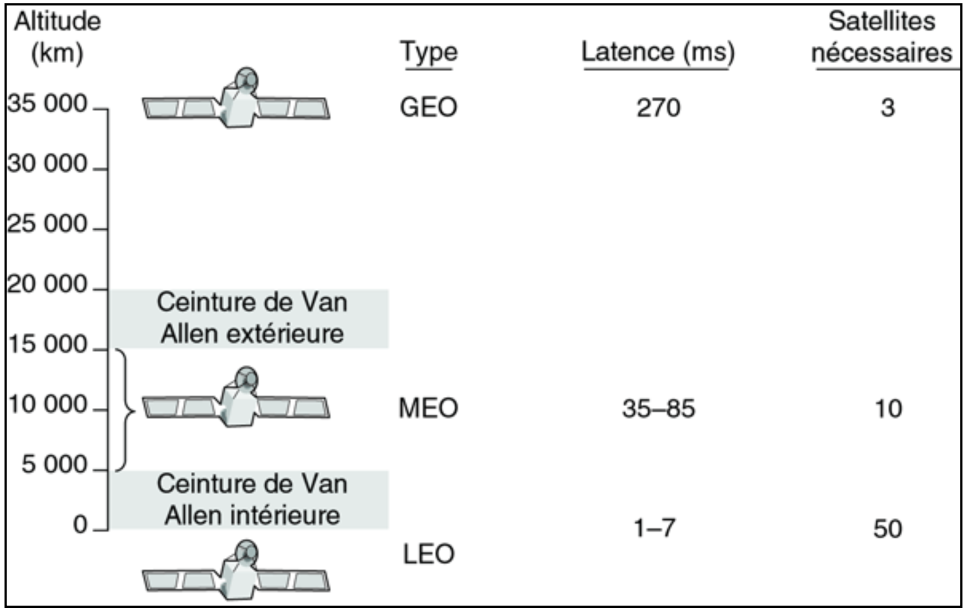


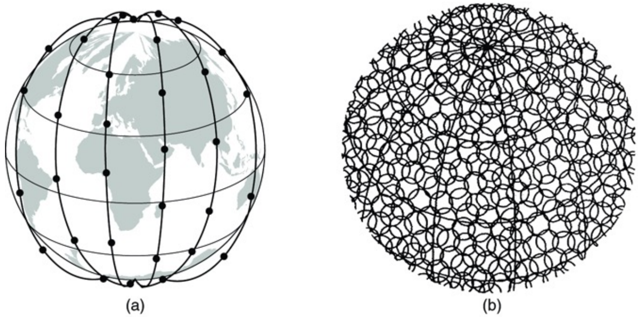
Wireless networks: WiFi

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

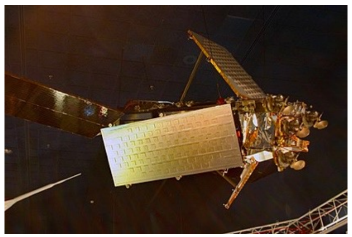
Wireless networks: Bluetooth

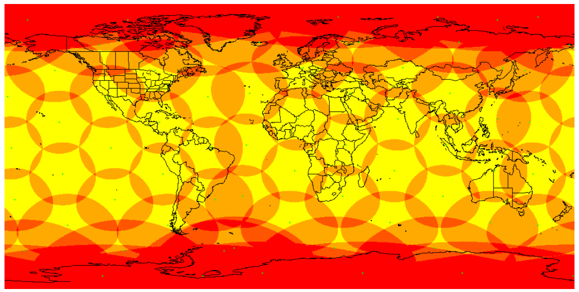
Wireless networks: Satellites



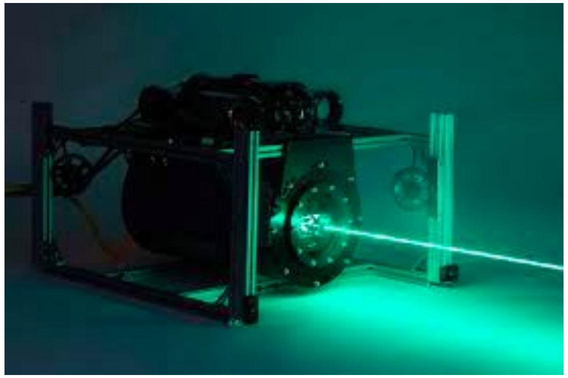


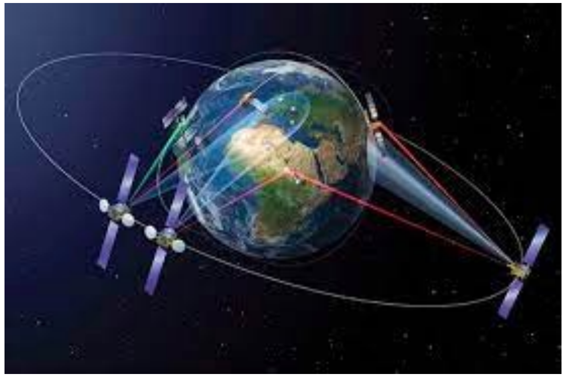
Iridium, 66 satellites
Initially 77

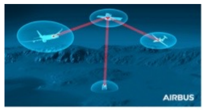




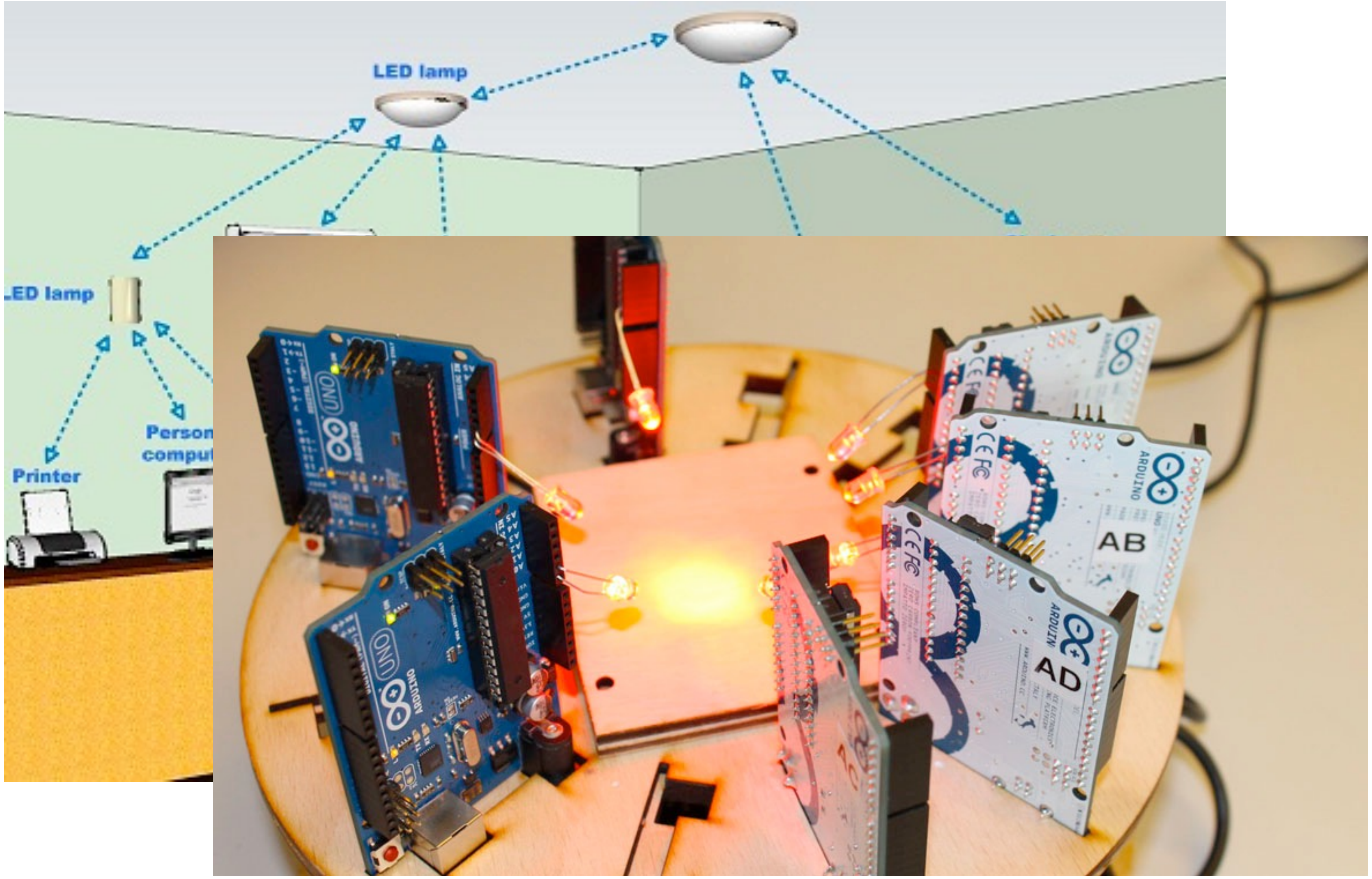
Wireless networks: Laser/Optical





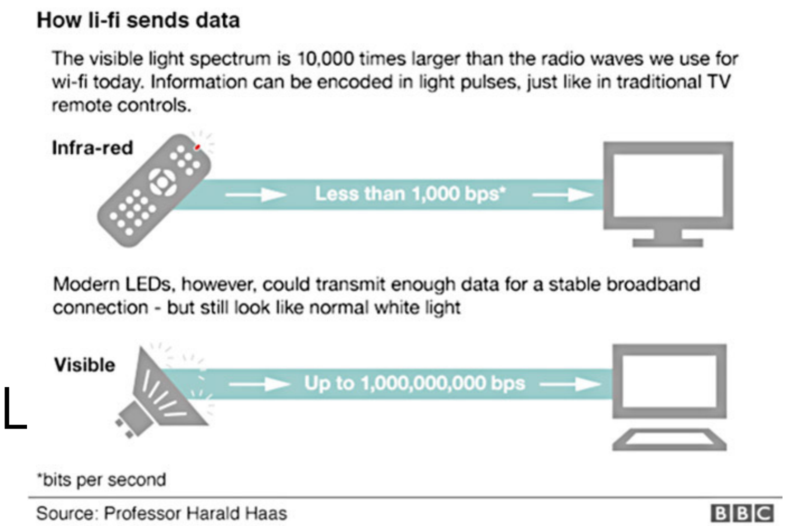


Wireless networks: Visible Light

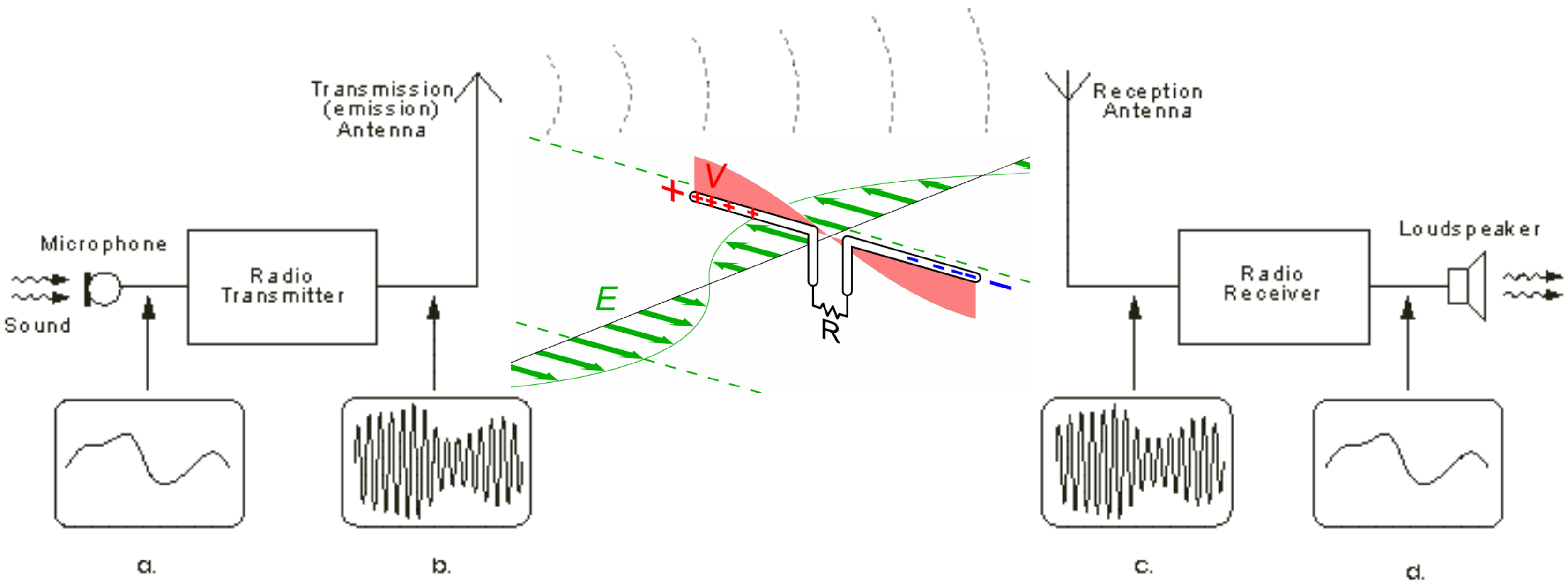


