

# INTEL-IRRIS

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



Intel-Irris



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



## Wireless Communication Essentials

### Understanding radio & LoRa technologies in IoT



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<http://www.univ-pau.fr/~cpham>  
Université de Pau, France



# Wireless networks: WiFi



<p><b>1973</b></p> <p>Ethernet developed at Xerox's Palo Alto Research Center (PARC)</p>	<p><b>1977</b></p> <p>Ethernet patented by Xerox</p>	<p><b>1997</b></p> <p><b>802.11 Standard</b></p> <p>The 802.11 standard is created. Products using the 2.4 GHz band have a maximum data rate of 2 Mbps</p> <p>2.40 GHz</p> <p>Max Data Rate</p> <p><b>2 Mbps</b></p>	<p><b>2007</b></p> <p><b>802.11n Standard (I)</b></p> <p>The 802.11n standard is considered the fourth generation. Products are created for 2.4 GHz and 5 GHz bands and both have a maximum data rate of 450 Mbps.</p> <p>5.0 GHz</p> <p>Max Data Rate</p> <p><b>450 Mbps</b></p>	<p><b>2009</b></p> <p><b>802.11 Standard (II)</b></p> <p>The second wave of 802.11n is created and products operating in both the 2.4 GHz and 5 GHz bands now support a maximum data rate of 600 Mbps.</p> <p>5.0 GHz</p> <p>Max Data Rate</p> <p><b>600 Mbps</b></p>	<p><b>2011</b></p> <p>The 802.11v, 802.11k and 802.11u standards are created. 11k is designed to improve the way wireless traffic is distributed through a network by determining which access points (APs) have available capacity. 11u allows users to know what wireless services a network offers before they are connected to it. It is most beneficial in crowded areas with multiple wireless services.</p>
<p><b>1999</b></p> <p><b>802.11a Standard</b></p> <p>The 802.11b and 802.11a standards are created. 802.11b drives the implementation of widespread use of WLAN technology. It is considered the first generation of wireless local area network technology. Products use 2.4 GHz and have a maximum data rate of 11 Mbps. 802.11a is considered the second generation. Products use the 5 GHz band and have a maximum data rate of 54 Mbps.</p> <p>5.0 GHz</p> <p>Max Data Rate</p> <p><b>54 Mbps</b></p>	<p><b>2003</b></p> <p><b>802.11g Standard</b></p> <p>The 802.11g standard is considered third generation; this standard permits products to use the 2.4 GHz band and match the 54 Mbps throughput of 5 GHz devices.</p> <p>2.40 GHz</p> <p>Max Data Rate</p> <p><b>54 Mbps</b></p> <p>&gt;&gt; Throughput of 5 GHz devices</p>	<p><b>2005</b></p> <p><b>802.11e Standard</b></p> <p>The 802.11e standard is created. It is intended to take 11b and 11a to the next level with quality of service (QoS) features capable of prioritizing data, talk and video transmissions. Networks using 11e operate at radio frequencies of up to 5.850 GHz. It is most suitable for networks with multimedia capabilities.</p> <p>5.85 GHz</p>	<p><b>2013</b></p> <p><b>802.11ac Standard (I)</b></p> <p>The 802.11ac standard, so-called gigabit Wi-Fi, is ratified. In the first wave, Wi-Fi certified products have a maximum data rate of 1.3 Gbps and operate only in the 5 GHz band. Among other technological enhancements, this standard allows APs to send multiple streams to one client at a time. It is considered the fifth generation.</p> <p>5.0 GHz</p> <p>Max Data Rate</p> <p><b>1.3 Gbps</b></p>	<p><b>2014</b></p> <p><b>802.11ac Standard (II)</b></p> <p>Second-wave 802.11ac products hit the market. These products also use the 5 GHz band, but at a speed of 6.93 Gbps. It expands AP capabilities through the support of multiple input, multiple output (MIMO) technology, which enables APs to send multiple streams to multiple clients instead of just one at a time. The second wave also employs wider 160 MHz channels that can be used to give high-throughput applications their own exclusive pathways, thus further improving performance.</p> <p>5.0 GHz</p> <p>Max Data Rate</p> <p><b>6.93 Gbps</b></p>	<p><b>TechTarget</b></p> <p>For up-to-date news, analysis and advice on networking visit <a href="http://SearchNetworking.com">SearchNetworking.com</a>.</p> <p>Information by Sonia Grefly/TechTarget Design by Brian Linnshay/TechTarget</p>

# Wireless networks: 2G/3G/4G/5G/... Intel-IrriS

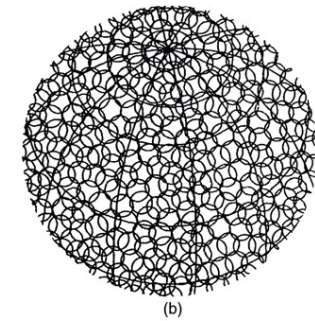
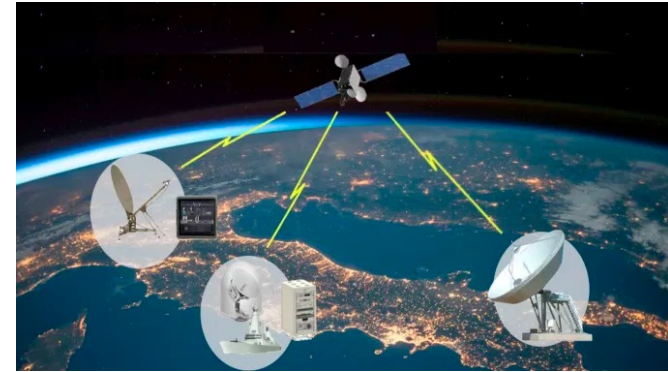


## How Bluetooth is Transforming Consumer Electronics



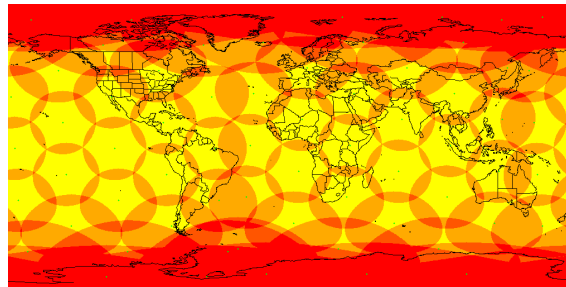
# Wireless networks: Satellites

Altitude (km)	Type	Latence (ms)	Satellites nécessaires
35 000	GEO	270	3
15 000 - 20 000	Ceinture de Van Allen extérieure		
10 000	MEO	35-85	10
5 000 - 10 000	Ceinture de Van Allen intérieure		
1-7	LEO	1-7	50

