The Internet of Things:
Low Power Wide Area Networks

Course website: http://site.unibo.it/iot

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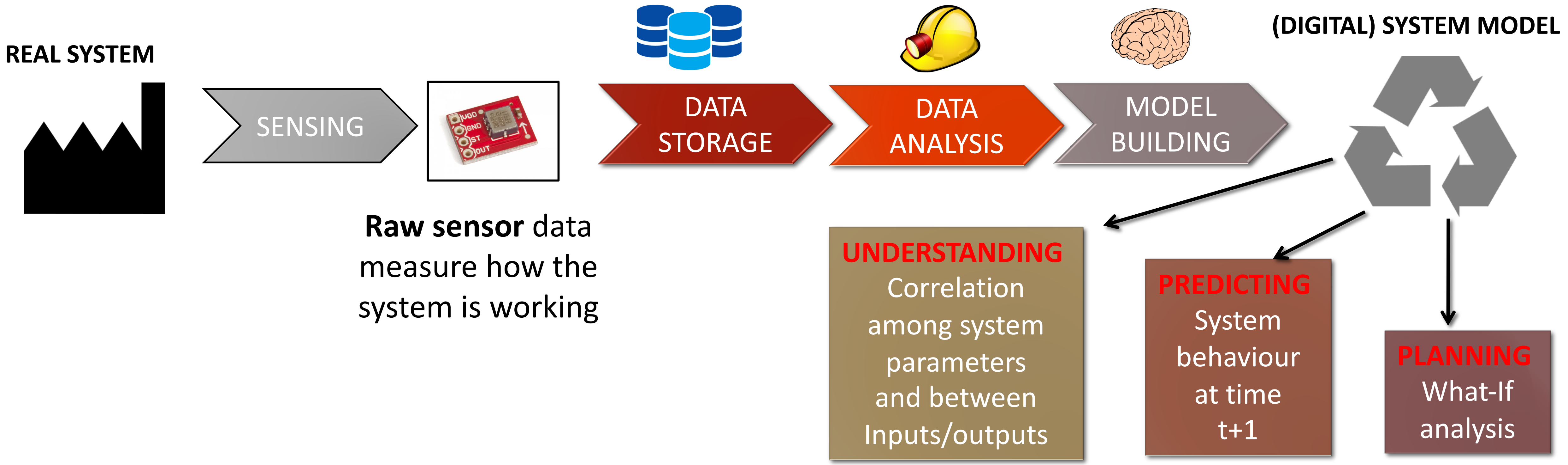
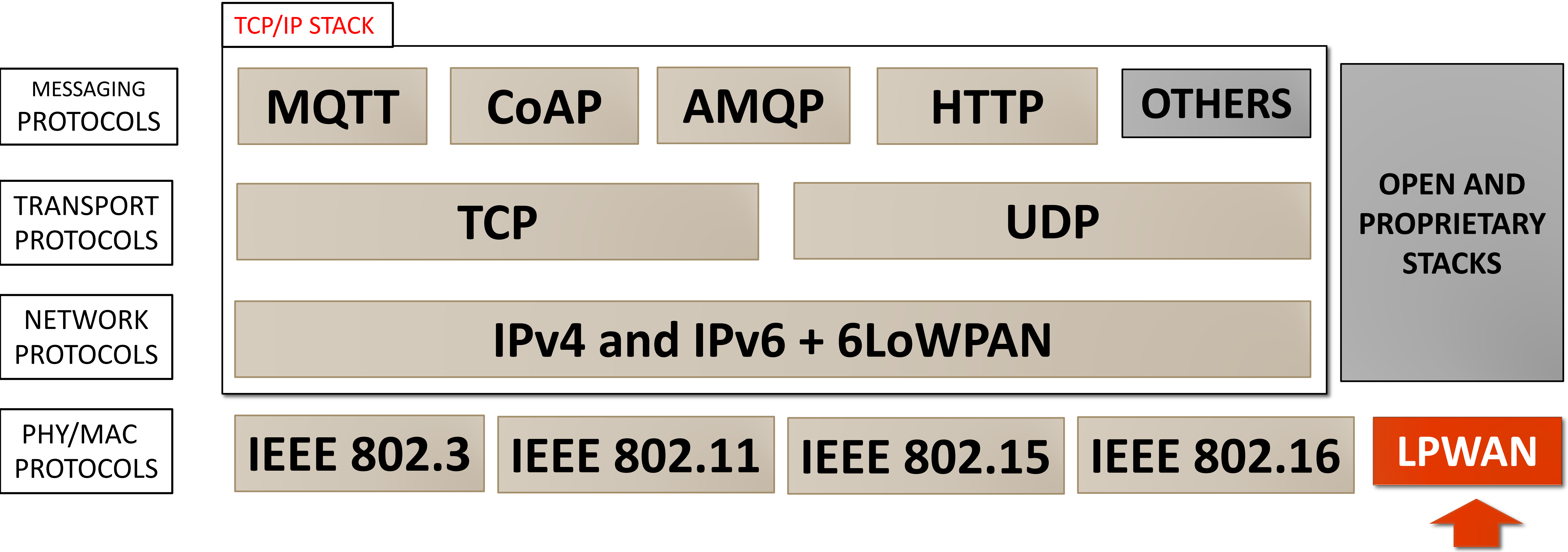
IoT & Big-data

✧Putting all the **IoT components** together …



IoT Protocol Stack



LPWAN Technologies

- Low Power Wide Area Networks (**LPWAN**).
  - Novel range of wireless communication technologies providing wide-area connectivity for low power and low data rate devices.
    - **Complementary** to WLAN technologies on several novel IoT use-cases (e.g. sensor network deployments over rural areas).
    - **Alternative** to WLAN technologies on some existing IoT use-cases, but introducing some unique advantages (e.g. reduction of costs for infrastructure deployment).

LPWAN Technologies

- Design Goal: **Long Range**.
  - Wide Area coverage (in the order of Kms) and enhanced signal propagation in hard-to-reach indoor locations (e.g. basements). Target: +20db gain over cellular systems.
    - Use of **Sub-1GHz Band** → reliable communication at low power budget , reduced attenuation caused by obstacles.
    - Use of robust **Modulation Techniques** → sensitivity of LPWA receivers can reach as low as -130dbm.
    - **Narrowband** vs **Spread Spectrum** techniques.

LPWAN Technologies

- Design Goal: **Low Power Operations**.
  - **Topology** → Mainly star topology, direct connection between LPWAN end-devices and the base station, no multi-hop.
  - **Duty cycling** → Turn off radio transceiver of LPWAN devices when not needed and/or according to regional regulations.
  - **Lightweight Medium Access Control** (MAC) → Employ basic random access MAC protocols (e.g. ALOHA).
  - **Offloading Complexity From End Devices** → Keep end-devices as cheap as possibile, offload tasks to the backend system.

LPWAN Technologies

- Design Goal: **Low Cost.**
  - **Reduction in Hardware Complexity** → LPWA transceivers need to process less complex waveforms.
  - **Minimum Infrastructure** → Use of a single base-station in order to provide coverage over a wide area.
  - **Using License-Free or Owned Licensed Bands** → Most of LPWA transceivers operate in the Industrial, Scientific and Medical (ISM) bands. Some of them may share the cellular bands already owned by the LPWAN provider.

LPWAN Technologies

- Design Goal: **Scalability**.
  - **Diversity techniques →** Multi-channel and multi-antenna communications in order to parallelize transmissions of LPWAN devices.
  - **Adaptive Channel Selection and Data Rate →** Adapt link communication parameters (e.g. modulation, power, bandwidth) in order to achieve better per-link performance.
  - **Densification →** Coordinated resource allocation among base-stations to cope with high-density of end-user scenarios.