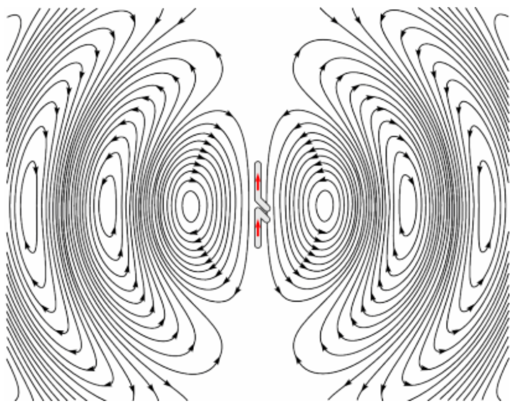
Visible Light Communications, con't

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

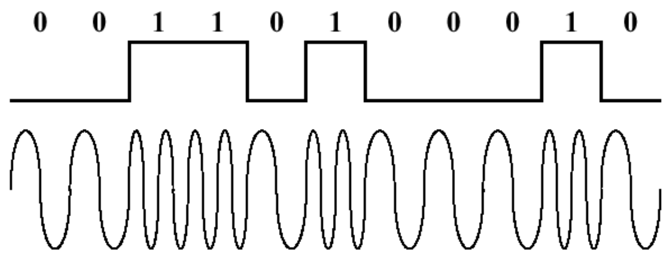


Wireless radio transmission basics



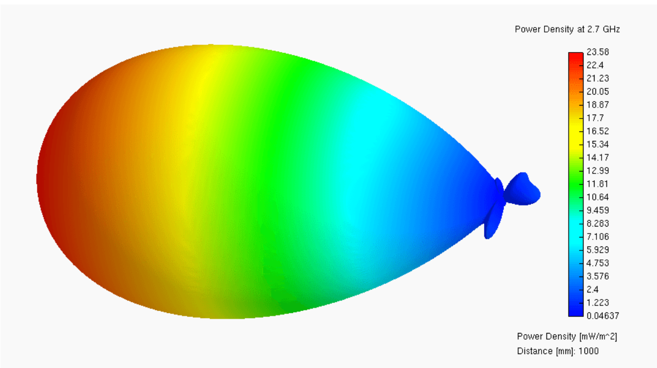


datal modulation



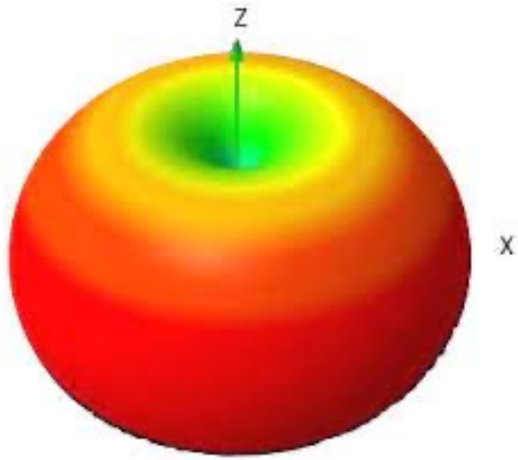
(b) Frequency-shift keying

Antenna types

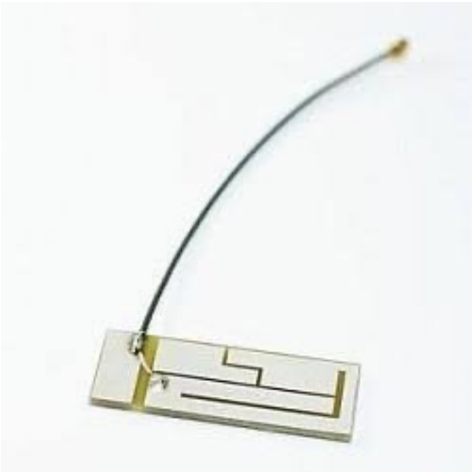


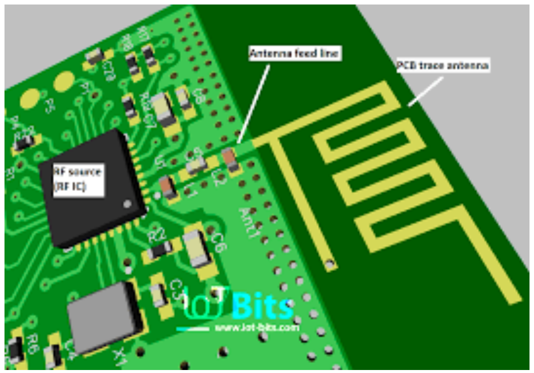
Directional antenna

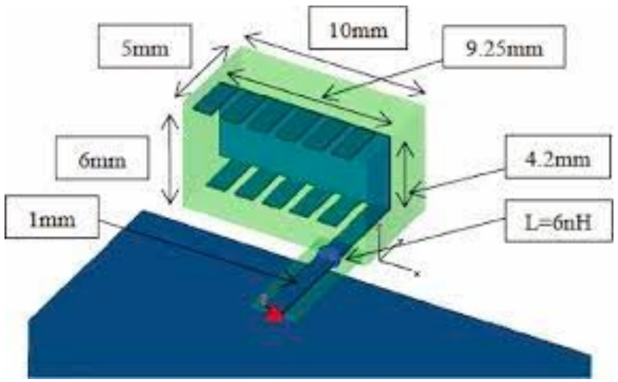
Omni-directional antennas



PCB, patch, ceramic,…







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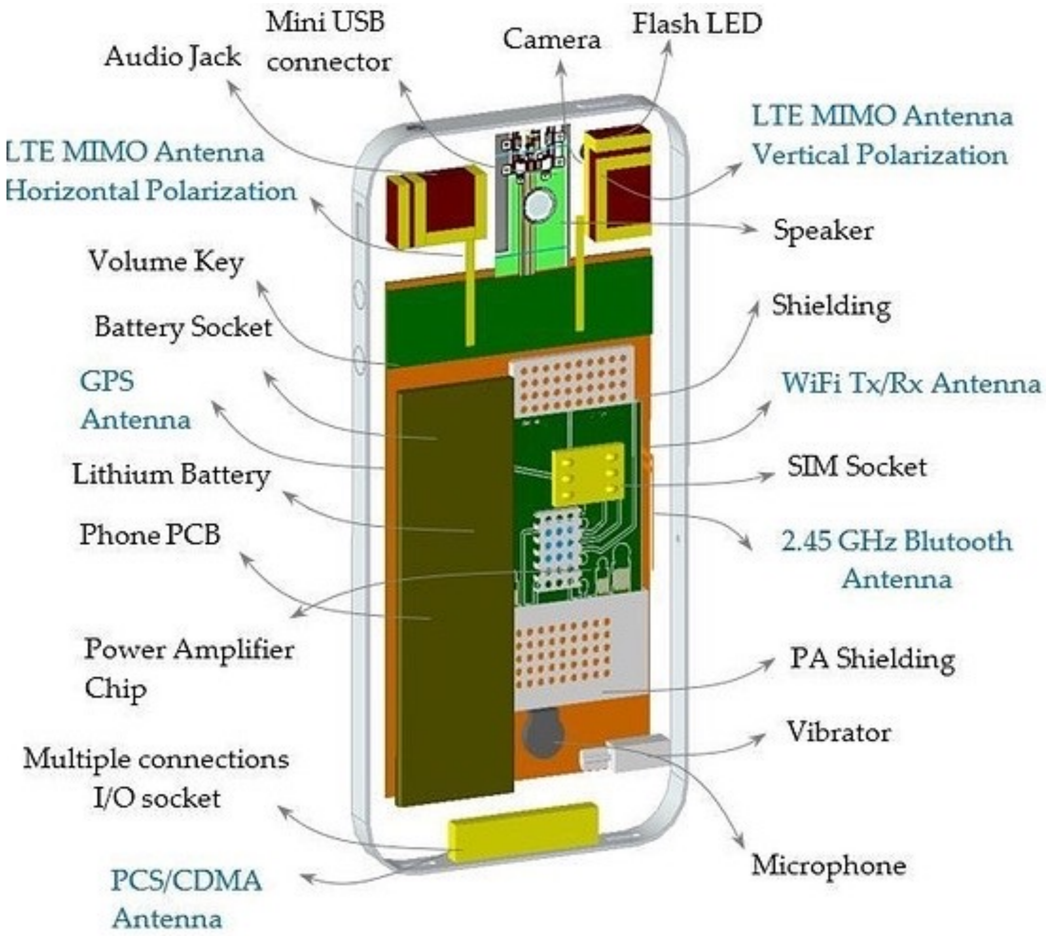
Antennas in a smartphones!