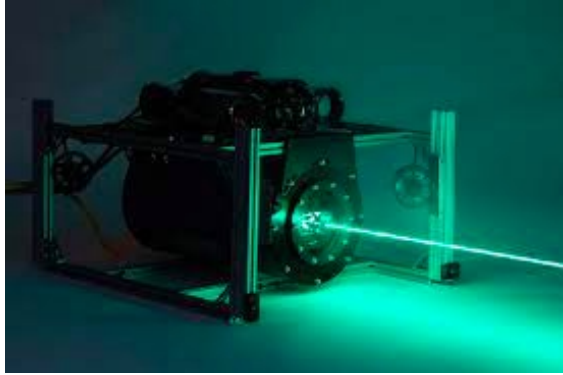


© Pearson Education France

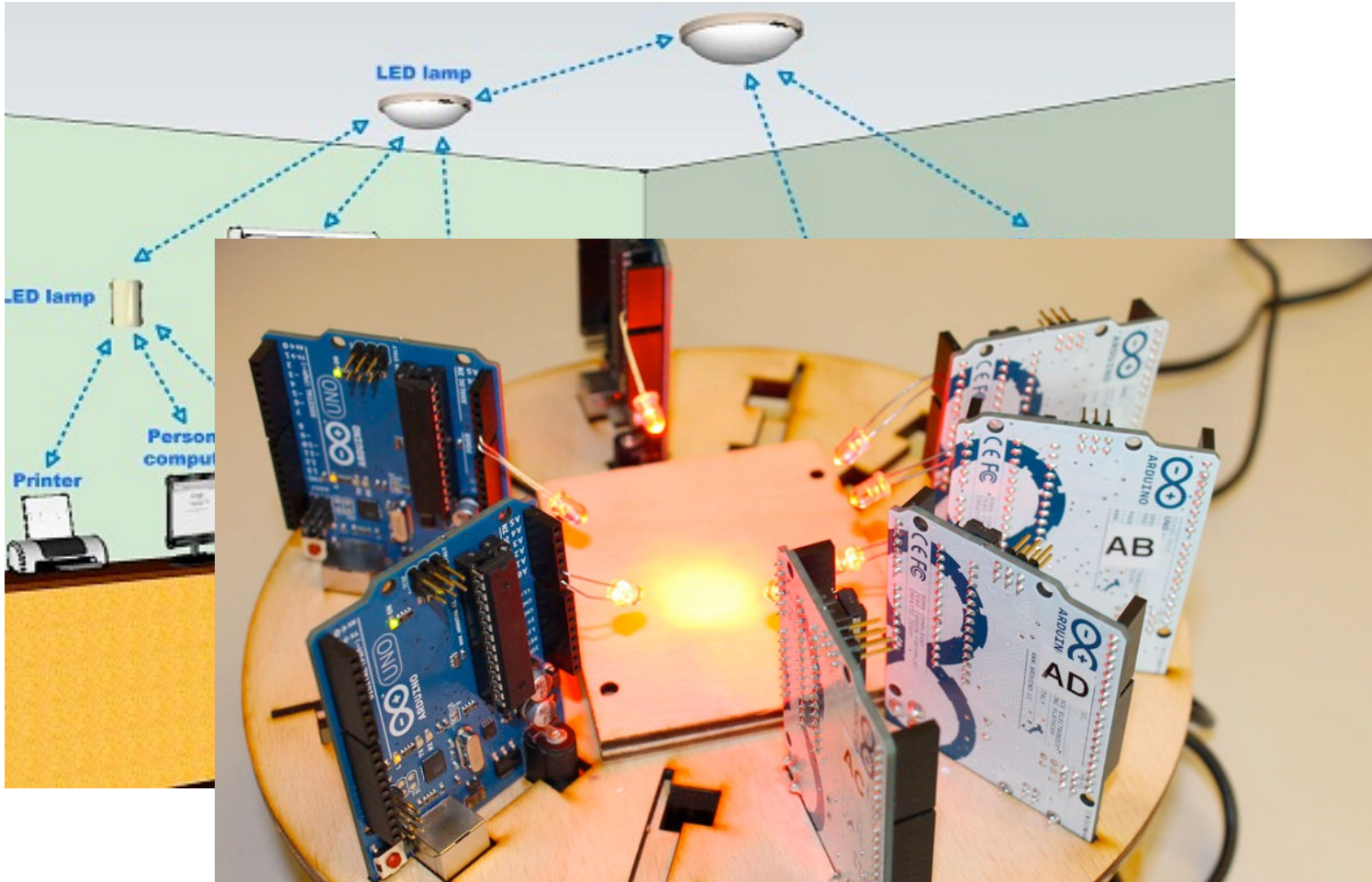
Iridium, 66 satellites  
 Initially 77



# Wireless networks: Laser/Optical



# Wireless networks: Visible Light





# Visible Light Communications, cont

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

## How li-fi sends data

The visible light spectrum is 10,000 times larger than the radio waves we use for wi-fi today. Information can be encoded in light pulses, just like in traditional TV remote controls.



Modern LEDs, however, could transmit enough data for a stable broadband connection - but still look like normal white light



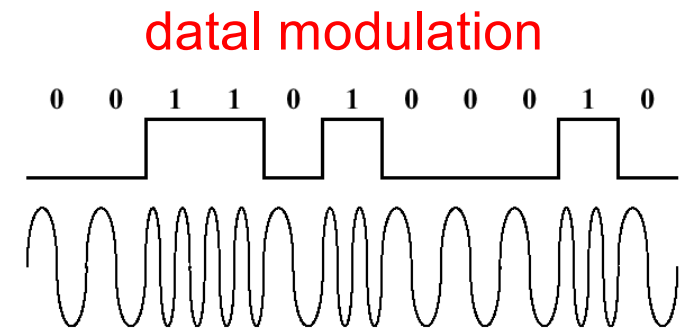
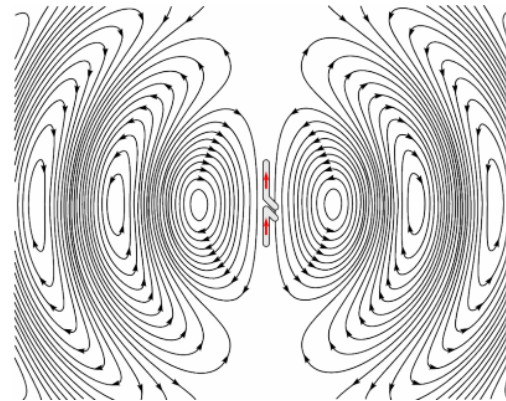
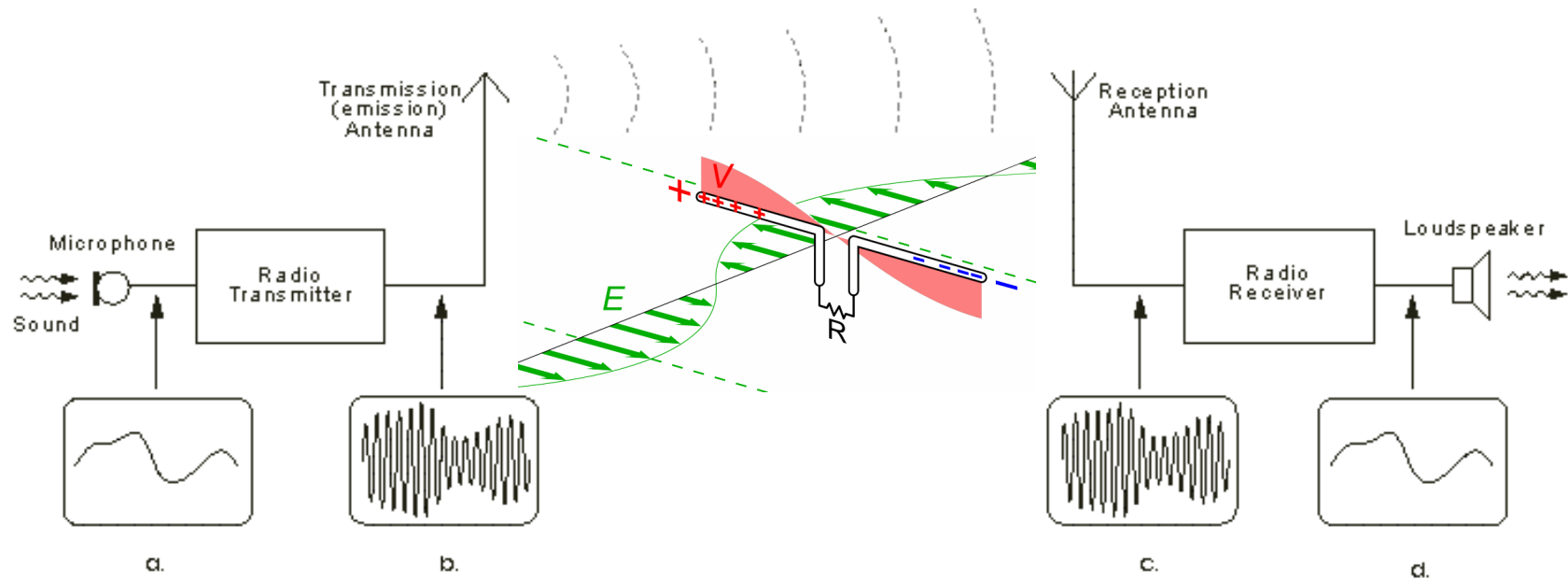
\*bits per second

Source: Professor Harald Haas

BBC



# Wireless radio transmission basics

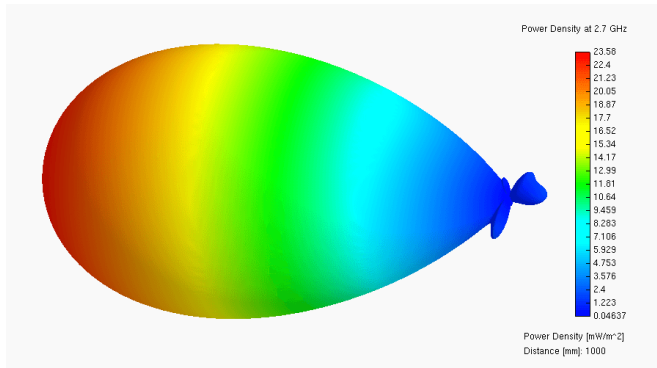


(b) Frequency-shift keying

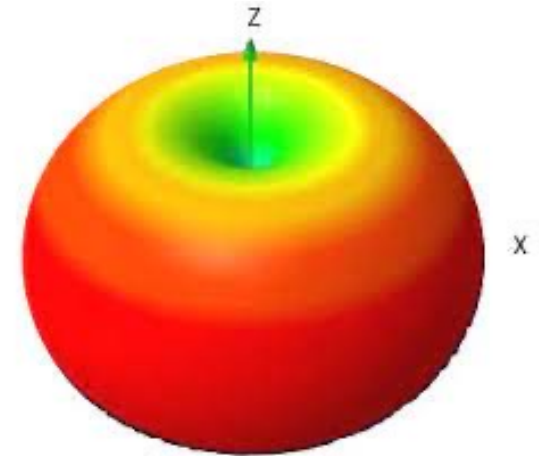
# Antenna types



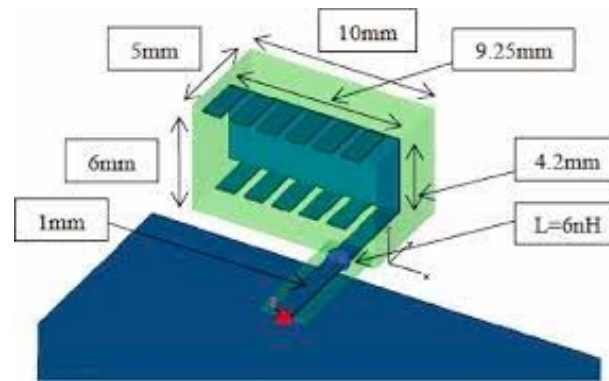
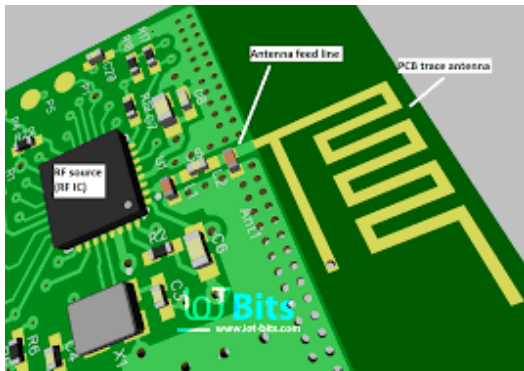
## Omni-directional antennas



