INTEL-IRRIS

Intelligent Irrigation System for Low-cost Autonomous Water Control in Small-scale Agriculture

This project is part of the PRIMA Programme supported by the European Union

Intel-IrriS

PRIMA
PARTNERSHIP FOR RESEARCH AND INNOVATION IN THE MEDITERRANEAN AREA

Intelligent Irrigation System for Low-cost Autonomous Water Control in Small-scale Agriculture

Intel-IrriS

Wireless Communication Essentials

Understanding radio & LoRa technologies in IoT

PRIMA
PARTNERSHIP FOR RESEARCH AND INNOVATION IN THE MEDITERRANEAN AREA

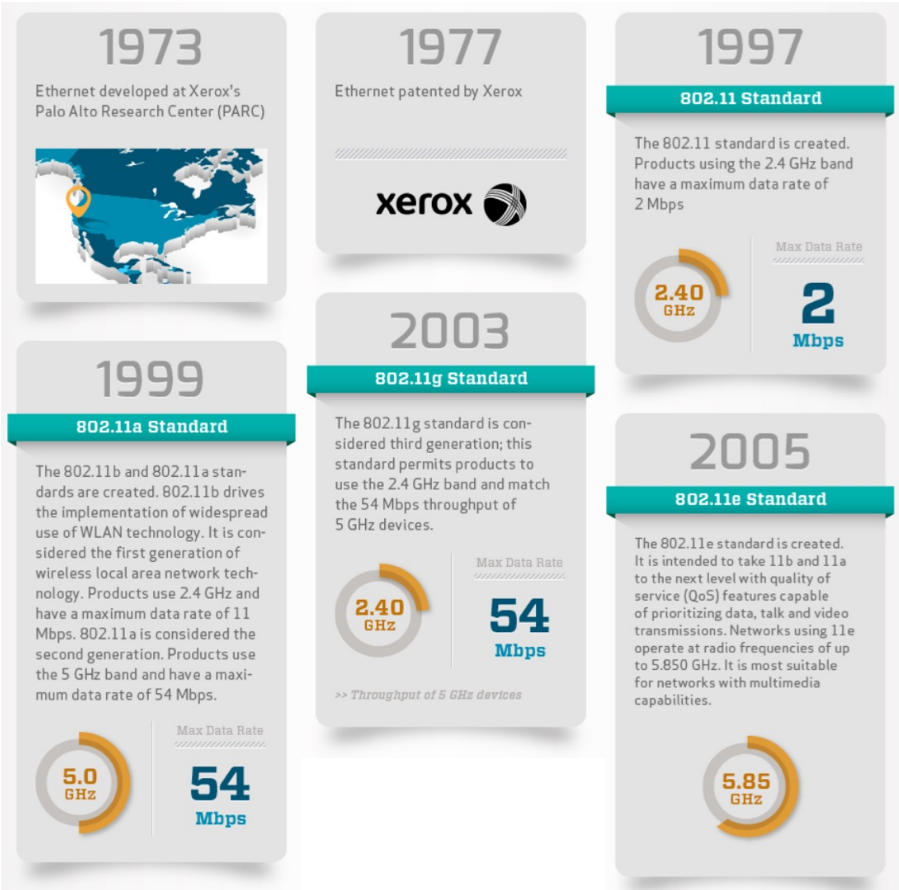
Prof. Congduc Pham
http://www.univ-pau.fr/~cpham
Université de Pau, France

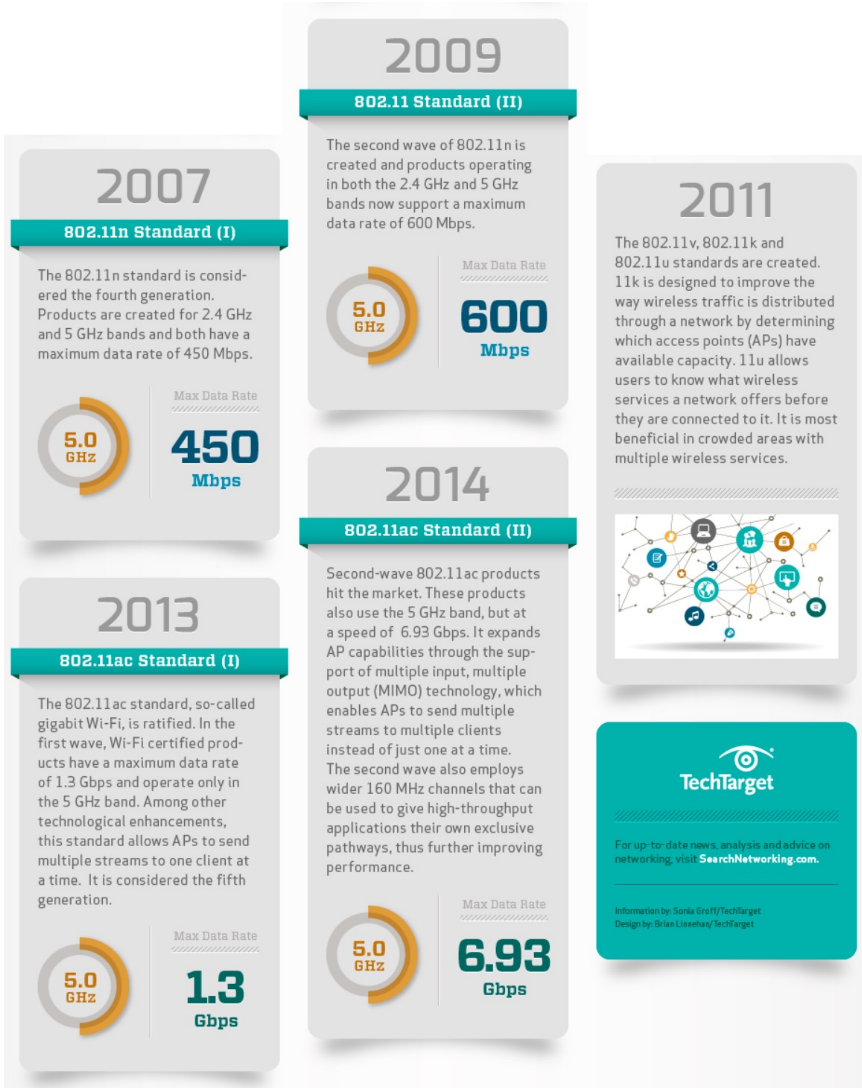
UNIVERSITÉ DE PAU ET DES PAYS DE L'ADOUR

LIUPPA

WAZIUP
IoT – from idea to reality
WAZIHUB

Wireless networks: WiFi

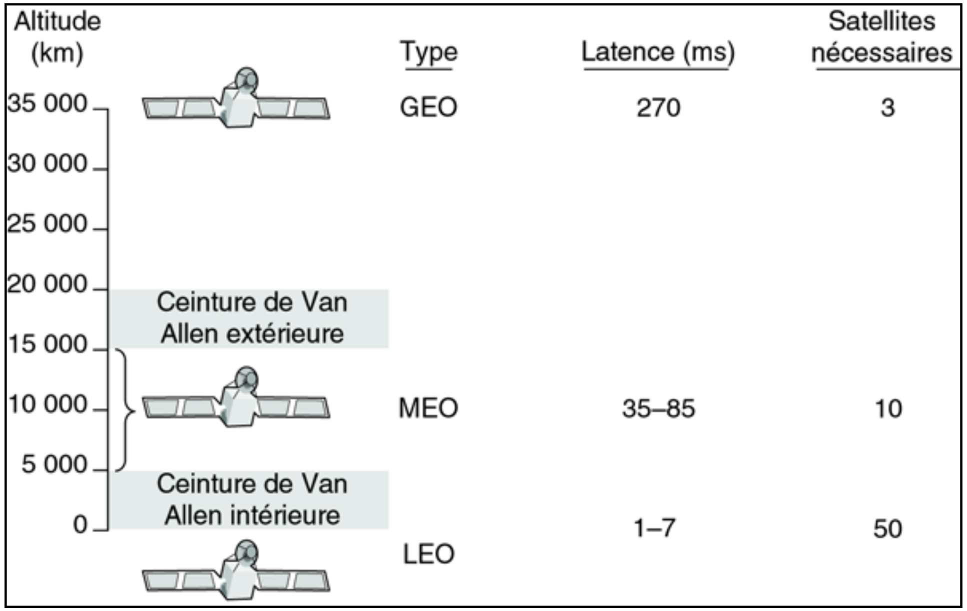


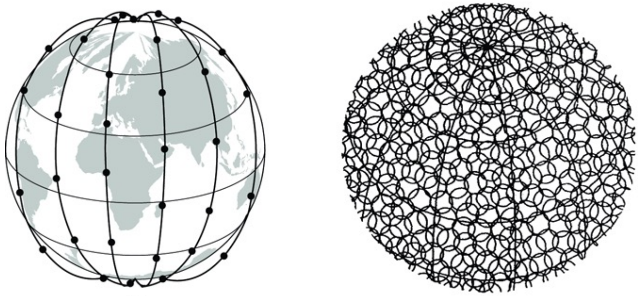


Wireless networks: 2G/3G/4G/5G/…

Wireless networks: Bluetooth

Wireless networks: Satellites



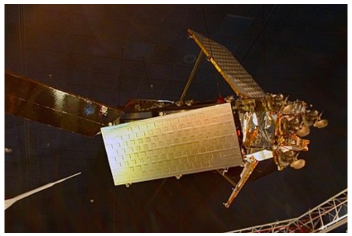


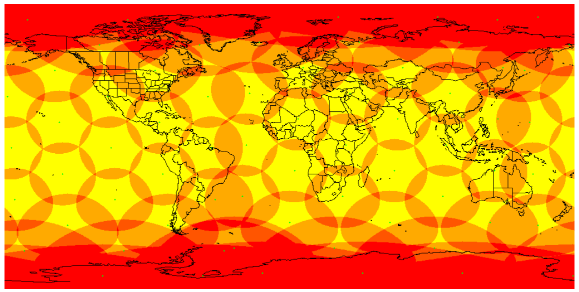
(a) (b)