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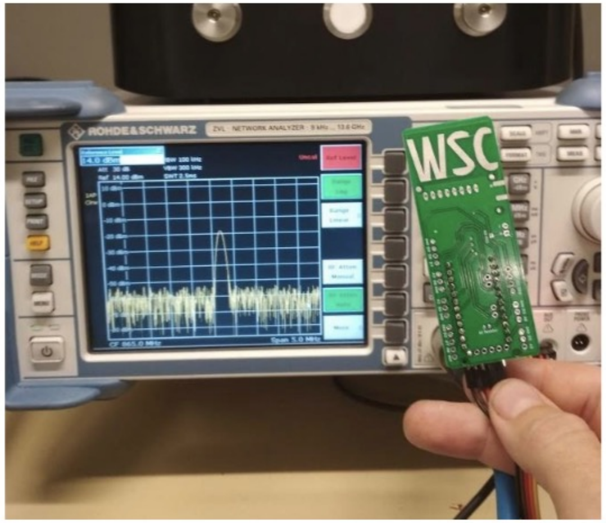
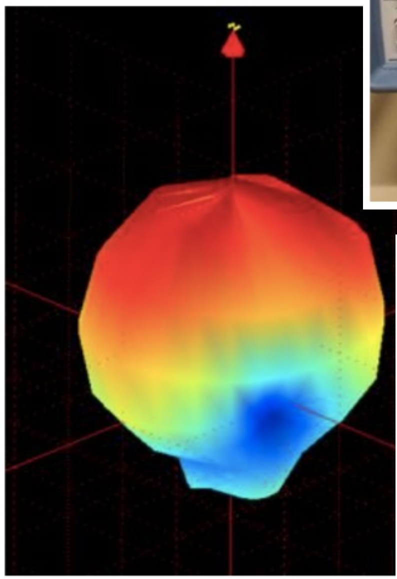
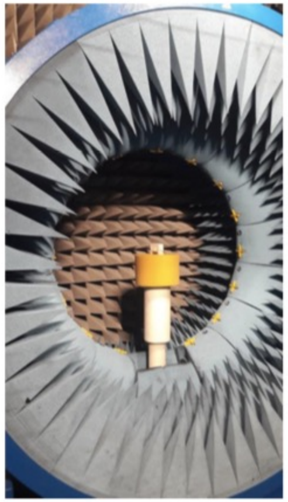
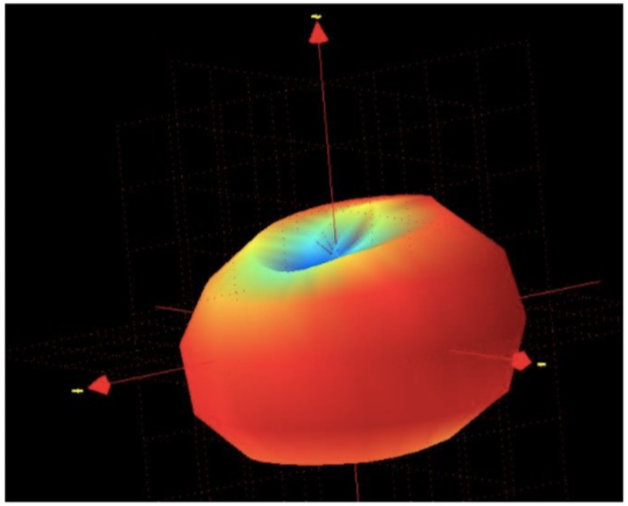
Testing antennas

- Source: F. Ferrero, University of Nice



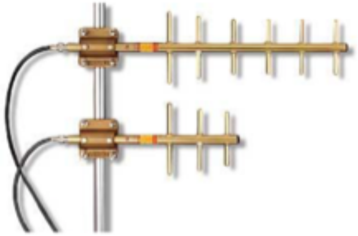


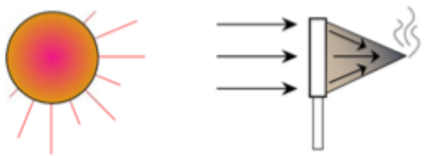




Antenna gain (1)

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





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

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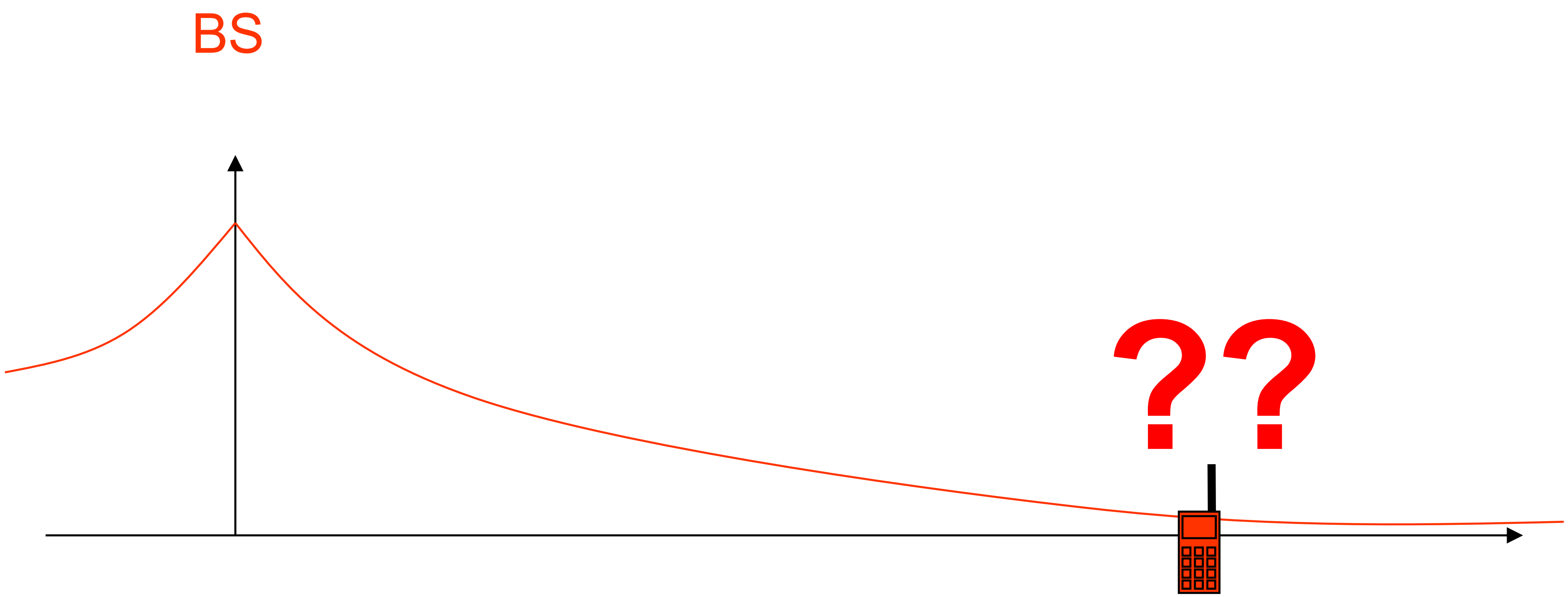
Antenna gain (2)

- 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

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

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

Attenuation in practice

- For an ideal antenna (theoretic)

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

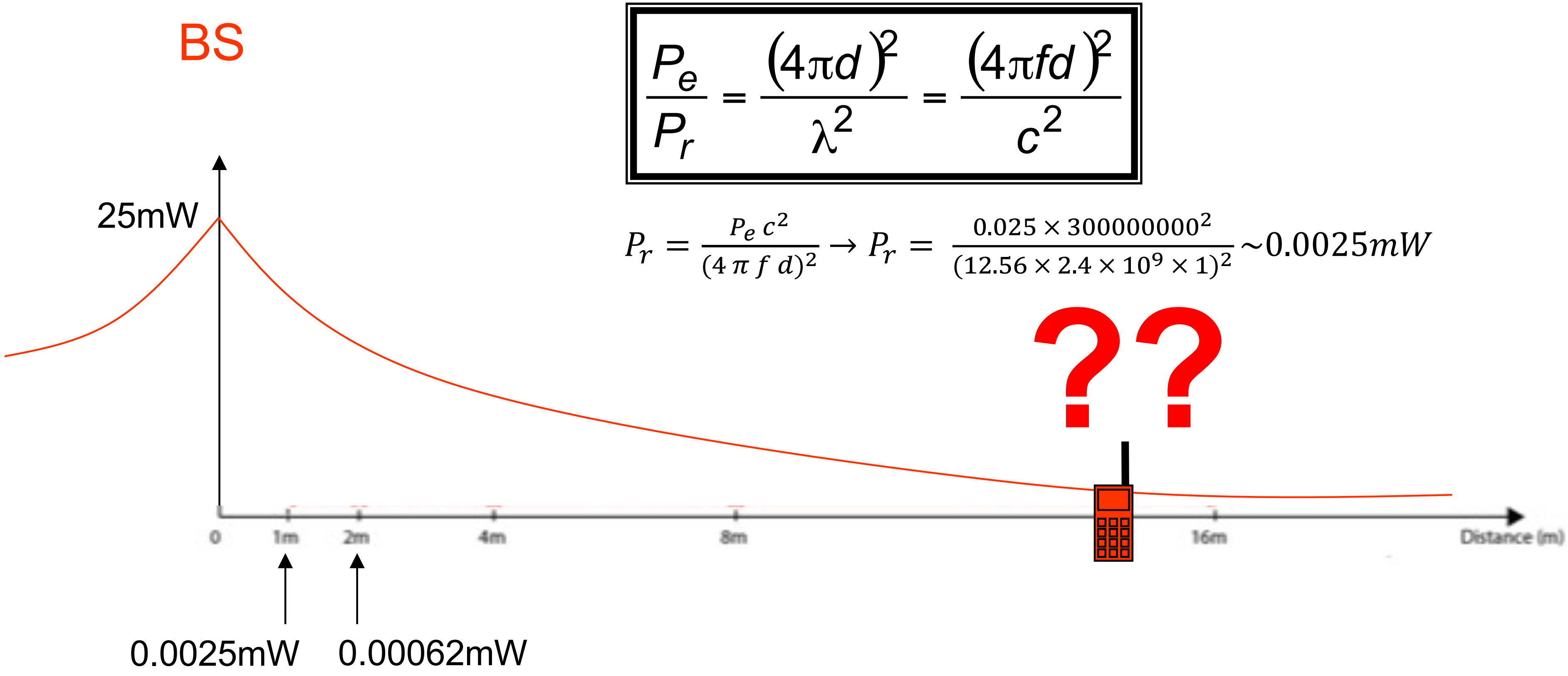
- P_e = transmitted power
- P_r = received power
- P_e / P_r is high when P_r is small → high attenuation
- d = distance between antennas
- c = light speed in space 3.10^8 m/s
- λ= wave length of the signal=c/f
- Higher frequencies f means higher attenuation!