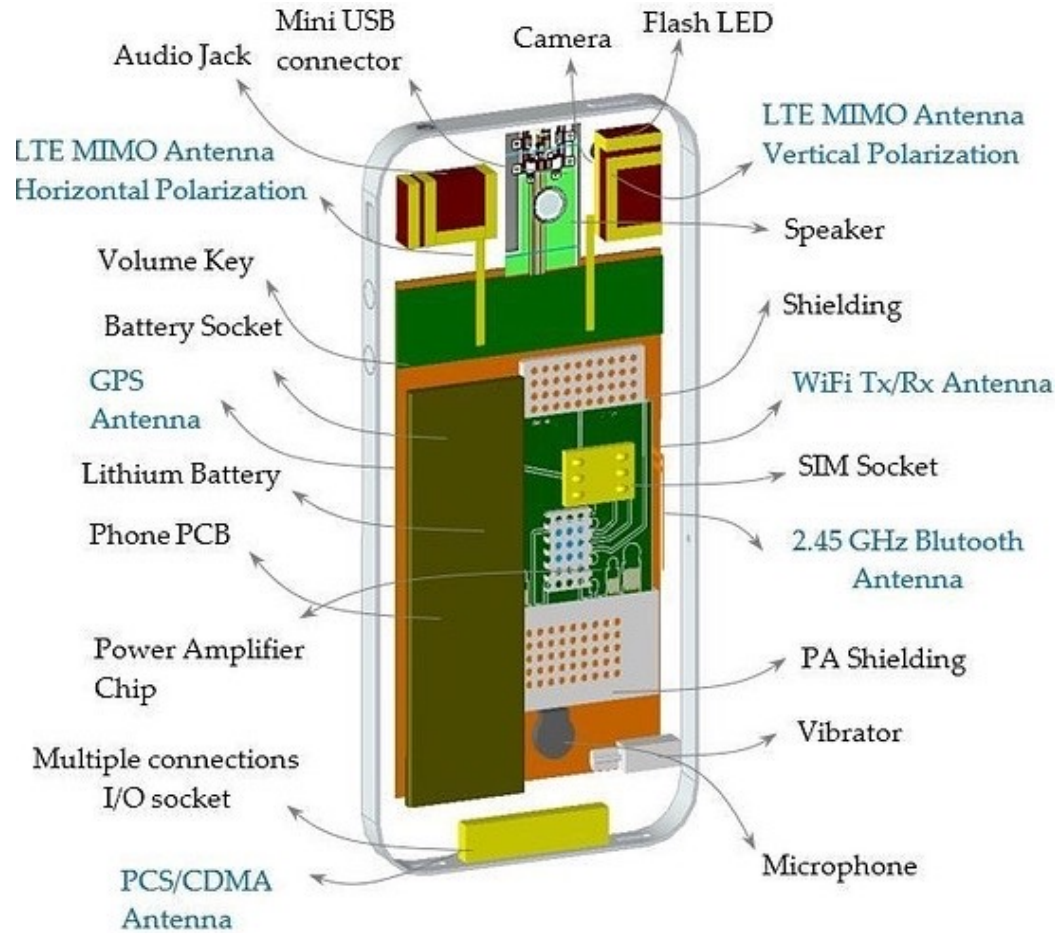
Directional antenna



# PCB, patch, ceramic,...

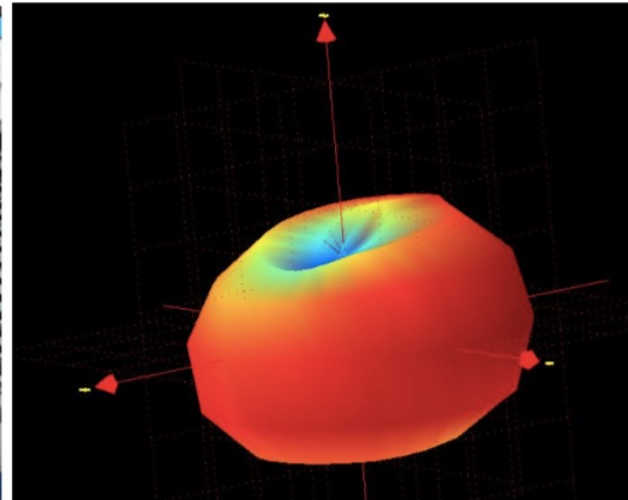
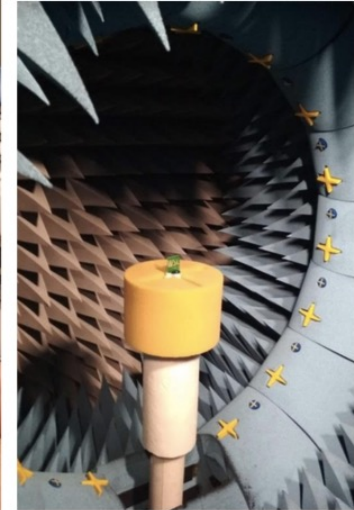
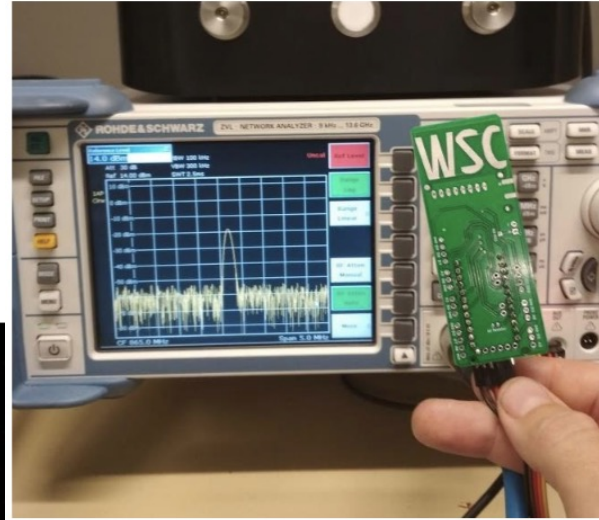
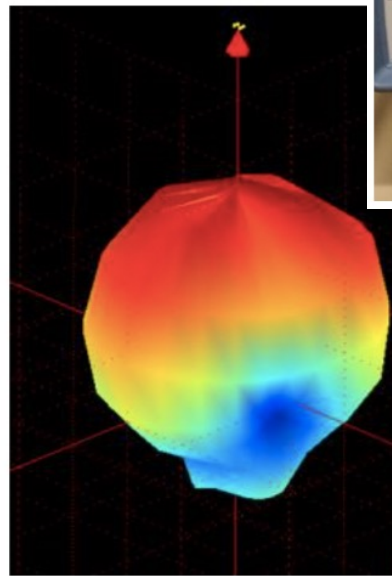


# Antennas in a smartphones!



# Testing antennas

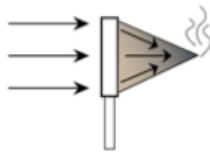
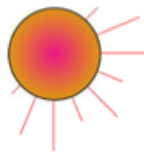
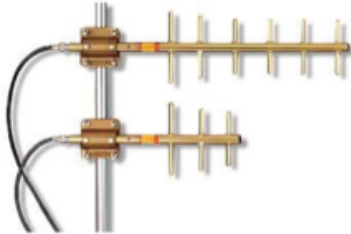
Source: F. Ferrero,  
University of Nice



# 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



# Antenna gain (2)

- ⦿ Antenna gain and its effective surface

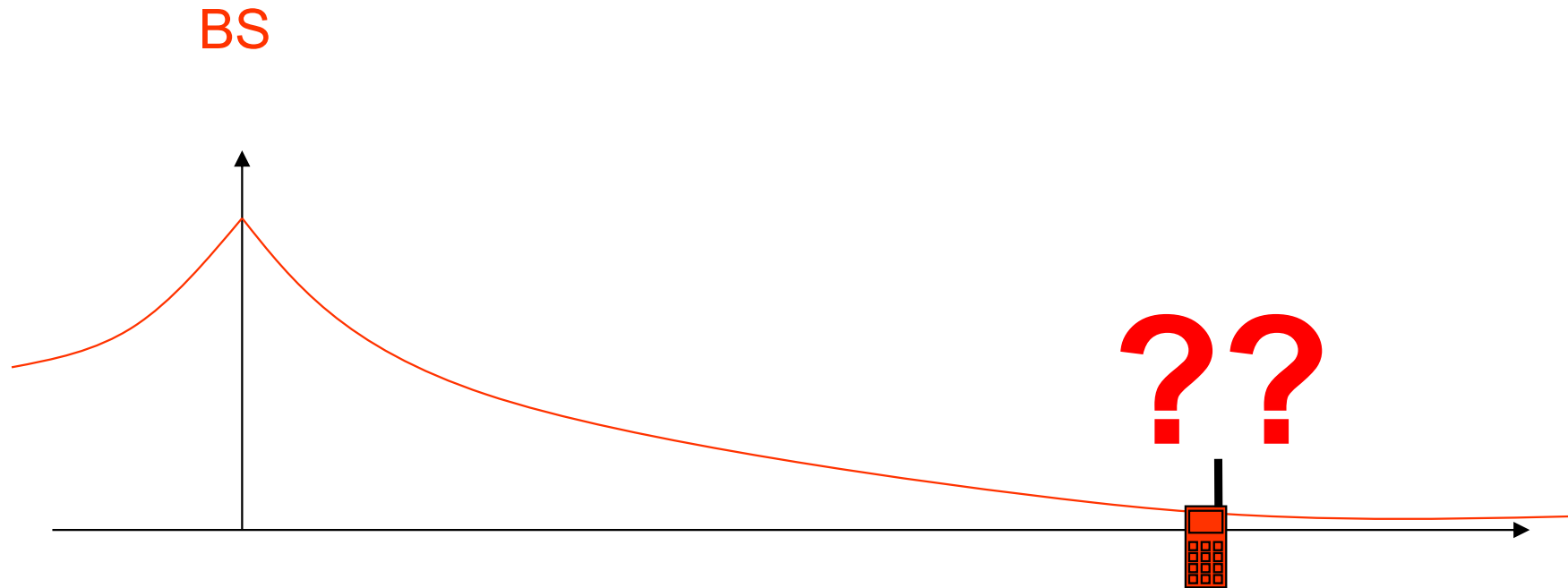
$$G = \frac{4\pi A_e}{\lambda^2} = \frac{4\pi f A_e}{c^2}$$