WISHLIST

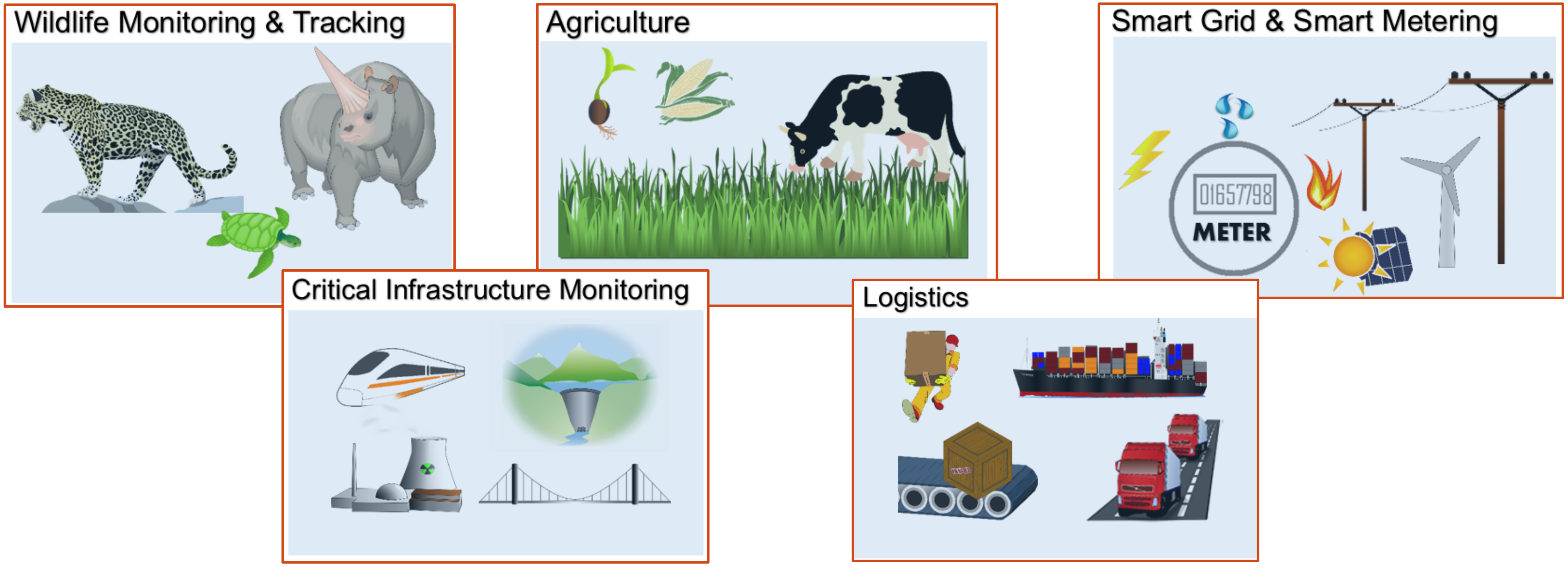
LPWAN Technologies

- **Drawbacks** of LPWAN technologies.
  - ✧ In several cases, high range and low power operations come at the expense of:
  - ✧ **Reduced data-rate →** up to 50 kbps (LoRa)
  - ✧ **Limited payload length →** up to 250 Byte **(LoRa)**.
  - ✧ **High delay →** Depends on modulation scheme in use, in the order of seconds (LoRa) under specific configurations.

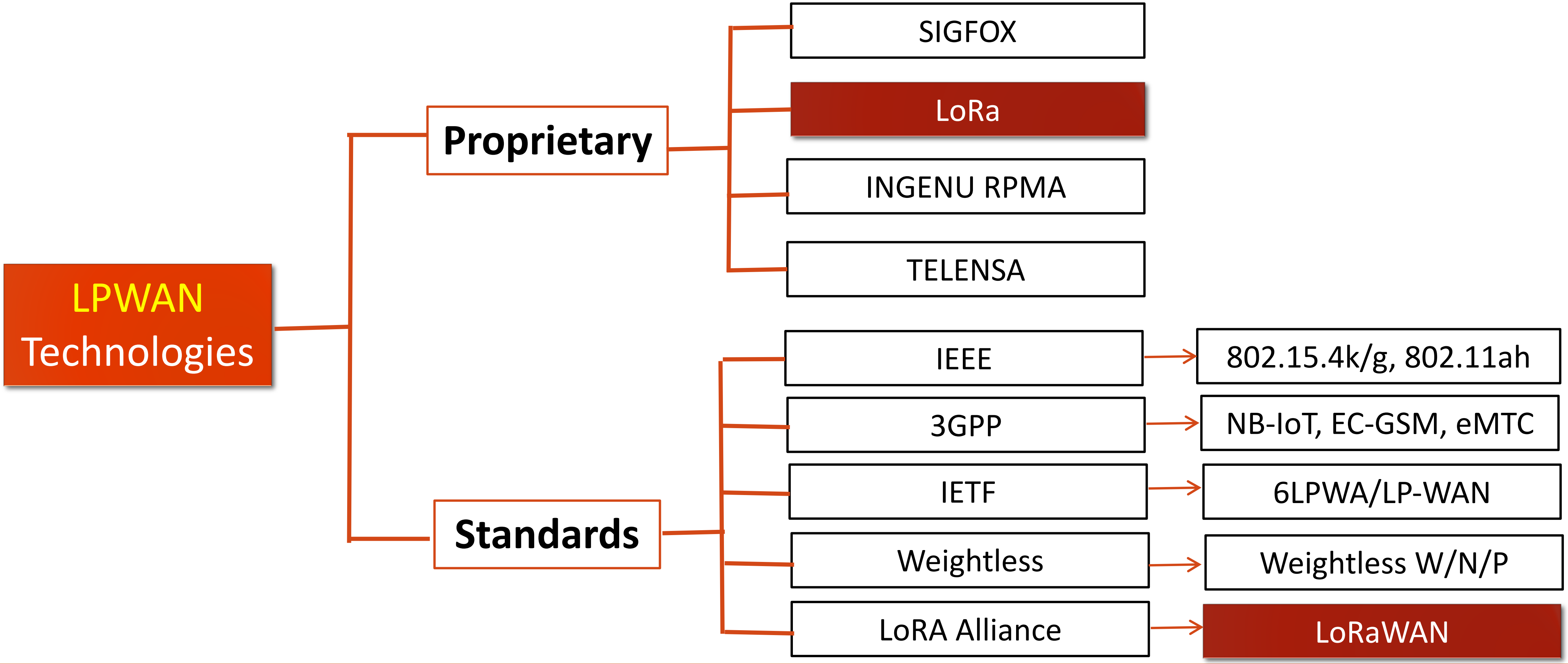
U. Raza, P. Kulkarni and M. Sooriyabandara, Low Power Wide Area Networks: An Overview, IEEE Communication Surveys and Tutorials, 19(2), pp. 855-874, 2017.

LPWAN Technologies

- Main use-cases of LPWAN technologies.



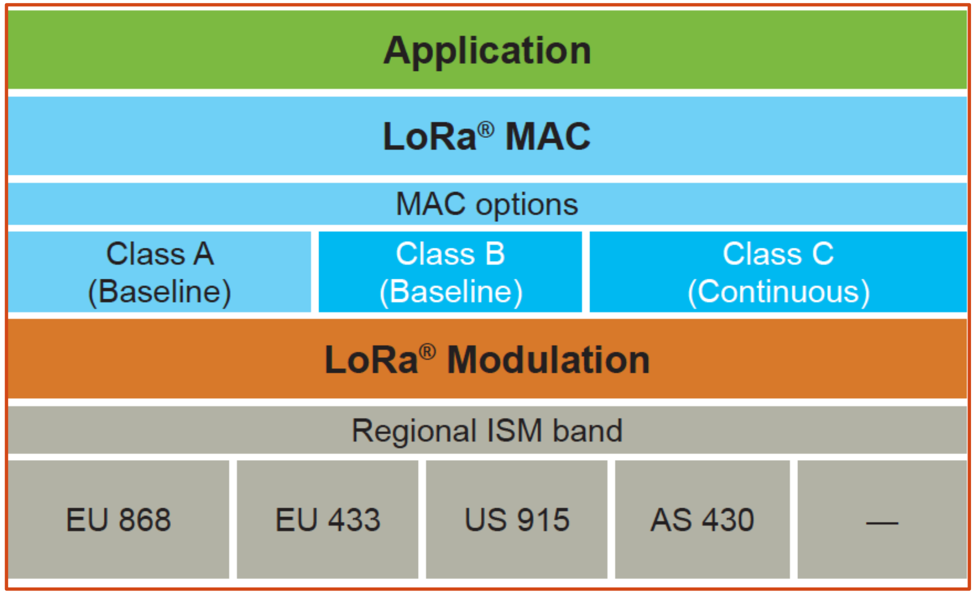
LPWAN Technologies



LoRA Alliance: https://www.lora-alliance.org/lorawan-white-papers

LoRa and LoRaWAN Technologies

- **Sub-GhZ** LPWAN **stack.**
  - LoRa defines the **Physical layer**
    - Proprietary, developed by Semtech
  - LoRaWAN defines the **MAC Layer** and the overall **network/system architecture.**
    - Open, defined by the LoRa Alliance
    - Specification available at: https://www.lora-alliance.org



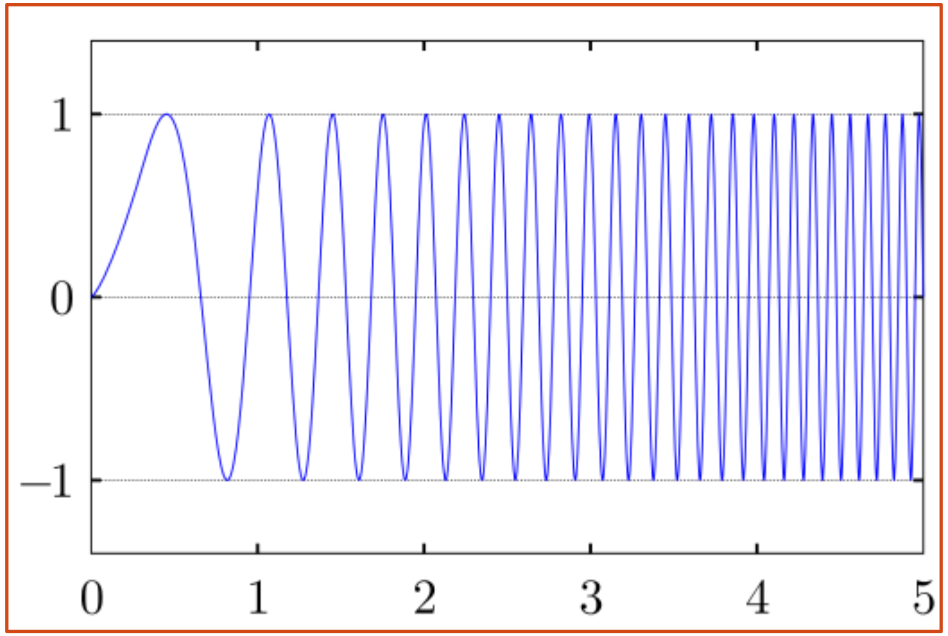
LoRa and LoRaWAN Technologies

- LoRa transceivers are mapped to different **Sub-GhZ frequencies**, based on **national regulations.**

	Europe	North America	China	Korea	Japan	India
Frequency band	867-869MHz	902-928MHz	470-510MHz	920-925MHz	920-925MHz	865-867MHz
Channels	10	64 + 8 +8	In definition by Technical Committee	In definition by Technical Committee	In definition by Technical Committee	In definition by Technical Committee
Channel BW Up	125/250kHz	125/500kHz				
Channel BW Dn	125kHz	500kHz				
TX Power Up	+14dBm	+20dBm typ (+30dBm allowed)				
TX Power Dn	+14dBm	+27dBm				
SF Up	7-12	7-10				
Data rate	250bps- 50kbps	980bps-21.9kpbs				
Link Budget Up	155dB	154dB				
Link Budget Dn	155dB	157dB				

LoRa and LoRaWAN Technologies

- LoRa PHY is based on Chirp Spread Spectrum (CSS) modulation.