© Pearson Education France

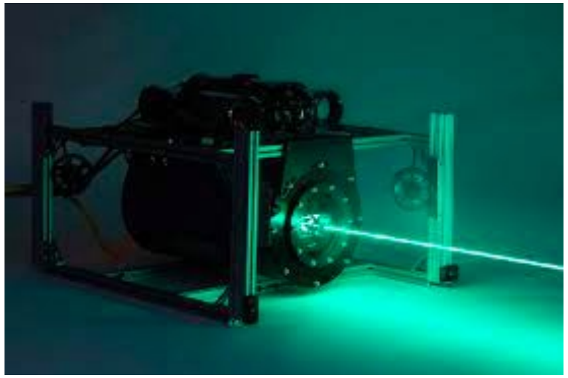
Iridium, 66 satellites

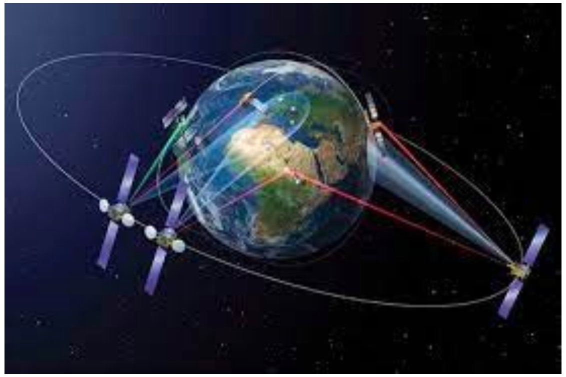
Initially 77

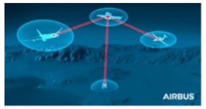




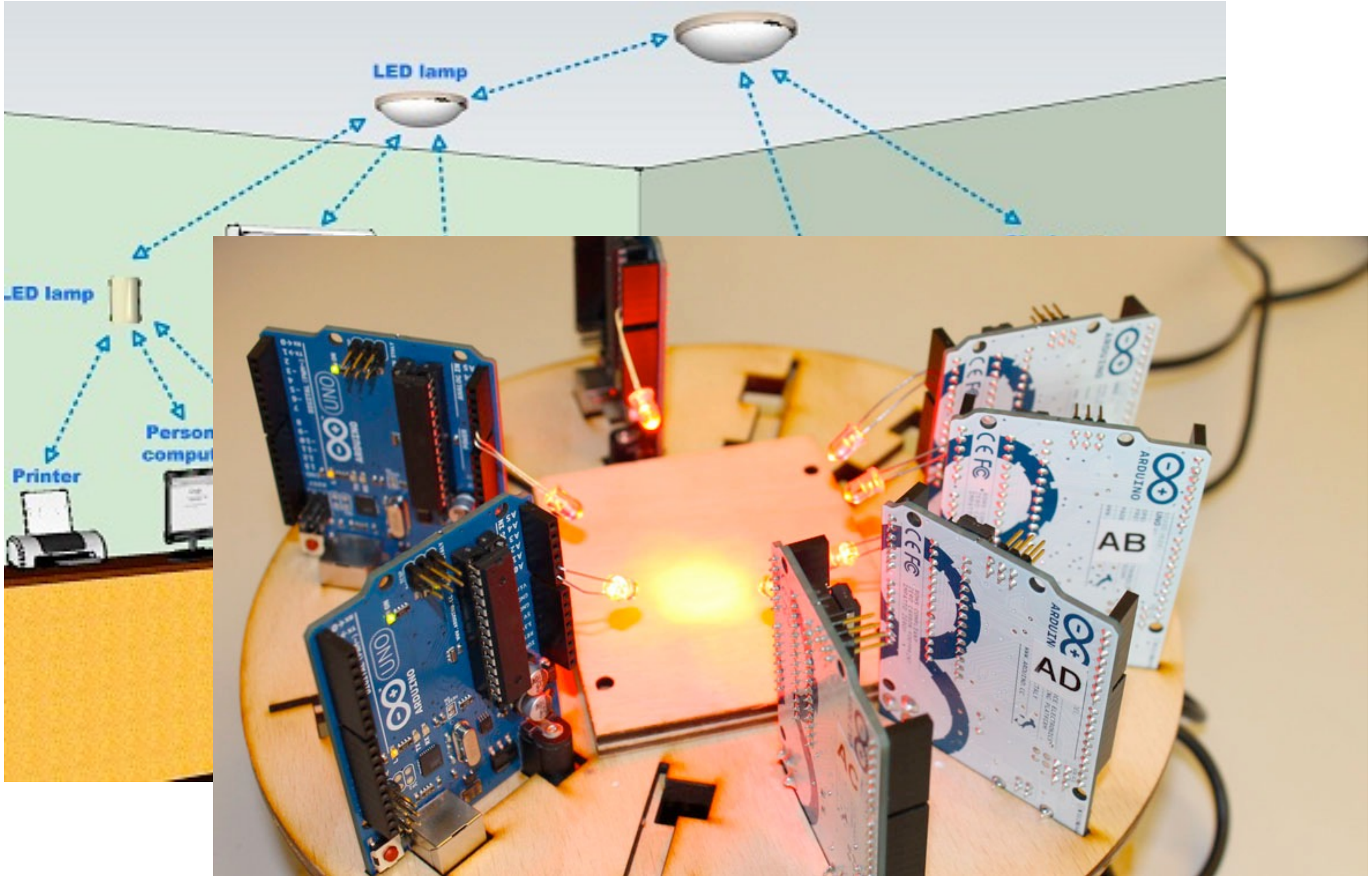
Wireless networks: Laser/Optical





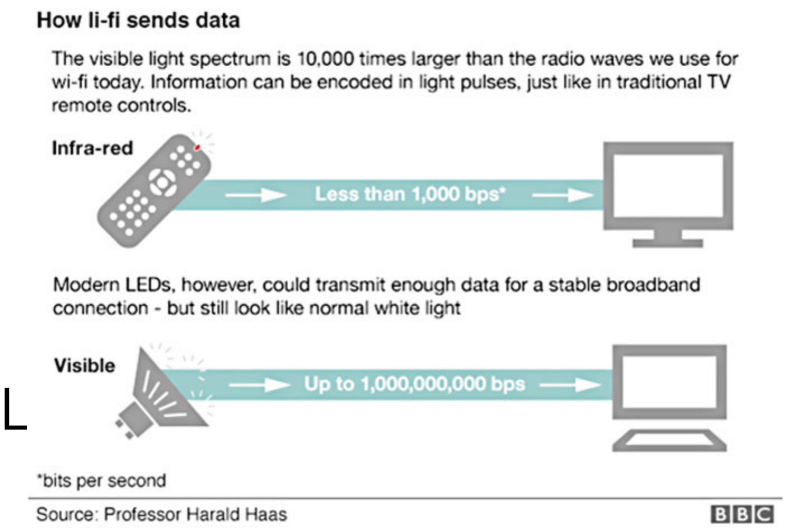


Wireless networks: Visible Light

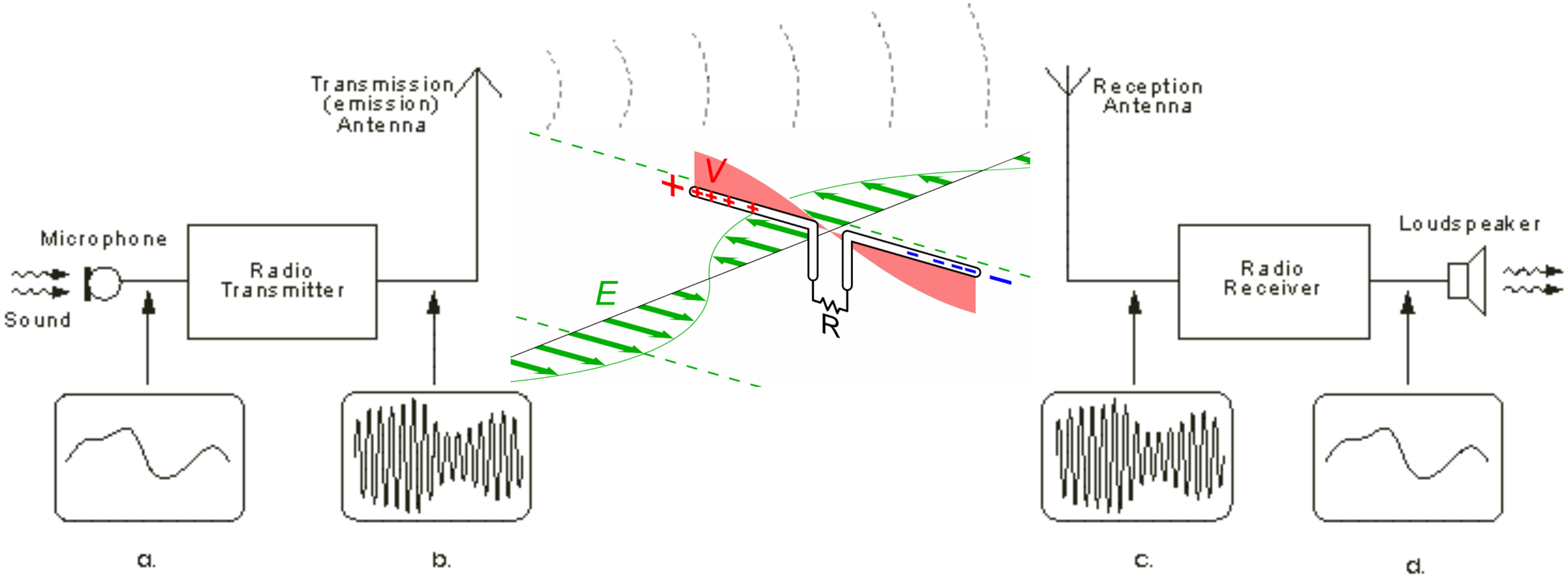


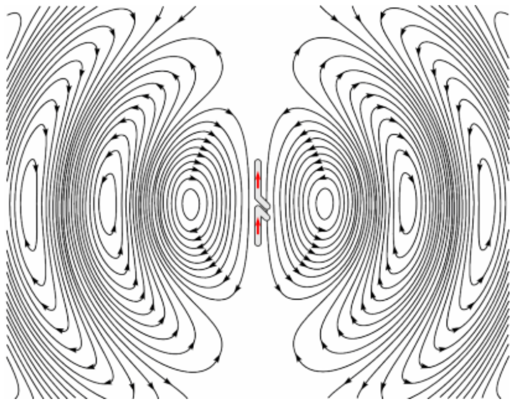
Visible Light Communications, con't

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

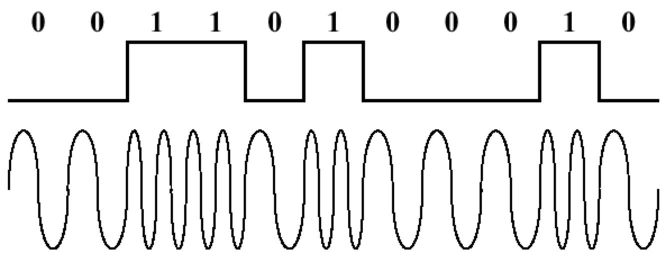


Wireless radio transmission basics





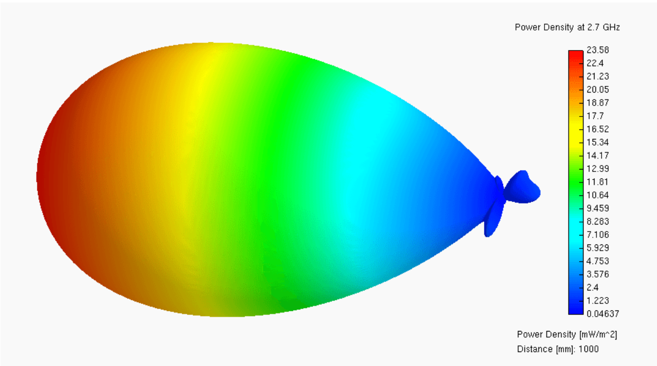
datal modulation



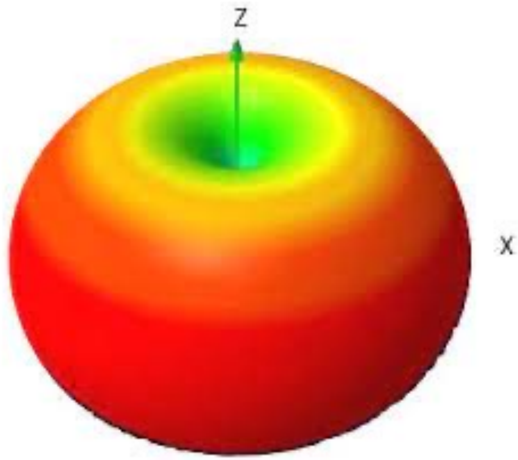
(b) Frequency-shift keying

Antenna types

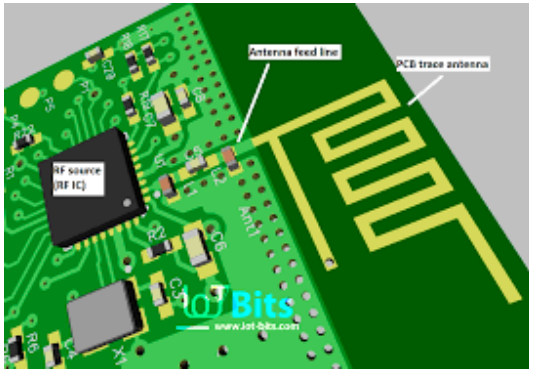
Omni-directional antennas

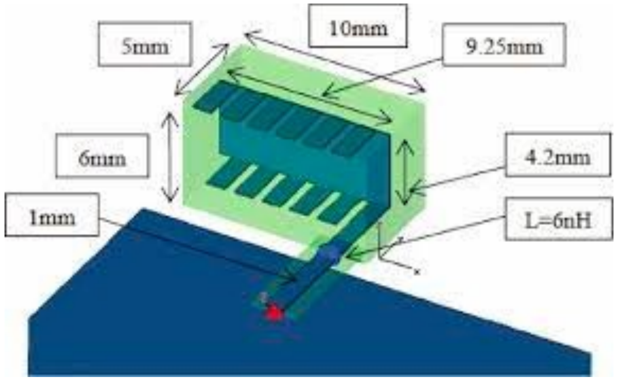


Directional antenna



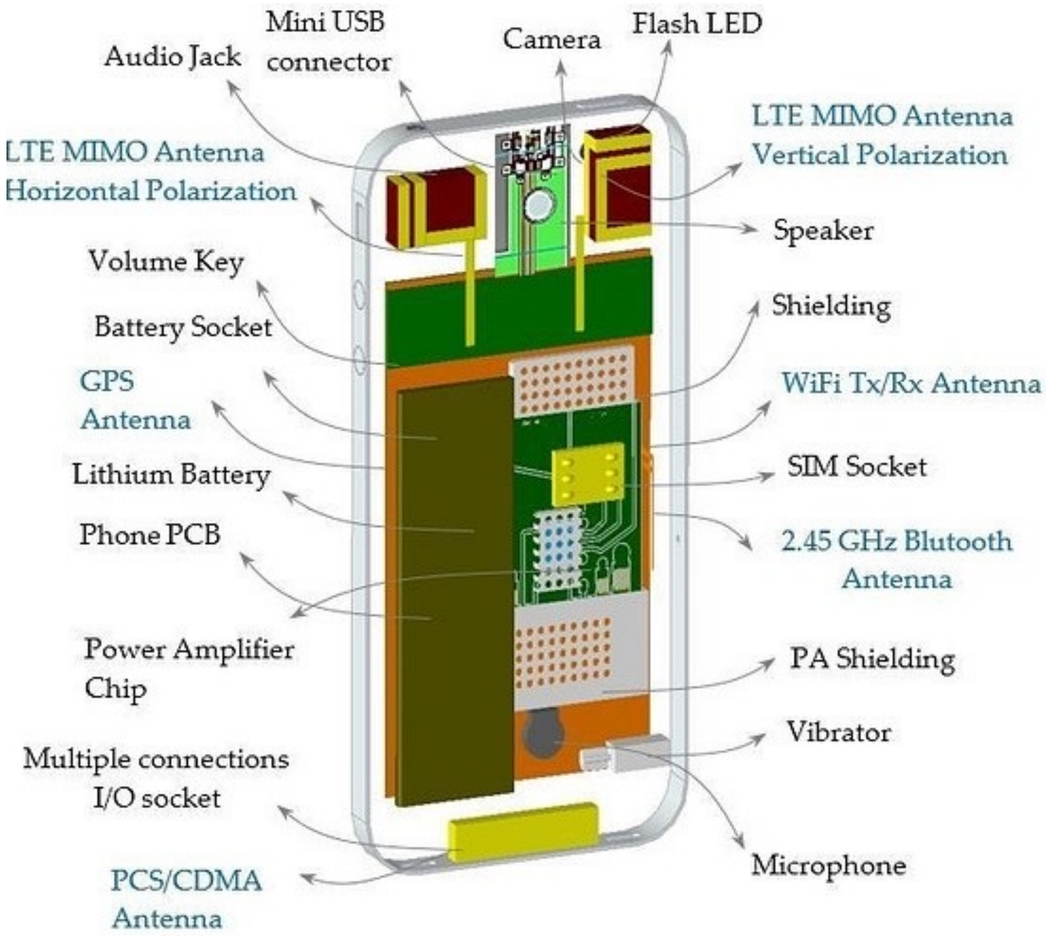
PCB, patch, ceramic,...