- ⦿ with

- $G$  = gain
- $A_e$  = effective surface
- $f$  = signal frequency
- $c$  = light speed in space  $3 \cdot 10^8$  m/s
- $\lambda$  = 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
  - $\alpha$  from 2 to 4

# Attenuation in practice

- ⦿ For an ideal antenna (theoretic)

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

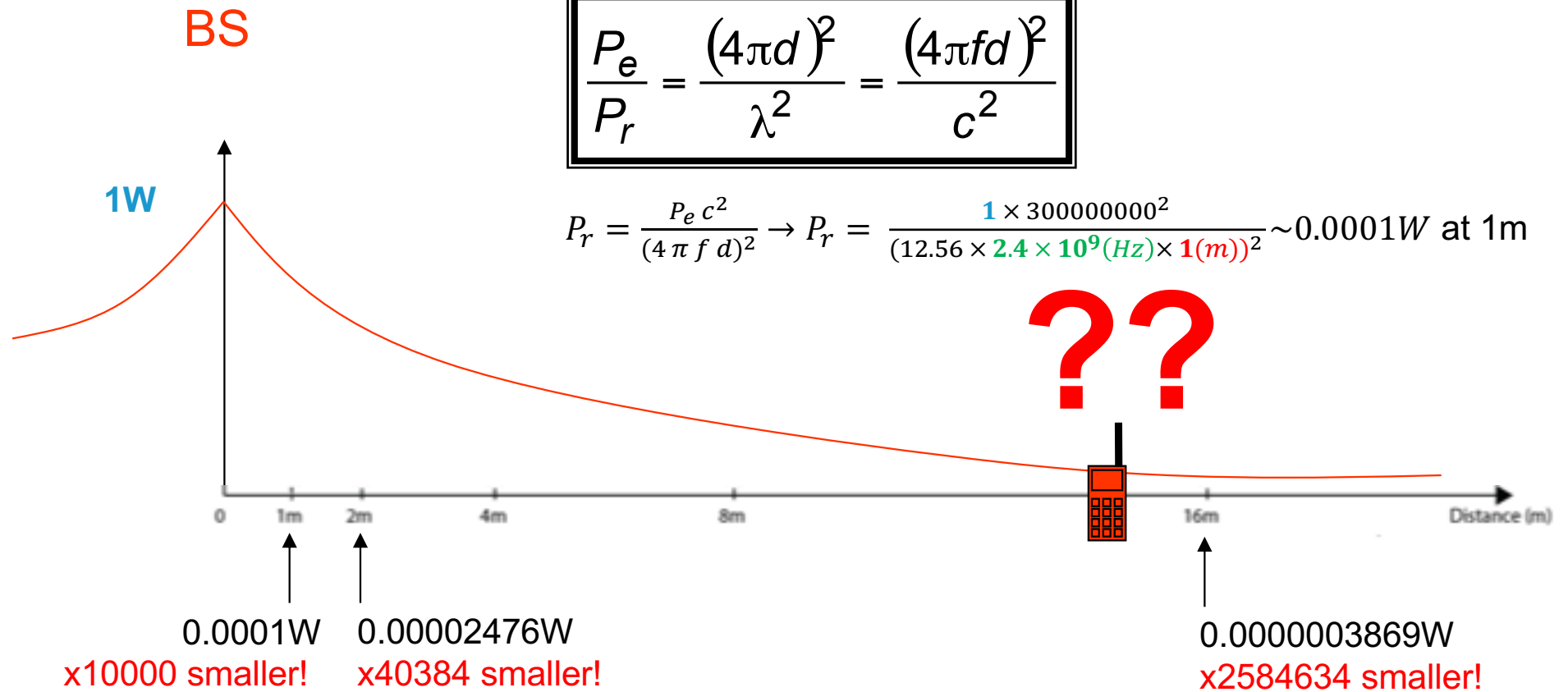
- $P_e$  = transmitted power
- $P_r$  = received power
- $P_e / P_r$  is high when  $P_r$  is small → high attenuation
- $d$  = distance between antennas
- $c$  = light speed in space  $3 \cdot 10^8$  m/s
- $\lambda$  = wave length of the signal =  $c/f$
- Higher frequencies  $f$  means higher attenuation!

# Attenuation, values in watts

Free Space Path Loss model

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

$$P_r = \frac{P_e c^2}{(4\pi f d)^2} \rightarrow P_r = \frac{1 \times 300000000^2}{(12.56 \times 2.4 \times 10^9 \text{ (Hz)} \times 1 \text{ (m)})^2} \sim 0.0001 \text{ W at 1m}$$



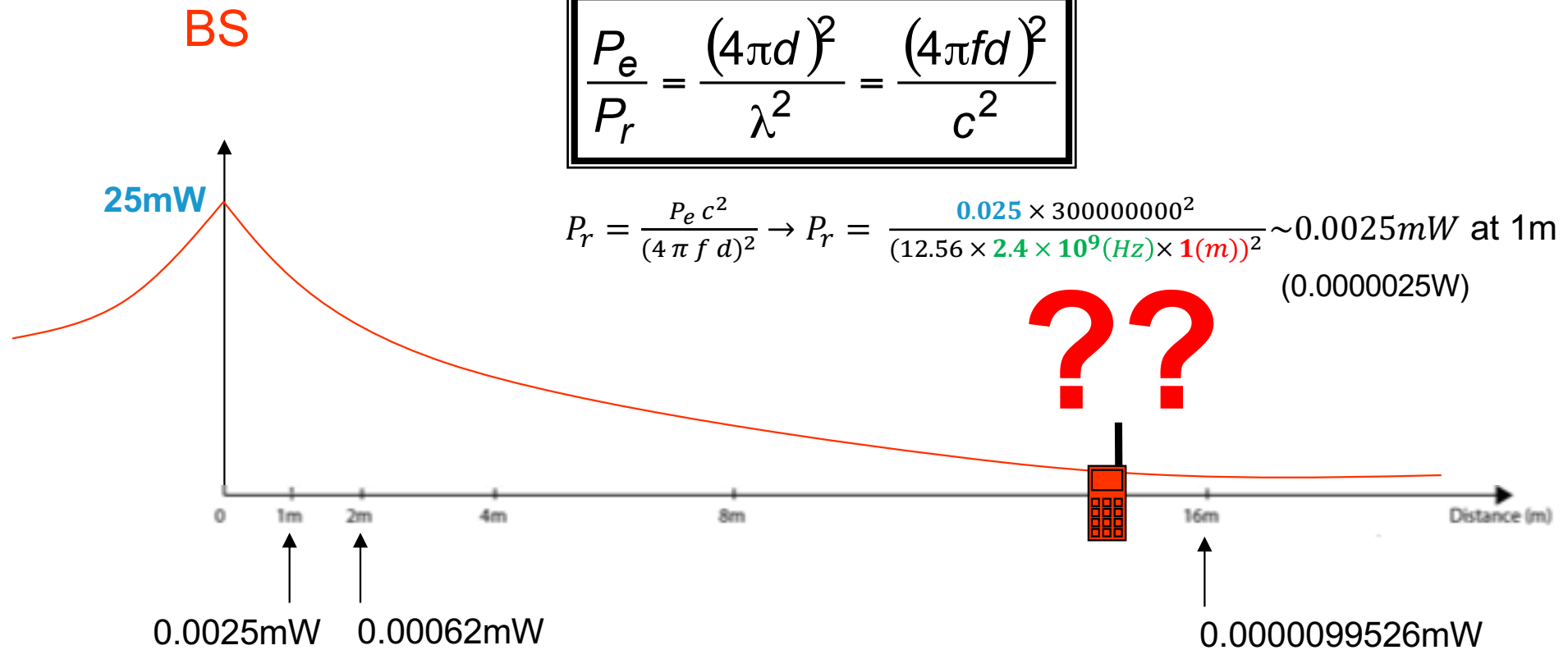
# Attenuation, values in watts

Free Space Path Loss model

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

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

(0.0000025W)