Attenuation, value in watts

- Free Space Path Loss model

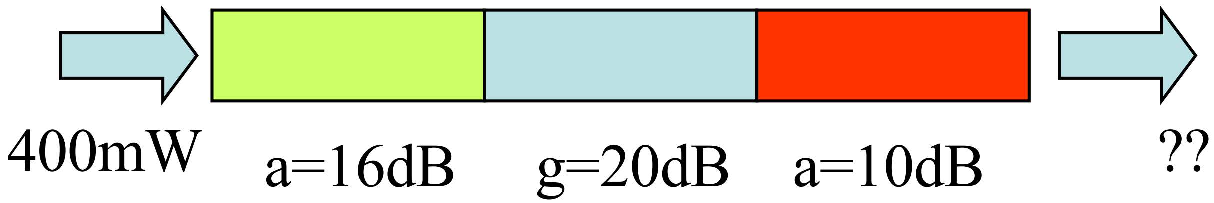
$$\frac{P_e}{P_r} = \frac{(4\pi d)^2}{\lambda^2} = \frac{(4\pi f d)^2}{c^2}$$

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



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

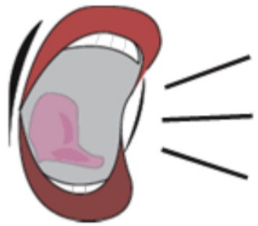


-16dB + 20dB - 10dB = -6dB, so it is an attenuation

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

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 = $10\text{Log}_{10}(\text{mW}/1000) + 30$).

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

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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

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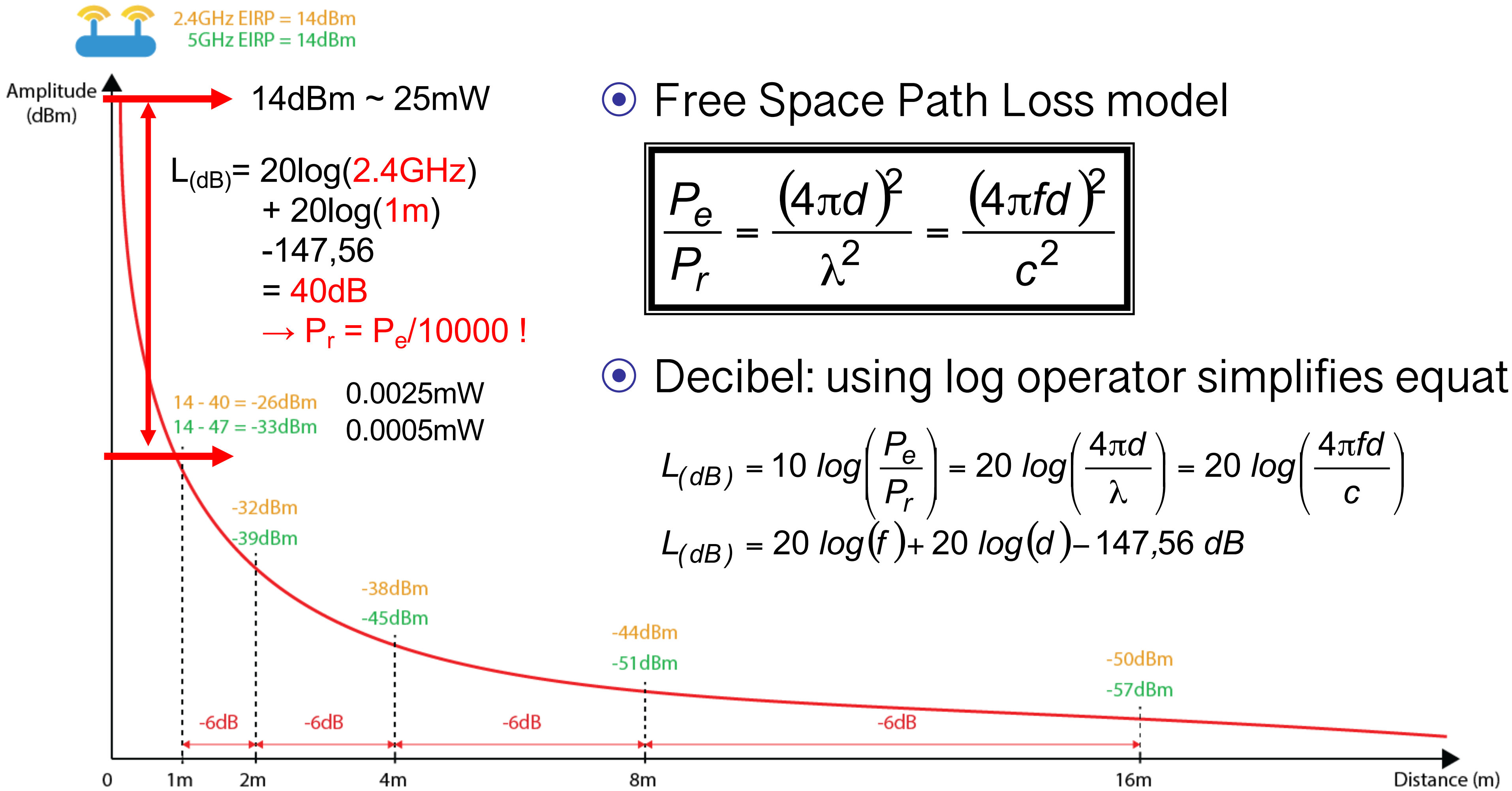
HORIZON 2020

Attenuation, using dBm & dB



- Free Space Path Loss model

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

- Decibel: using log operator simplifies equation

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

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

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

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

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

Impact of signal frequency

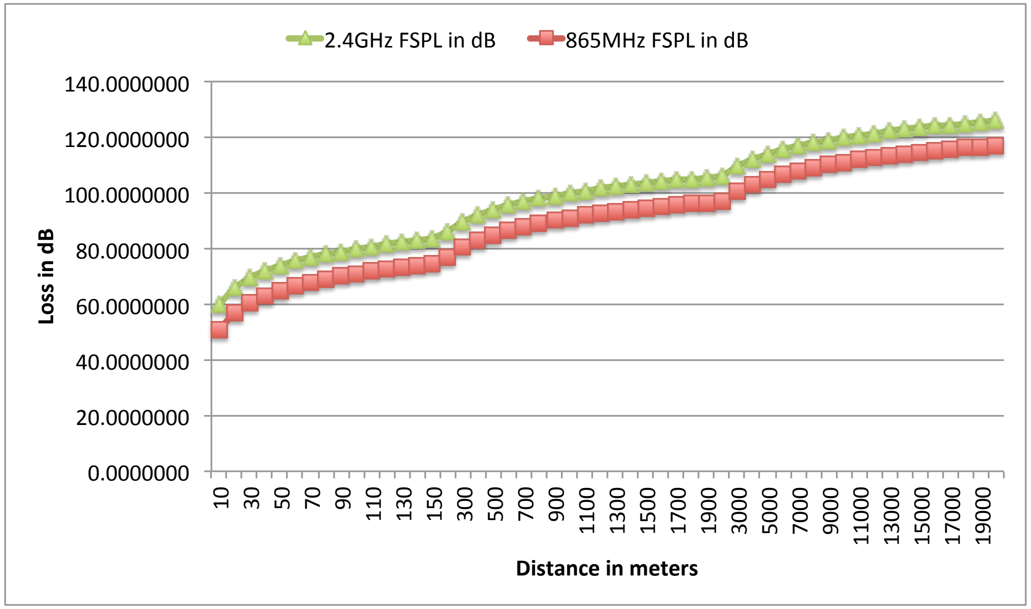
- Free Space Path Loss model

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

FSPL assume Gt=Gr=1

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

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

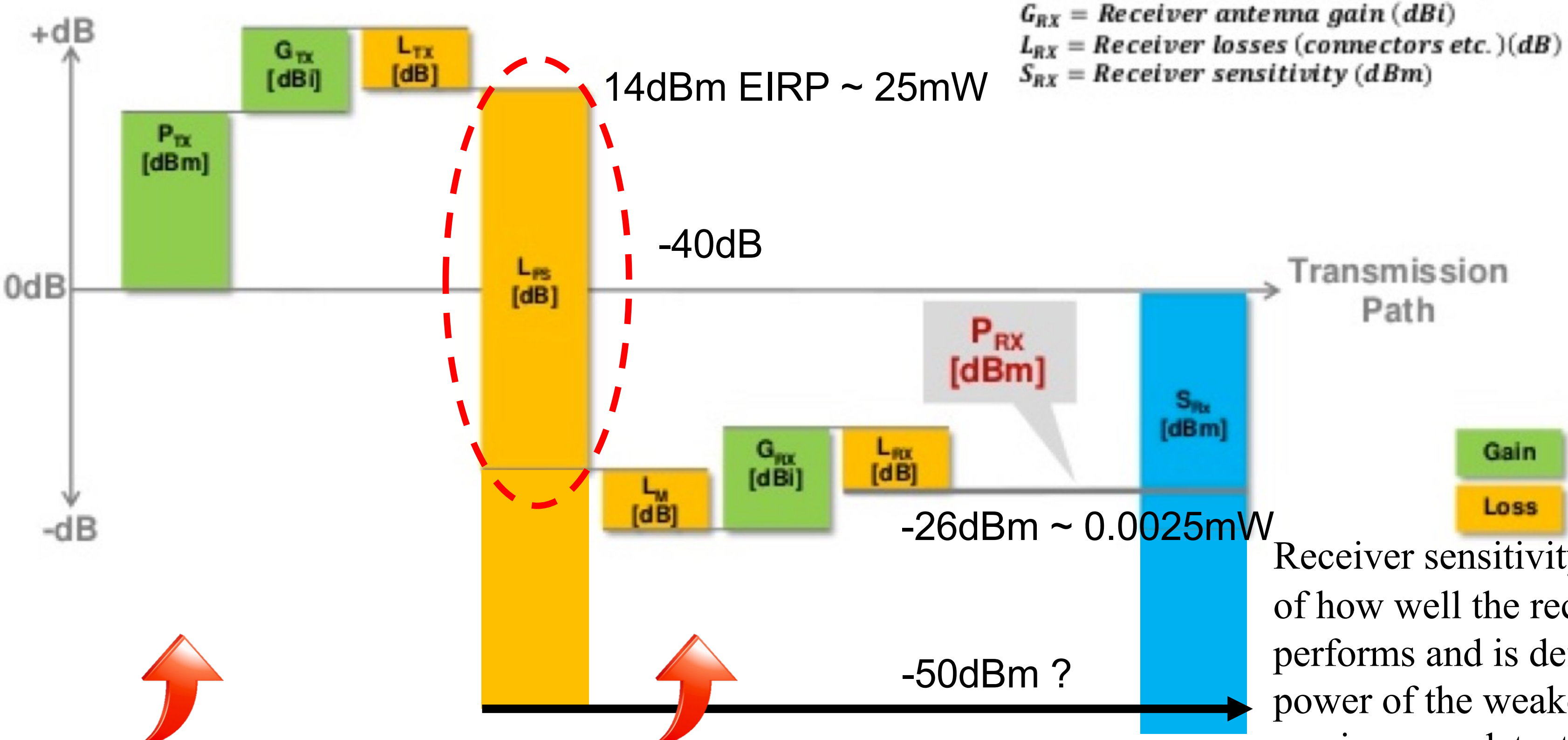


Link budget in wireless system

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

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



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

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

Receiver's sensitivity

- Receiver's sensitivity is a measure of how well the receiver performs and is defined as the power of the weakest signal the receiver can detect
- How low can you go?