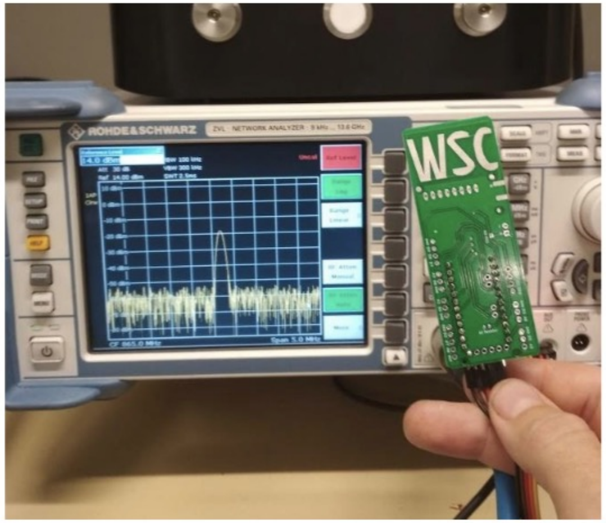
12

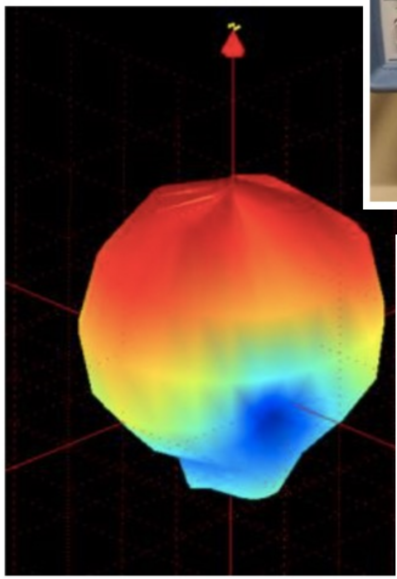
Antennas in a smartphones!

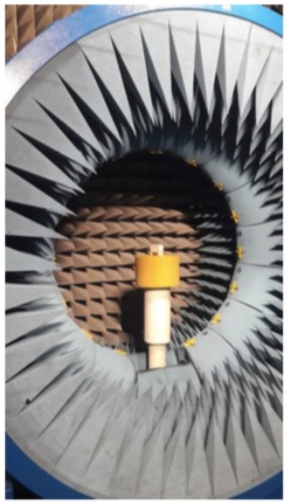


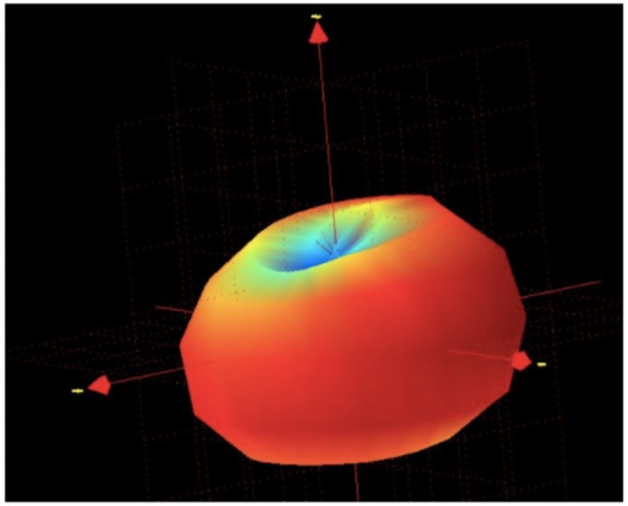
Testing antennas

- Source: F. Ferrero, University of Nice



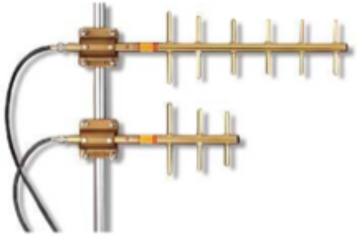


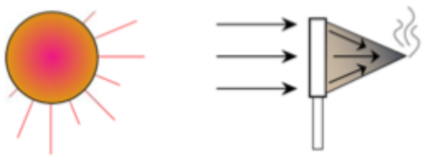




Antenna gain (1)

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





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

RF Essentials from Digi

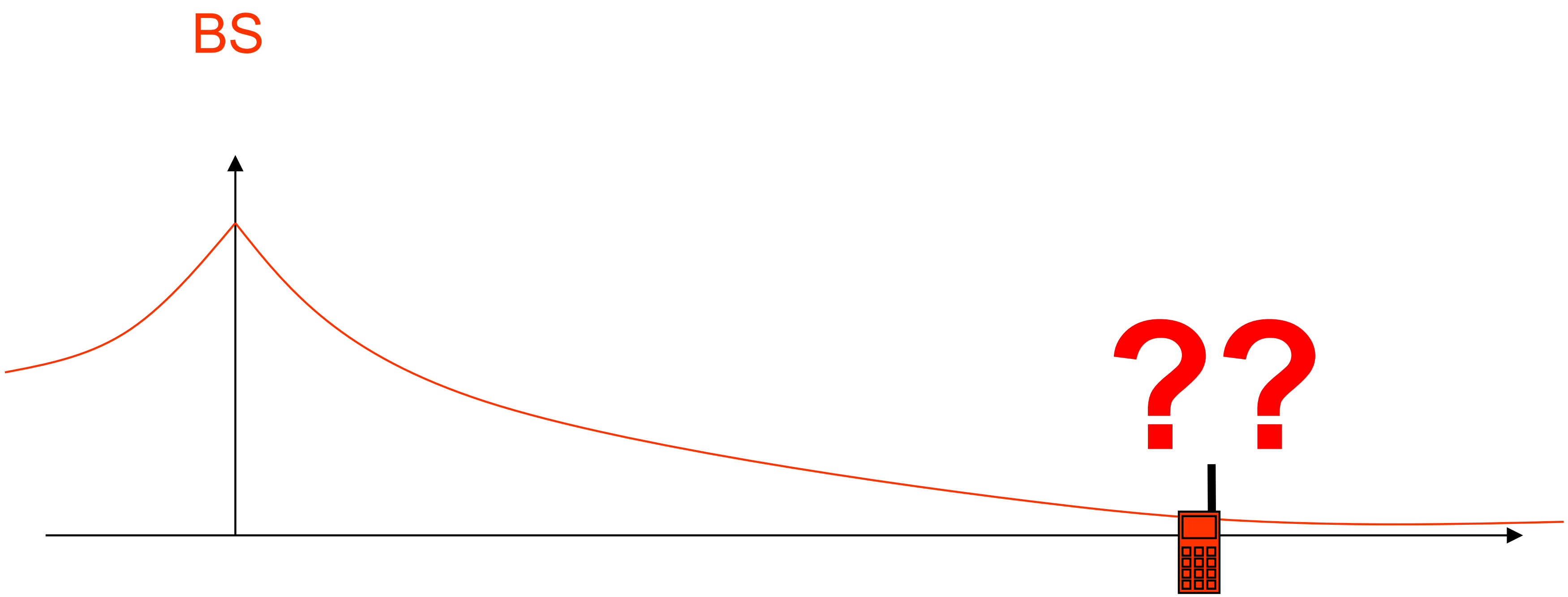
Antenna gain (2)

- 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

18

Attenuation in practice

- For an ideal antenna (theoretic)

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

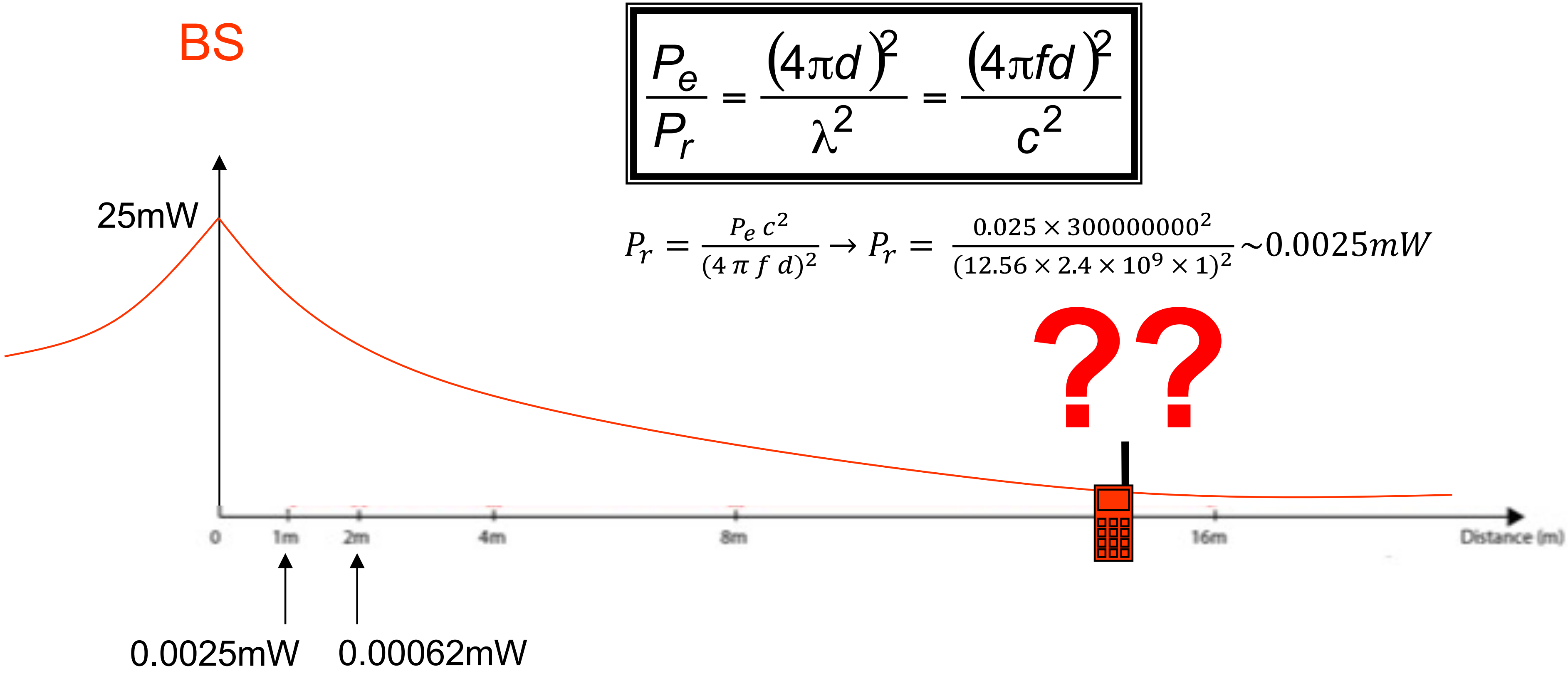
- P_e = transmitted power
- P_r = received power
- P_e / P_r is high when P_r is small → high attenuation
- d = distance between antennas
- c = light speed in space 3.10^8 m/s
- λ= wave length of the signal=c/f
- Higher frequencies f means higher attenuation!

Attenuation, value in watts

- Free Space Path Loss model

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

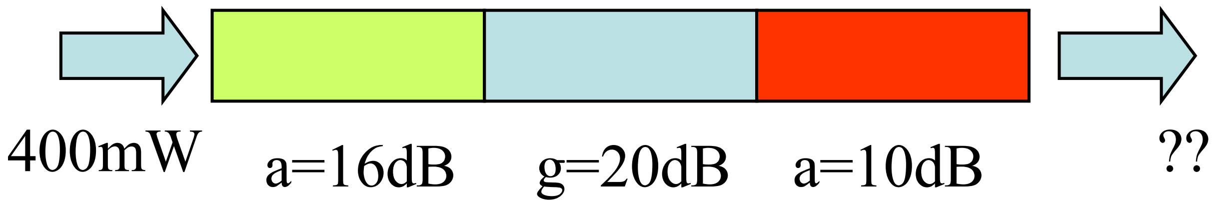
$$P_r = \frac{P_e\, c^2}{(4\,\pi\, f\, d)^2} \rightarrow P_r = \frac{0.025 \times 300000000^2}{(12.56 \times 2.4 \times 10^9 \times 1)^2} \sim 0.0025mW$$



Prof. Congduc Pham
http://www.univ-pau.fr/~cpham

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

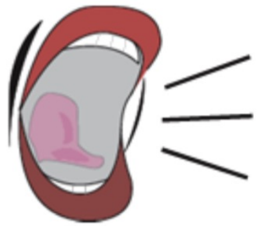


-16dB + 20dB - 10dB = -6dB, so it is an attenuation

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

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.