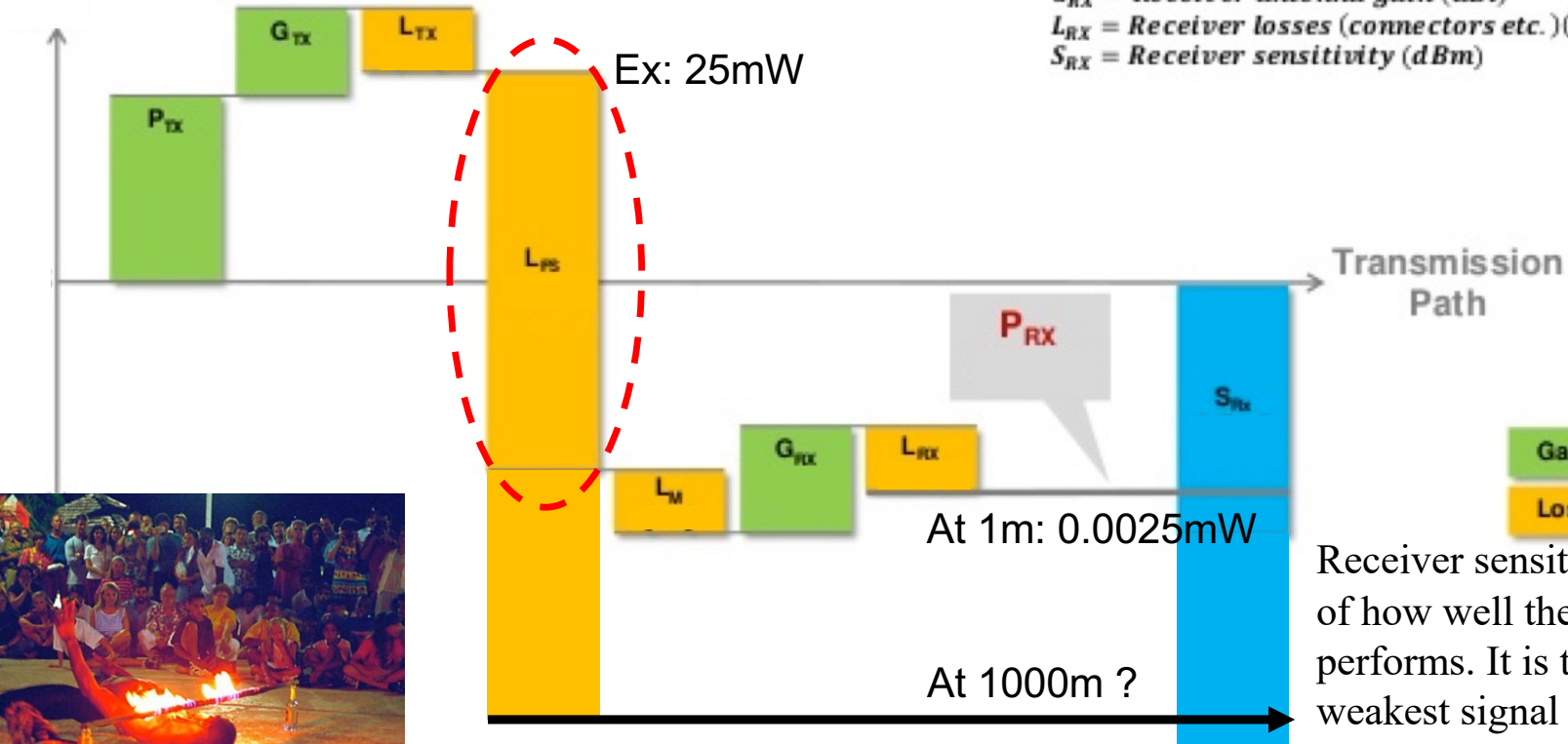


# Link budget in wireless system – (simplified)

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

- $P_{RX}$  = 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



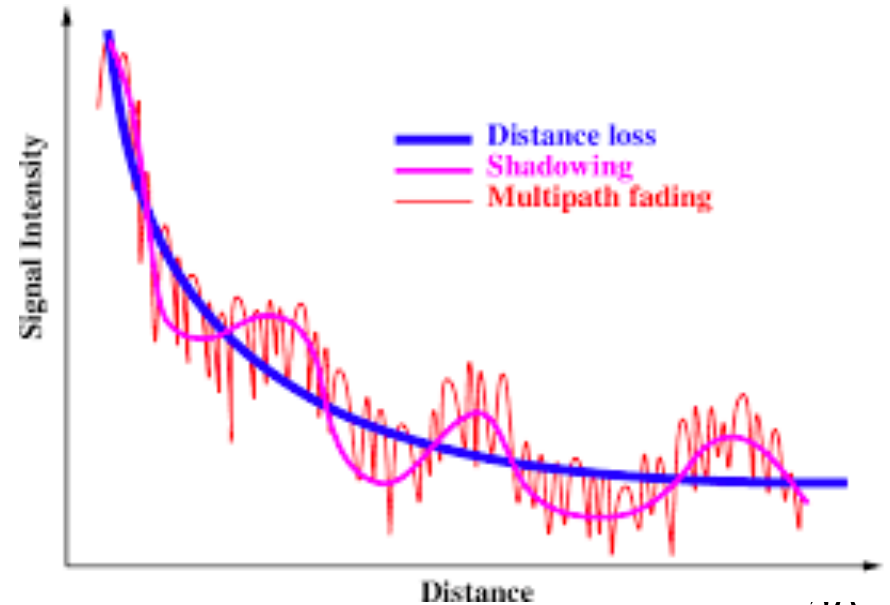
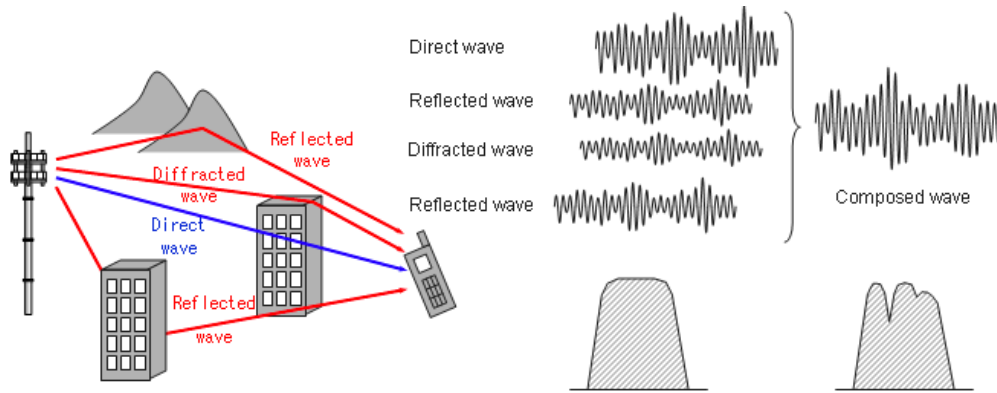
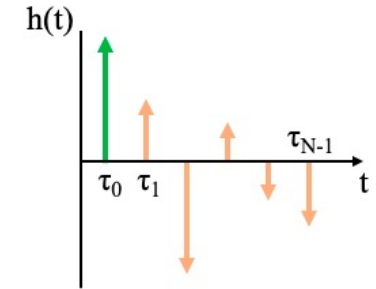
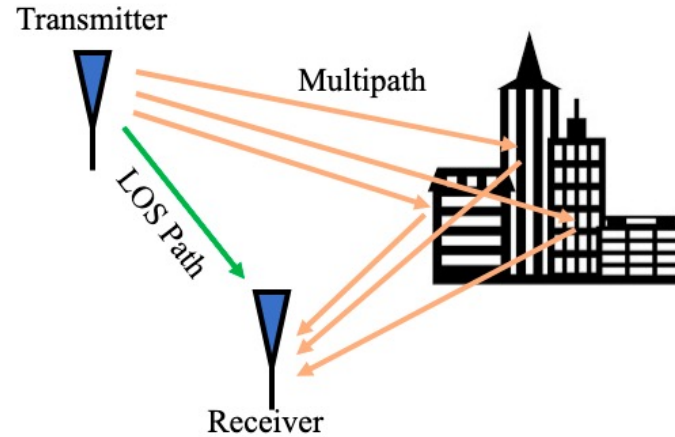
Receiver sensitivity is a measure of how well the receiver performs. It is the power of the weakest signal the receiver can detect

How low can you go?



# Shadow fading & Multi-path fading

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



# How can we increase range?

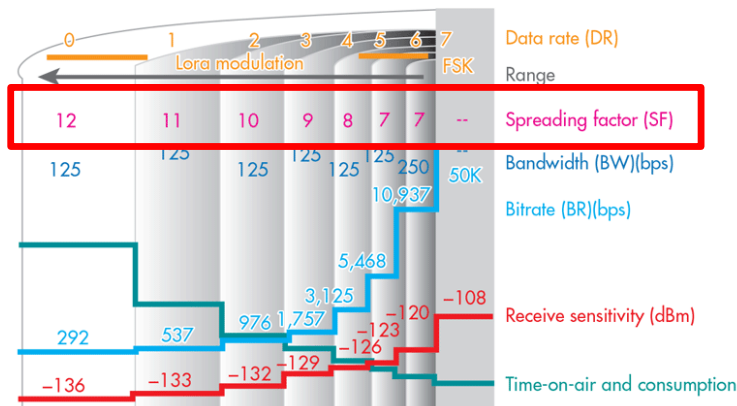


I'm not fluent in idiot  
could you please speak



more slowly?

