IoT and TinyML Workshop for UNAM (University of Namibia)

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Intro to IoT and applications

Internet of Things (IoT)

“The IoT can be viewed as a global **infrastructure** for the information society, enabling advanced services by interconnecting (**physical** and **virtual**) things based on existing and evolving interoperable information and communication technologies (ICT).”— Recommendation ITU-T Y.2060

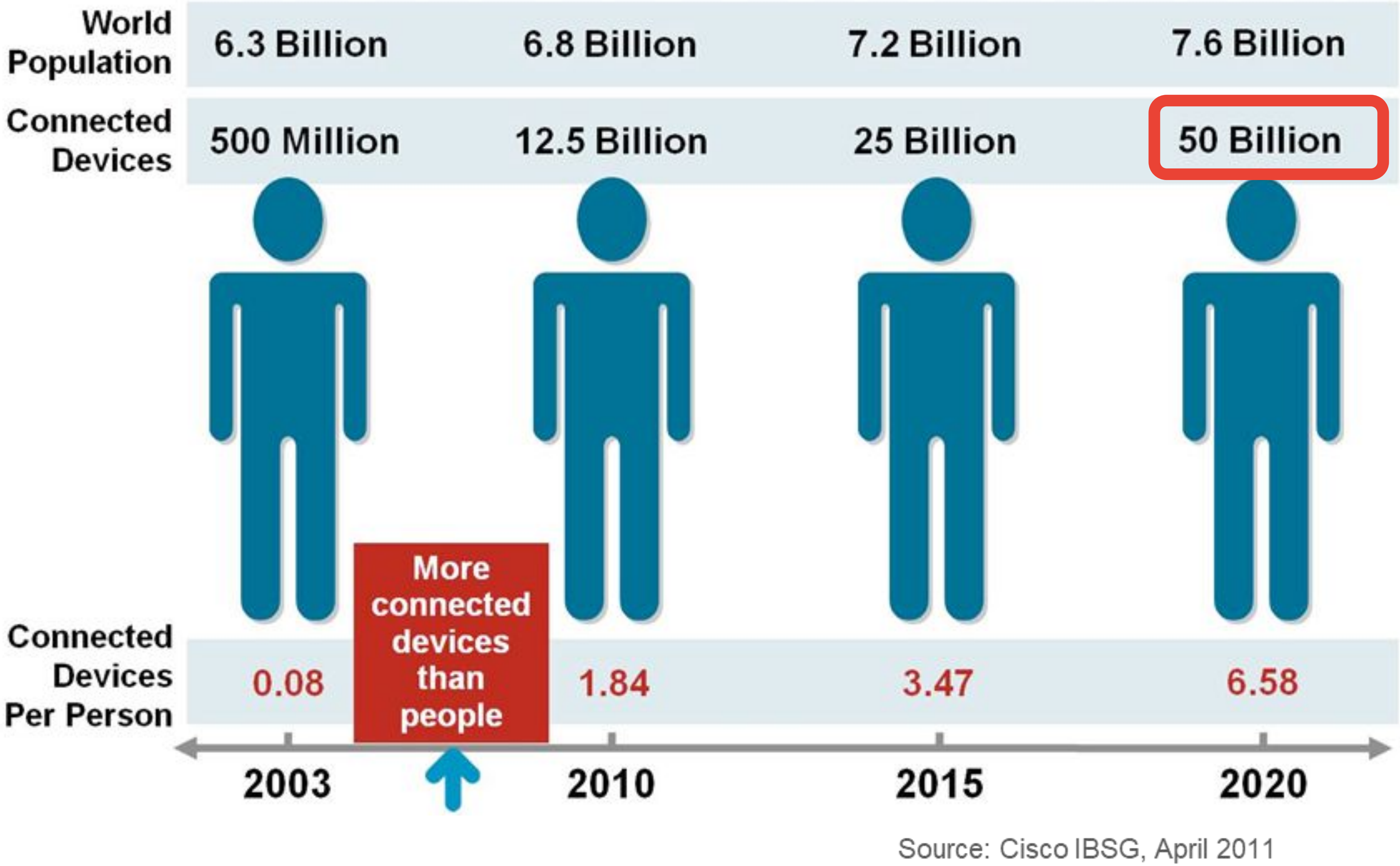
Device — ITU definition

“A device is a piece of equipment with the **mandatory capabilities** of **communication** and optional capabilities of sensing, actuation, data capture, data storage and data processing. Some devices also execute operations based on information received from the information and communication networks.”

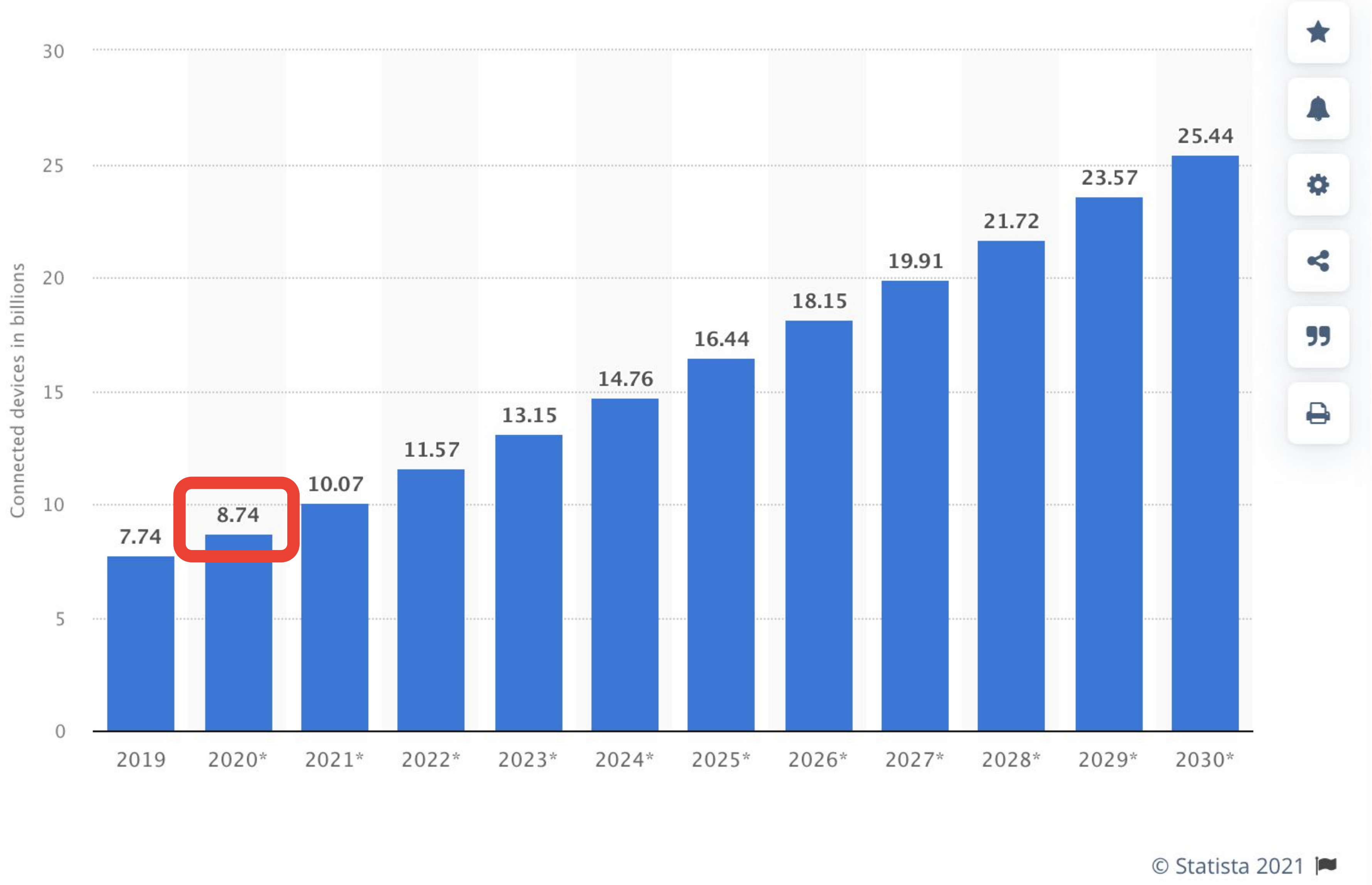
— Recommendation ITU-T Y.2060

Fundamental characteristics — ITU

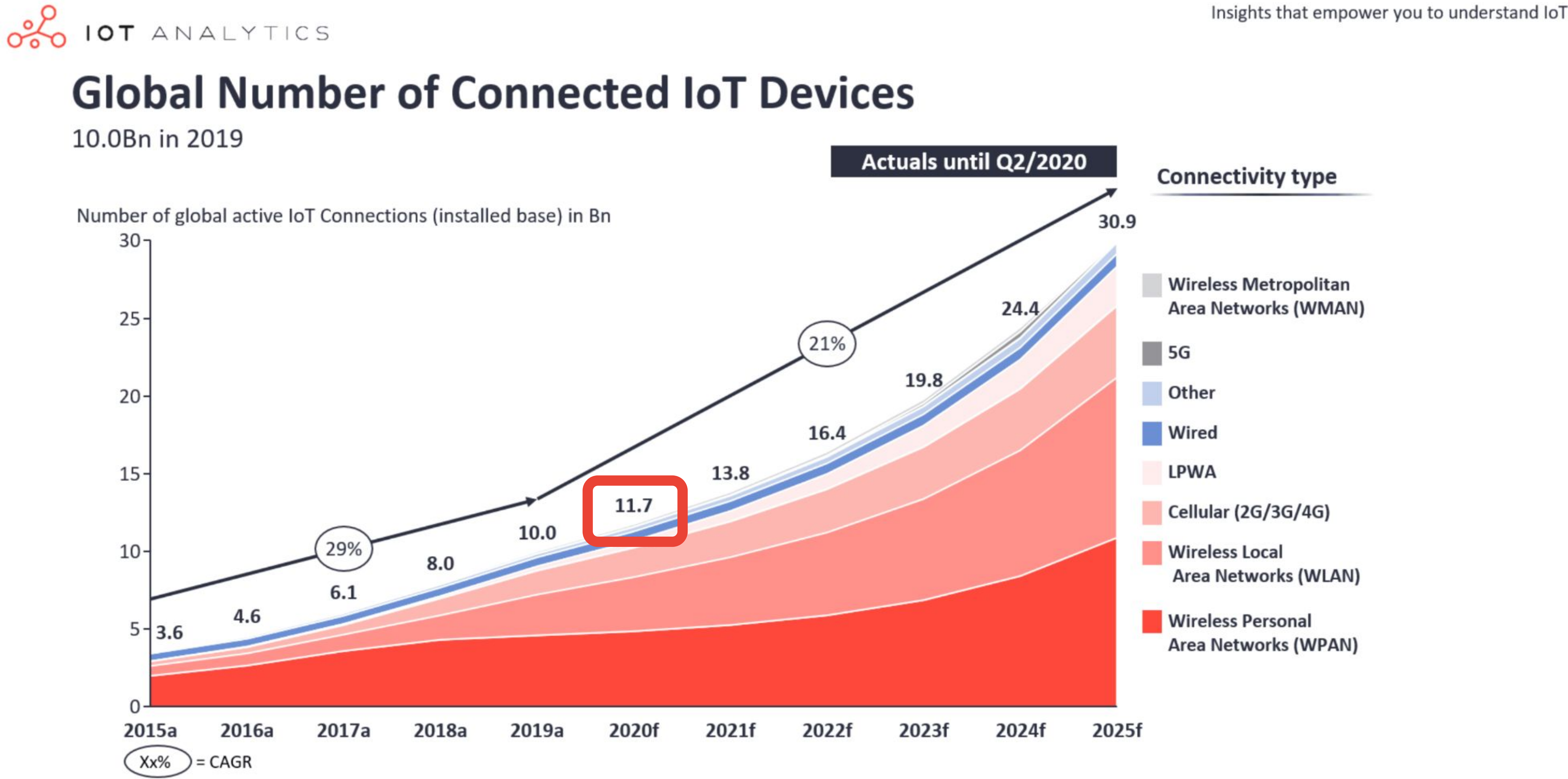
Enormous scale: The number of devices that need to be managed and that communicate with each other will be at least an order of magnitude larger than the devices connected to the current Internet. The ratio of communication triggered by devices as compared to communication triggered by humans will noticeably shift towards device-triggered communication.