- CSS used also for radar applications.
- In a Chirp signal, **frequency either increase or decrease with time**.
- Chirp Spread Spectrum uses the complete bandwidth to transmit a signal.
- Chirp spread spectrum is resistive to **Doppler shift**.

LoRa and LoRaWAN Technologies

- ❑ LoRa PHY is based on Chirp Spread Spectrum (CSS) modulation.

TRANSMITTING **PARAMETERS**

- ✧ **Bandwidth** → Portion of Spectrum occupied by chirp
- ✧ **Chirp rate** → Number of Chirps per second
- ✧ **Spreading Factor** → Number of bits encoded per chirp
- ✧ **Coding Rate** → Amount of redundancy applied to data

LoRa Bit Rate Formula [2]

$$R_b = SF * \frac{\left[\frac{4}{4+CR}\right]}{\left[\frac{2^{SF}}{BW}\right]} * 1000$$

SF = Spreading Factor (6,7,8,9,10,11,12)

CR = Code Rate (1,2,3,4)

BW = Bandwidth in KHz (10.4,15.6,20.8,31.25,41.7,62.5,125,250,500)

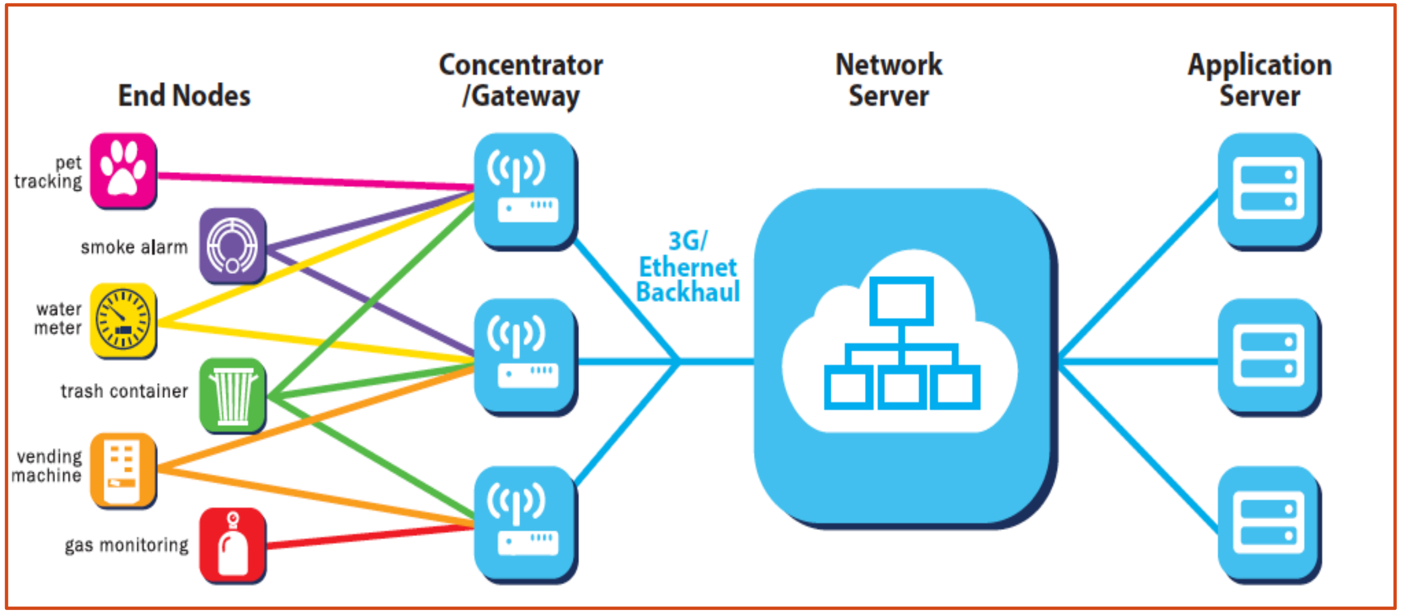
Rb = Data rate or Bit Rate in bps

LoRa and LoRaWAN Technologies

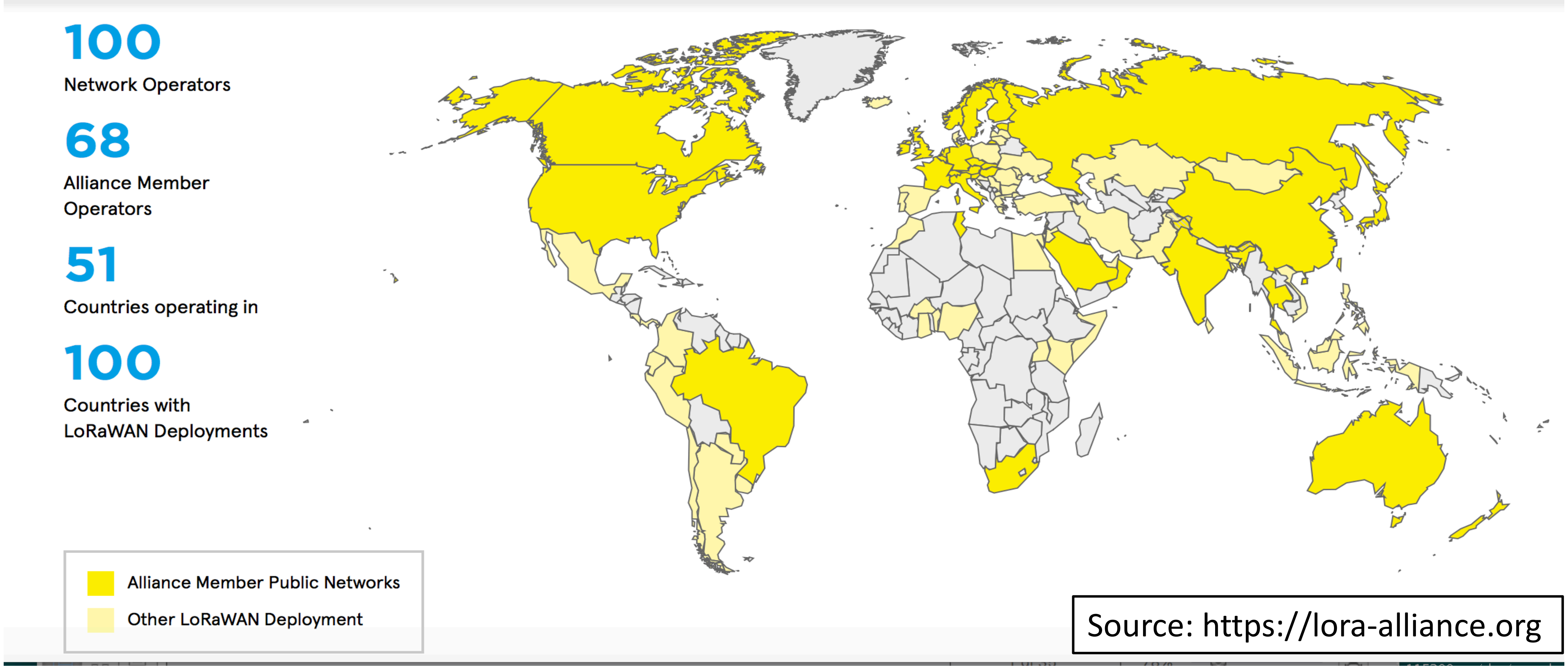
- LoRaWAN architecture is made of four network components:

- ✧ **End-Devices**
- ✧ **Gateways**
- ✧ **Network Server** (back-end)
- ✧ **Application Server** (back-end)

STAR of STARS TOPOLOGY



LoRa and LoRaWAN Technologies



Source: https://lora-alliance.org

LoRa and LoRaWAN Technologies

- LoRaWAN architecture is made of four components:

LoRA end-devices

- A simple **ALOHA** (random access) scheme is used at the MAC Layer.
- Multiple devices can communicate at the same time on the medium, by using different frequencies or spreading factors (LoRA PHY).
- End-devices are not associated with any specific gateway; data transmitted can be received by multiple gateways.
- Messages sent can be non-confirmable or confirmable (i.e. ACK requested).
- Retransmissions may occur but at the discretion of the end devices.