22

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
0	1.0 mW
1	1.3 mW
2	1.6 mW
3	2.0 mW
4	2.5 mW
5	3.2 mW
6	4 mW
7	5 mW
8	6 mW
9	8 mW
10	10 mW
11	13 mW
12	16 mW
13	20 mW
14	25 mW
15	32 mW

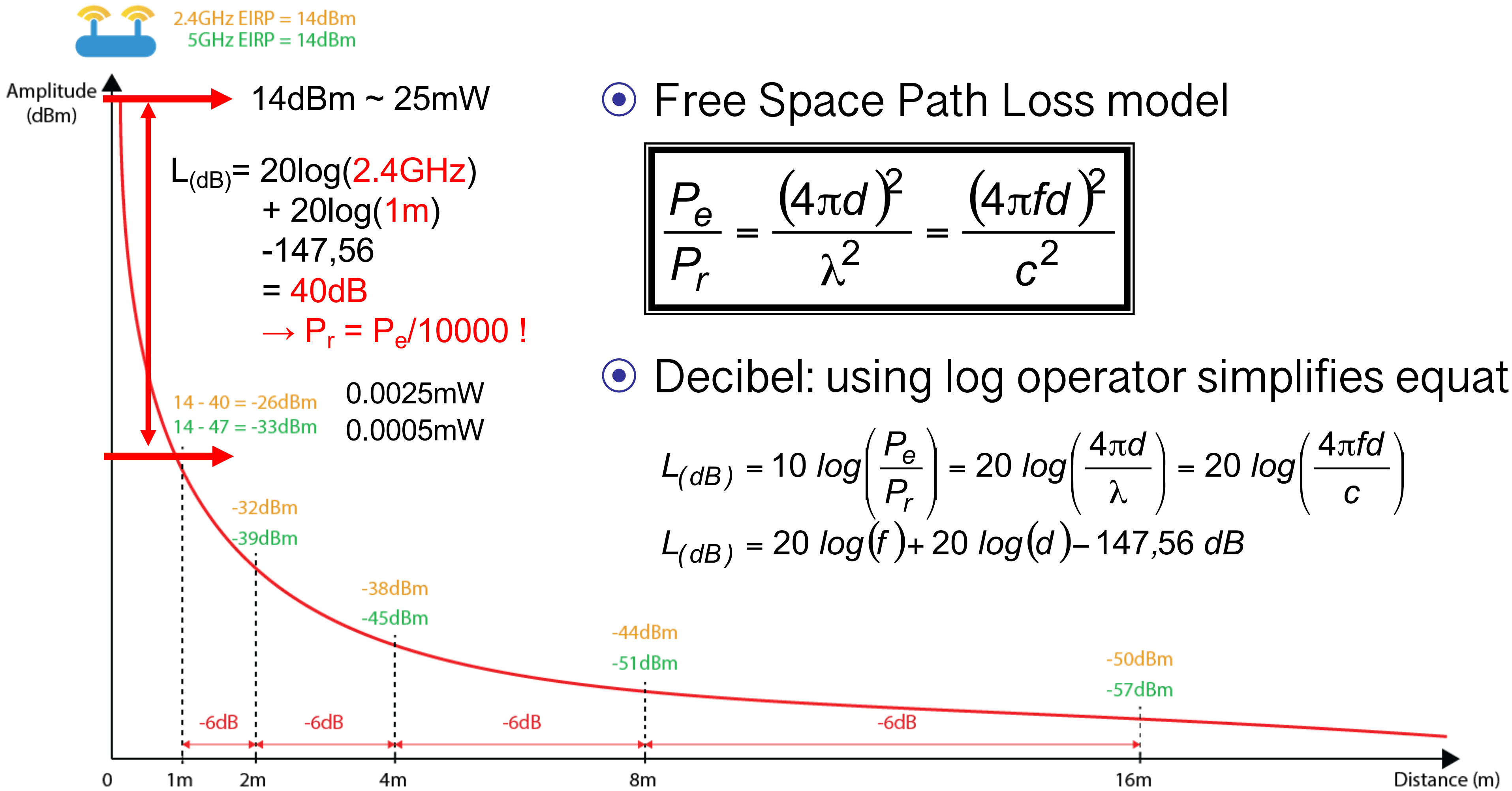
dBm	Watts
16	40 mW
17	50 mW
18	63 mW
19	79 mW
20	100 mW
21	126 mW
22	158 mW
23	200 mW
24	250 mW
25	316 mW
26	398 mW
27	500 mW
28	630 mW
29	800 mW
30	1.0 W
31	1.3 W

dBm	Watts
32	1.6 W
33	2.0 W
34	2.5 W
35	3.2 W
36	4.0 W
37	5.0 W
38	6.3 W
39	8.0 W
40	10 W
41	13 W
42	16 W
43	20 W
44	25 W
45	32 W
46	40 W
47	50 W

RF Essentials from Digi

23

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

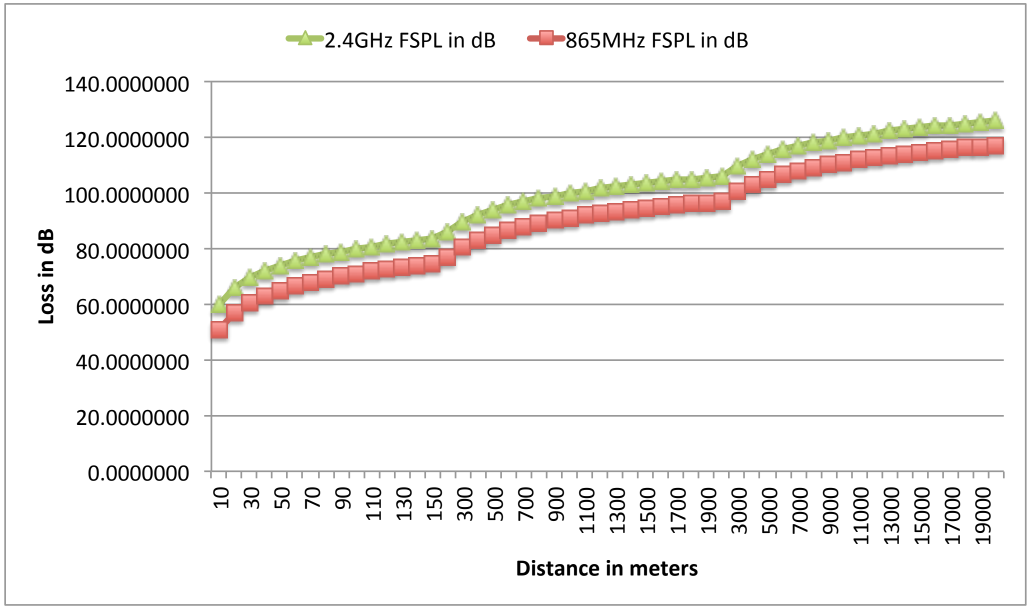
- Free Space Path Loss model

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

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

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

FSPL assume Gt=Gr=1

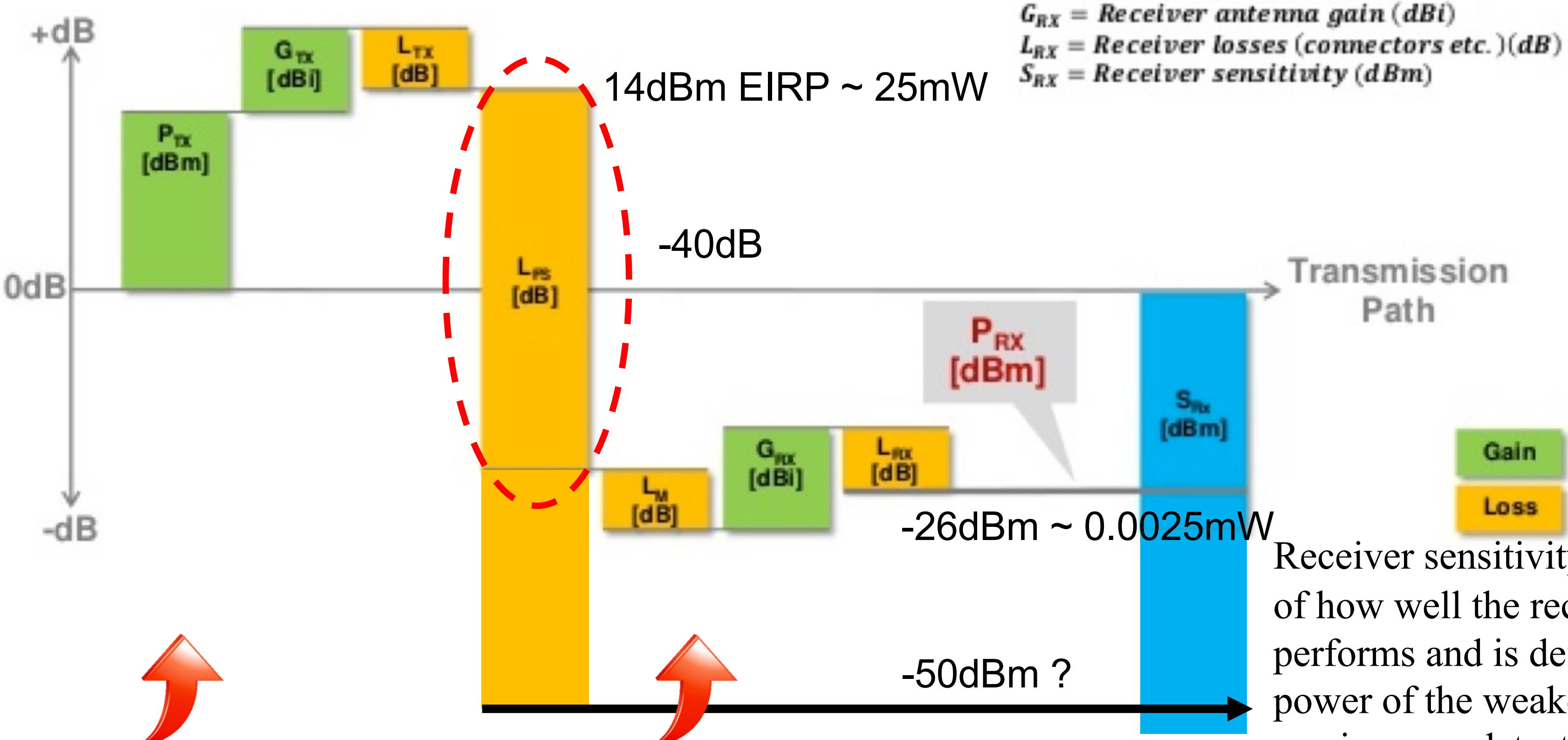


Link budget in wireless system

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

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



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

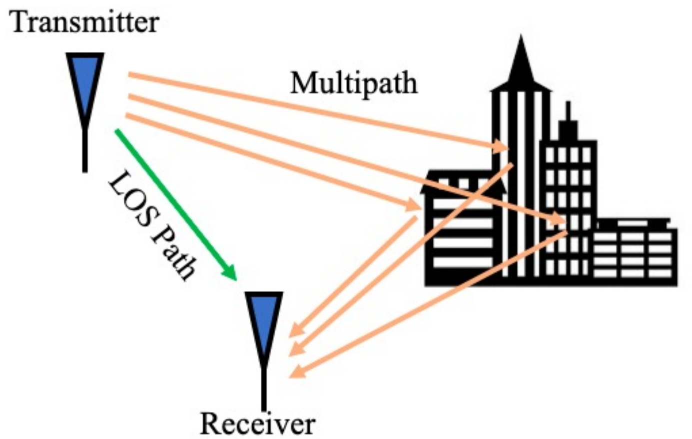
Receiver sensitivity is a measure of how well the receiver performs and is defined as the power of the weakest signal the receiver can detect

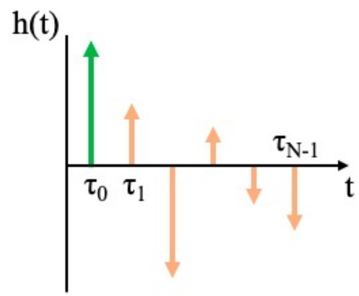
Receiver's sensitivity

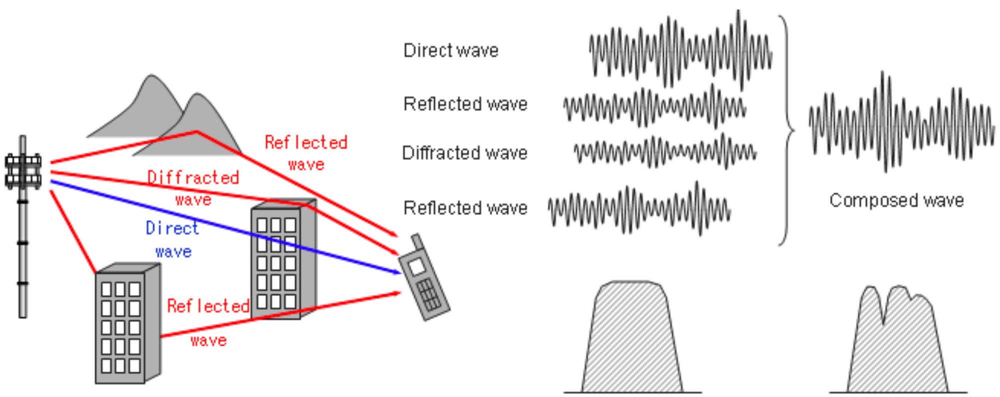
- Receiver's sensitivity is a measure of how well the receiver performs and is defined as the power of the weakest signal the receiver can detect
- How low can you go?