World Population
6.3 Billion
6.8 Billion
7.2 Billion
7.6 Billion
Connected Devices
500 Million
12.5 Billion
25 Billion
50 Billion
Connected Devices Per Person
0.08
More connected devices than people
1.84
3.47
6.58
2003
2010
2015
2020
Source: Cisco IBSG, April 2011

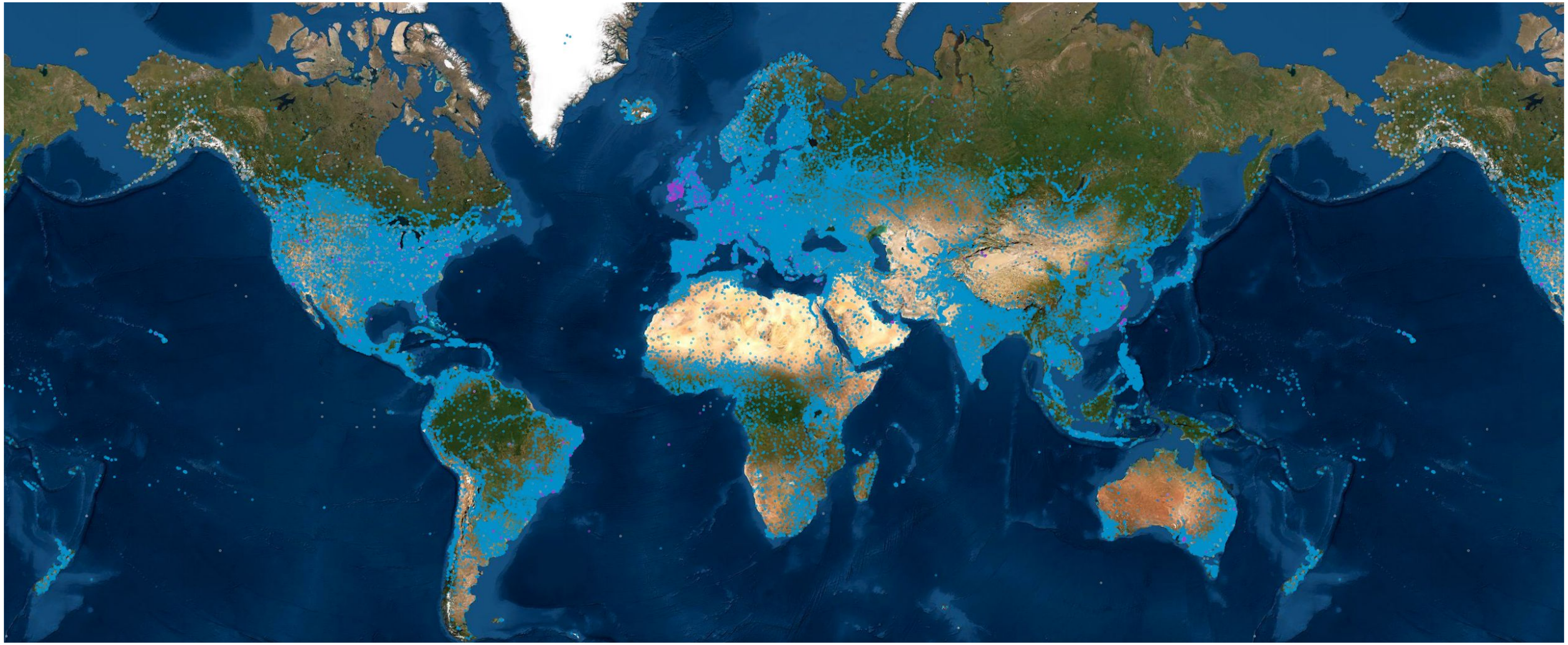
2020 statistics



2020 statistics

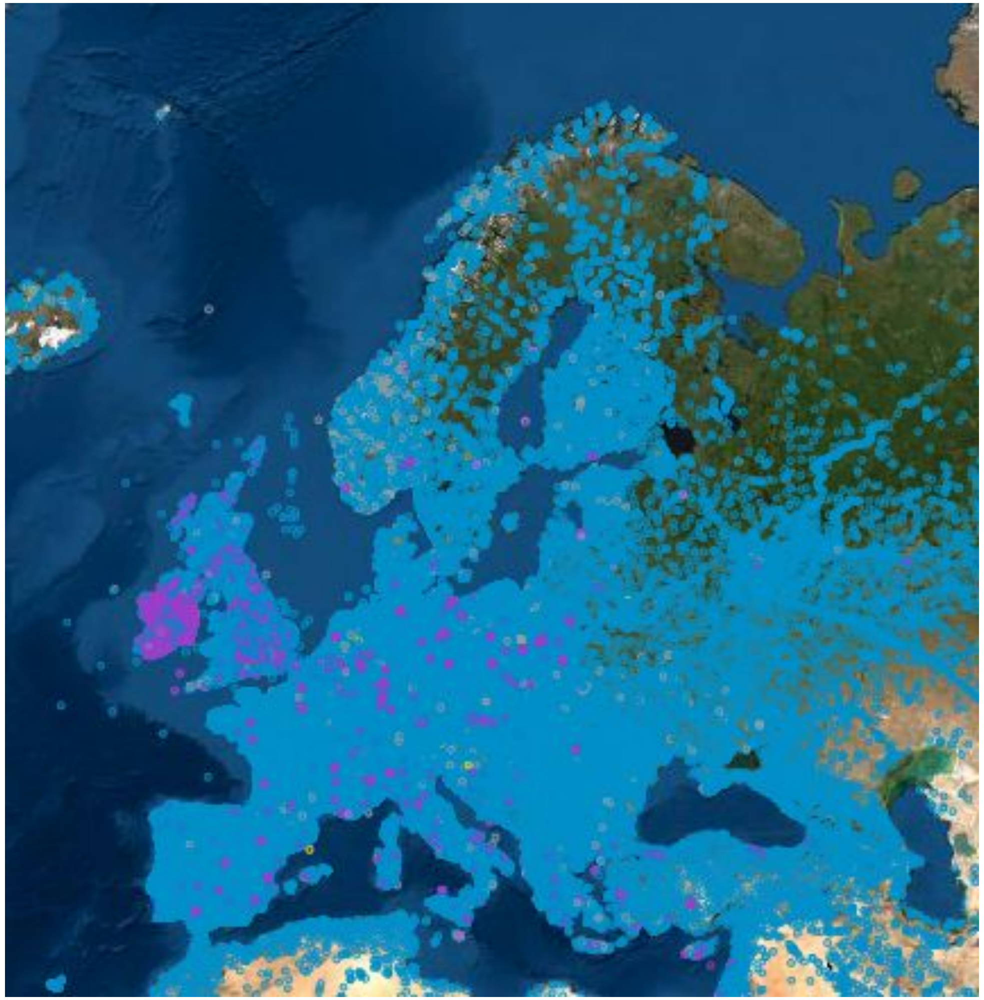


Worldwide distribution



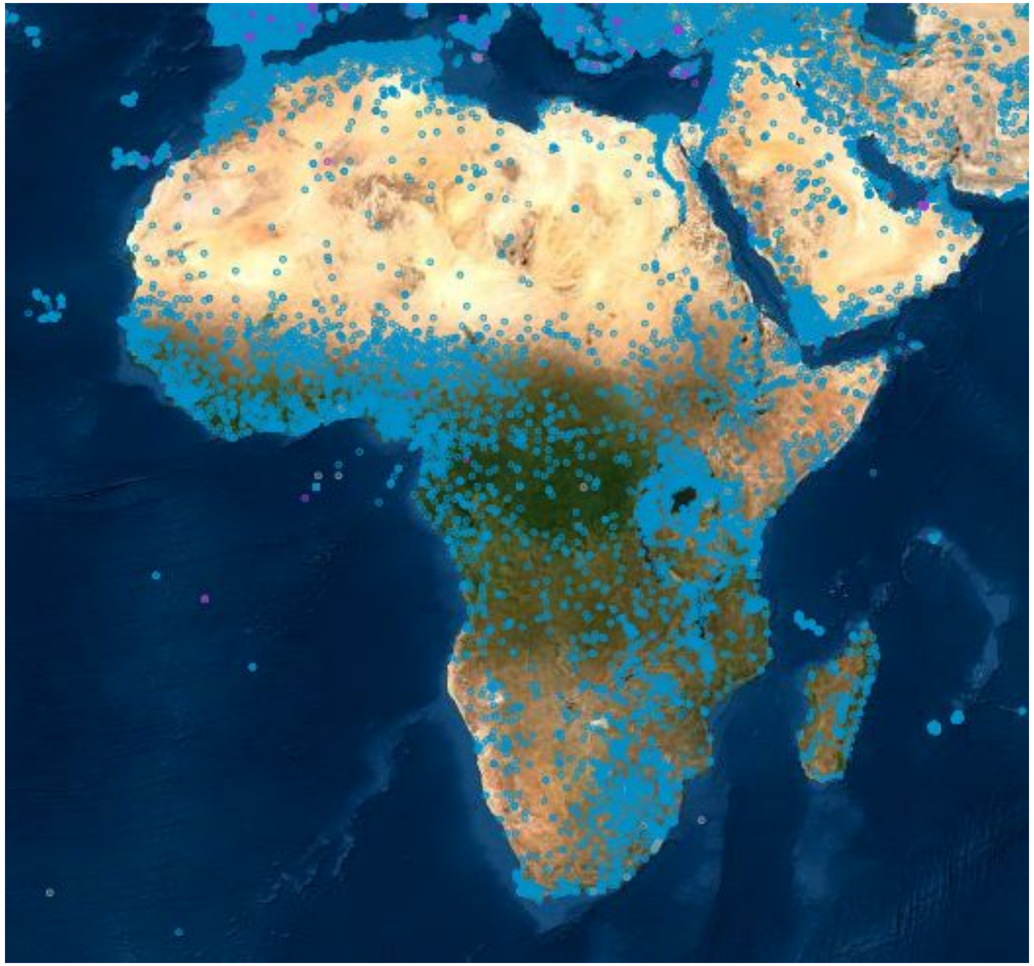
Credit: https://www.thingful.net

Worldwide distribution



Credit: https://www.thingful.net

Worldwide distribution



Credit: https://www.thingful.net

IoT and SDG


SUSTAINABLE DEVELOPMENT GOALS
17 GOALS TO TRANSFORM OUR WORLD
1 NO POVERTY
2 ZERO HUNGER
3 GOOD HEALTH AND WELL-BEING
4 QUALITY EDUCATION
5 GENDER EQUALITY
6 CLEAN WATER AND SANITATION
7 AFFORDABLE AND CLEAN ENERGY
8 DECENT WORK AND ECONOMIC GROWTH
9 INDUSTRY, INNOVATION AND INFRASTRUCTURE
10 REDUCED INEQUALITIES
11 SUSTAINABLE CITIES AND COMMUNITIES
12 RESPONSIBLE CONSUMPTION AND PRODUCTION
13 CLIMATE ACTION
14 LIFE BELOW WATER
15 LIFE ON LAND
16 PEACE, JUSTICE AND STRONG INSTITUTIONS
17 PARTNERSHIPS FOR THE GOALS
SUSTAINABLE DEVELOPMENT GOALS

IoT and SDG

➤ SDG 2: ZERO HUNGER:

An estimated 821 million people were undernourished in 2017. Annual cereal production will need to rise to about 3 billion tonnes and annual meat production will need to rise by over 200 million tonnes to reach 470 million tonnes to feed 9.1 billion people by 2050.