LoRa and LoRaWAN Technologies

- ALOHA-Like MAC Protocol
  - No **Channel Feedback** (Listen-Before-Talk not implemented)
  - Time is **slotted**, i.e. divided into intervals of fixed length.
  - Transmit data on the channel whenever the radio is ready after a random number of slots.
  - The first packet on the head of the queue is transmitted.
  - In case of confirmable messages (i.e. ACK required), the sender might retransmit the message after a random interval.

LoRa and LoRaWAN Technologies

- LoRaWAN architecture is made of four components:

GATEWAYs

- Gateways receive **data from multiple clients** on the LoRa link, and forward them to a **network server** via a backhaul (wired) connection.
- In order to make a long range star network viable, the gateway must have a very high capacity or capability to receive messages from a very high volume of nodes.
- Gateways can support multi-channel technology, i.e. listen on multiple channels simultaneously, and/or decode packets sent with different LoRa spreading factors simultaneously.

LoRa and LoRaWAN Technologies

- LoRaWAN architecture is made of four components:

NETWORK SERVER

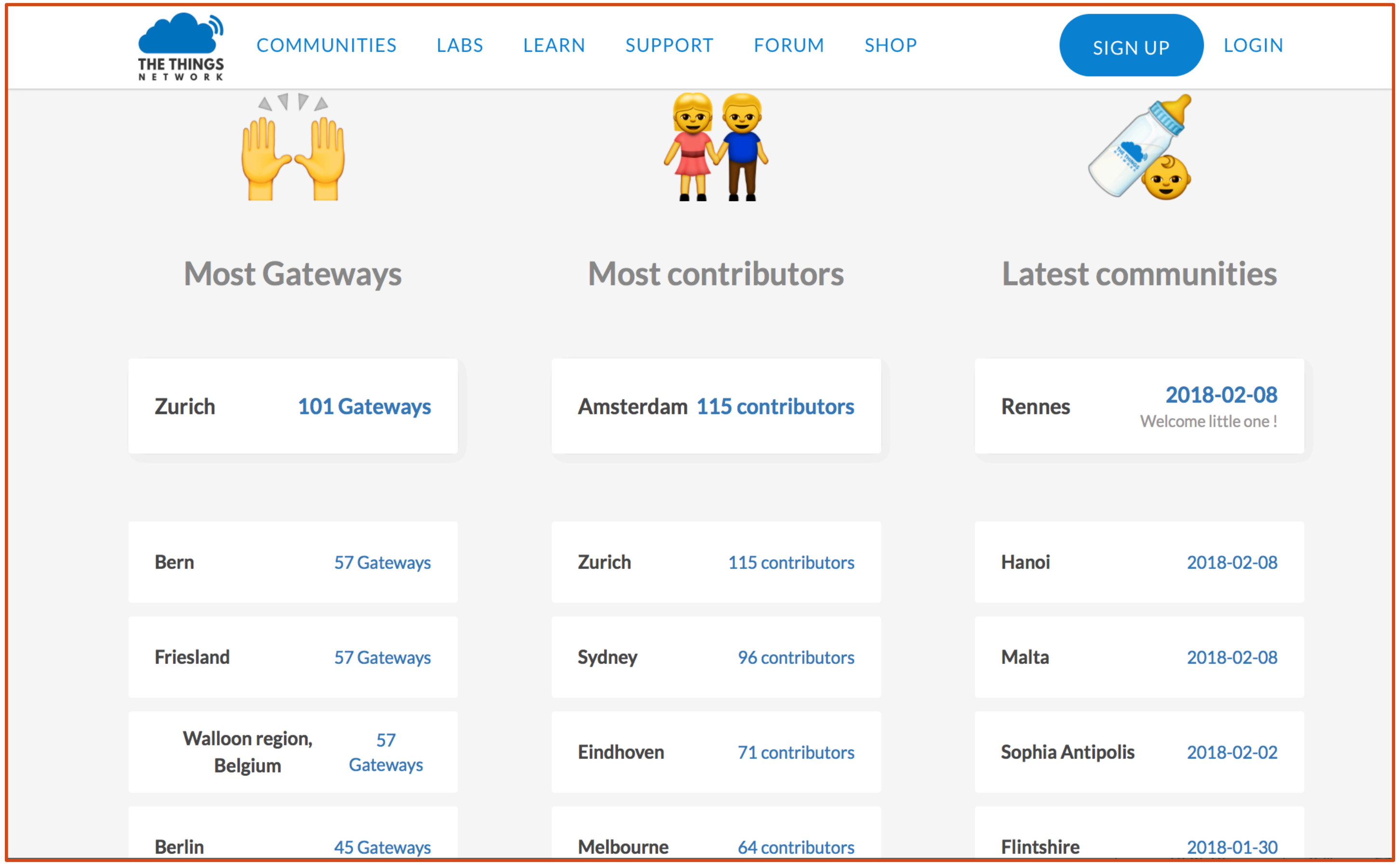
- Back-end component delegated to complex tasks.
- Performs duplicate detection and filtering.
- Implements the **Adaptive Data Rate control** of the LoRa devices.
- Decrypts messages and routes them to the application server.

APPLICATION SERVER

- IoT Application, Performs application-specific data processing.
- No standard interface between the network server and the app server.

LoRA Alliance: https://www.lora-alliance.org/lorawan-white-papers

LoRa and LoRaWAN Technologies



Example of LoRaWAN Network Server Provider

The Things Network

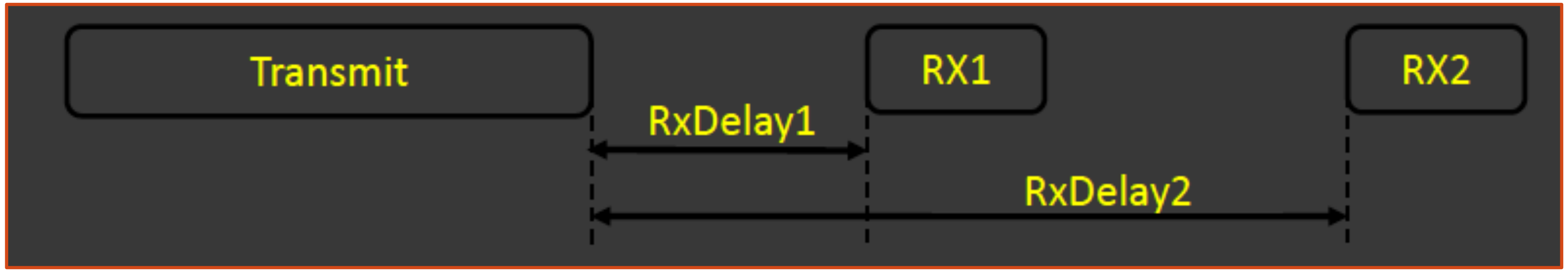
https://www.thethingsnetwork.org/community

LoRa and LoRaWAN Technologies

- LoRaWAN utilizes three classes of devices:

CLASS A Devices

- ✧ Bi-directional, **Battery powered** End Devices
- ✧ End Devices initiates communication (**uplink**)
- ✧ Each uplink transmission is followed by two (**short**) downlink periods
- ✧ Downlink communications from the server will have to wait until the next scheduled uplink.

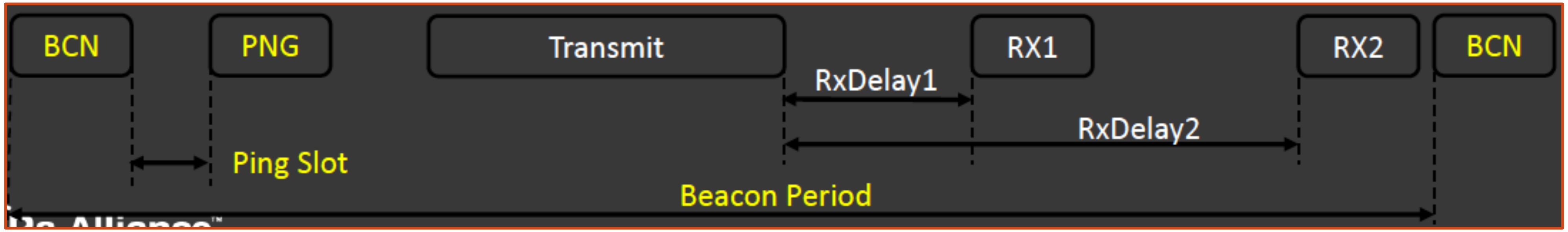


LoRa and LoRaWAN Technologies

- LoRaWAN utilizes three classes of devices:

CLASS B Devices

- Bi-directional, **Battery powered** End Devices
- Similar to class A, but they can also open extra receive windows at scheduled time.
- End devices receives a time synchronized beacon from the gateway.
- This allows the server to know when the end-device is listening.