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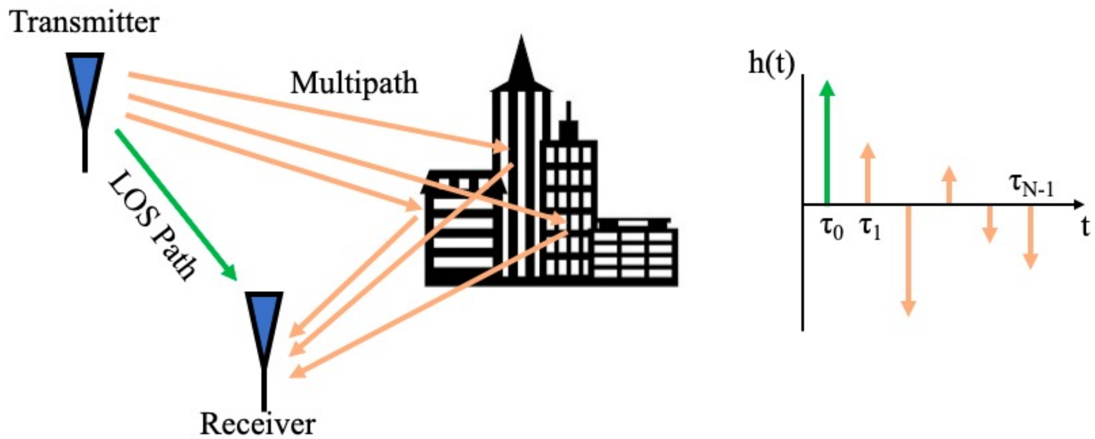
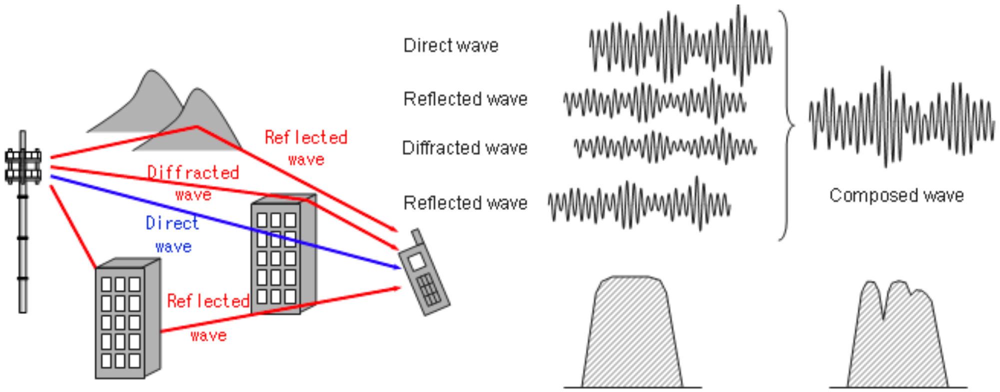
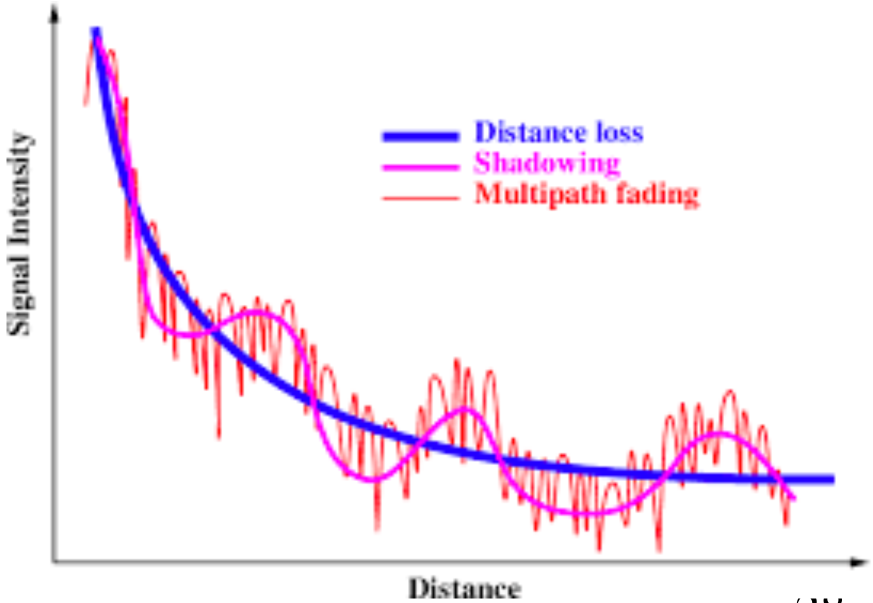
Shadow fading & Multi-path fading

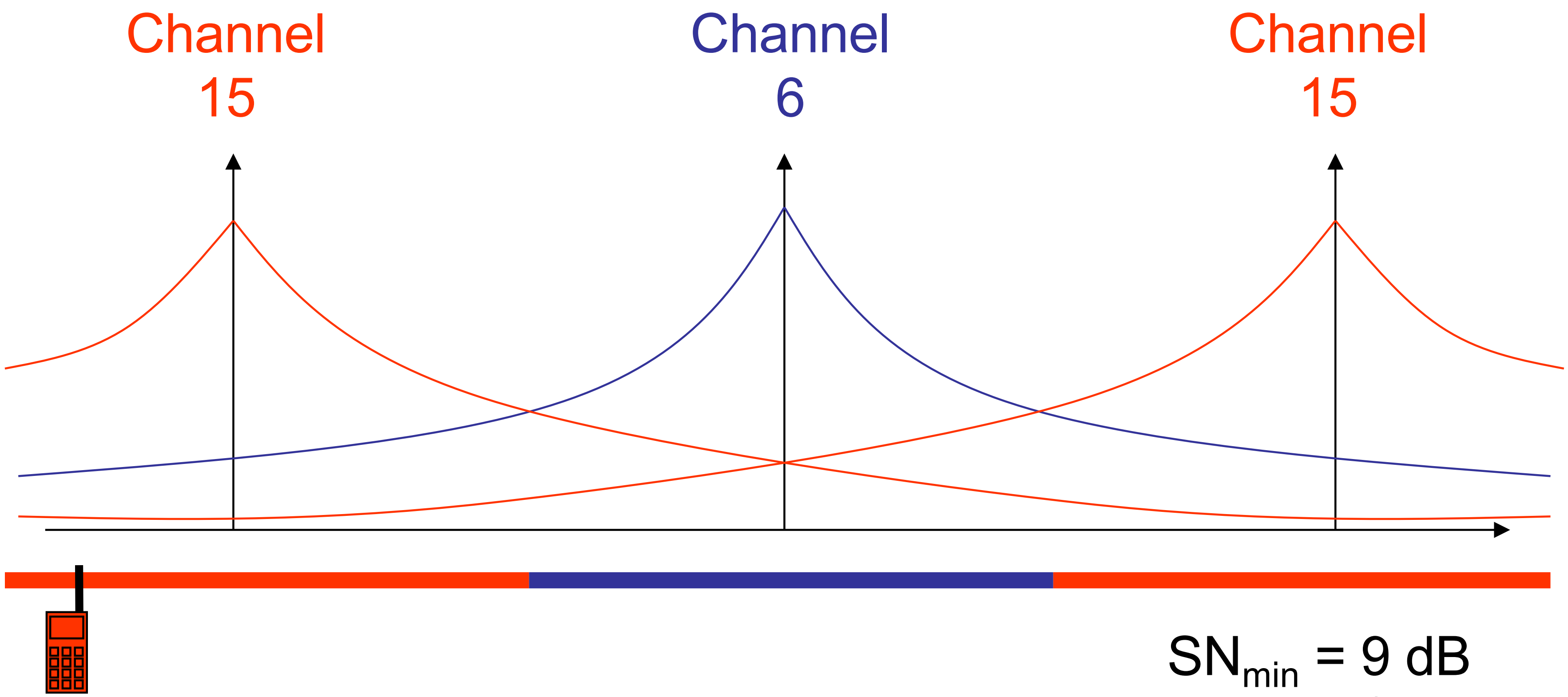
- Things are getting even worse!
- Shadow fading by obstacles
- Multi-path fading
- …