➤ SDG 13 & 15: CLIMATE ACTION and LIFE ON LAND:

Given current concentrations and on-going emissions of greenhouse gases, it is likely that by the end of this century, the increase in global temperature will exceed 1.5°C. Global emissions of carbon dioxide (CO_2) have increased by almost 50 per cent since 1990

LPWAN

LPWAN

Low Power, Wide Area Networks

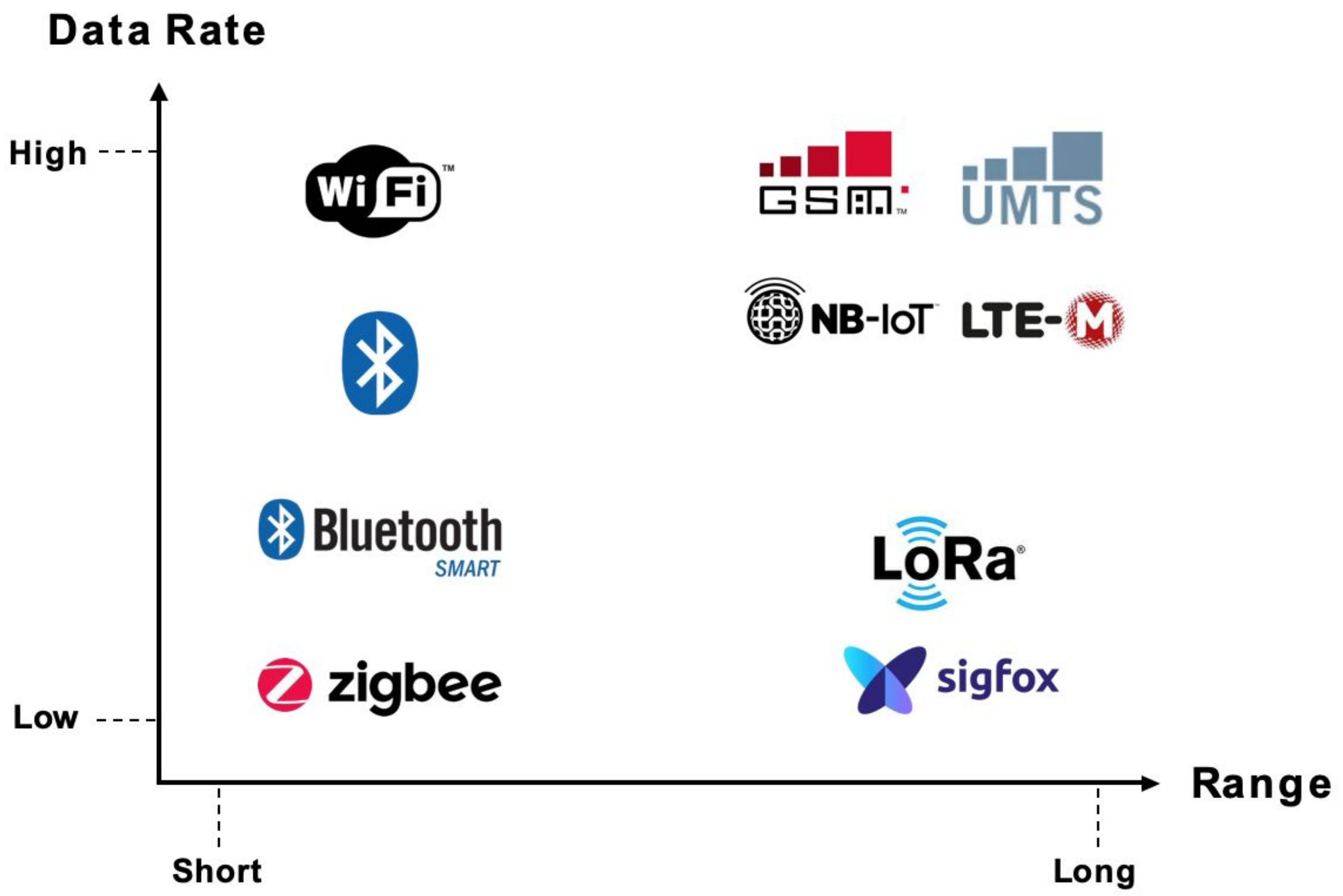
Connectivity designed specifically for IoT

Low data throughput = High sensitivity = Long range

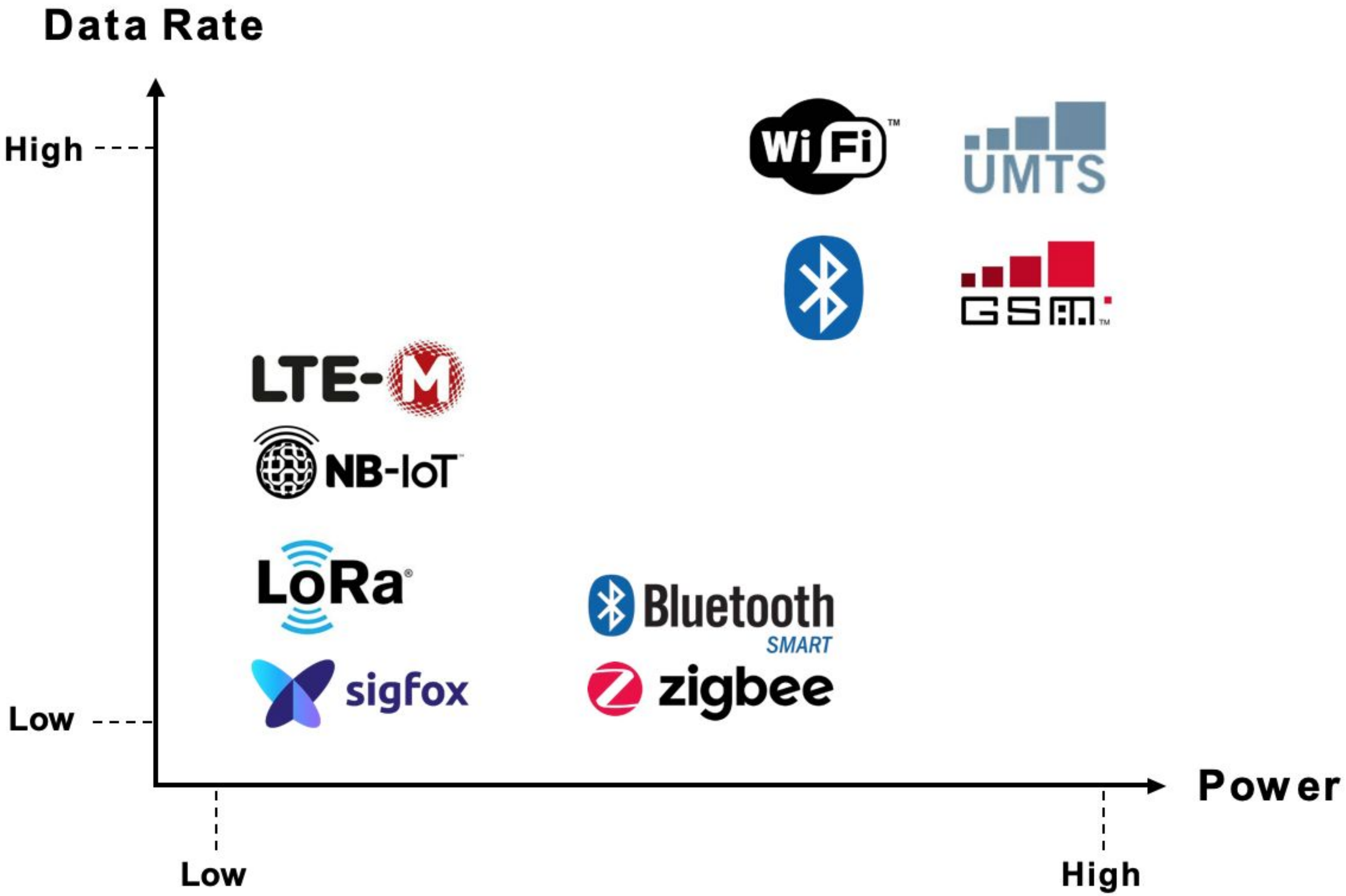
(Relatively) low cost

Using licensed or unlicensed spectrum

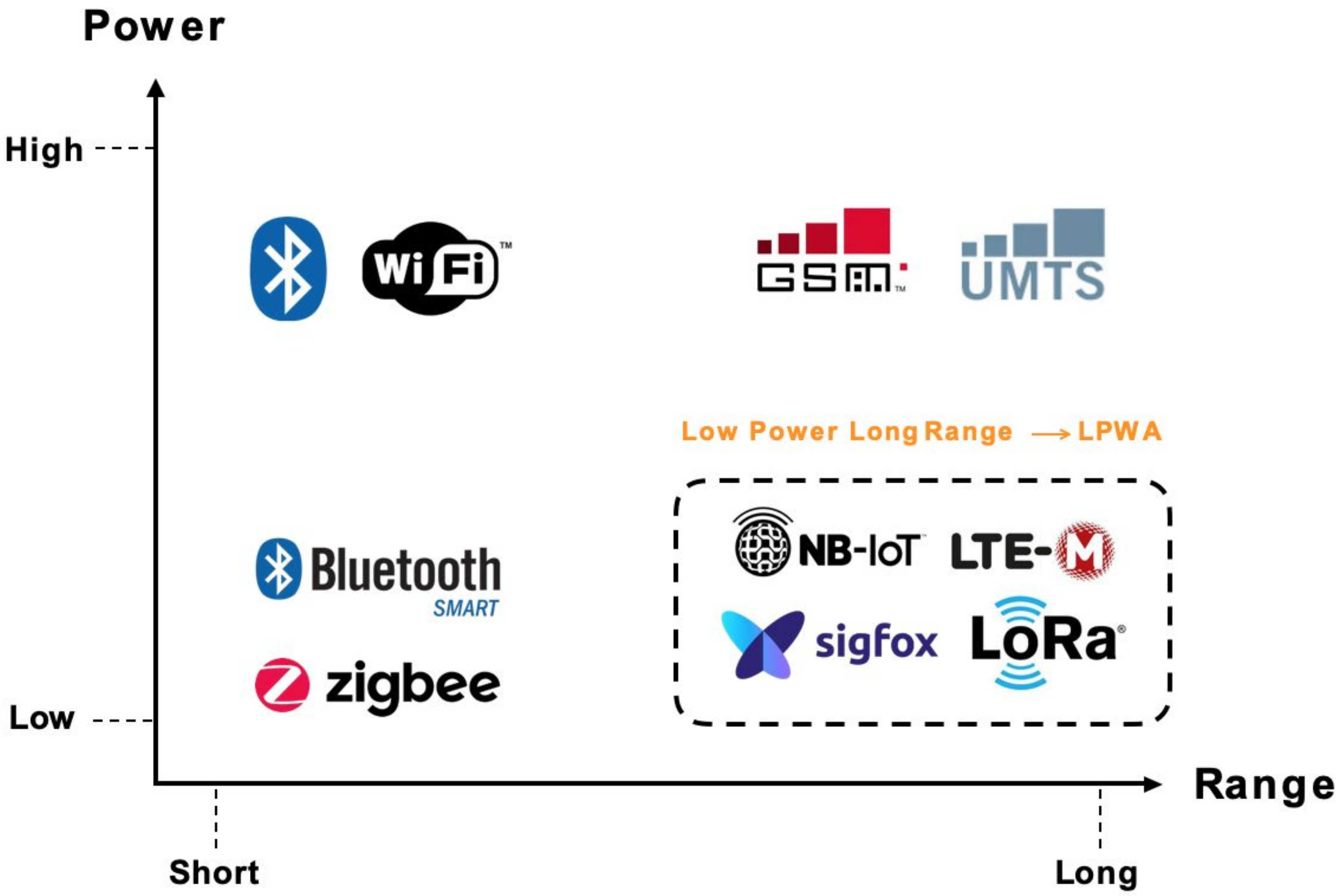
LPWAN


Data Rate
High
Low
Wi Fi
Bluetooth
SMART
zigbee
GSM
UMTS
NB-IoT
LTE-M
LoRa
sigfox
Range
Short
Long

LPWAN


Data Rate
High
Low
Power
Low
High
Wi Fi
UMTS
GSM
LTE-M
NB-IoT
LoRa
Bluetooth SMART
sigfox
zigbee

LPWAN



What is LoRa

Wireless modulation technology, based on Semtech's proprietary Chirp Spread Spectrum (CSS)

Physical (PHY) layer for long range wireless communications

Operates in the license-free Industrial Scientific Medical (ISM) bands all around the world

Based on spread spectrum, trading bandwidth for S/N.

What is LoRa

Sub-GHz frequency, e.g: 433, 868, 915 MHz, depends on the country’s regulation

Regulated power, duty-cycle, and bandwidth.