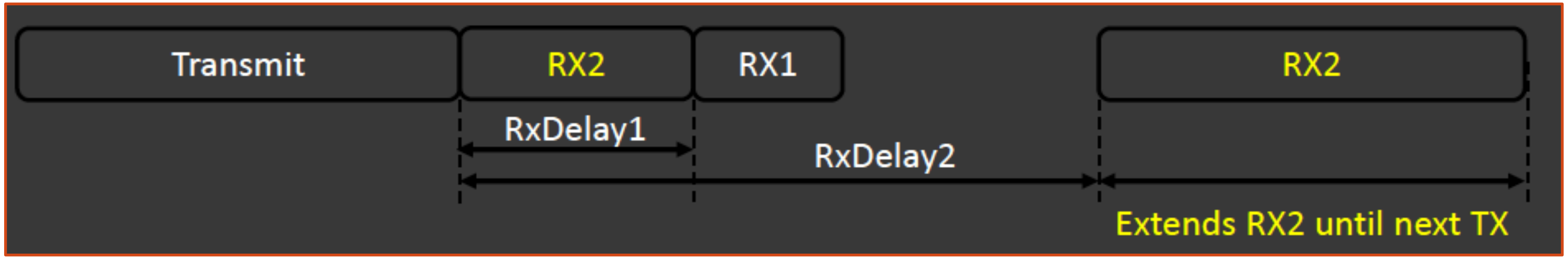


LoRa and LoRaWAN Technologies

- ❑ LoRaWAN utilizes three classes of devices:

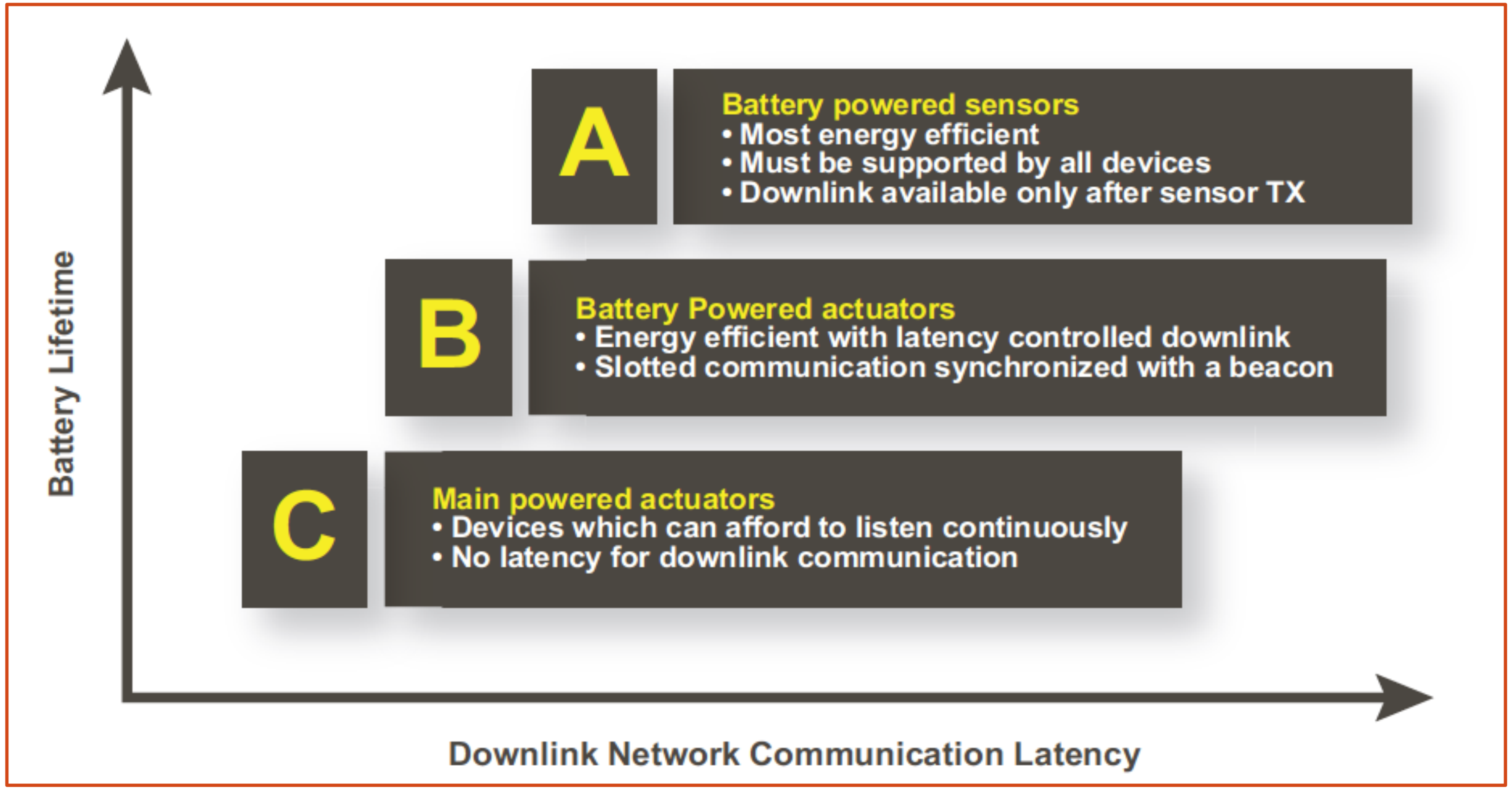
CLASS C Devices

- ✧ Bi-directional, **non-Energy Constrained** End Devices
- ✧ Receiving window of end-devices is always open (except while transmitting).
- ✧ Server can send data anytime.
- ✧ End-devices can send both unicast and multicast messages.



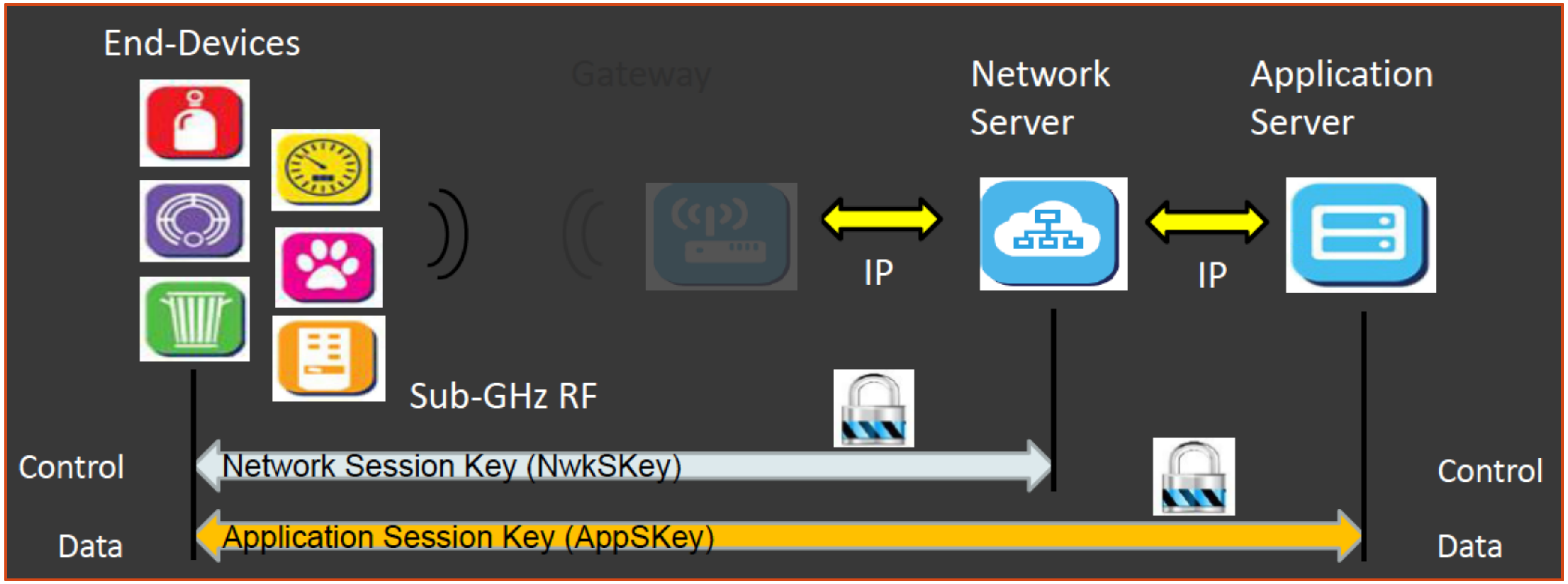
LoRa and LoRaWAN Technologies

- ❑ LoRaWAN utilizes three classes of devices:



LoRa and LoRaWAN Technologies

- LoRaWAN utilizes **two layers of security**: one for the network and one for the application.