Frequency re-use

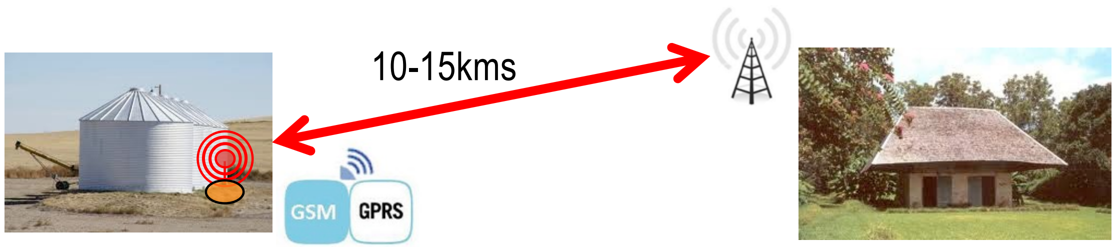


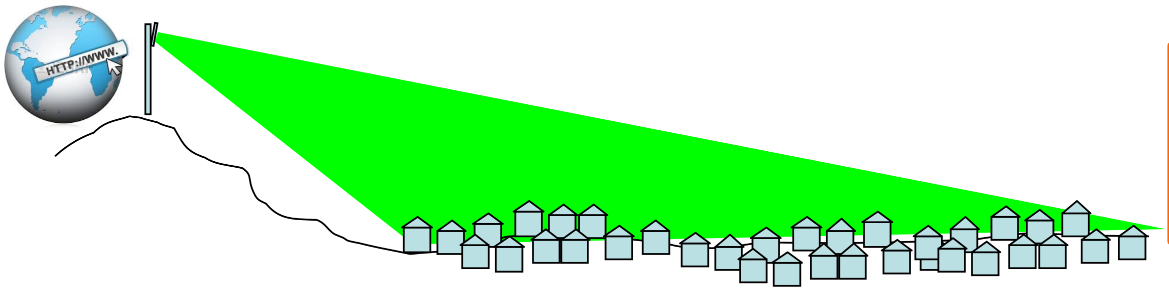
SN_{min} = 9 dB

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

2nd challenge: energy cost

Moisture/
Temperature of
storage areas



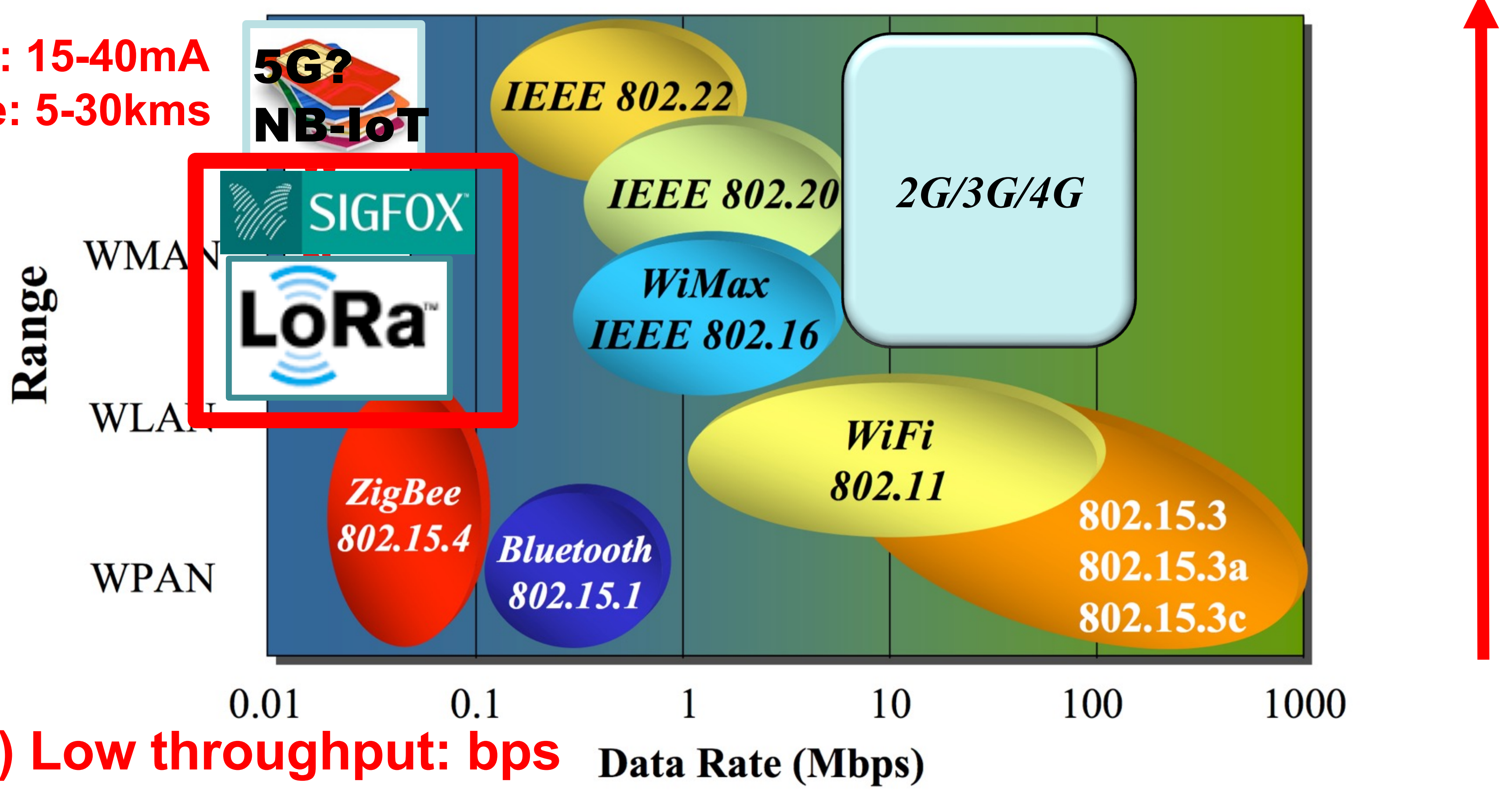


Technology	2G	3G	LAN
Range (I=Indoor, O=Outdoor)	N/A	N/A	O: 300m I: 30m
Tx current consumption	200-500mA	500-1000mA	100-300mA
Standby current	2.3mA	3.5mA	NC

Low-power, long-range radios for IoT systems: LPWAN networks

Energy-Range dilemma

LPWAN
Low-power: 15-40mA
Long-range: 5-30kms

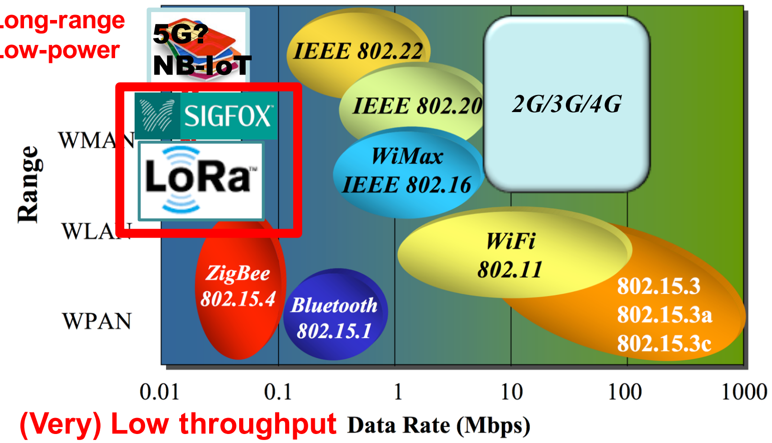


(Very) Low throughput: bps

Energy consumption comparaison

Energy-Range dilemma

Long-range
Low-power



(Very) Low throughput

Energy

2G	3G	LAN	ZigBee	Lo Power WAN
N/A	N/A	O: 300m I: 30m	O: 90m I: 30m	Same as 2G/3G
200-500mA	500-1000mA	100-300mA	18mA	18mA-40mA
2.3mA	3.5mA	NC	0.003mA	0.001mA

2500mA

TX power: 500mA. Mean consumption: (8sx500+3592sx0.005)/3600=1.11mA

2500/1.11=2252h = 93 days = 3 months ☹

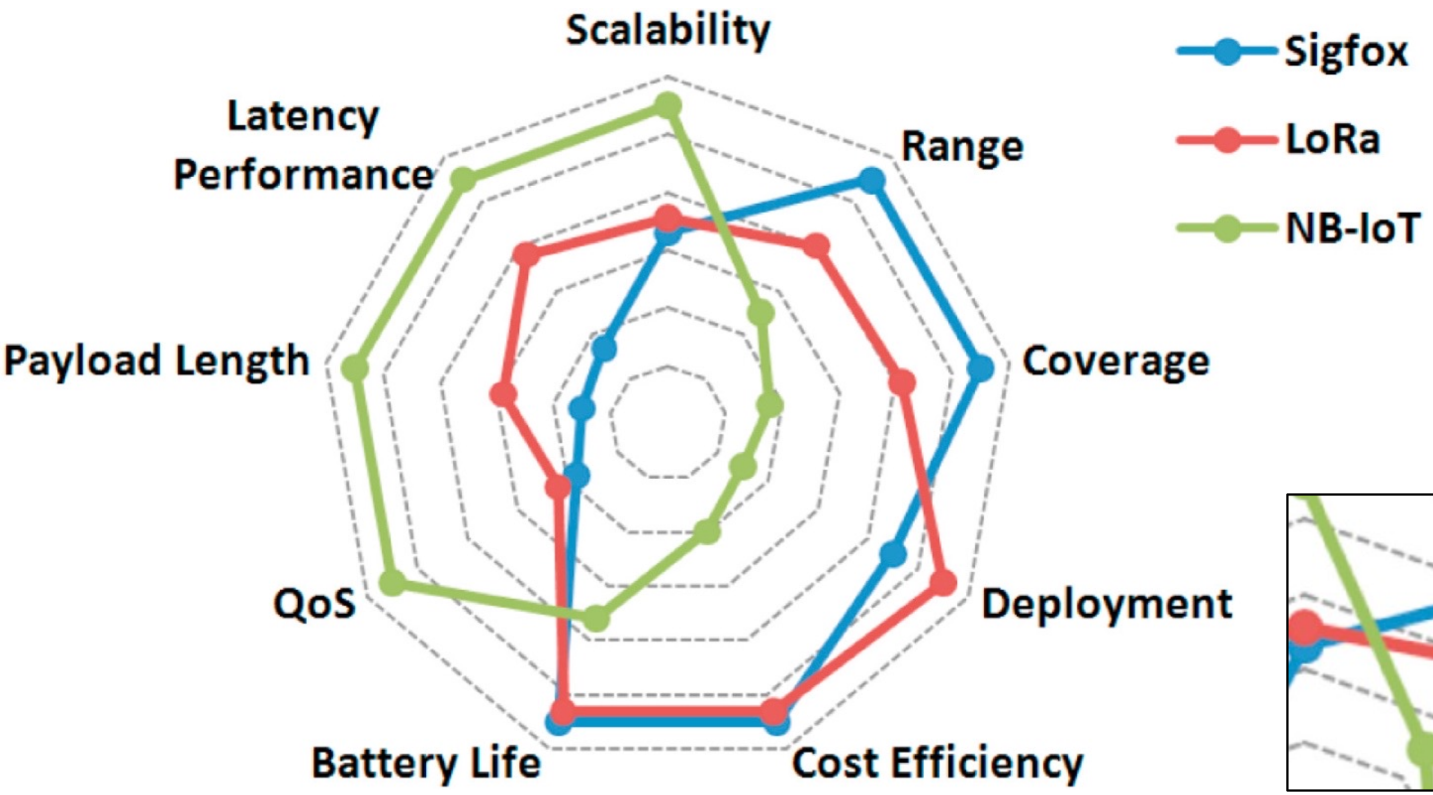
In most cellular networks, the device is still maintaining communication with BS even if it is inactive

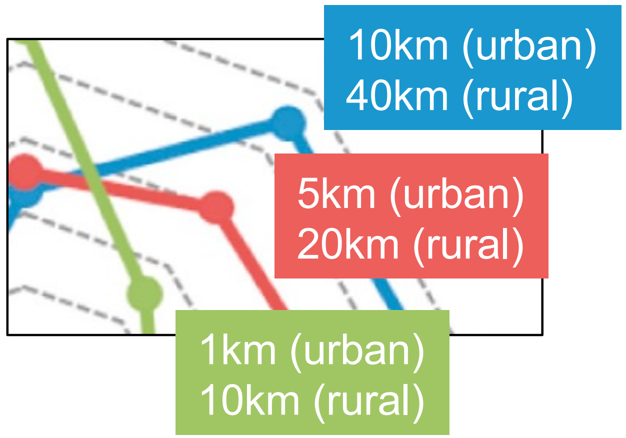
TX power: 40mA. Mean consumption: (2sx40+3598sx0.005)/3600=0.027mA