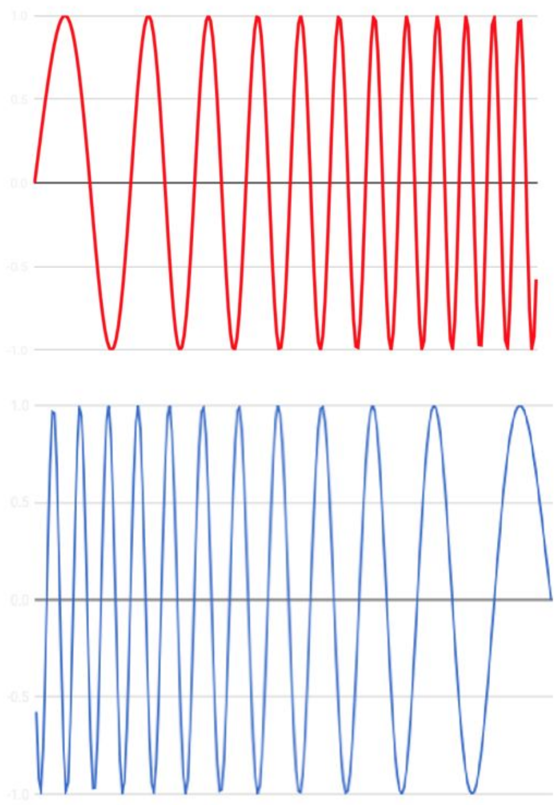
E.g: in EU, **1%** per sub-band duty-cycle limitation (per hour, meaning transmission is allowed for 36 sec in each 1 hour)

What is LoRa

Country	Frequency Plan	Regulatory document
Namibia	EU863-870 EU433	CRASA follows CEPT Rec. 70-03

LoRa modulation

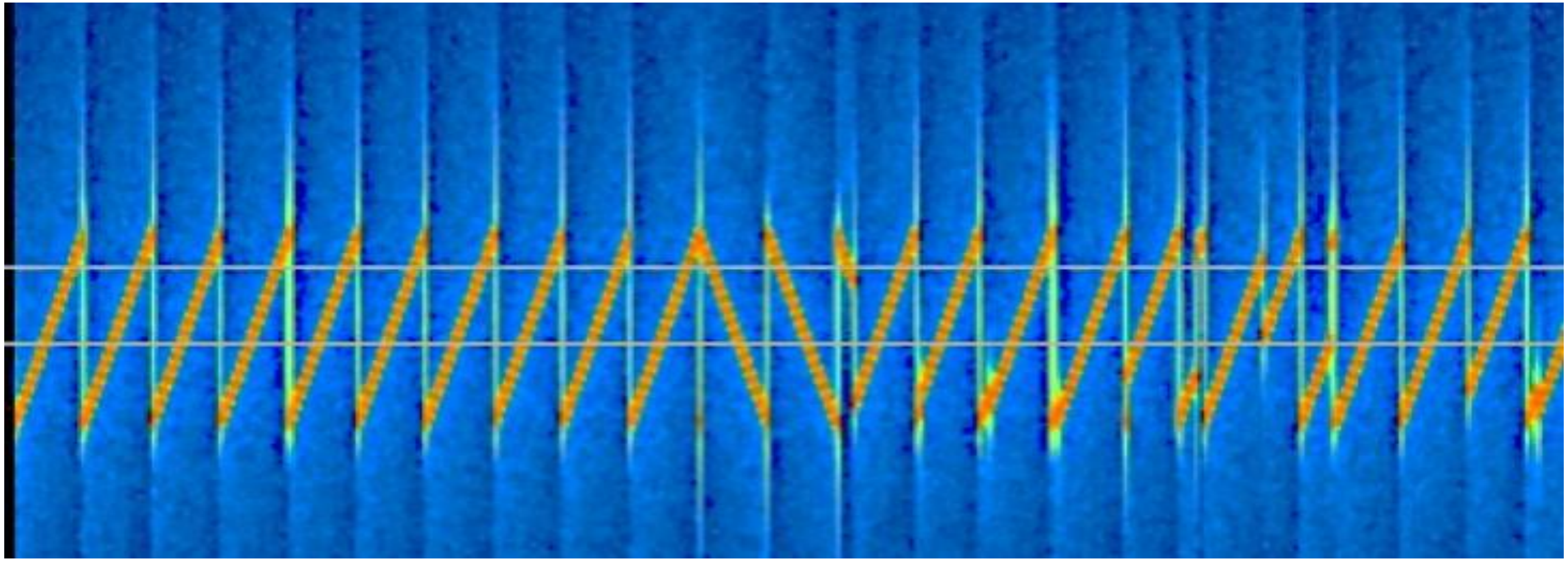
Uses linearly varying frequency pulses called "**chirps**" inspired in radar signals.



Up-chirp:
sinusoidal signal of linearly increasing frequency

Down-chirp:
sinusoidal of linearly decreasing frequency

LoRa Physical Layer



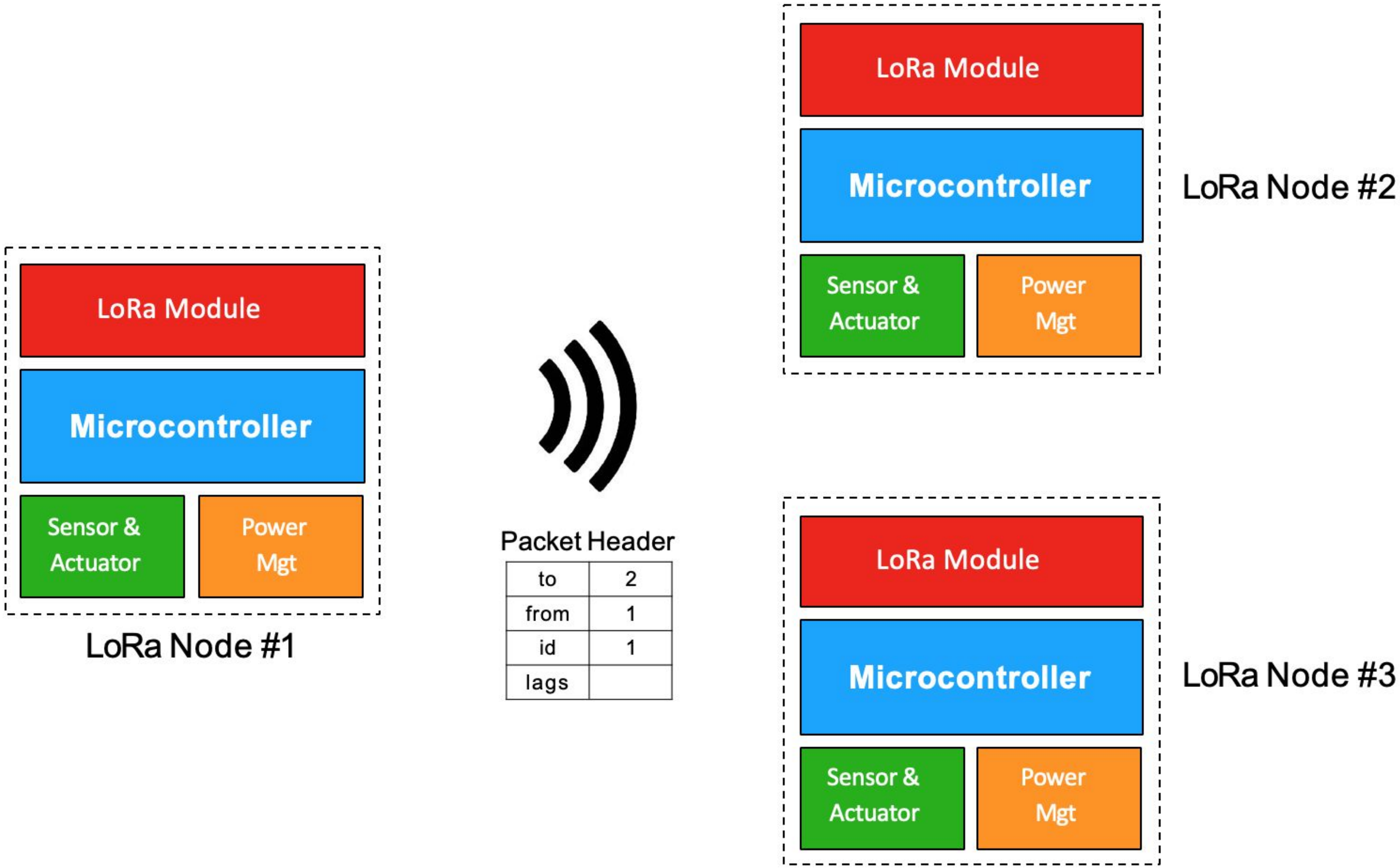
Preamble: at least 10 up-chirps followed by 2.25 down-chirps

Data: information transmitted by the instantaneous frequency transitions

LoRa physical layer consists of many parameters which can be configured into 6720 different settings!

SeRing	Values	DeSnition	ETects
Bandwidth	125, …,500 kHz	Width of spectrum occupied by chirp	A higher bandwidth is required for transmiRing data at high rates (1 kHz = 1kcps). However, increasing this parameter decreases the communication range and sensitivity.
Spreading Factor	2^6, …,2^{12} chips/ symbol	Number of bits encoded per symbol. Symbol is RF state representing some quantity of information. SF12 means 2^{12} chips/symbol, 12 bits of data	A higher spreading factor (*SF*) increases the communication range, radio sensitivity, and the signal-to-noise ratio (SNR). However, energy consumption consequently increases.
Coding Rate	1,…,4 or 4/5, …,4/8	Propoaion of transmiRed bits that caries actual data, as opposed to error correction bits. CR1 · 4/(4+1) = 4/5	Bigger coding rates increase the protection against decoding errors and intecerence bursts at the expense of longer packets, longer air time, and higher power consumption.
Transmission Power	−4, …,20 dBm	Transmission power can be adjusted from −4 to 20 dBm, in 1dB steps. Because of hardware implementation limits, the range is o<en limited to 2 to 20 dBm.	The signal-to-noise ratio is increased by increasing the transmission power at the cost of energy expenditure.
Carrier Frequency	137, …,1020 MHz	CF represents the central transmission frequency used in a band, can be programmed between 137 MHz to 1020 MHz, in steps of 61 Hz.	Lower frequency enables to achieve higher communication ranges for the same transmission power. However, selected CF needs to comply with country's regulation.

LoRa nodes


LoRa Module
Microcontroller
Sensor & Actuator
Power Mgt
LoRa Node #1
Packet Header
to 2
from 1
id 1
lags
LoRa Module
Microcontroller
Sensor & Actuator
Power Mgt
LoRa Node #2
LoRa Module
Microcontroller
Sensor & Actuator
Power Mgt
LoRa Node #3

What is LoRaWAN

Communications protocol and architecture utilizing the LoRa physical layer

Open Source and freely available, specified by LoRa Alliance

Star of Starts Topology: **nodes connect to multiple gateways**

What is LoRaWAN

Adaptive Data Rate (ADR) to improve performance

Built-in multiple levels of security: network or application level encryption, frame counter, etc

LoRaWAN end device/mote

Communicates with LoRaWAN gateways, never directly with other motes.

Has 64 bit globally unique identifier: **DevEUI**.

When joining a network, it receives a 32 bit unique identifier: DevAddr.

Defined 3 device classes: A, B, and C

LoRaWAN device classes

Class A

Device-initiated communication; lowest power

Devices are typically in deep sleep and send messages on intervals and/or events

After uplink transmission, device opens two receive windows at specified times for downlink messages

Best fit for most battery-powered sensor applications

Class B

Time-synchronized communication, deterministic downlink

Extend Class A by adding scheduled receive windows for downlink messages from backend

Using time-synchronized beacons transmitted by the gateway, the devices periodically open receive windows

Best for most downlink intensive applications

Class C

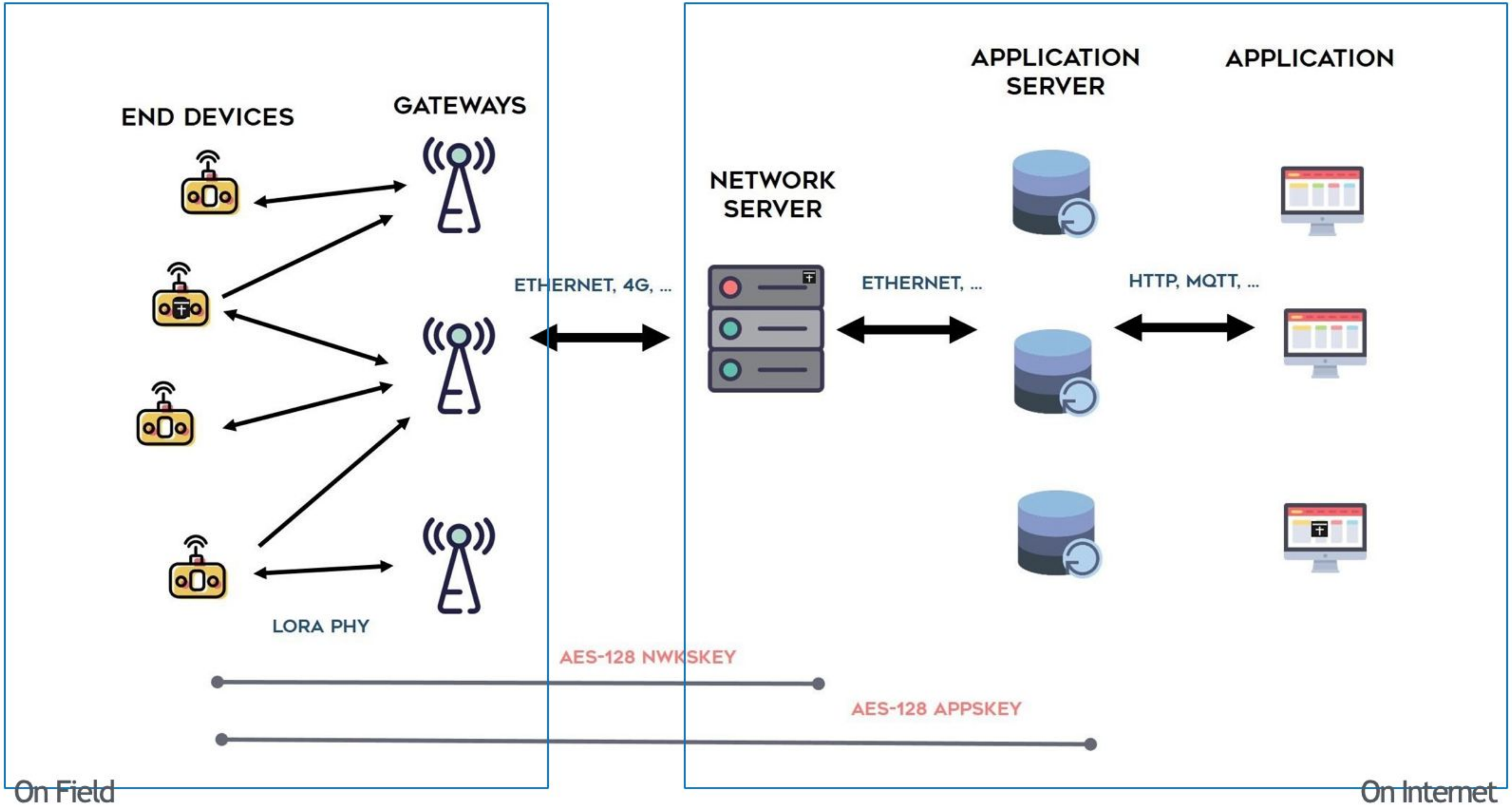
Network-initiated communication; lowest latency