LoRa and LoRaWAN Technologies

- Before an end-device can communicate on the LoRAWAN, it must be **activated**, i.e. it must get:
  - Device Address (DevAddr)
    - ✓ **Unique (within the network) 32 bit identifier**
    - ✓ Shared with Network and Application Server
  - Network Security Key (NwkSKey)
    - **128 bit AES encryption key**
    - Shared between the end device and the network server
    - Guarantees **message integrity on the network infastructure**

LoRa and LoRaWAN Technologies

- Before an end-device can communicate on the LoRAWAN, it must be **activated**, i.e. it must get:
  - Application Security Key (AppSKey)
    - **128 bit AES encryption key**
    - Shared between the end device and the application server
    - Used to **encrypt/decrypt** the payload
    - Guarantees **confidentiality of the message payload**

LoRa and LoRaWAN Technologies

- How can the end-device get the **activation data**?
  - **Over the Air Activation** (OTAA)

1. End-device transmits a **JOIN Request** to the Application Server with:
   - Globally unique end-device identifier (DevEUI)
   - Application Identifier (APPEUI)
   - Application Key (AppKey)

2. End-device receives **JOIN REPLY** from the Application Server with:
   - Device Address (DevAddr)
   - Network Security Key (NwkSKey)
   - Application Security Key (AppSKey)

LoRa and LoRaWAN Technologies

- LoRa and LoRaWAN **Real-World** Deployments

SMART MINING SOLUTIONS at TRANSCO

SMART INDUSTRIAL MANAGEMENT at EASYREACH

LoRa and LoRaWAN Technologies

❑ LoRa and LoRaWAN **Real-World** Deployments

SMART IRRIGATION SOLUTIONS in the SWAMP project

SMART LIGHTING in the ORION M2M DEVICES

LoRa and LoRaWAN Technologies

- LoRa and LoRaWAN **Real-World** Deployments

Compilation of LoRa-based applications for smart-cities at:
http://www.semtech.com/lora/lora-applications/smart-cities

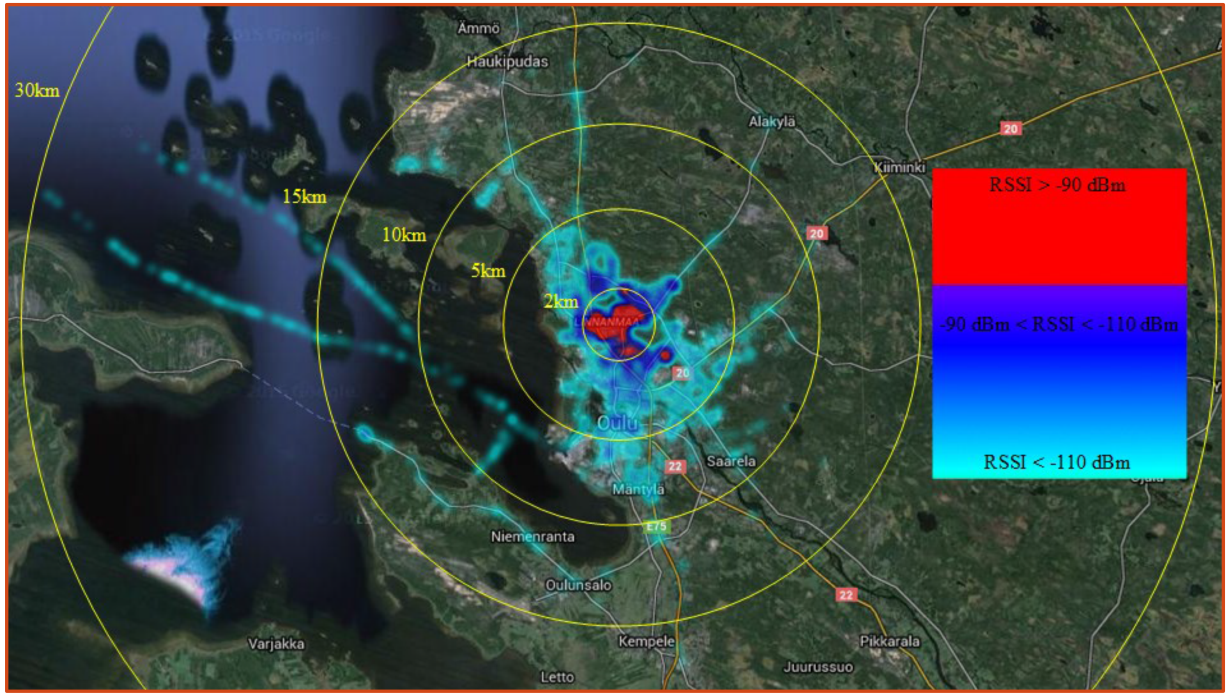
SMART IRRIGATION SOLUTIONS in the SWAMP project

SMART LIGHTING in the ORION M2M DEVICES

J. Petajajarvi, K. Mikhaylov, A. Roivanen, T. Hanninen and M. Pettissalo, “On the Coverage of LPWANs: Range Evaluation and channel attunuation model for LoRa technology”, Proc. of IEEE ITST, Copenhagen, Denmark, 2015.

LoRa and LoRaWAN Technologies

❑ Experimental Results: **Range Estimation**



Received signal strength from different locations in Oulu, Finland,

TABLE II. RESULTS OF MEASUREMENTS WITH CAR

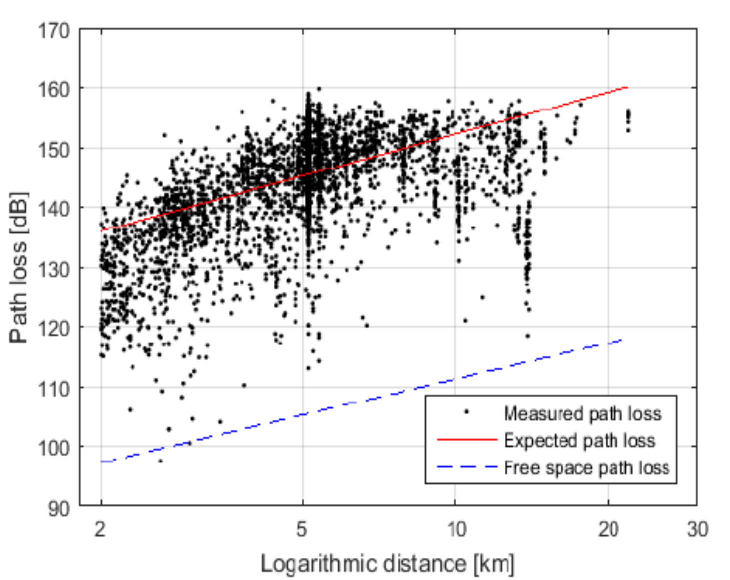
Range	Number of transmitted packets	Number of received packets	Packet loss ratio
0-2 km	894	788	12 %
2-5 km	1215	1030	15 %
5-10 km	3898	2625	33 %
10-15 km	932	238	74 %
Total	6813	4506	34 %

TABLE III. RESULTS OF MEASUREMENTS WITH BOAT

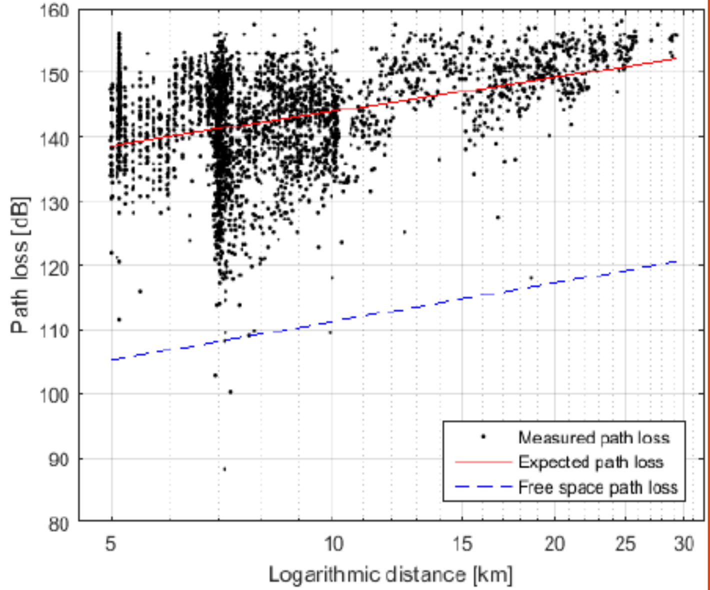
Range	Number of transmitted packets	Number of received packets	Packet loss ratio
5-15 km	2998	2076	31 %
15-30 km	690	430	38 %
Total	3688	2506	32 %