- ⦿ 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)**

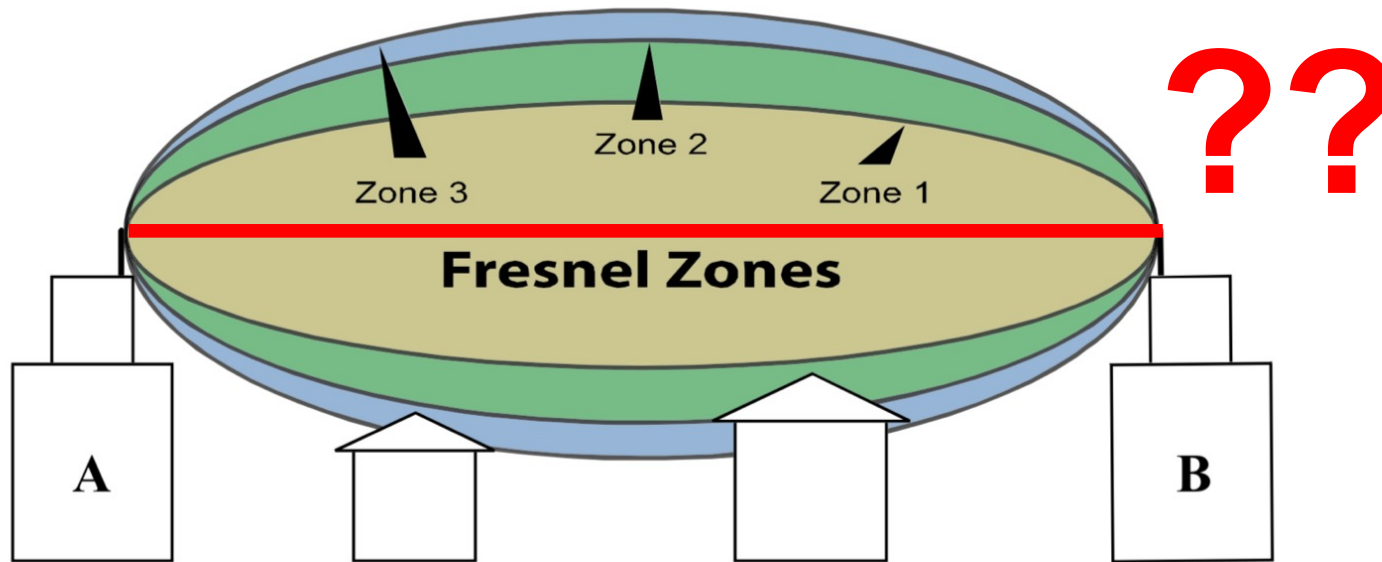


- WiFi 802.11n: 450 000 000 bps (450Mbps)
- WiFi 802.11g: 54 000 000 bps (54Mbps)
- Bluetooth3&4: 25 000 000 bps (25Mbps)
- Bluetooth BLE: 2 000 000 bps (2Mbps)
- 3G/4G : 20Mbps-200Mbps
- **LoRa** : **200bps-37500bps (0.0002-0.0375Mbps)**
- **3G/LoRa ratio: 20,000,000bps/200bps=100000!**



# Line-of-Sight & Fresnel zone

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

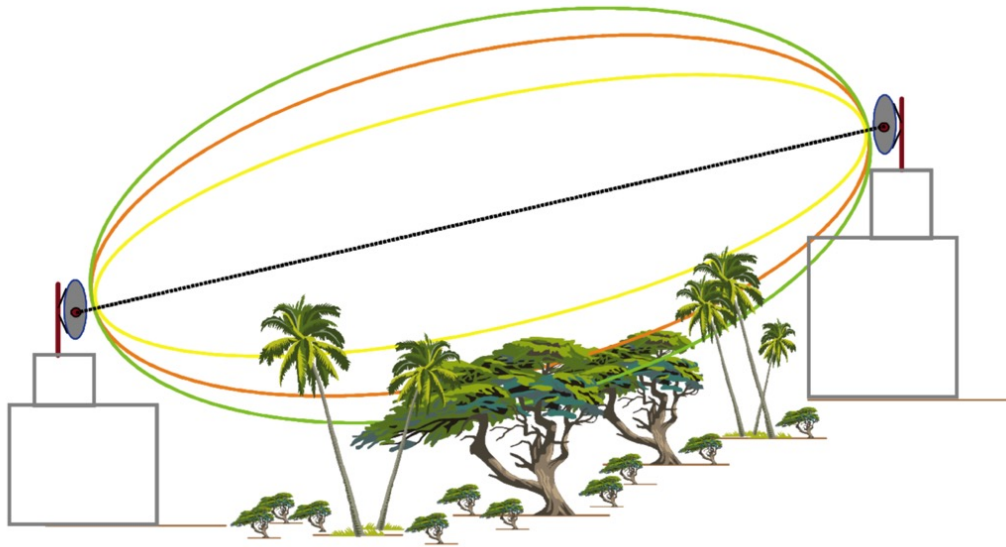


# In real environment!

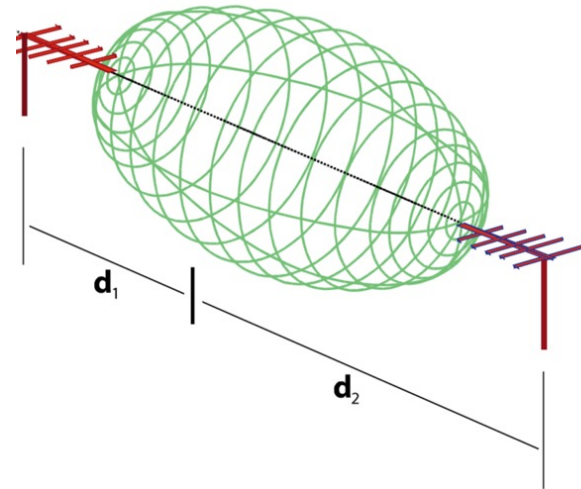


**Obstacles:  
Attenuation, Multi-path fading,...**

# Clearing the Fresnel zone? Raise antennas!



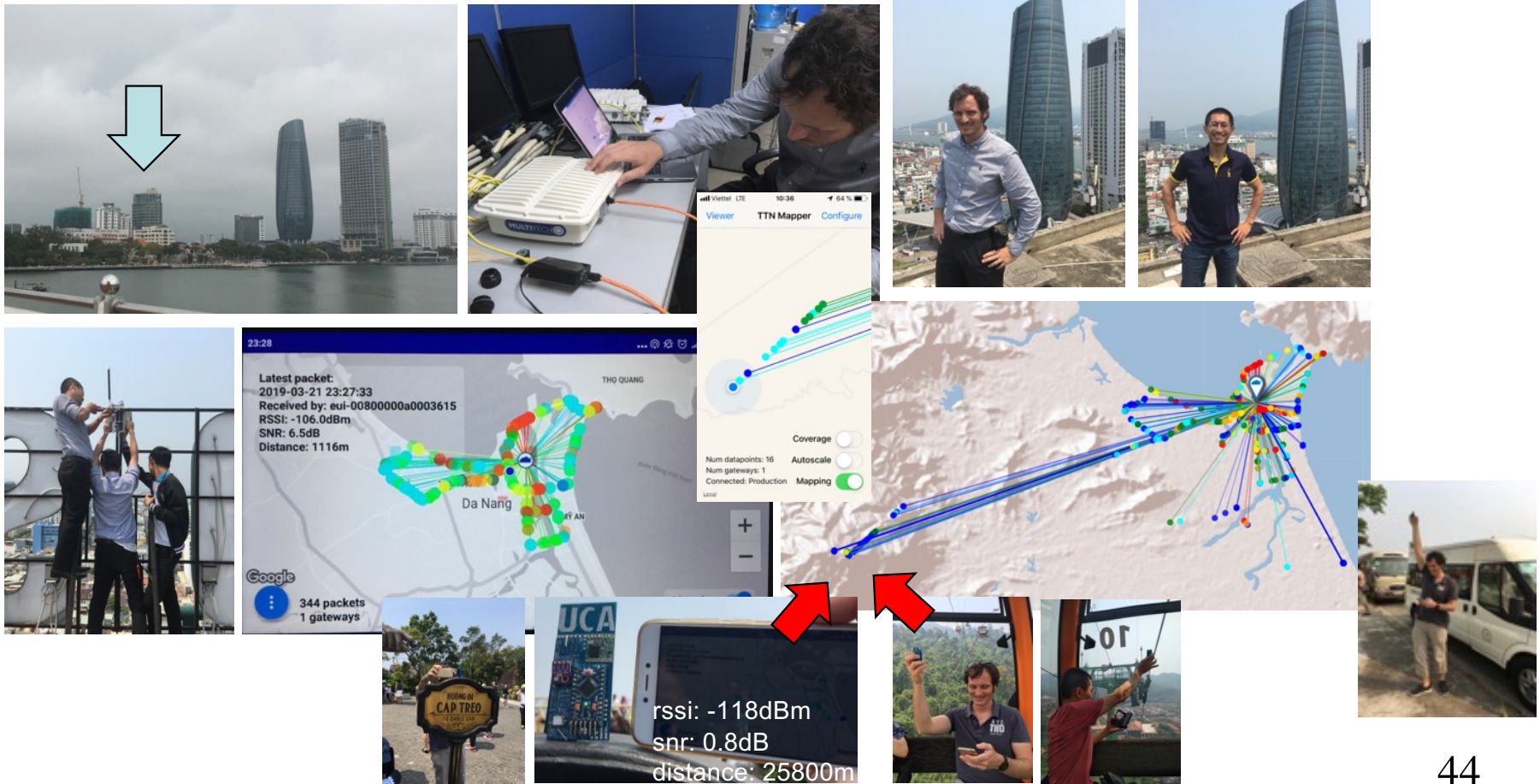
$$r_n = \sqrt{\frac{d_1 d_2}{d_1 + d_2}}$$