Extend Class A by keeping the receive windows open unless uplink-transmitting

The backend can send downlink message at any given time

Best for downlink intensive applications that require low latencies, non battery-powered

LoRaWAN architecture



Source: http://www.frugalprototype.com/technologie-lora-reseau-lorawan/

LoRaWAN products

LoRaWAN Certified^{CM} Products

A huge array of certified products available now to fulfill the wide-ranging spectrum of IoT use cases served by LoRaWAN™.

Soon this will be extended to include LoRa Alliance™ member services, software and full solutions in addition to these certified devices. This will be a comprehensive directory of all our Members' products and services with tools to find the right solution for every LPWAN requirement.

ED1608

1M2M

1M2M's ED1608 is an out of the box, ready to use universal Low Power WAN Smart Sensor/GPS Tracker. It has on board 3D accelerometer,

ED1608 Rail Temperature Sensor

1M2M

The ED1608RTS is a rail temperature sensor that can be used to measure the temperature

LoRaWAN – characteristics

Range	10km
Multihop capabilities	no
Battery consumption	low
Security	yes
Cost (device)	low
Cost (service)	free
Availability	good
Regulation	good

Drivers and obstacles for IoT

↑ Low cost of devices (MCU and sensors)

↑ Wireless standards (LoRa!)

↓ Lack of Internet connectivity

↓ Lack of IoT infrastructure

↓ Complex ecosystem

Device — ITU definition

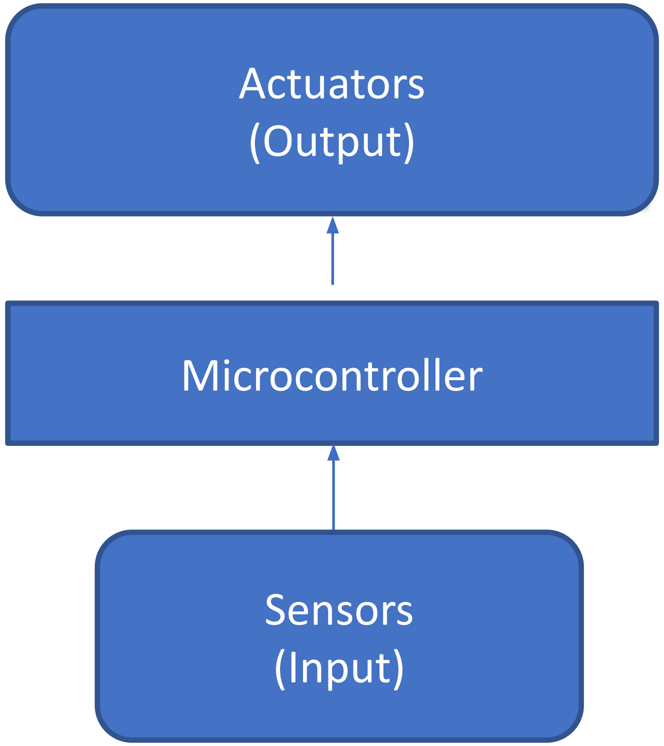
“A device is a piece of equipment with ~~the mandatory capabilities of communication and optional~~ capabilities of sensing, actuation, data capture, data storage and data processing. Some devices also execute operations ~~based on information received from the information and communication networks~~.”
— Recommendation ITU-T Y.2060