LoRa and LoRaWAN Technologies

❑ Experimental Results: **Range Estimation**



On-Ground Transmissions



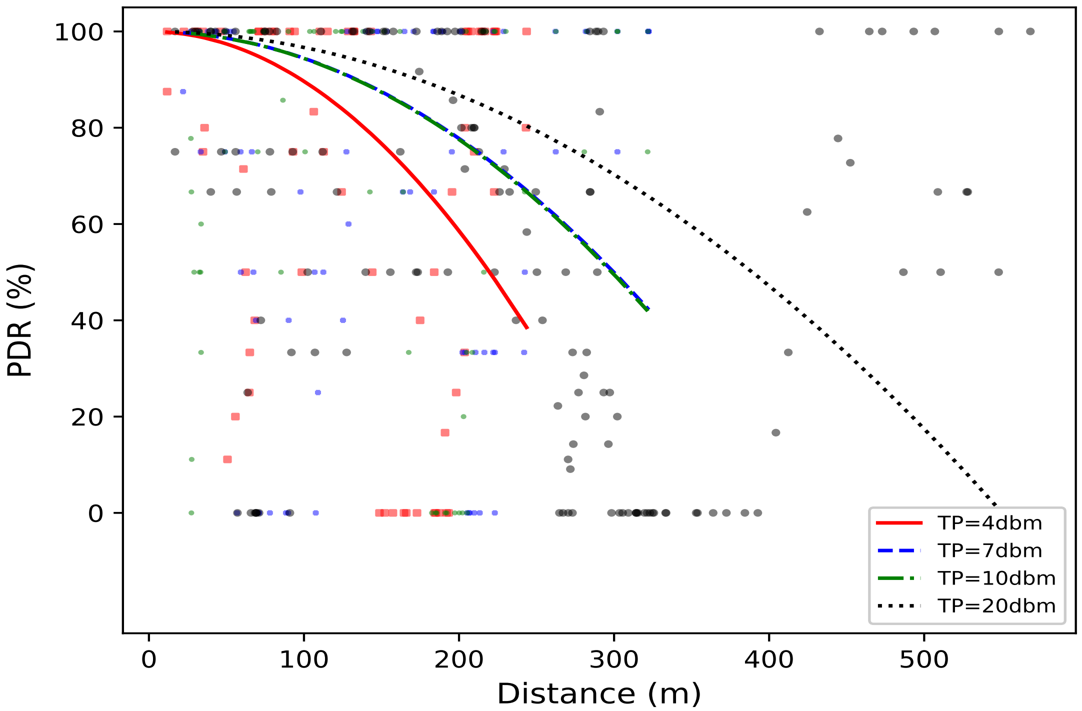
On-Air Transmissions

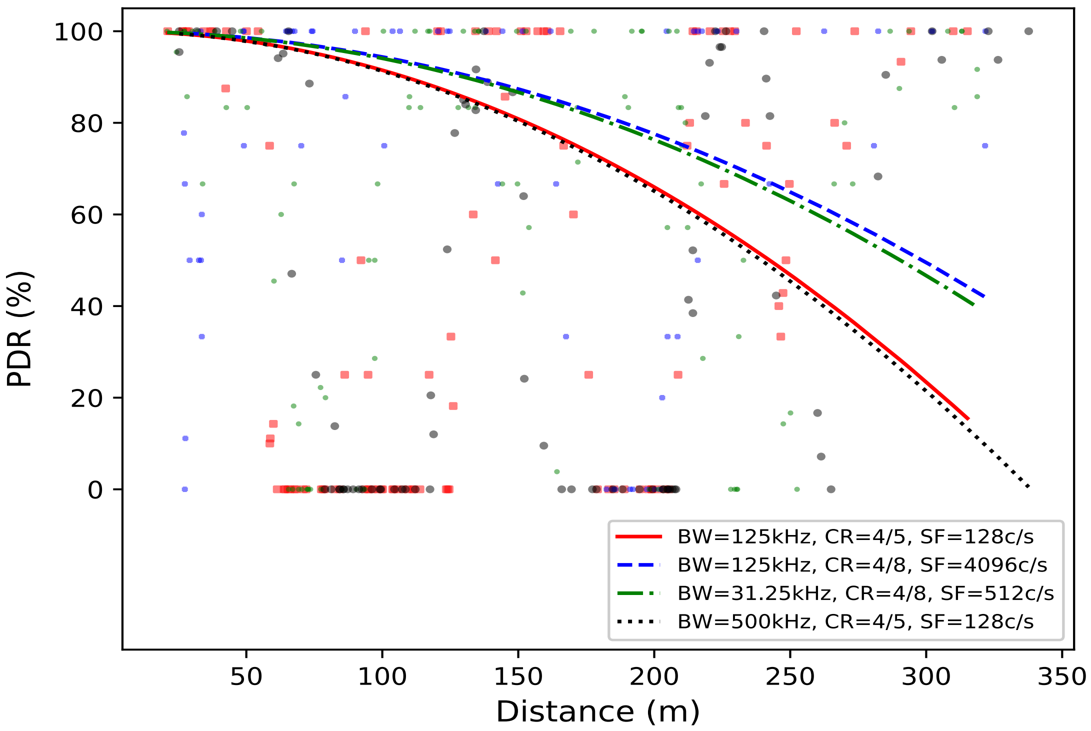
TABLE IV. CHANNEL CHARACTERISTICS

Metric	Measurement scenario: Car	Measurement scenario: Boat	Free space
Path loss exponent (n)	2.32	1.76	2.00
Path loss intercept (B)	128.95	126.43	91.22
Shadow fading (σ_{SF})	7.8 dB	8.0 dB	-

LoRa and LoRaWAN Technologies

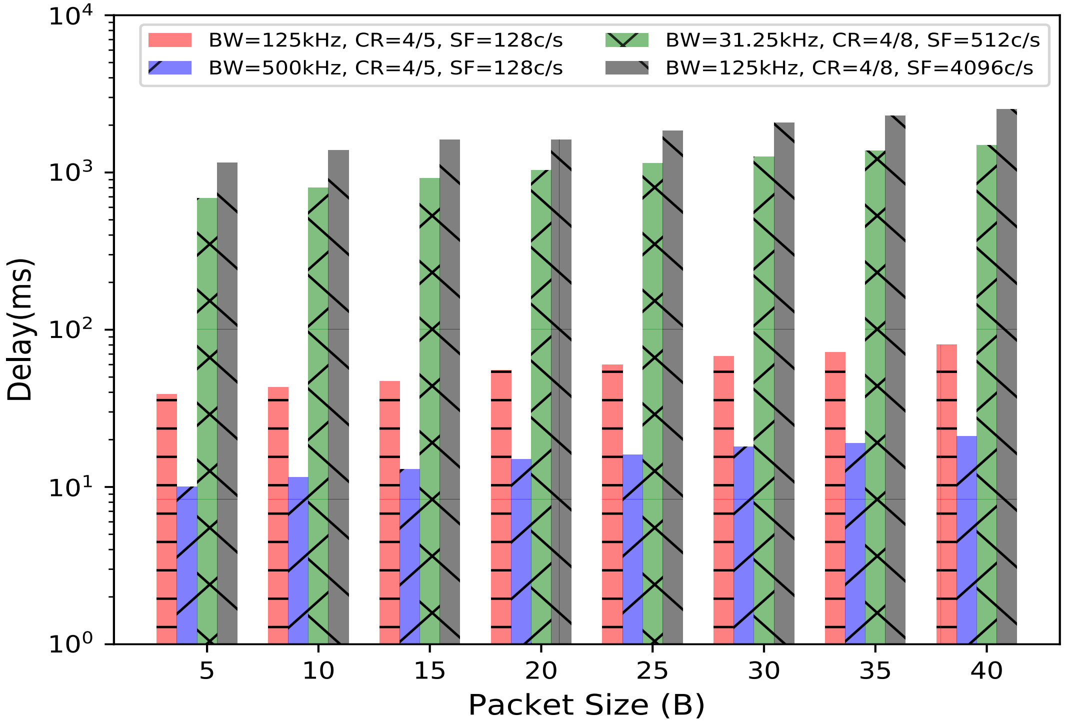
- Experimental Results: **Range Estimation**