2500/0.027=92592h = 3858 days = 10 y. ☺

LPWAN does not need to maintain connection if not in used

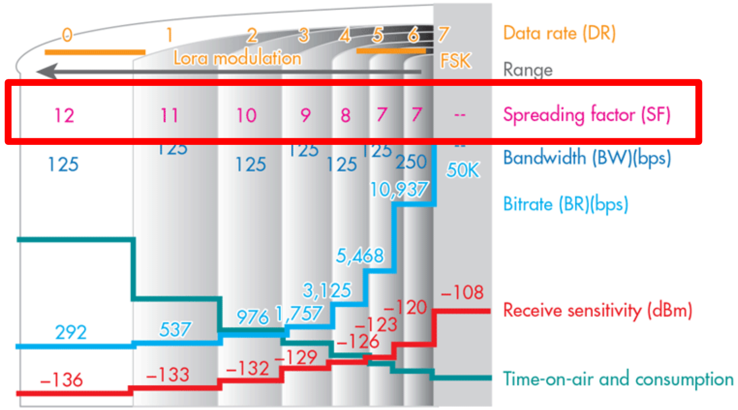
Expected range?





How can we increase range?

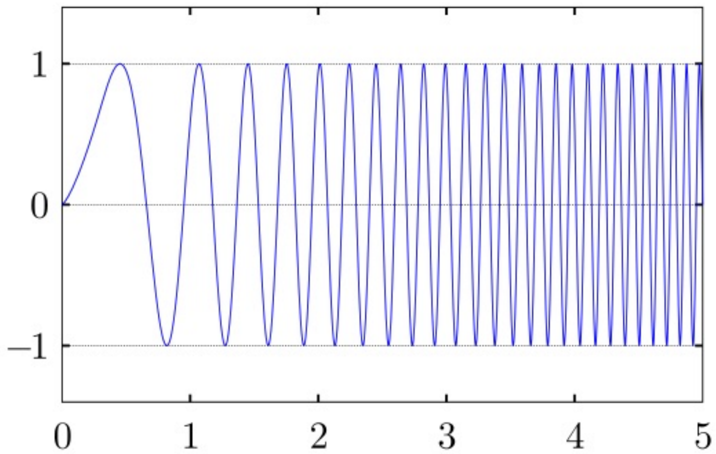
- Increase TX power and/or improve RX sensitivity
- Generally, RX sensitivity (~robustness) can be increased when transmitting (much) slower (like speaking slower!)
- LoRa uses spread spectrum approach to increase RX sensitivity
  - Spreading Factor defines how many chips will be used to code a symbol. More chip/symbol=longer transmission time ➠ more robustness
- **The price to pay for LPWAN**
  - LoRa has very low throughput: 200bps-37500bps (0.2-37.5kbps)



- WiFi 802.11n: 450 000 000 bps (450Mbps)
- WiFi 802.11g: 54 000 000 bps (54Mbps)
- Bluetooth3&4: 25 000 000 bps (25Mbps)
- Bluetooth BLE: 2 000 000 bps (2Mbps)
- 3G/4G : 20Mbps-200Mbps
- LoRa : 200bps-37500bps (0.0002-0.0375Mbps)
- 3G/LoRa ratio: 20,000,000bps/200bps=100000!

Chirp Spread Spectrum in LoRa

- Compressed High Intensity Radar Pulse (CHIRP) is a signal which frequency either increases or decreases in time, in a deterministic way



- Can be very low power, but then low data rate!
- Very high interference immunity
  - Thus adapted to very large distances
  - Better resistance to frequency shift (e.g. Doppler shift, low-cost oscillator)

LoRa spreading factor in image

- Higher spreading factor means lower data rate but increased receiver sensitivity

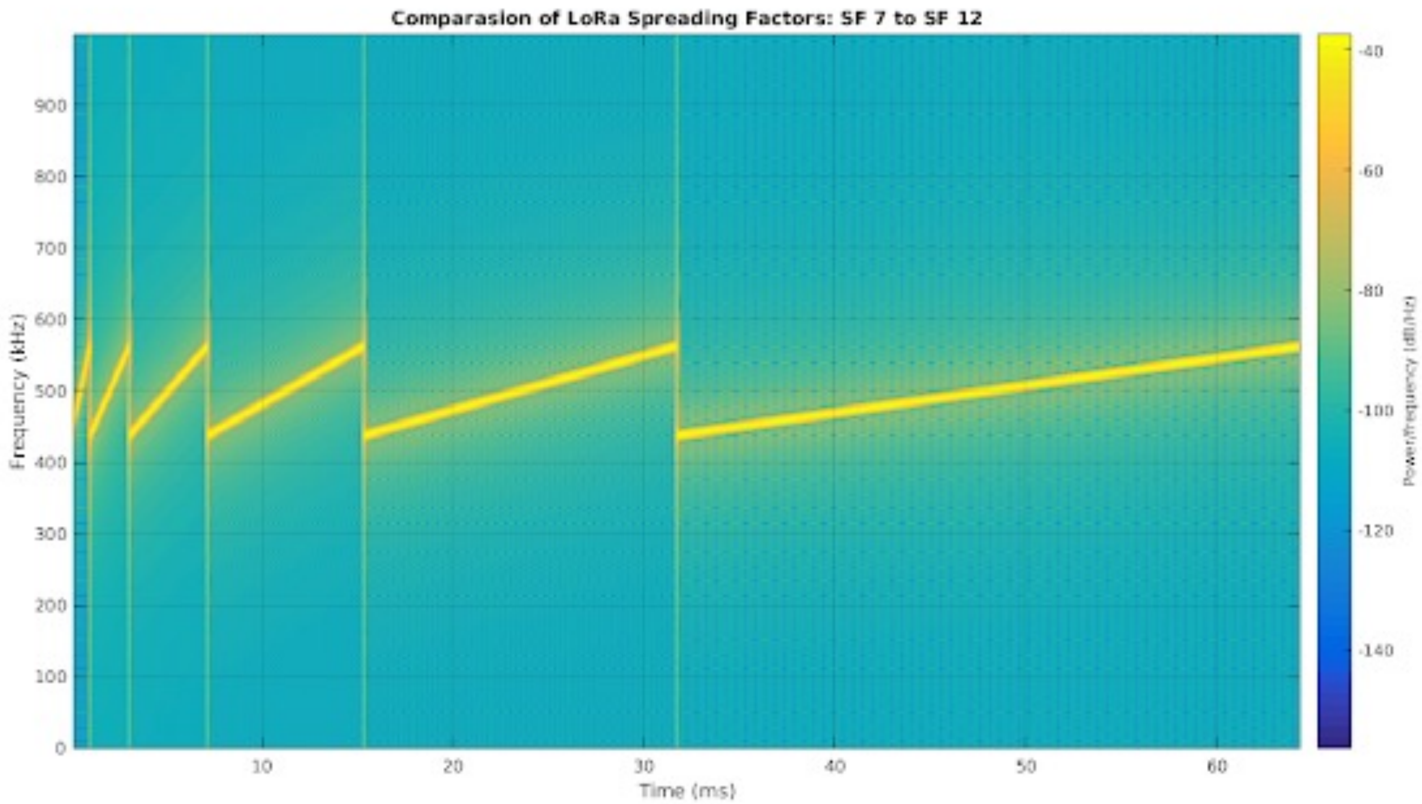
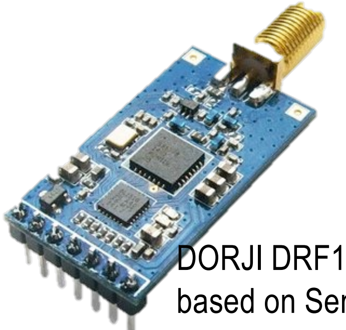


Figure from "All About LoRa and LoRaWAN", https://www.sghoslya.com

LoRa modules with Semtech's SX127x



DORJI DRF1278DM is based on Semtech SX1278 LoRa 433MHz

Libelium LoRa is based on Semtech SX1272 LoRa 863-870 MHz for Europe

inAir9 based on SX1276

Froggy Factory LoRa module (Arduino)

HopeRF RFM series

Hop… TRL…

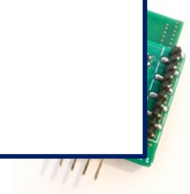
KEY PRODUCT FEATURES

- LoRa® Modem
- 168 dB maximum link budget
- +20 dBm - 100 mW constant RF output vs. V supply
- +14 dBm high efficiency PA
- Programmable bit rate up to 300 kbps
- High sensitivity: down to -148 dBm