TinyML

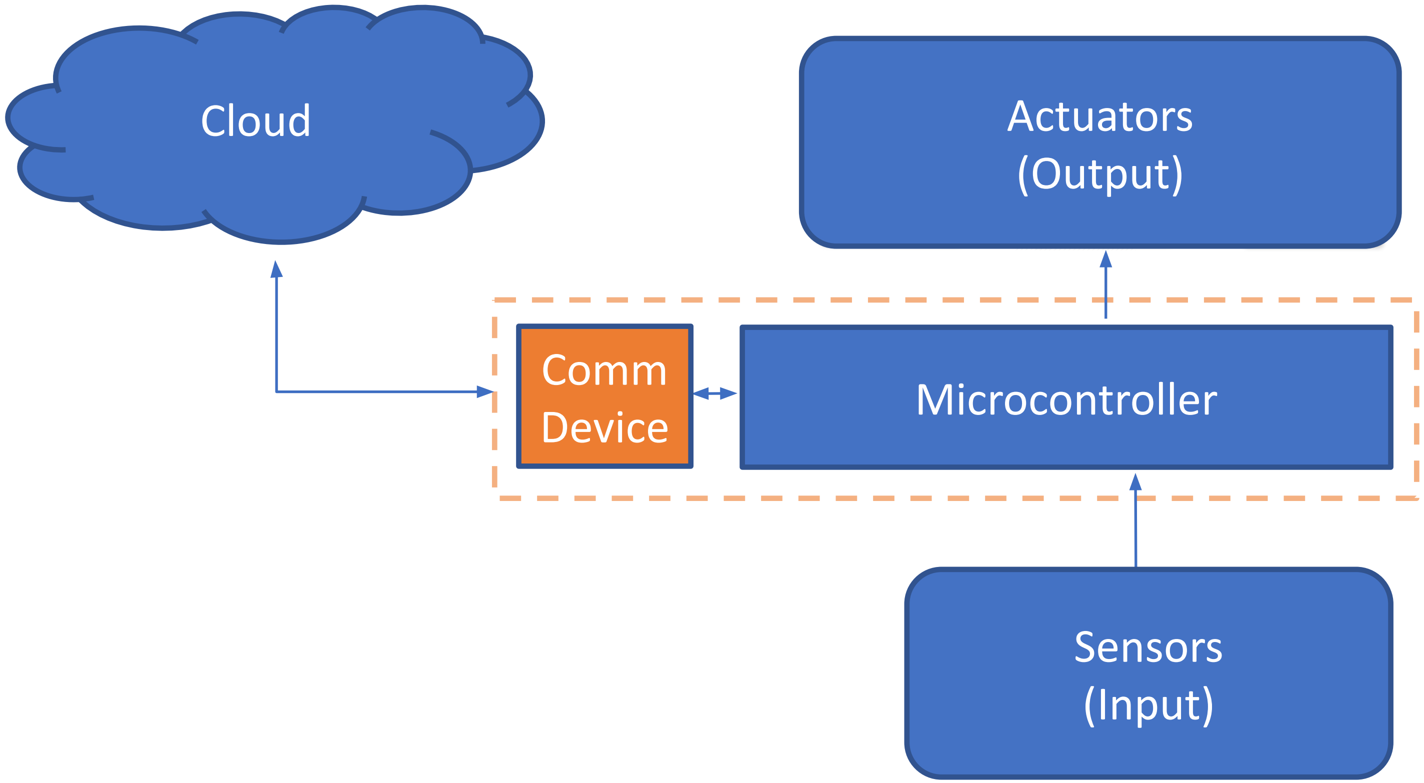
and why we are so excited about it

Typical IoT Project

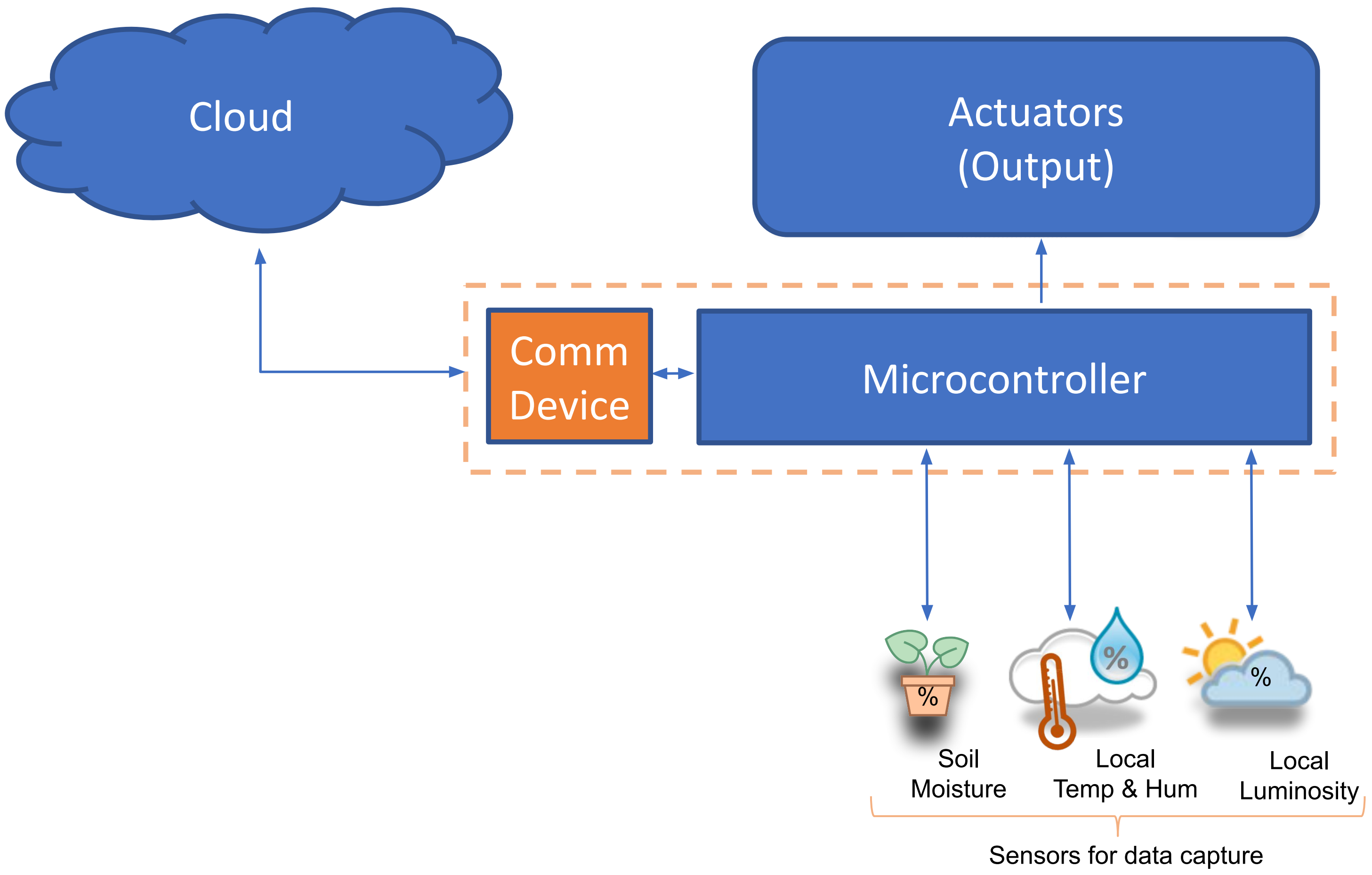
Typical IoT Project



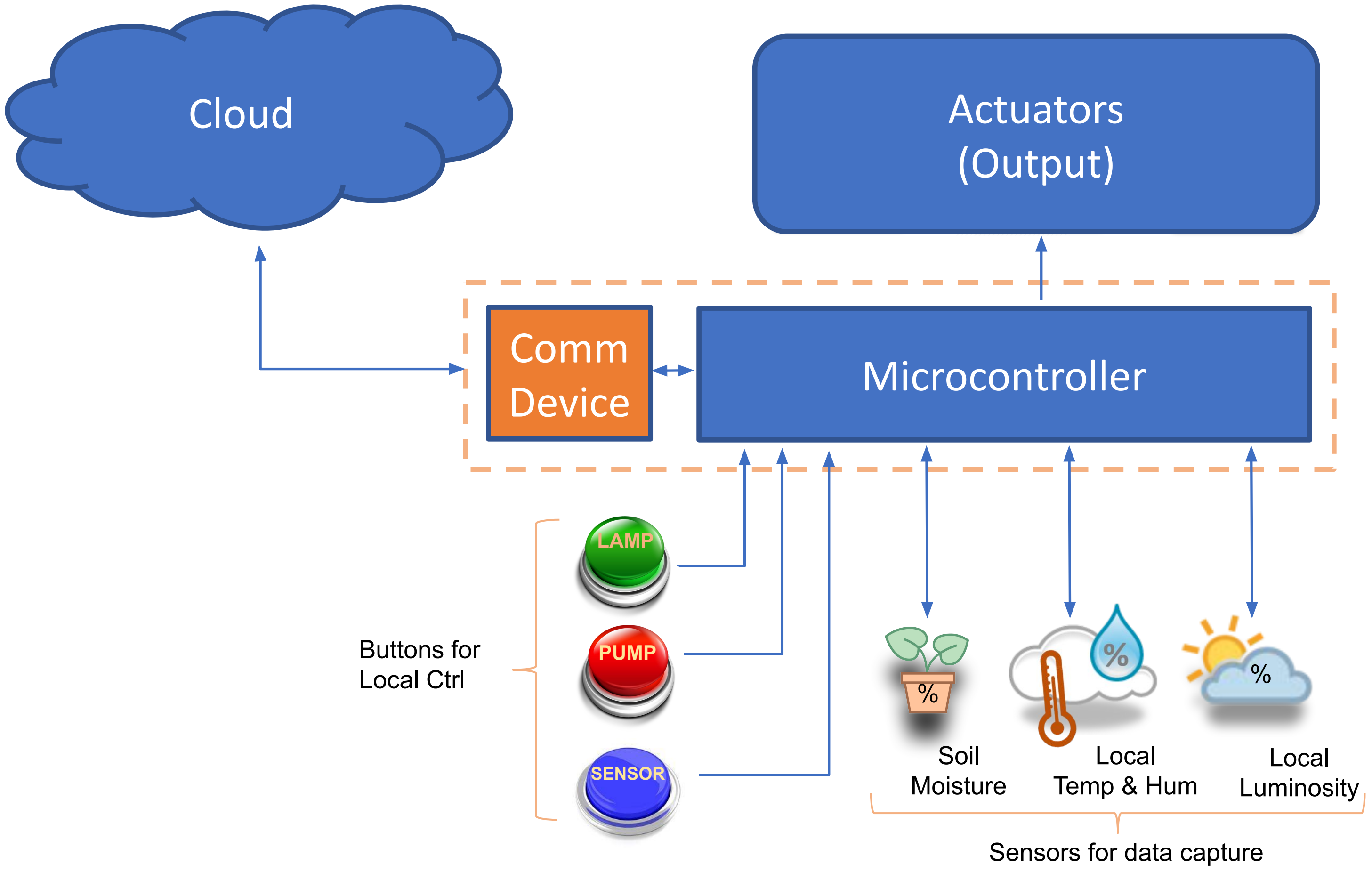
Typical IoT Project



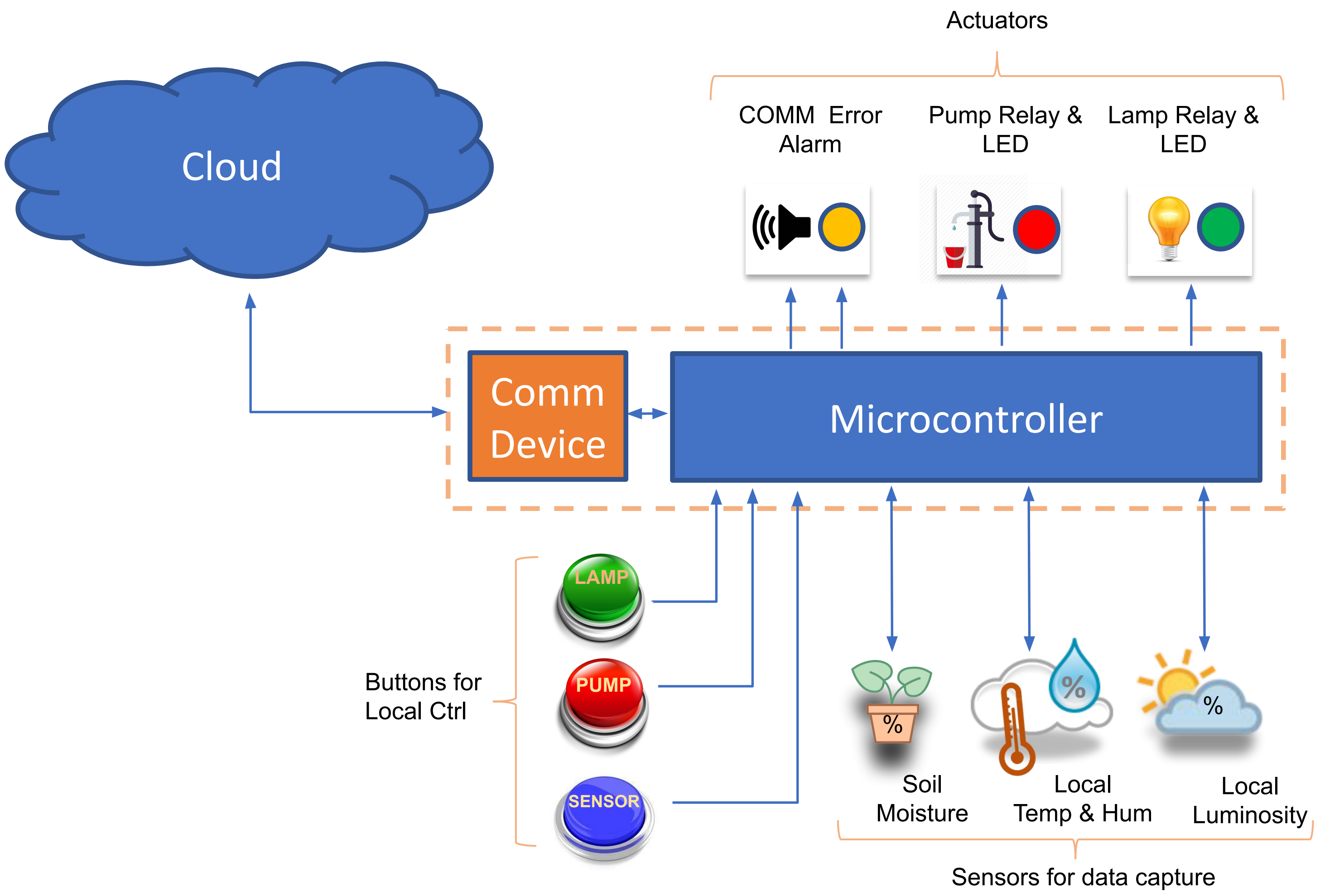
Typical IoT Project



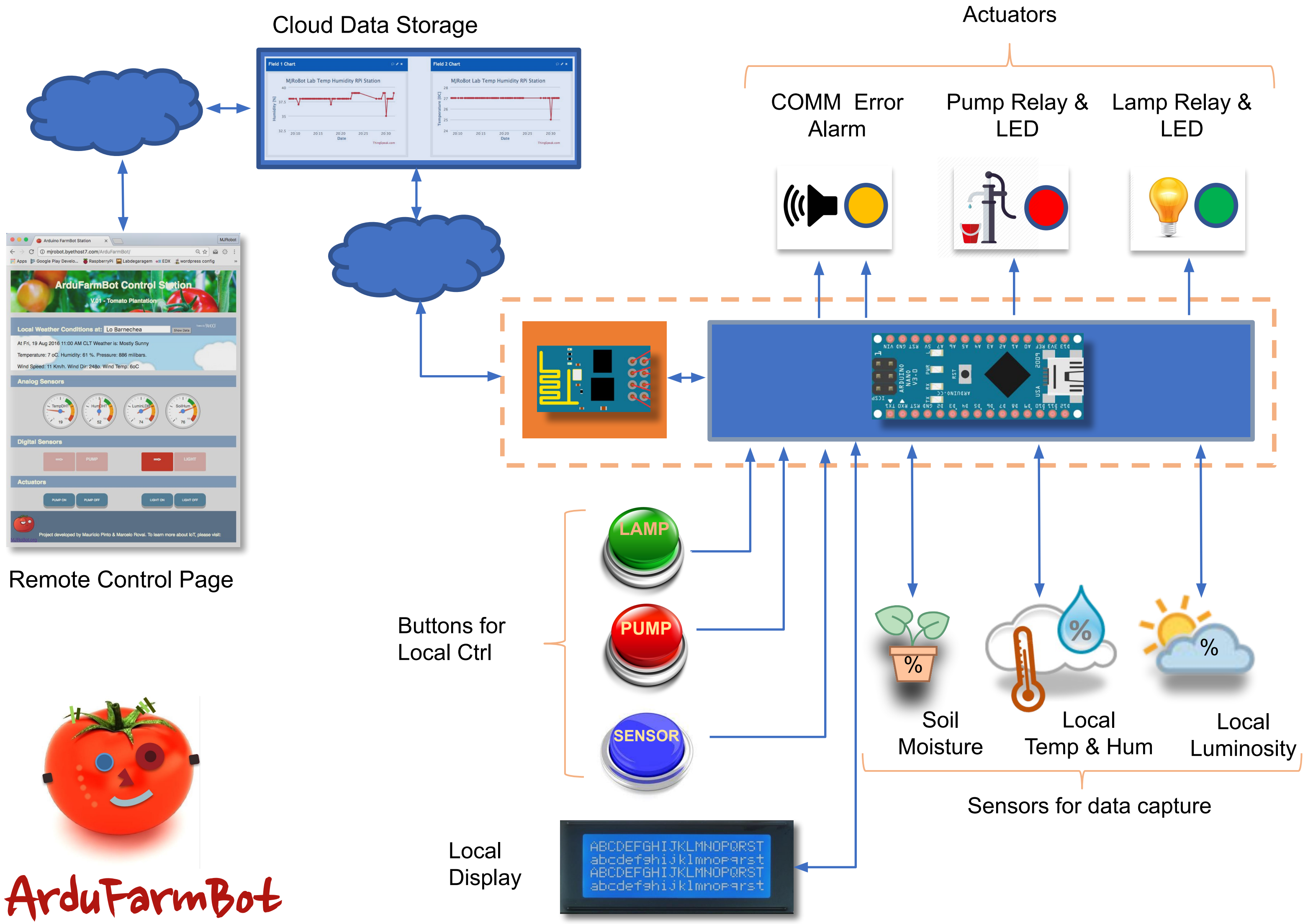
Typical IoT Project



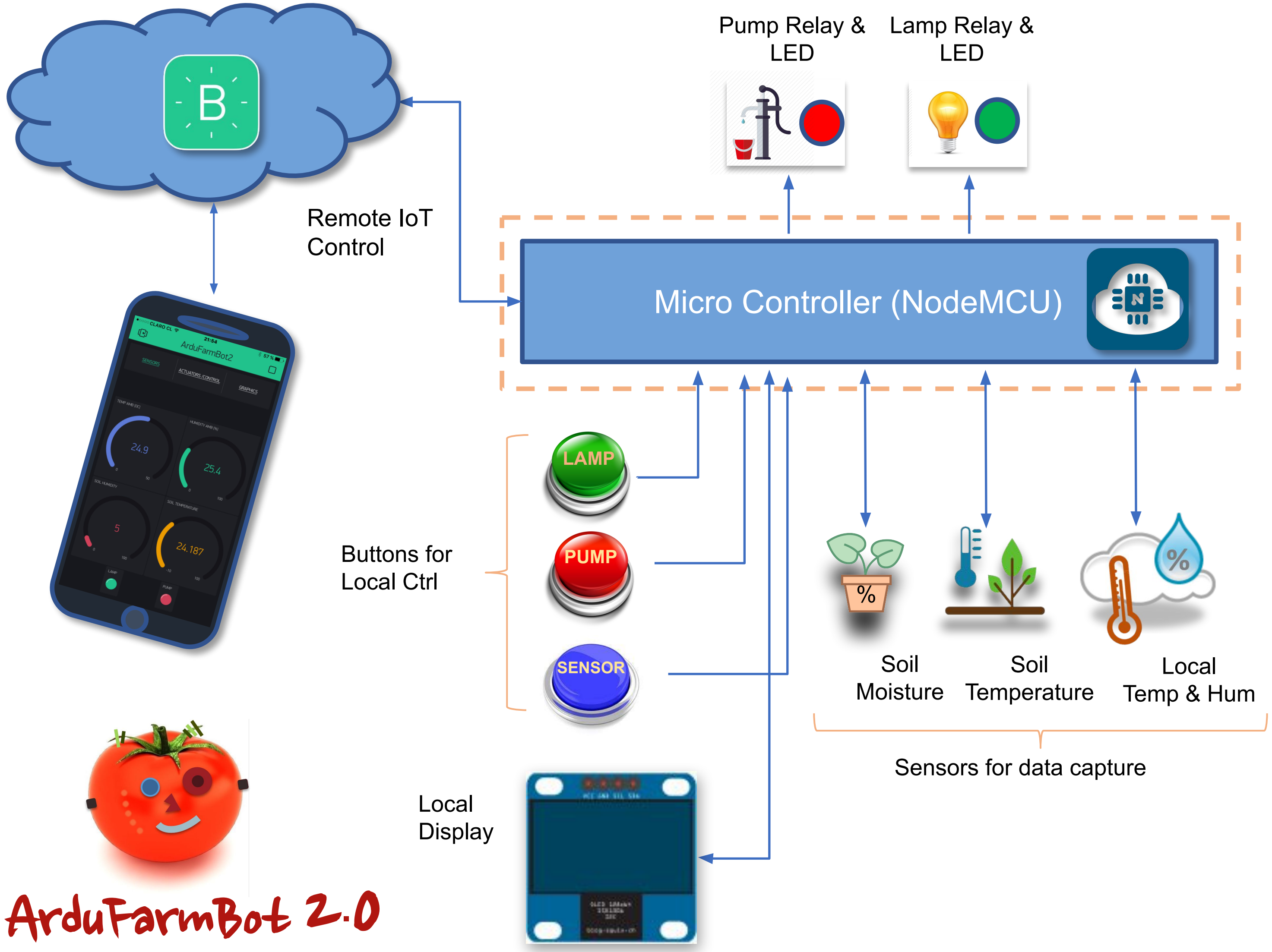
Typical IoT Project

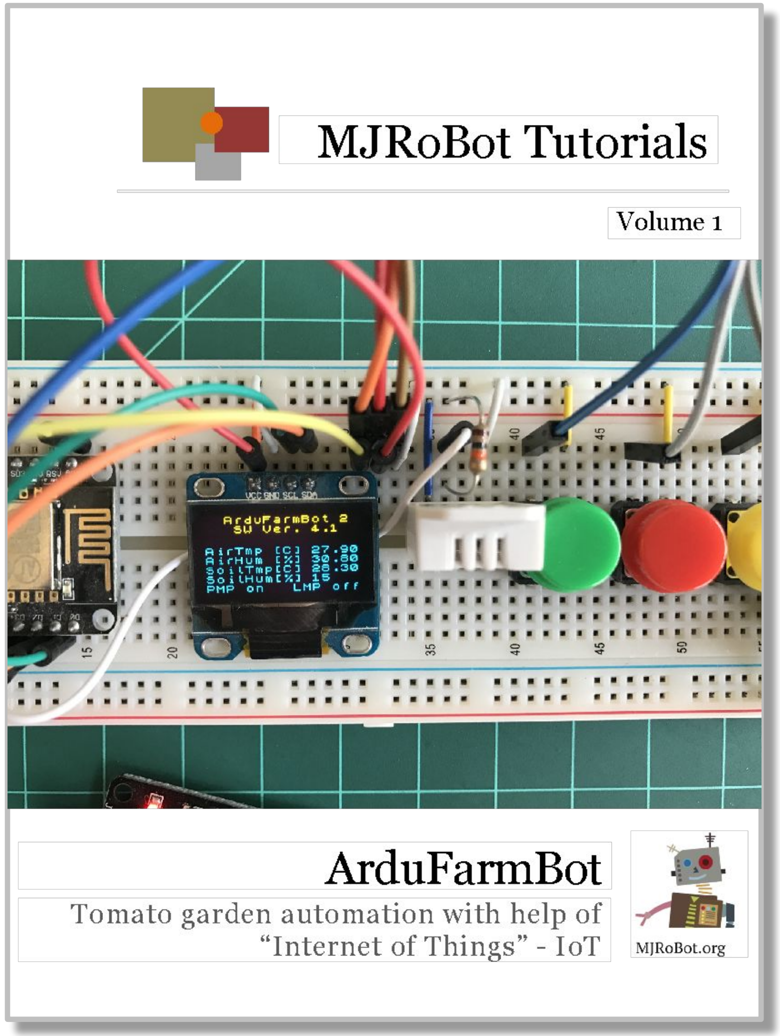


Typical IoT Project



Typical IoT Project

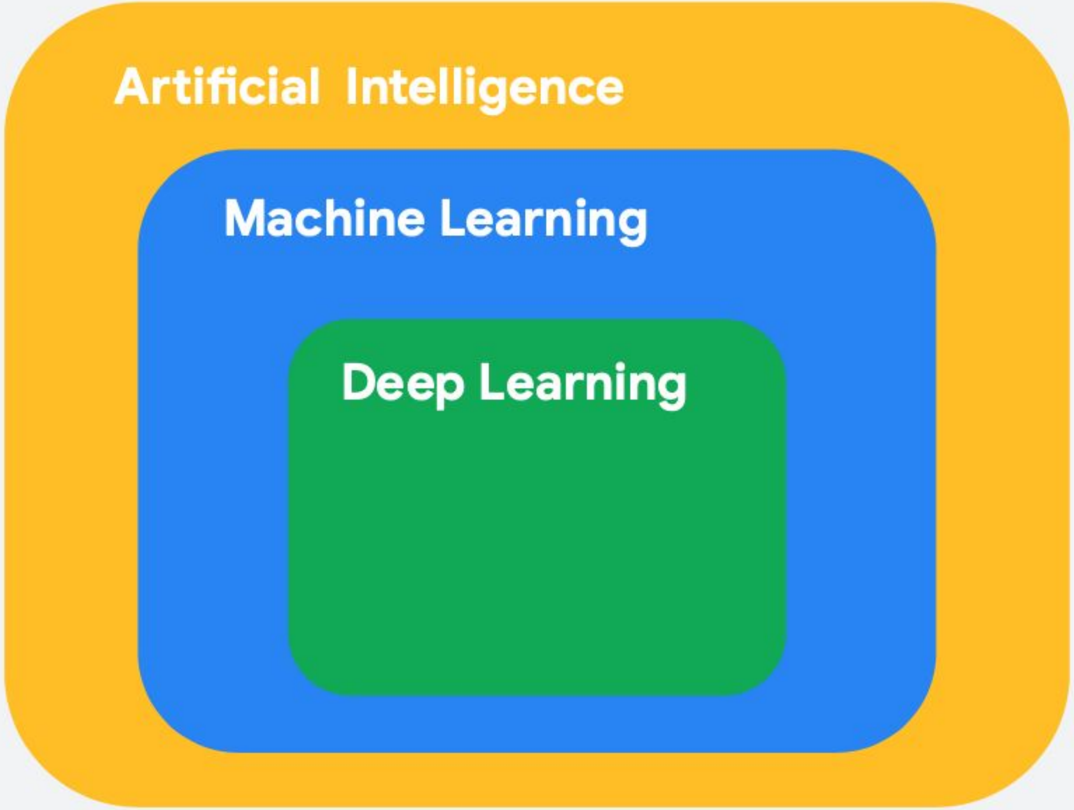




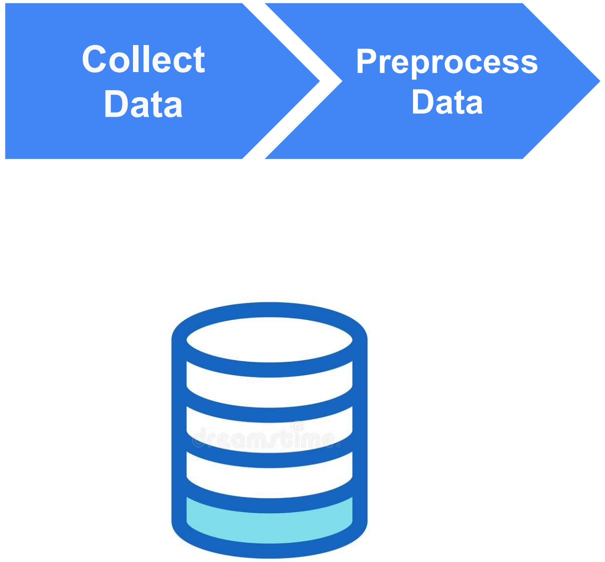
(Deep) Machine Learning

What is (Deep) Machine Learning?

1. Machine Learning is a subfield of Artificial Intelligence focused on developing algorithms that learn to solve problems by analyzing data for patterns
2. **Deep Learning** is a type of Machine Learning that leverages **Neural Networks** and **Big Data**



Machine Learning Project start with Data