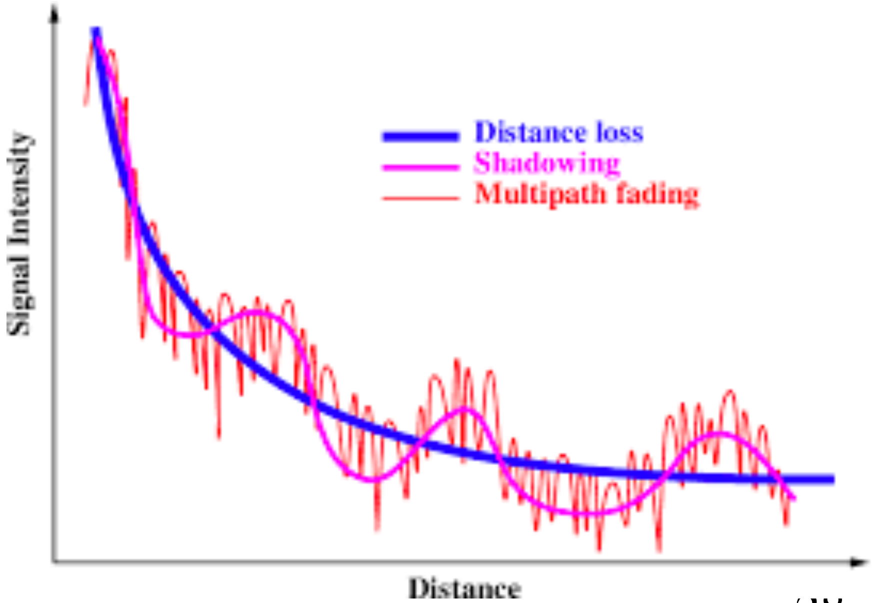
Shadow fading & Multi-path fading

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

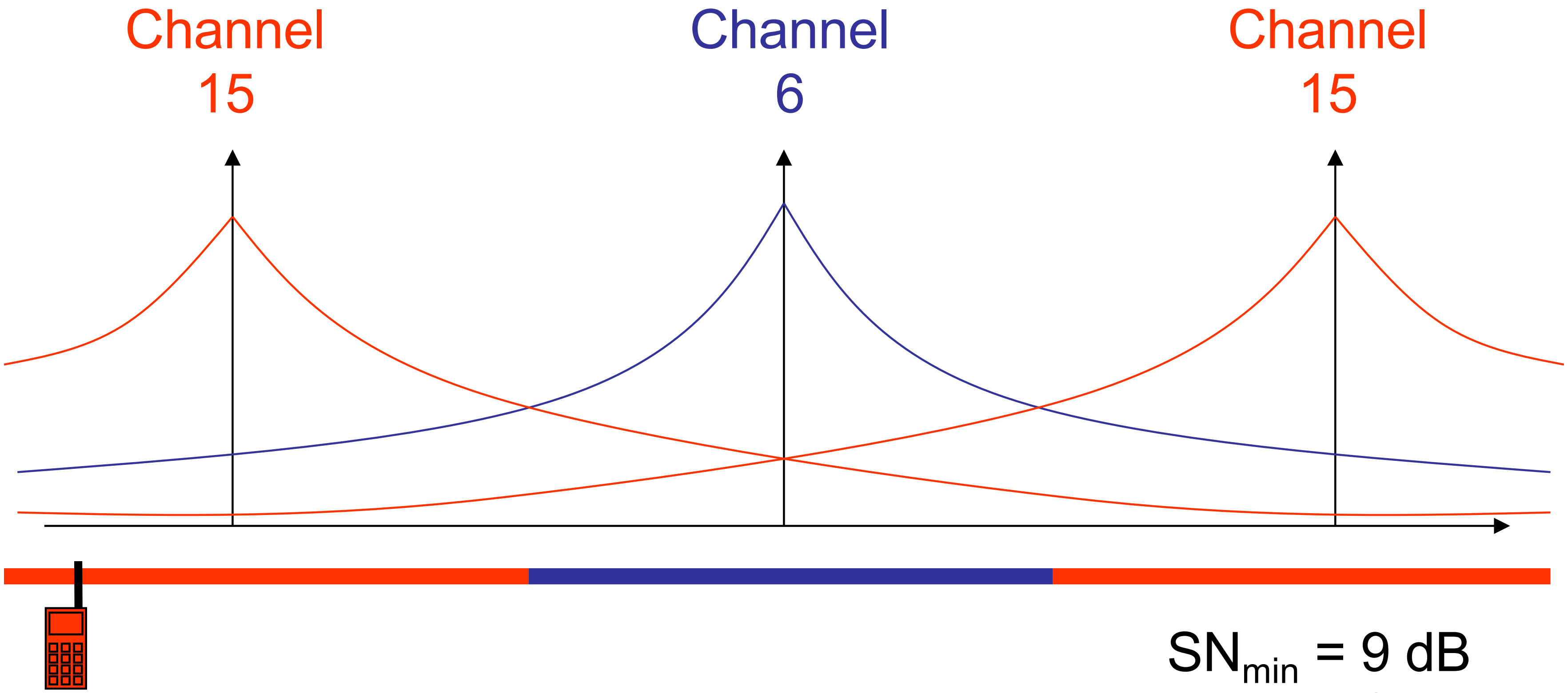








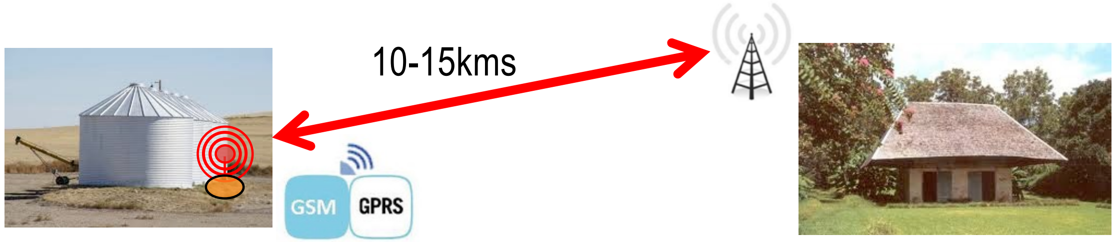
Frequency re-use

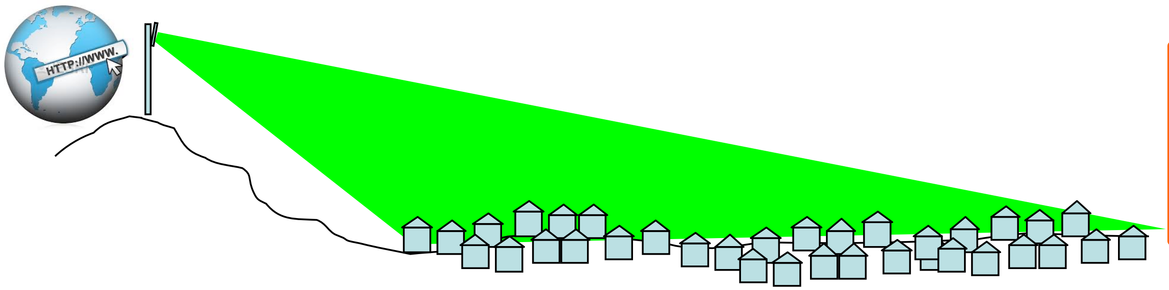


SN_{min} = 9 dB
$S/N=10^{9/10}=7.94$

2nd challenge: energy cost

Moisture/
Temperature of
storage areas

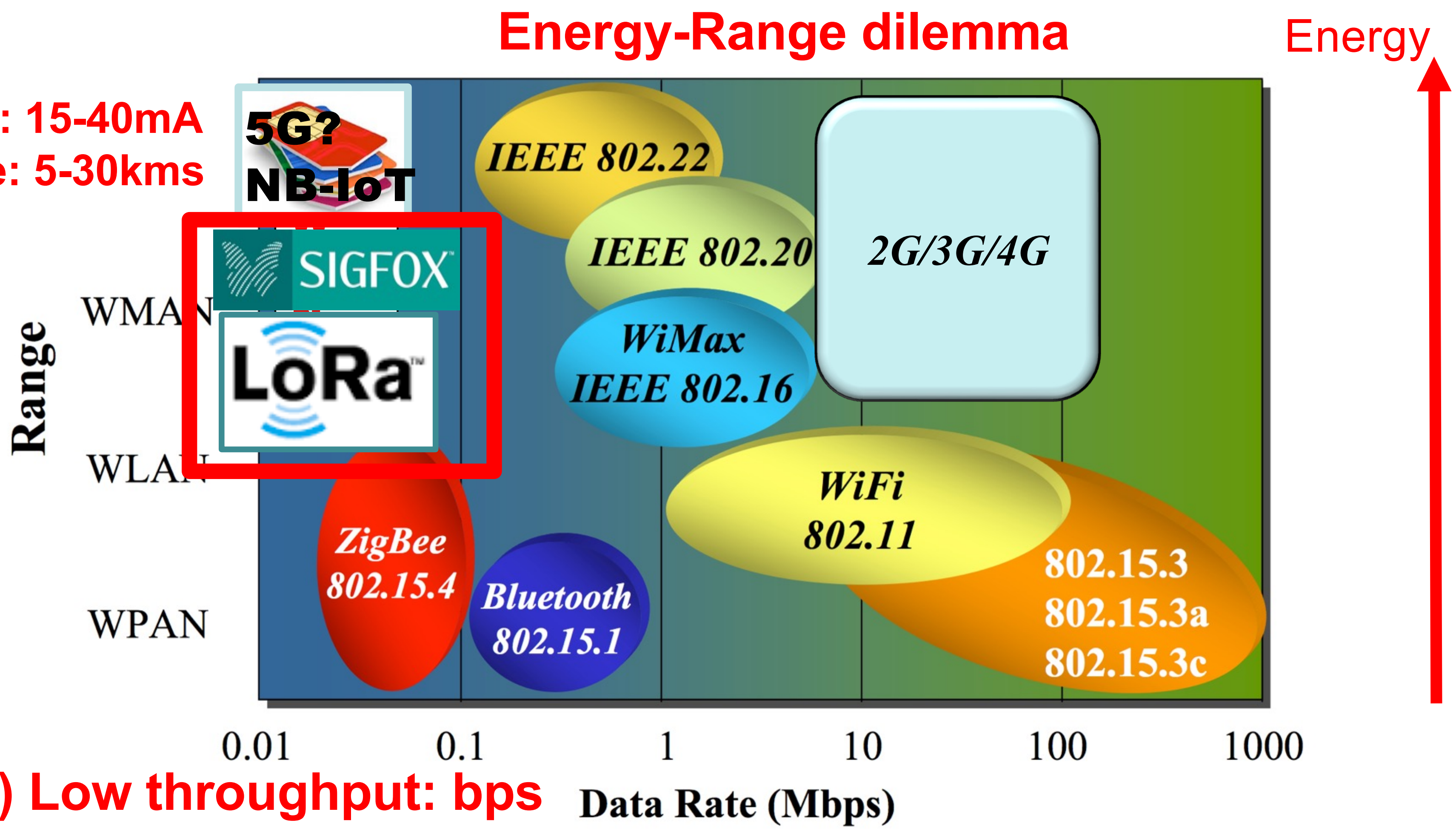




Technology	2G	3G	LAN
Range (I=Indoor, O=Outdoor)	N/A	N/A	O: 300m I: 30m
Tx current consumption	200-500mA	500-1000mA	100-300mA
Standby current	2.3mA	3.5mA	NC

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

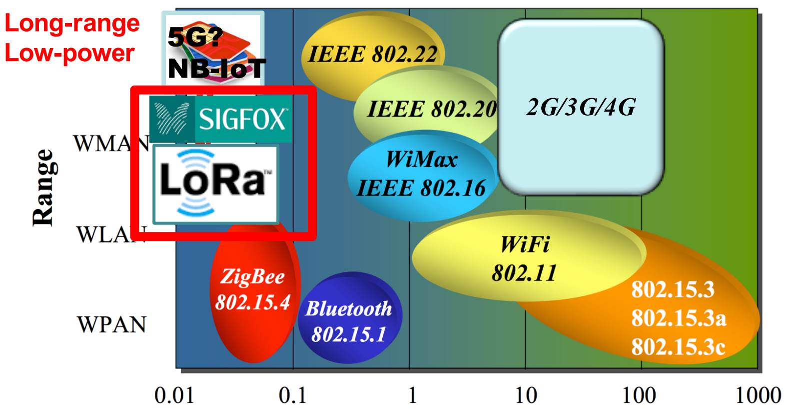
LPWAN
Low-power: 15-40mA
Long-range: 5-30kms