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)

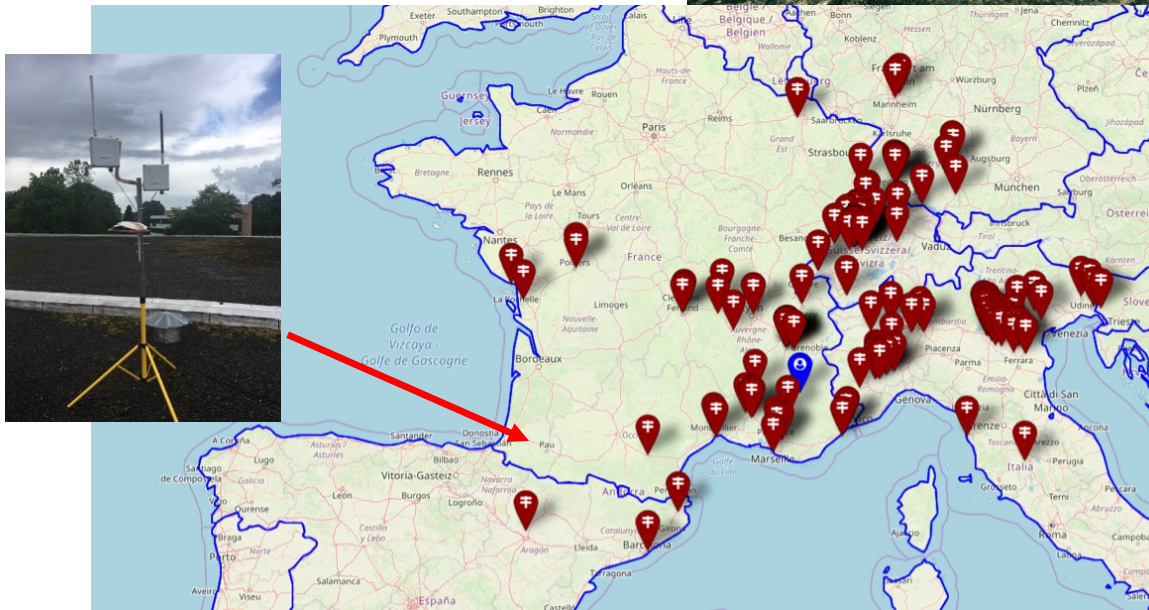
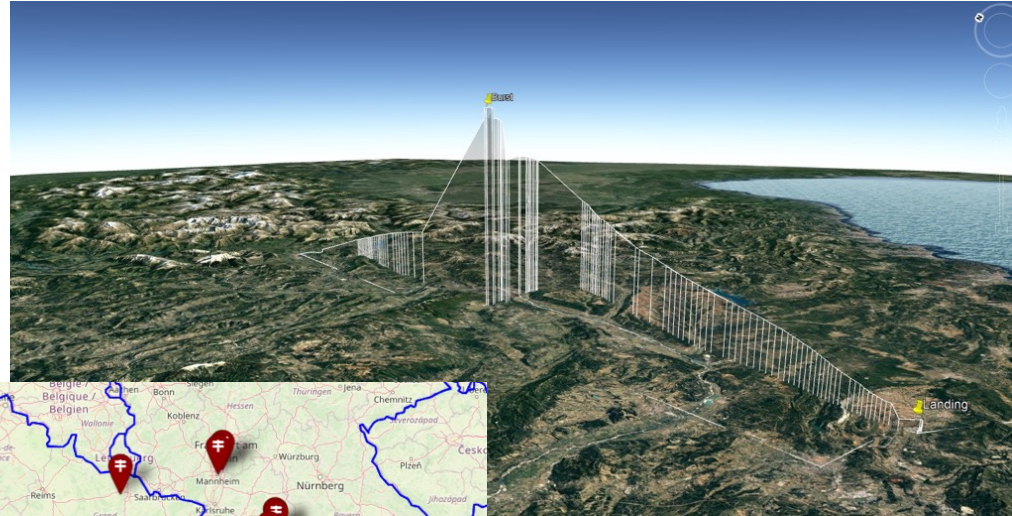
# Coverage test by Fabien Ferrero on March 21-22, 2019

- LoRaWAN gateway on top of Danang's DSP building by Fabien, U. Danang and DSP team. Almost 26kms! Congrats Fabien!



# Coverage test by Fabien Ferrero on June 11th, 2019

⦿ High Altitude Balloon




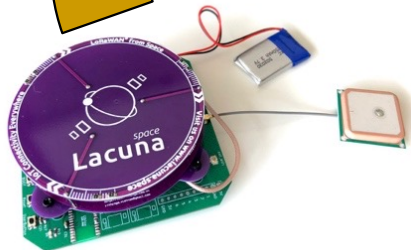
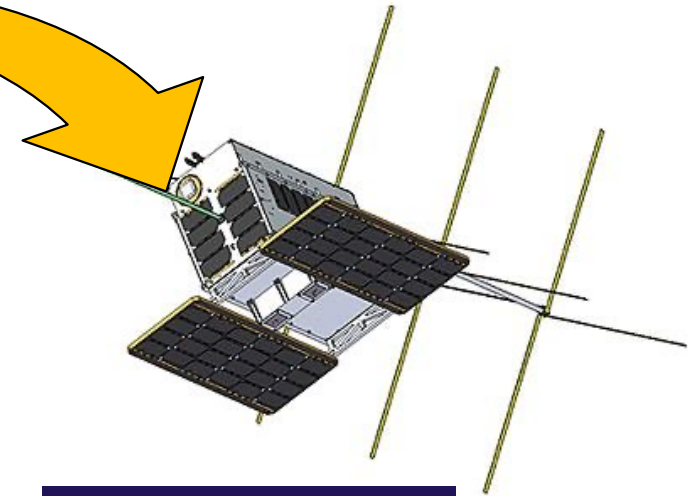
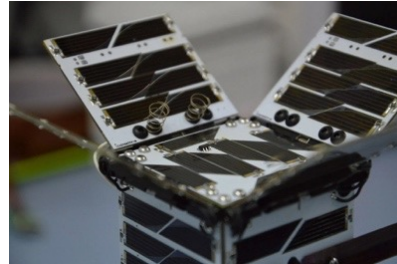
- ⦿ 31kms high
- ⦿ Reception at 642km (Udine, Italy)!
- ⦿ Current record at 702km with balloon at 38kms

[https://github.com/FabienFerrero/HAB\\_Relay\\_STM32Contest](https://github.com/FabienFerrero/HAB_Relay_STM32Contest)