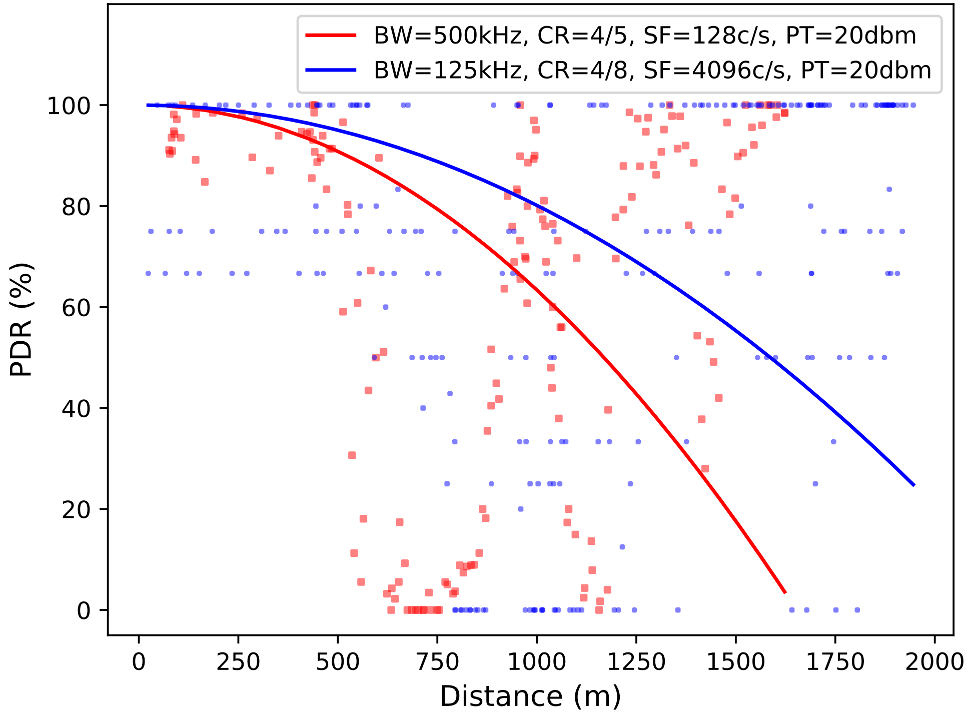




LoRa and LoRaWAN Technologies

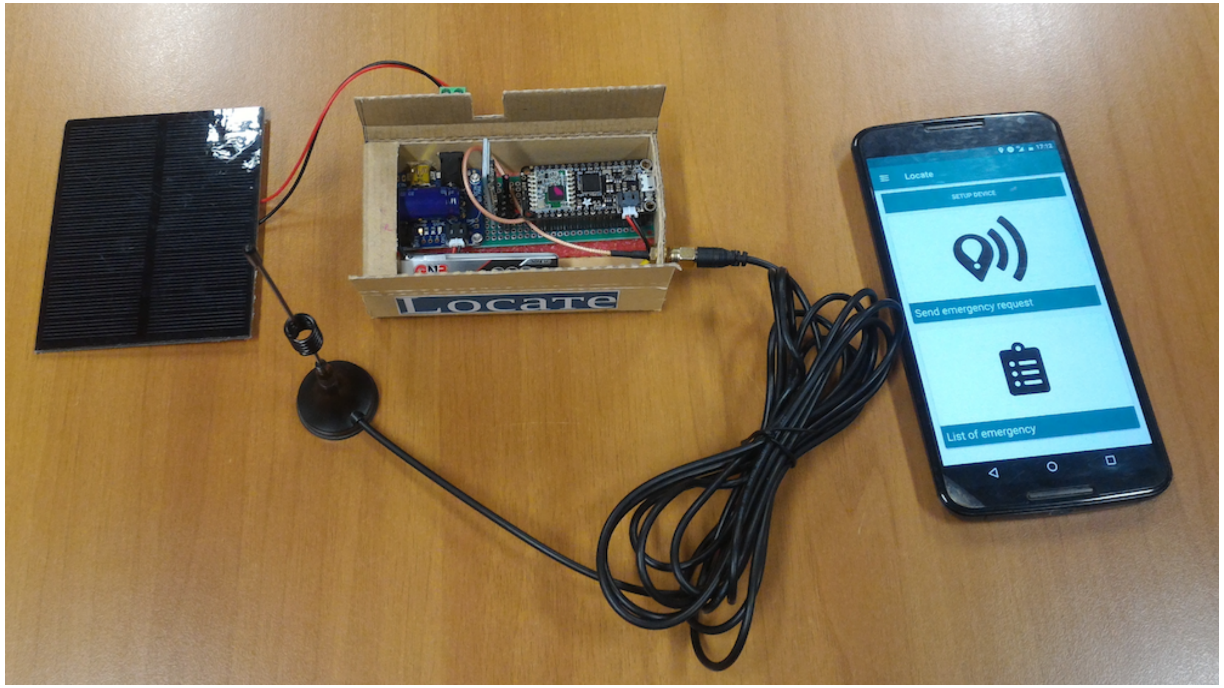
❑ Experimental Results: **Delay**

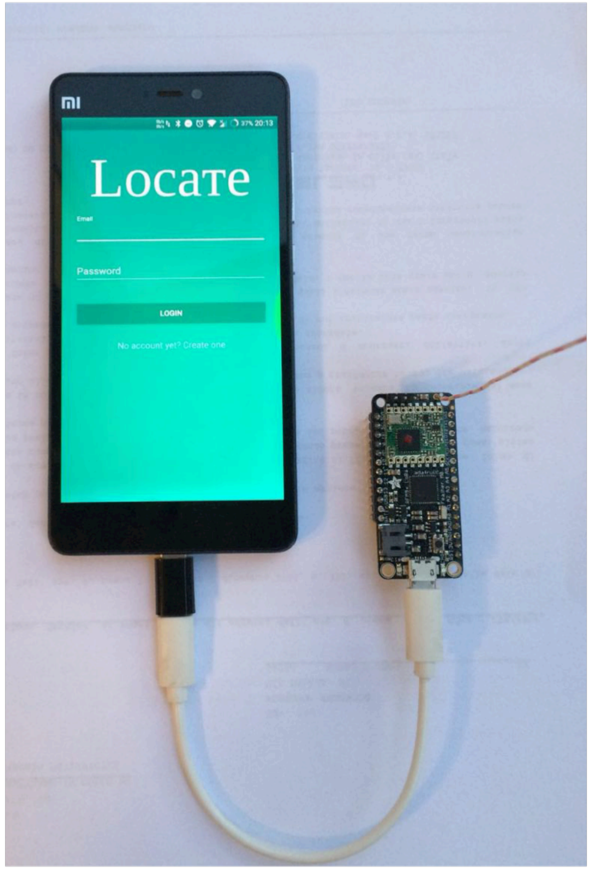




LoRa and LoRaWAN Technologies

- ❑ LoRa Application: the **LOCATE** system





LoRa and LoRaWAN Technologies

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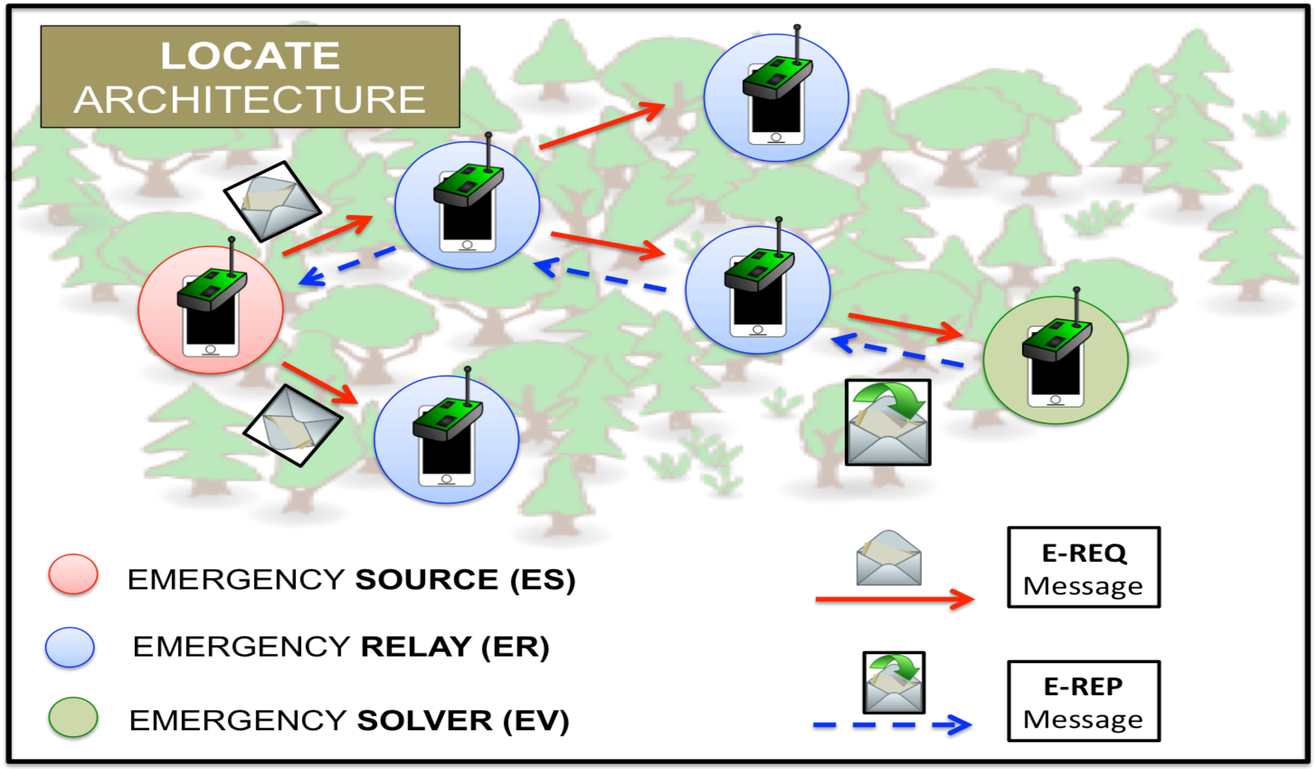

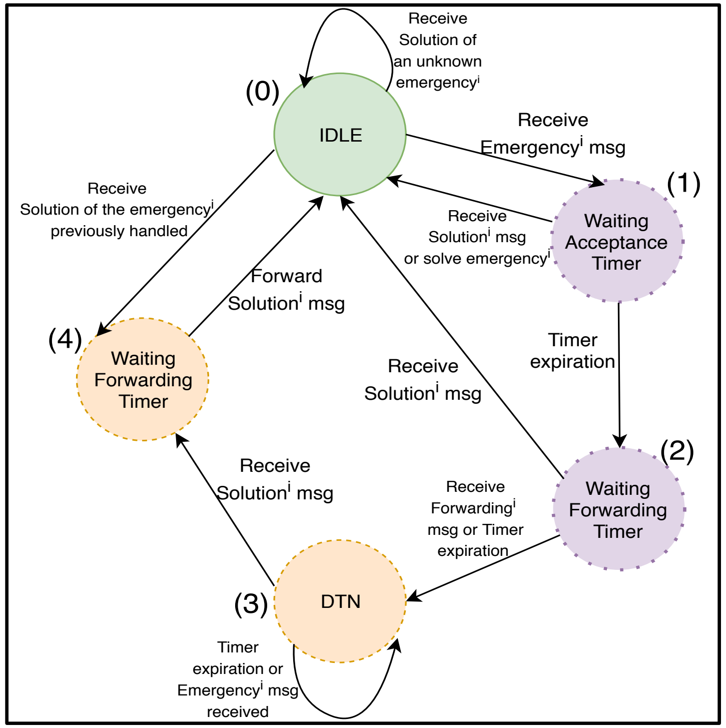

Luca Sciullo, Federico Fossemo, Angelo Trotta, Marco Di Felice: LOCATE: A LoRa-based mObile emergenCy mAnagement sysTEm. GLOBECOM 2018: 1-7

LoRa and LoRaWAN Technologies

LoRa DEMO

(P2P Communication)