(Very) Low throughput: bps

Energy consumption comparaison

Energy-Range dilemma



(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

2500mAh

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

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

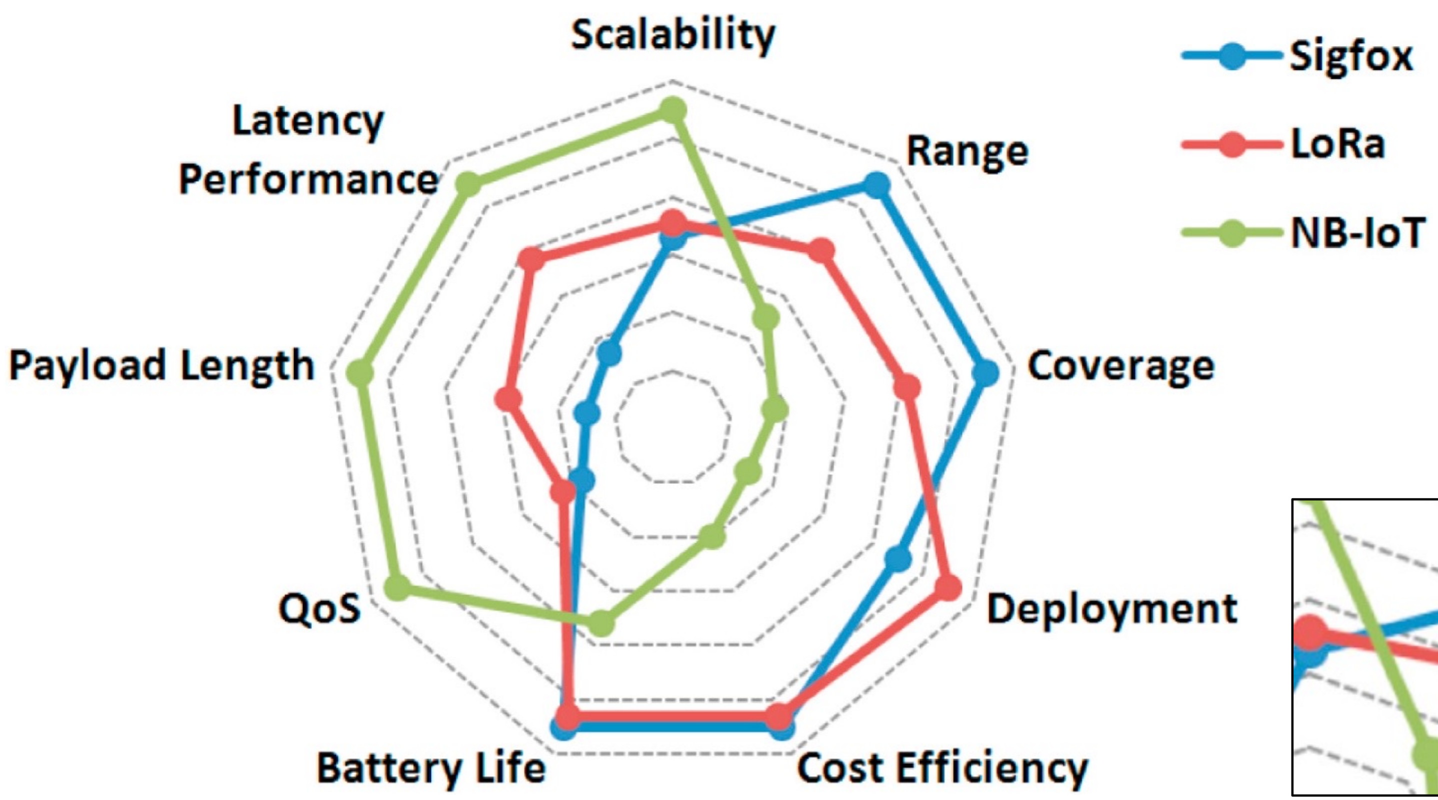
In most cellular networks, the device is still maintaining communication with BS even if it is inactive

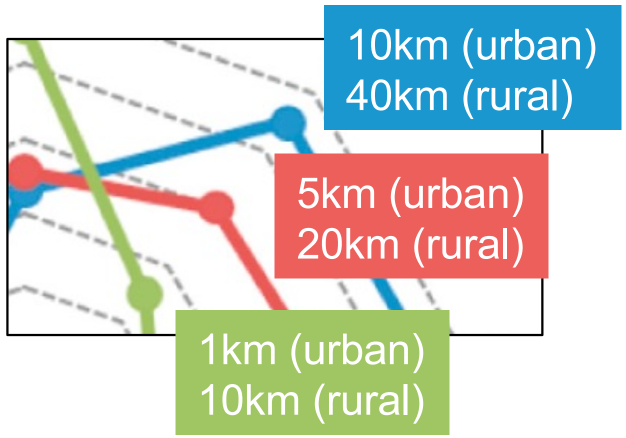
TX power: 40mA. Mean consumption: (2sx40+3598sx0.005)/3600=0.027mA

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

LPWAN does not need to maintain connection if not in used

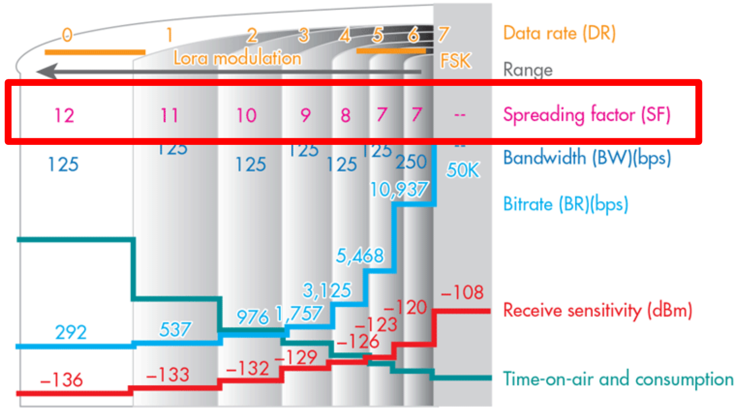
Expected range?





How can we increase range?

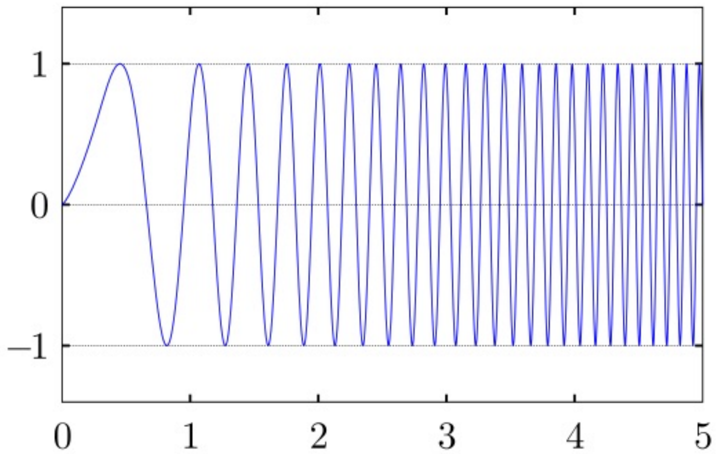
- Increase TX power and/or improve RX sensitivity
- Generally, RX sensitivity (~robustness) can be increased when transmitting (much) slower (like speaking slower!)
- LoRa uses spread spectrum approach to increase RX sensitivity
  - Spreading Factor defines how many chips will be used to code a symbol. 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

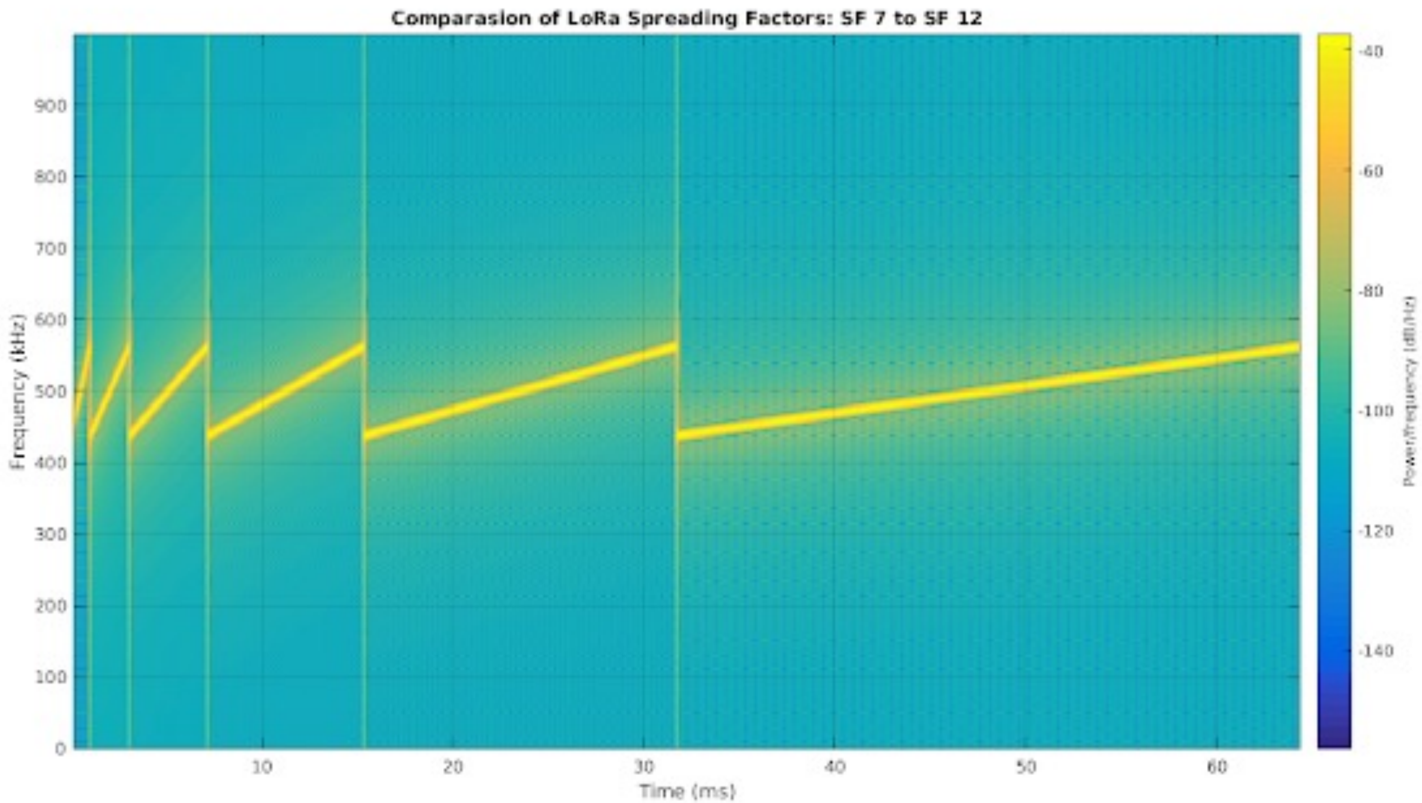
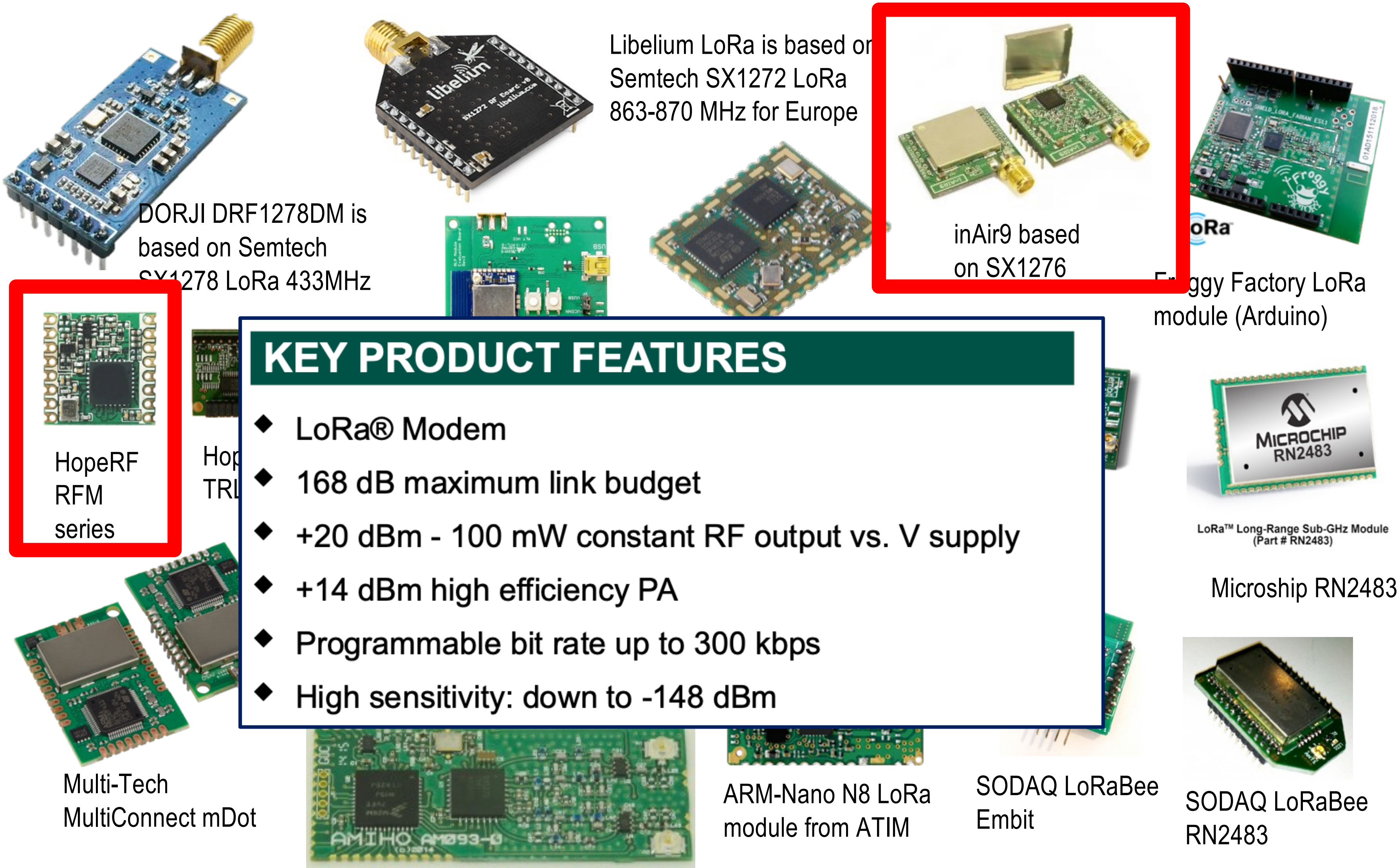