Microship RN2483

Multi-Tech MultiConnect mDot

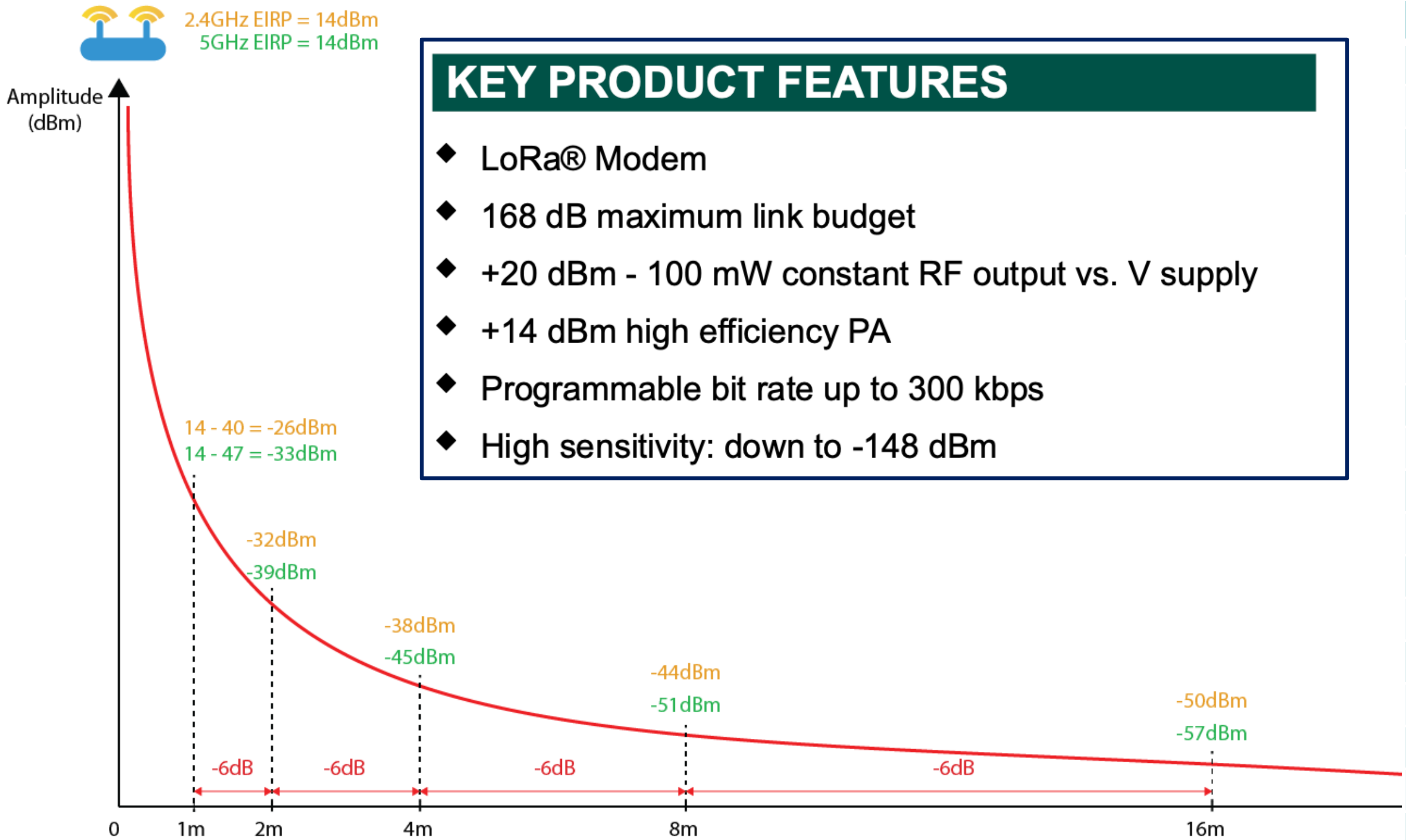
ARM-Nano N8 LoRa module from ATIM



SODAQ LoRaBee Embit

SODAQ LoRaBee RN2483

What distance for -148dBm?



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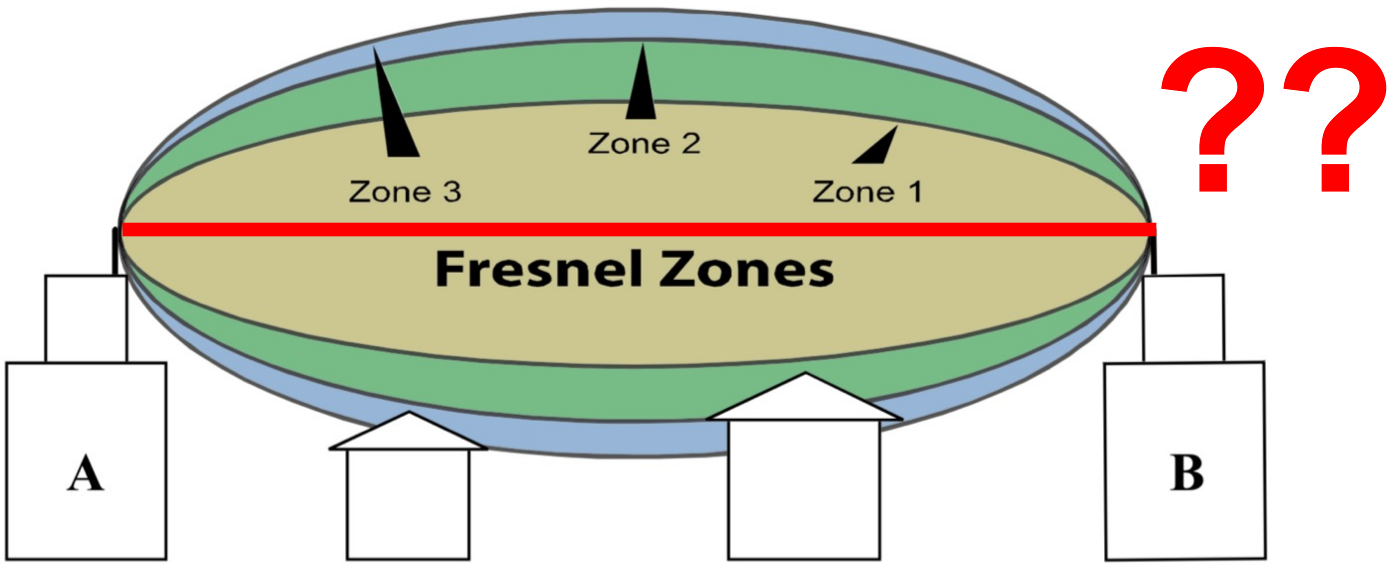
-26	1
-32	2
-38	4
-44	8
-50	16
-56	32
-62	64
-68	128
-74	256
-80	512
-86	1024
-92	2048
-98	4096
-104	8192
-110	16384
-116	32768
-122	65536
-128	131072
-134	262144
-140	524288
-146	1048576
-152	2097152

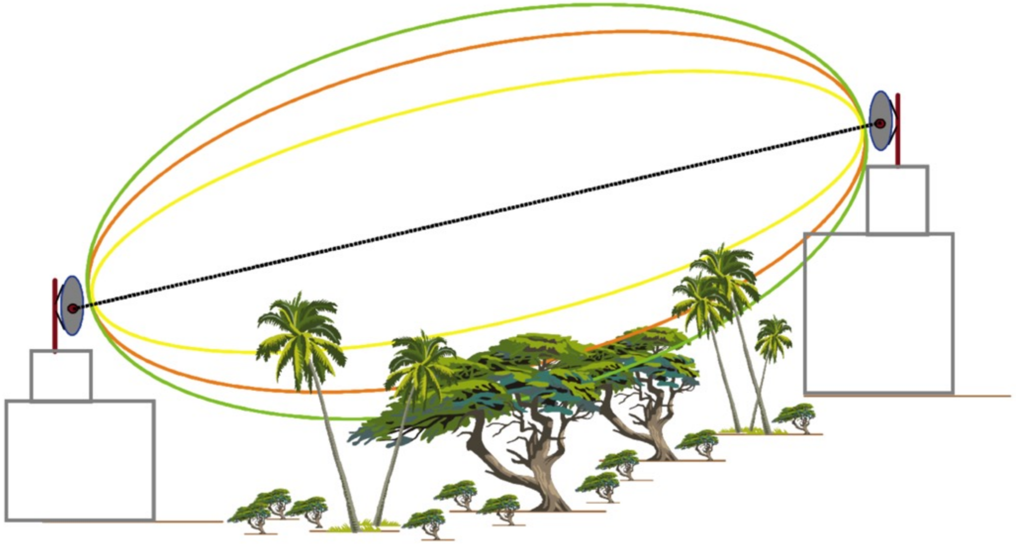
Line-of-Sight & Fresnel zone

- LoS means clear Fresnel zone
- Football (american) shape
- Acceptable = 60% of zone 1 + 3m

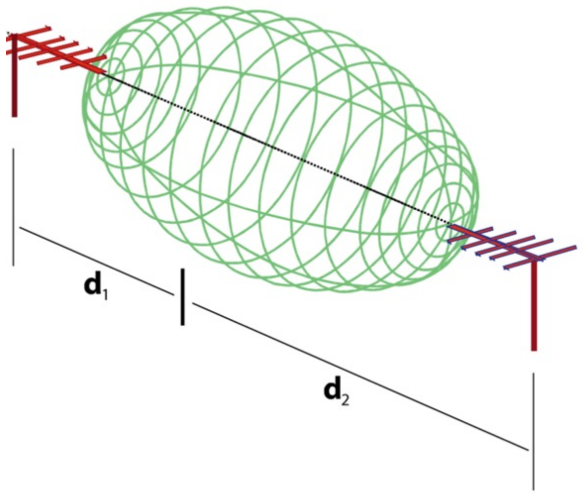


RF Essentials from Digi

Clearing the Fresnel zone? Raise antennas!



$r_n = \sqrt{\frac{\quad}{d_1 + d_2}}$



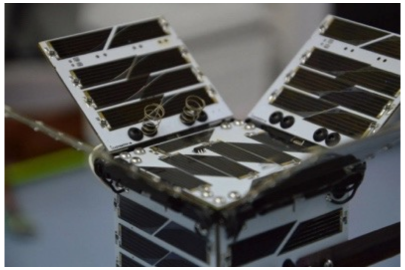
Range Distance	900 MHz Modems Required Fresnel Zone Diameter	2.4 GHz Modems Required Fresnel Zone Diameter
1000 ft. (300 m)	16 ft. (5 m)	11 ft. (3.4 m)
1 Mile (1.6 km)	32 ft. (10 m)	21 ft. (6.4 m)
5 Miles (8 km)	68 ft. (21 m)	43 ft. (13 m)
10 Miles (16 km)	95 ft. (29 m)	59 ft. (18 m)

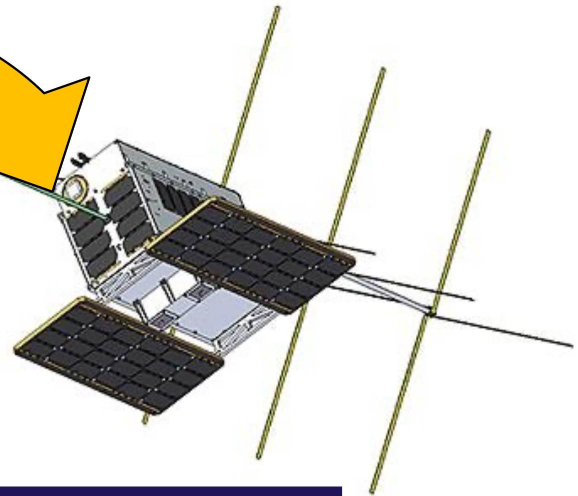
RF Essentials from Digi

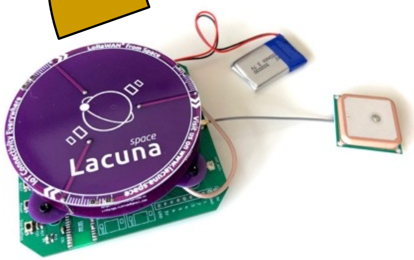
Clearing the Fresnel zone? Let's use satellite!

- Low-orbit, low-cost; compact satellite for global coverage

LoRa over 1200kms!







Lacuna space

Low-cost, simple and reliable global connections to sensors and mobile equipment. It just works everywhere, and all the time, so you can focus on using your data.

https://lacuna.space/first-successful-lacunasat-launch-in-2021/

IOT Online Course

Fundamentals of IoT

Continue with
F-IOT-2b: Understanding IoT Devices, Architecture & Ecosystem

IoT – from idea to reality