# 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/>

# LPWAN=star topology, gateway centric

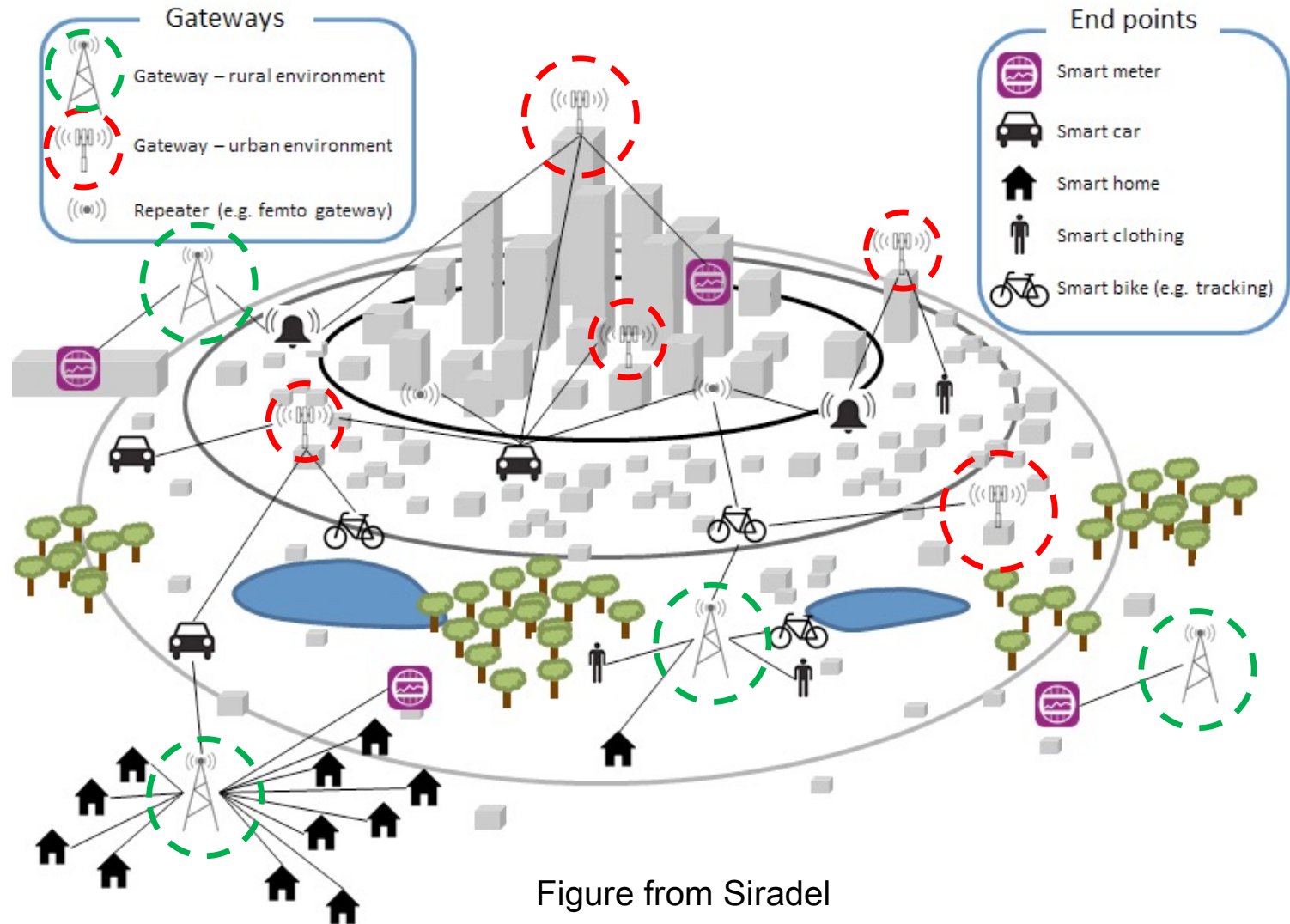
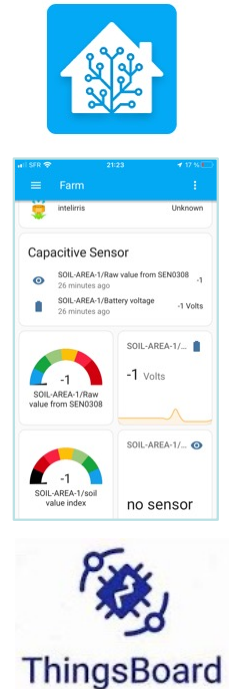
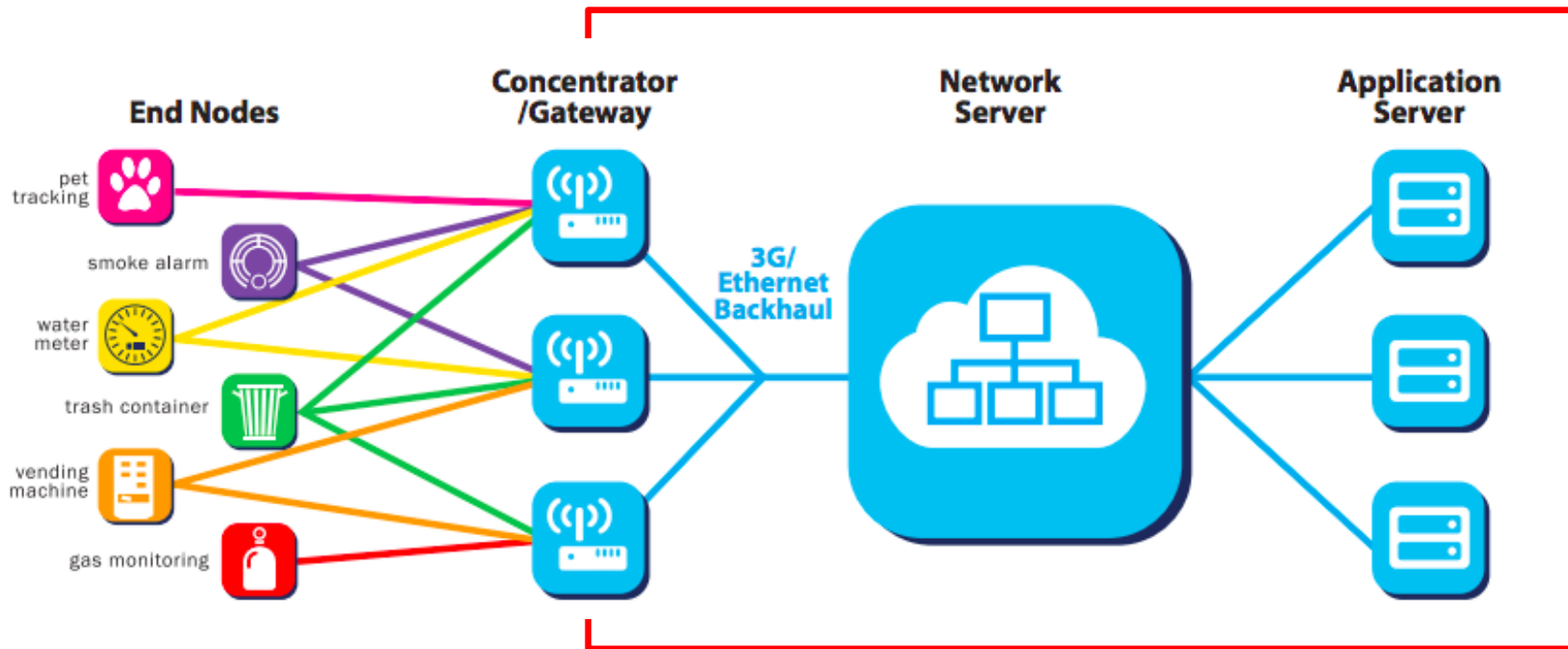


Figure from Siradel

# 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

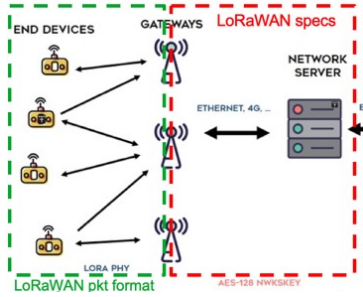




# Understanding LoRa vs LoRaWAN

- ⦿ 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

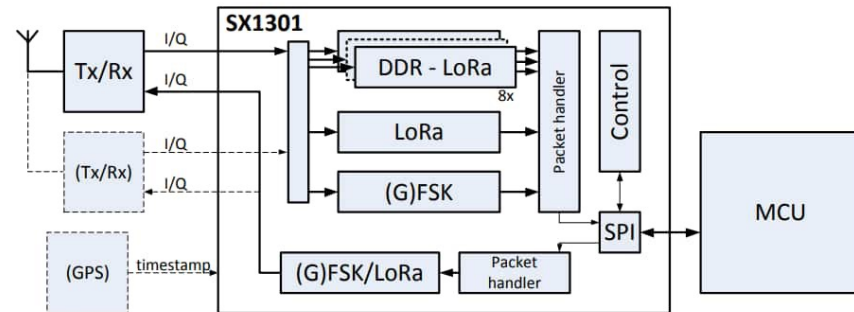
**EU863-870**

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



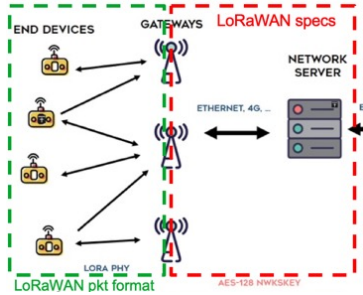
- They are mostly based on the Semtech SX1301 radio concentrator



# 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](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](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

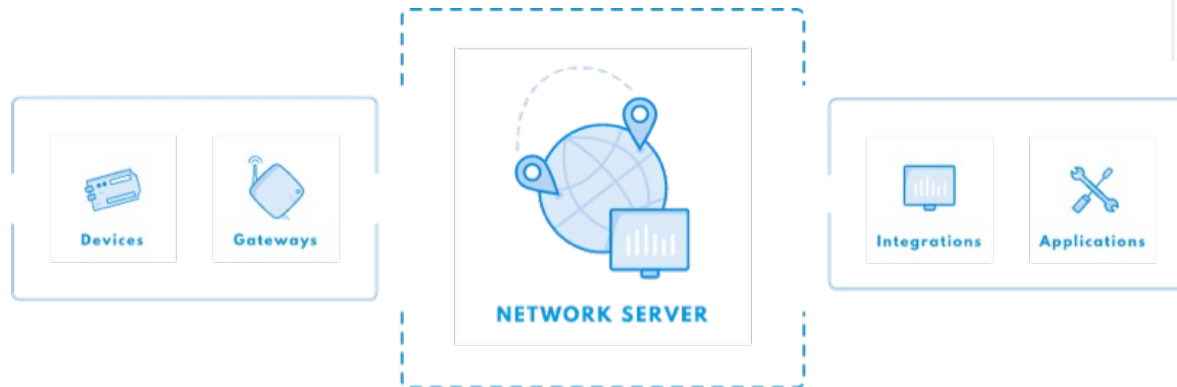
# LoRaWAN Network Server (LNS)



- 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

# TTN user console

**THE THINGS NETWORK CONSOLE** COMMUNITY EDITION

Applications > **pau\_lorawan\_testing** [documentation](#)

**Application ID** `pau_lorawan_testing`

**Description** Pau LoRaWAN testing

**Created** 9 months ago

**Handler** ttn-handler-eu (current handler)

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**APPLICATION EUIS** [manage euis](#)

< > ↕ `12AA34BB56CC78CC` 📄

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**DEVICES**

2 registered devices

**THE THINGS NETWORK CONSOLE** COMMUNITY EDITION

Applications > **pau\_lorawan\_testing** > Devices

Overview **Devices** Payload Formats Integrations Data Settings

**DEVICES** [register device](#)

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<code>pau_testing_device</code>	Pau testing device	XXXXXXXXXXXXXXXXXX	•
<code>pau_testing_otaa_device</code>		XXXXXXXXXXXXXXXXXX	•