Figure from "All About LoRa and LoRaWAN", https://www.sghoslya.com

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

HopeRF 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

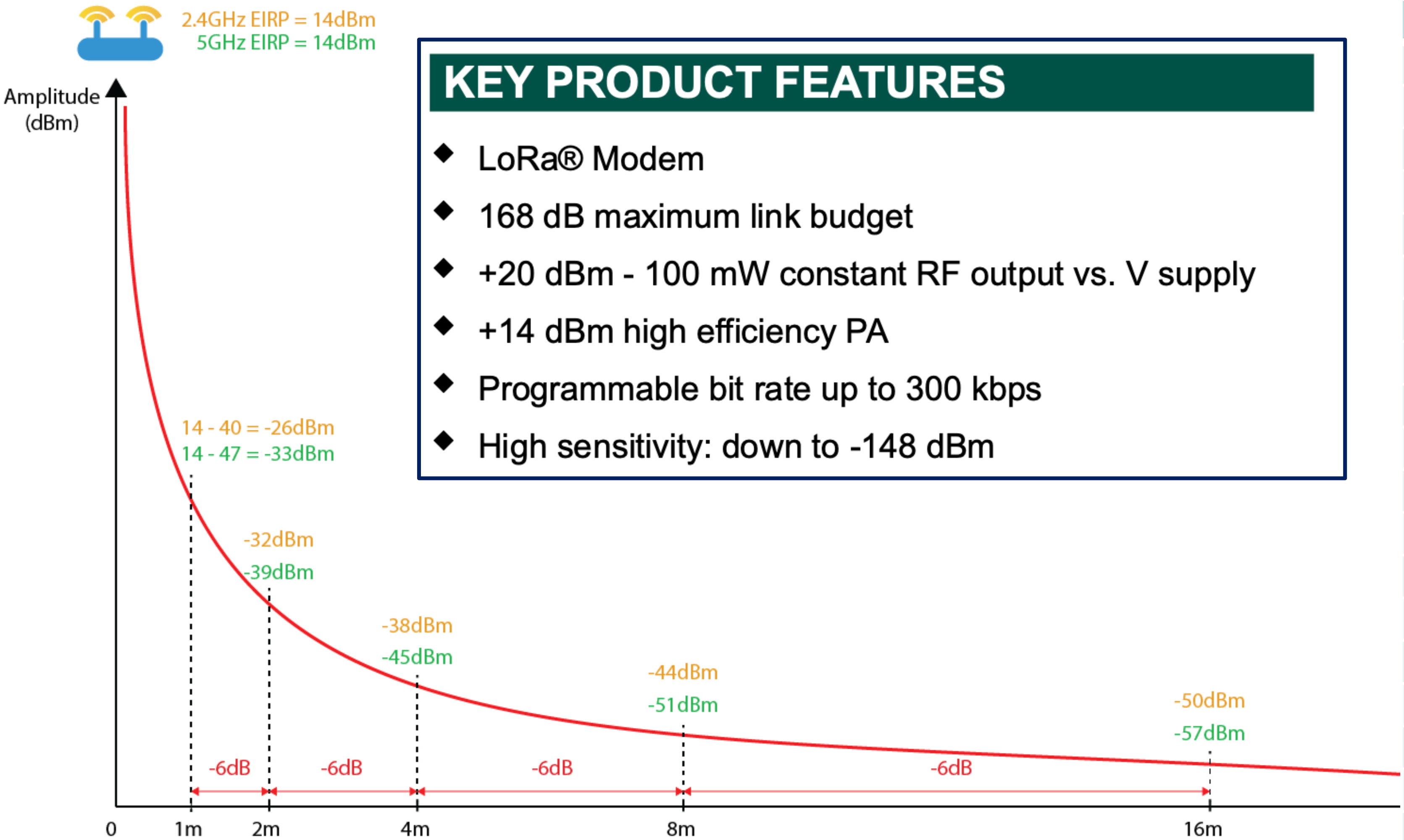
Multi-Tech MultiConnect mDot

ARM-Nano N8 LoRa module from ATIM

SODAQ LoRaBee Embit

SODAQ LoRaBee RN2483

What distance for -148dBm?



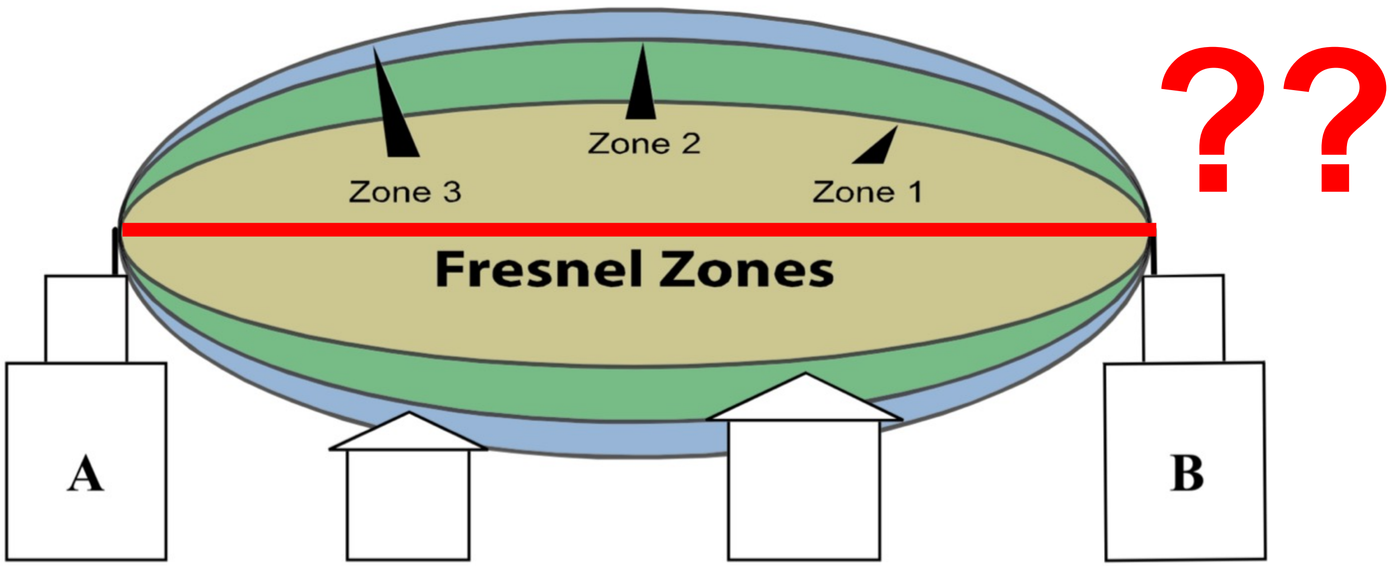
KEY PRODUCT FEATURES

- 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

-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

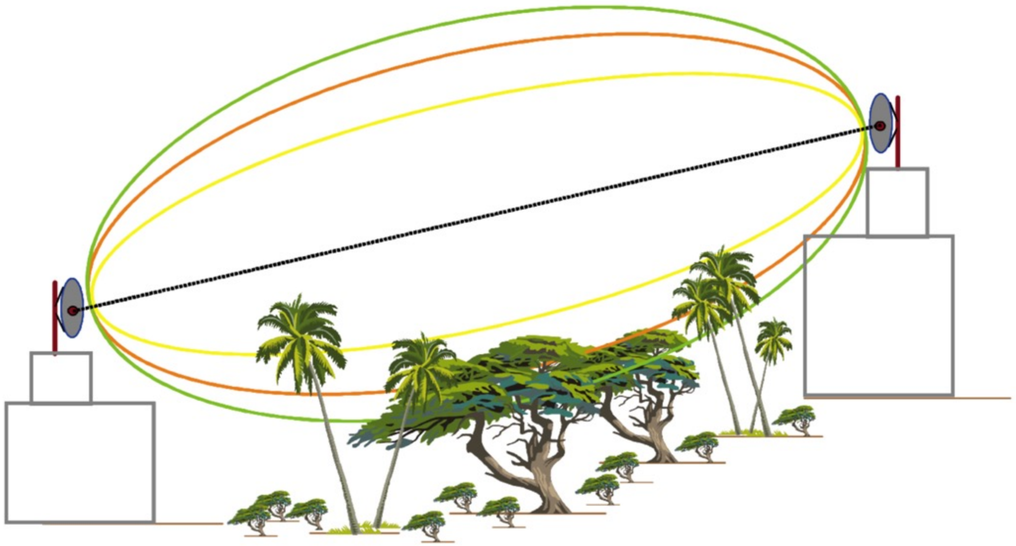
- LoS means clear Fresnel zone
- Football (american) shape
- Acceptable = 60% of zone 1 + 3m

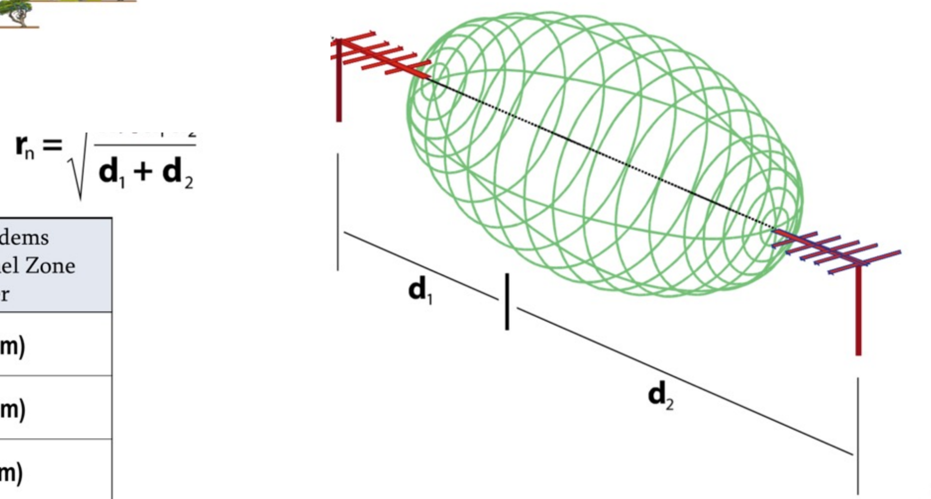


RF Essentials from Digi

In real environment!

Clearing the Fresnel zone? Raise antennas!





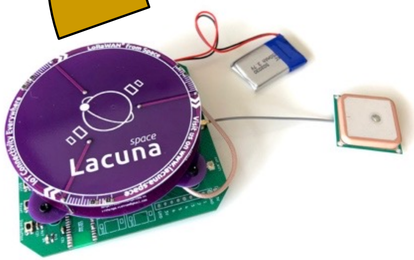
Range Distance	900 MHz Modems Required Fresnel Zone Diameter	2.4 GHz Modems Required Fresnel Zone Diameter
1000 ft. (300 m)	16 ft. (5 m)	11 ft. (3.4 m)
1 Mile (1.6 km)	32 ft. (10 m)	21 ft. (6.4 m)
5 Miles (8 km)	68 ft. (21 m)	43 ft. (13 m)
10 Miles (16 km)	95 ft. (29 m)	59 ft. (18 m)

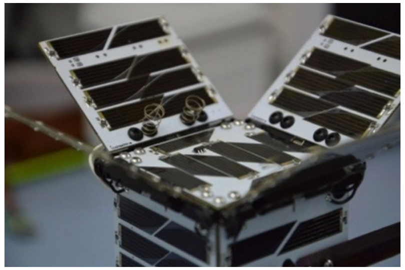
RF Essentials from Digi

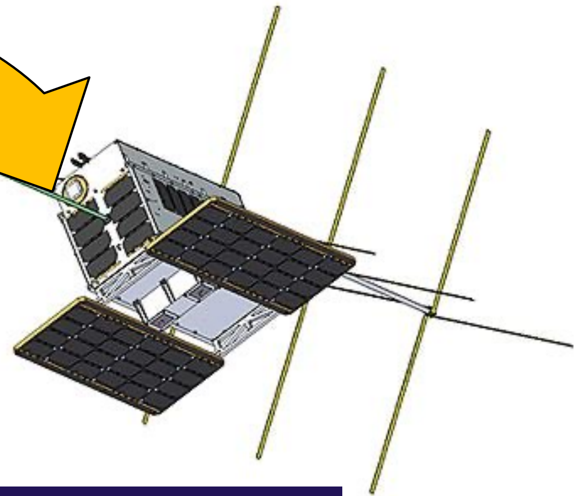
Clearing the Fresnel zone? Let's use satellite!

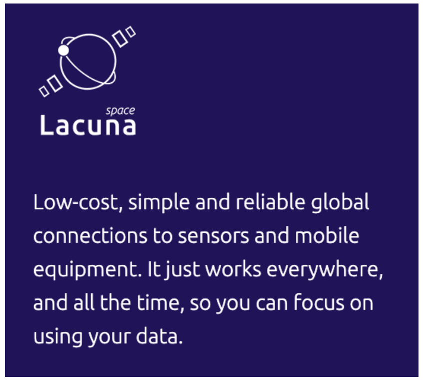
- Low-orbit, low-cost; compact satellite for global coverage

LoRa over 1200kms!









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

LPWAN=star topology, gateway centric

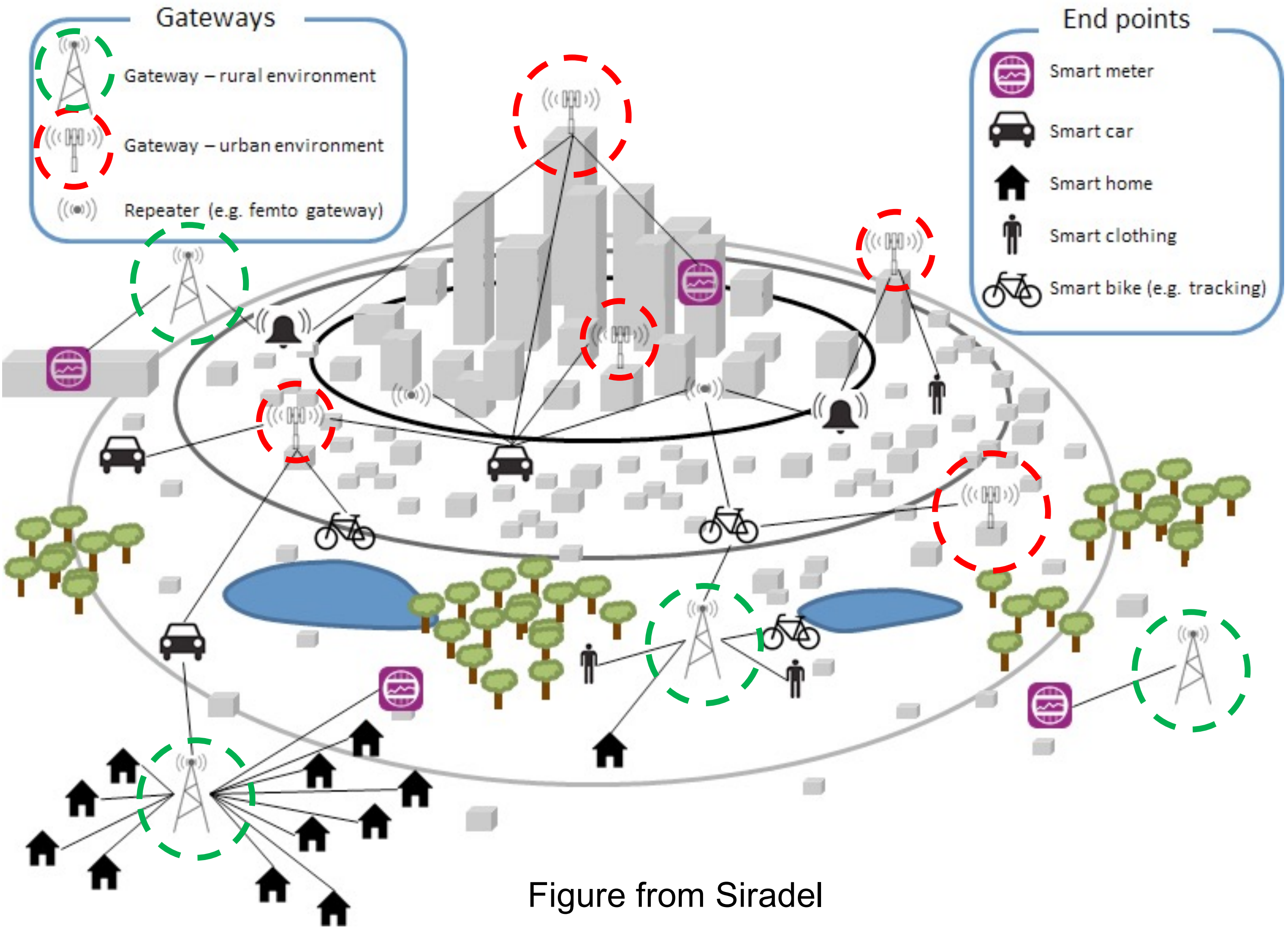
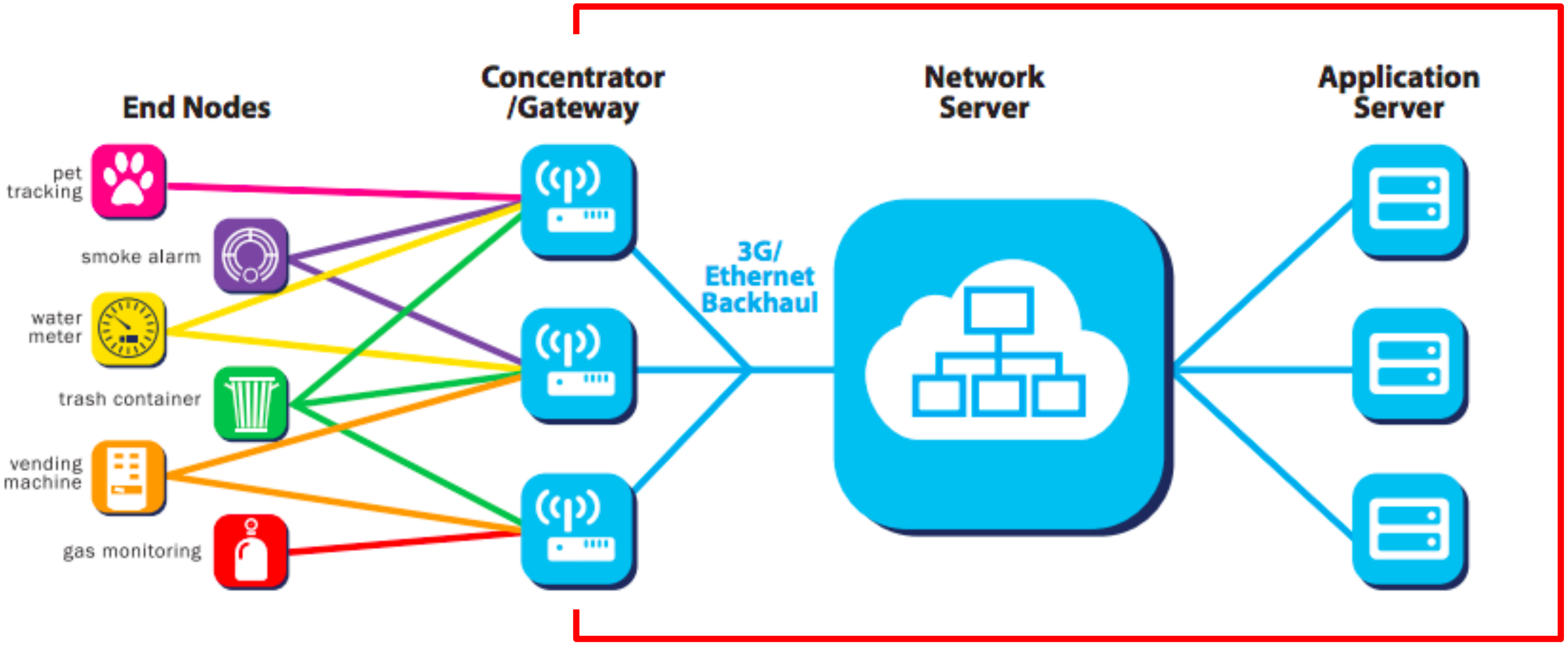
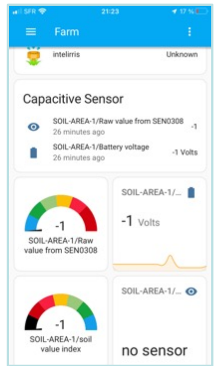


Figure from Siradel

LoRaWAN IoT networks

- LoRaWAN specifications/protocols run on top of LoRa physical networks. It is defined and managed by the LoRa Alliance
- Make possible to run large-scale, public LoRa networks



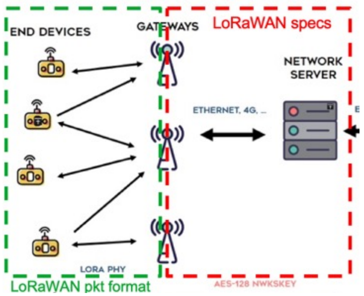


ThingsBoard

Undestanding LoRa vs LoRaWAN

- The physical layer, thus the long-range radio technology, is called LoRa
- A so-called 1-byte sync word is used to add a "filtering" level
- You can decide to transmit using only the LoRa physical layer and then define our own packet format
- With pure LoRa you can transmit from any device to any other device with same LoRa datarate, frequency and sync word
- LoRaWAN uses LoRa physical layer but defines its own packet format and uses sync word of 0x34 (public LoRaWAN)
- "In LoRaWAN, a gateway applies I/Q inversion on TX, and nodes do the same on RX. This ensures that gateways can talk to nodes and vice-versa, but gateways will not hear other gateways and nodes will not hear other nodes" [LMIC Arduino]

LoRaWAN gateway



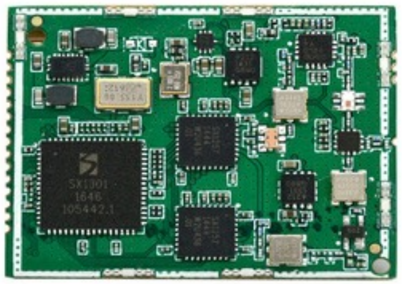
- A full LoRaWAN gateway should be able to listen on multiple channels and spreading factors

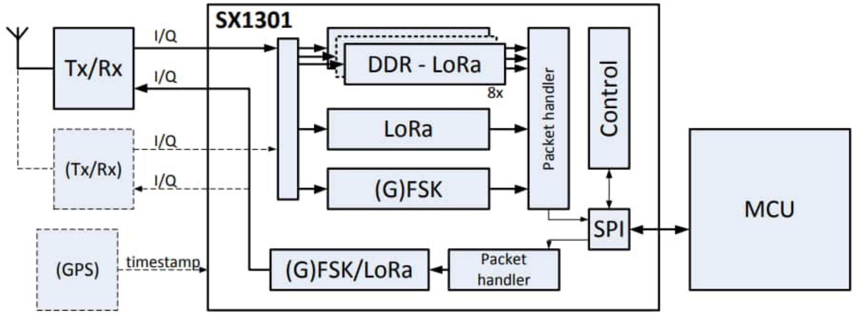
EU863-870

Uplink:

1. 868.1 - SF7BW125 to SF12BW125
2. 868.3 - SF7BW125 to SF12BW125
3. 868.5 - SF7BW125 to SF12BW125
4. 867.1 - SF7BW125 to SF12BW125
5. 867.3 - SF7BW125 to SF12BW125
6. 867.5 - SF7BW125 to SF12BW125
7. 867.7 - SF7BW125 to SF12BW125
8. 867.9 - SF7BW125 to SF12BW125
9. 868.8 - FSK

- They are mostly based on the Semtech SX1301 radio concentrator

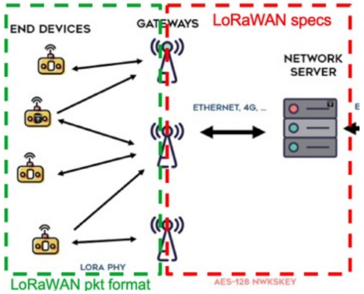




LoRaWAN gateway software

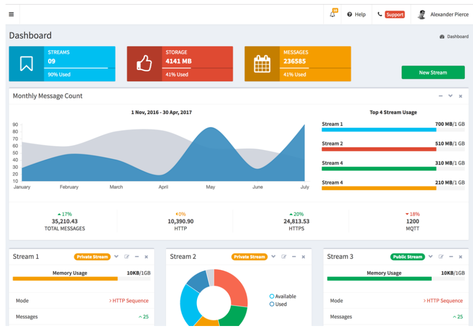
- Most of LoRaWAN gateways run the following software
  - the Semtech's concentrator gateway at the lowest level (https://github.com/Lora-net/lora_gateway)
  - The Semtech's LoRa packet forwarder on top of the low-level concentrator gateway (https://github.com/Lora-net/packet_forwarder)
- "*A LoRa packet forwarder is a program running on the host of a LoRa gateway that forwards RF packets receive by the concentrator to a server through a IP/UDP link, and emits RF packets that are sent by the server.*"
- The server is the so-called LoRaWAN Network Server (LNS) as described in the next slides
- The Network Server is usually linked to the Application Server which can be seen as a LoRaWAN cloud

LoRaWAN Network Server (LNS)

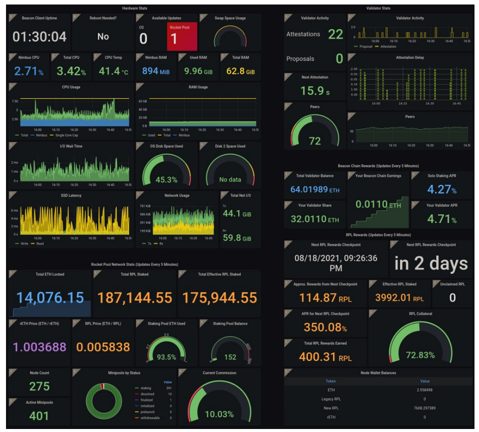


- LNS manages the state of the network, has knowledge of devices active on the network and is able to handle over-the-air-activation procedure (OTAA)
- When data is received by multiple gateways, the LNS can also de-duplicate this data
- When a message needs to be sent back to a device, the LNS forwards it to one of the gateways
- Currently, each LoRaWAN network provider will have their own LNS
  - The Packet Forwarder run on deployed gateways needs to identify an LNS
  - Therefore users need to be "bounded" to a particular LoRa network provider because end-devices need to be registered

TheThingNetwork (TTN)



- Popular LoRa Network Provider
- Provides the TTN Network Server



- Community-based deployment of LoRa gateways
  - User A can buy a LoRa gateway, register it and deploy it
  - User B then creates an account on TTN to register its devices
  - Messages from registered devices received by a TTN gateway will be made available for users on the TTN console

Prof. Congduc Pham
http://www.univ-pau.fr/~cpham

TTN user console