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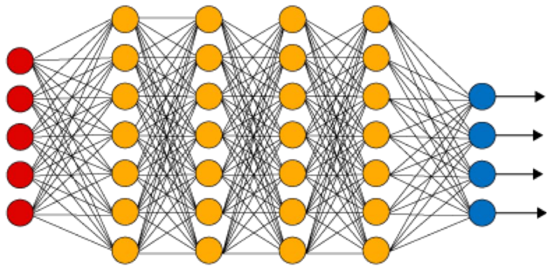
Machine Learning Model

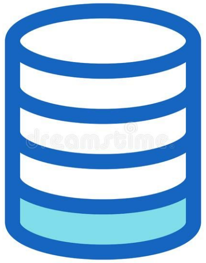


Collect Data

Preprocess Data

Design a Model

Train a Model



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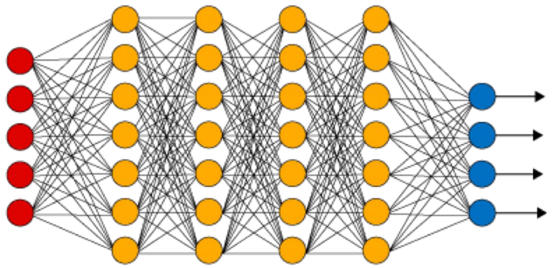
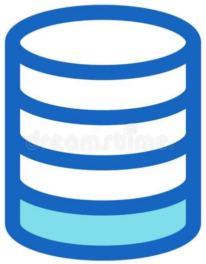
Machine Learning Model testing





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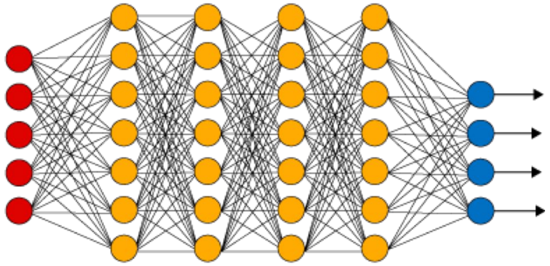
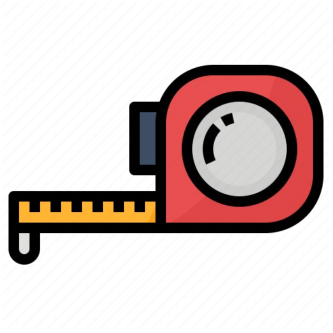
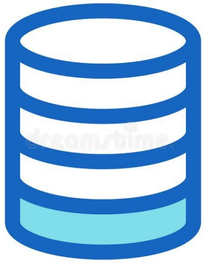
Machine Learning Deploy





Collect Data → Preprocess Data → Design a Model → Train a Model → Evaluate Optimize → Convert Model → Deploy Model → Make Inferences



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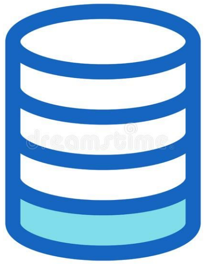
Dataset



The Dataset used in this work is the historical data retrieved from ThingSpeak website from September to December 2016 (*):

On the dataset, there are 47,164 samples divided into 10 columns:

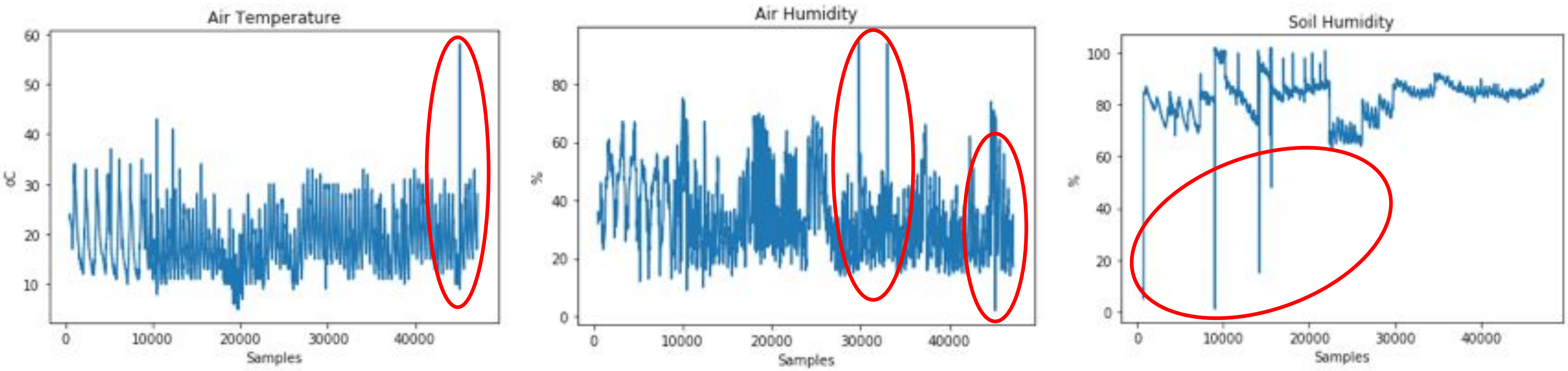
- ✔ “created_at",
- ✔ "entry_id",
- ✔ "Temperature",
- ✔ "Humidity",
- ✔ "Luminosity",
- ✔ "Soil Moisture",
- ✔ "Pump Echo",
- ✔ "Lamp Echo",
- ✔ "Capacitive Soil Moisture" and
- ✔ "Spare".

(*) https://thingspeak.com/channels/146159.

Data Preparation and Cleaning

Noise on data should be eliminated (all sample). The right range should be:

- ✔ Temperature lower than 45oC
- ✔ Air Humidity between 10% and 80%
- ✔ Soil Moisture with humidity greater than 60%



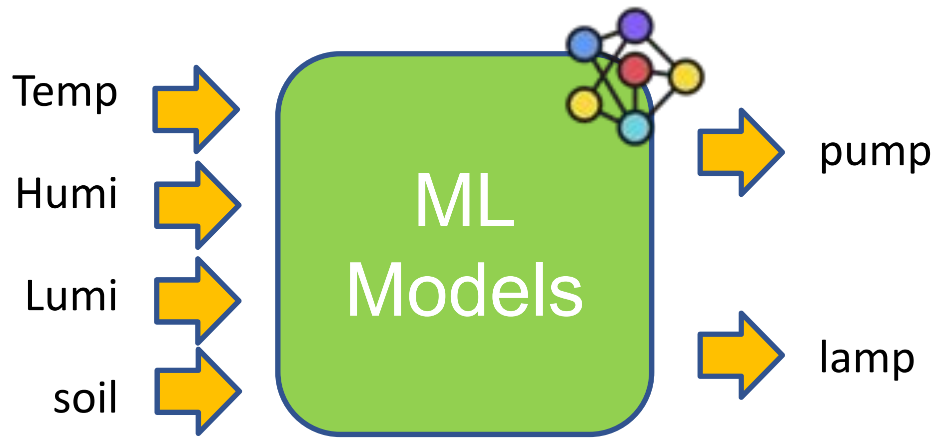
After total cleaning, around 17,700 samples are available for analyses.

Model Design and Training

- Input variables (Sensors): Temperature, Humidity, Luminosity, Soil Moisture,
- Output variables (Actuators): Pump and Lamp

	temp	humi	lumi	soil	pump	lamp
504	23.0	32.0	73.0	8.0	0.0	0.0
505	23.0	32.0	73.0	8.0	0.0	0.0
506	23.0	32.0	73.0	8.0	0.0	0.0
507	23.0	32.0	73.0	8.0	0.0	0.0
508	23.0	32.0	73.0	8.0	0.0	0.0

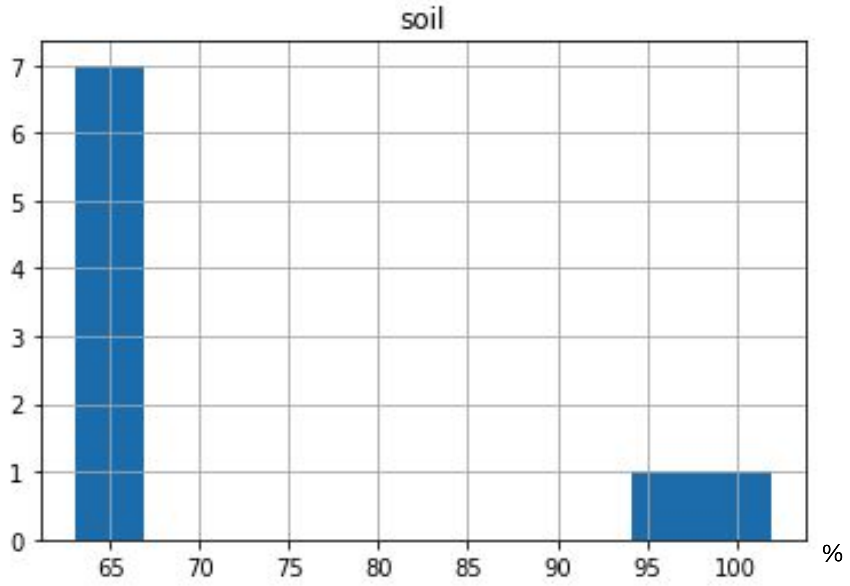
Sensors Actuators

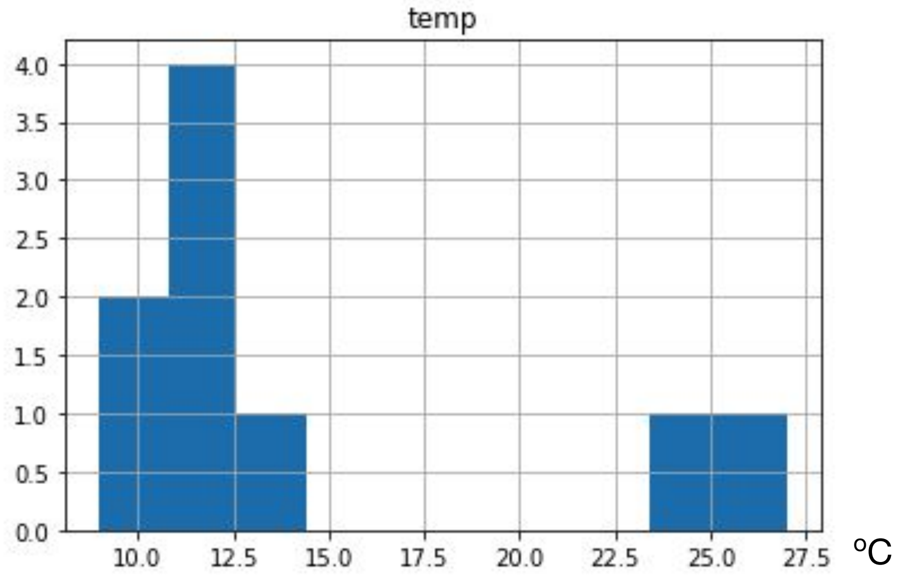


ML Models (Pump & Lamp:
Decision Tree Classificator

ML Pump Model Testing

- ✔ Applying the model on test data we got a 99% of accuracy
- ✔ Looking only on samples were target variable was “1” (Pump Turned ON), we get:

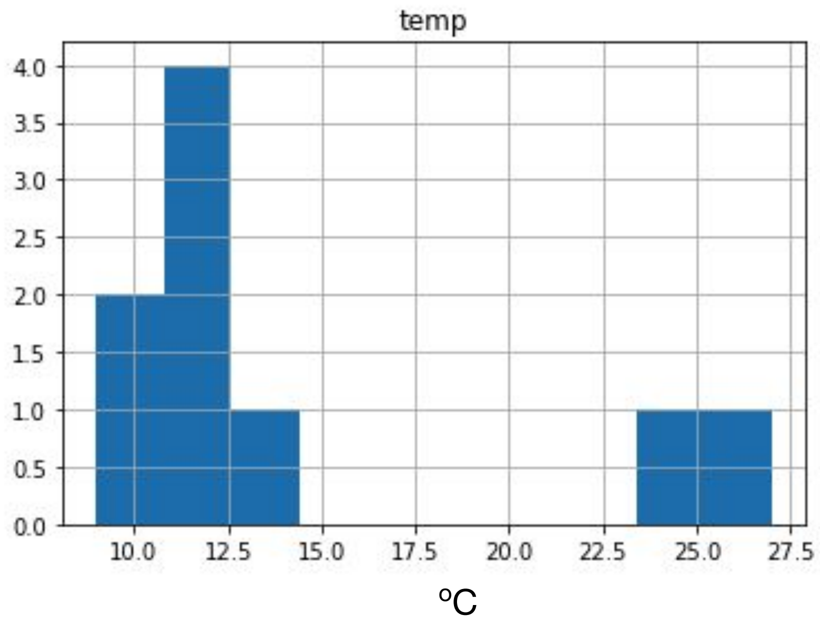




Pump is Turned ON automatically every time that soil humidity reaches its lowers at 65% and Temperature is low (10ºC to 15ºC). Some actuations also appears around 100% what should be manual commands

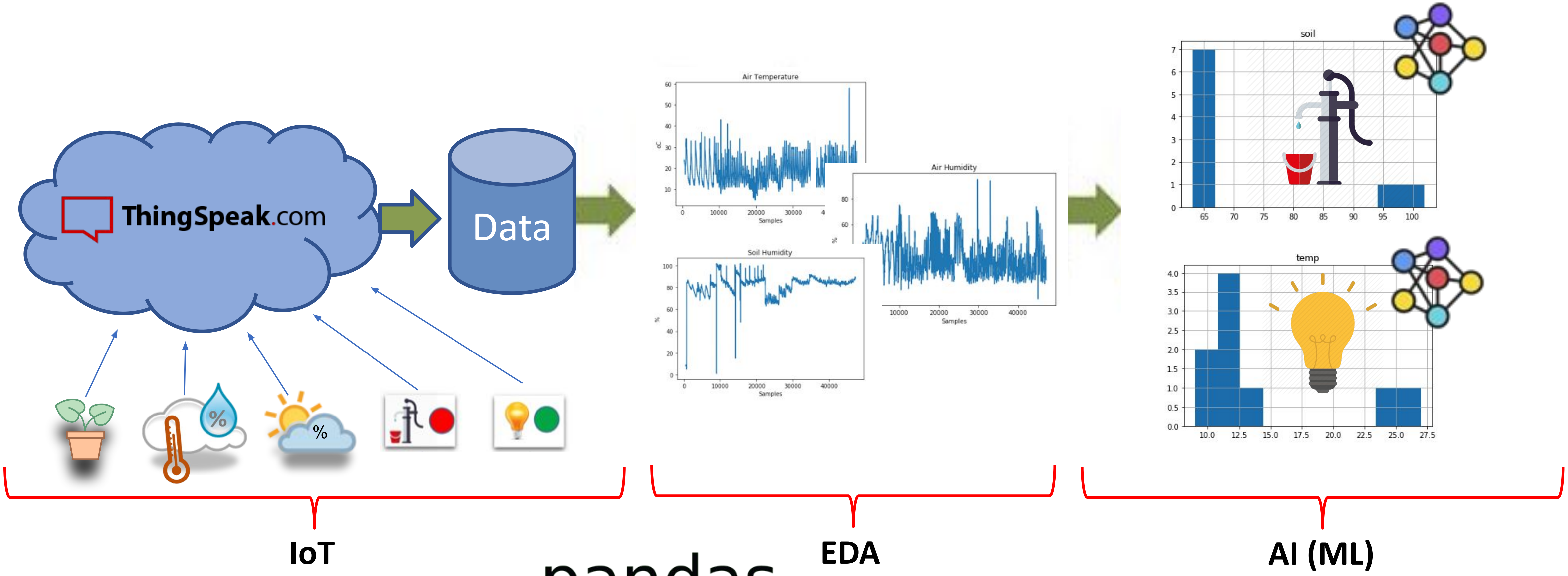
ML Lamp Model Testing

- ✔ Applying the model on test data we got a 93% of accuracy
- ✔ Looking only on samples were target variable was “1” (Lamp Turned ON), we get:



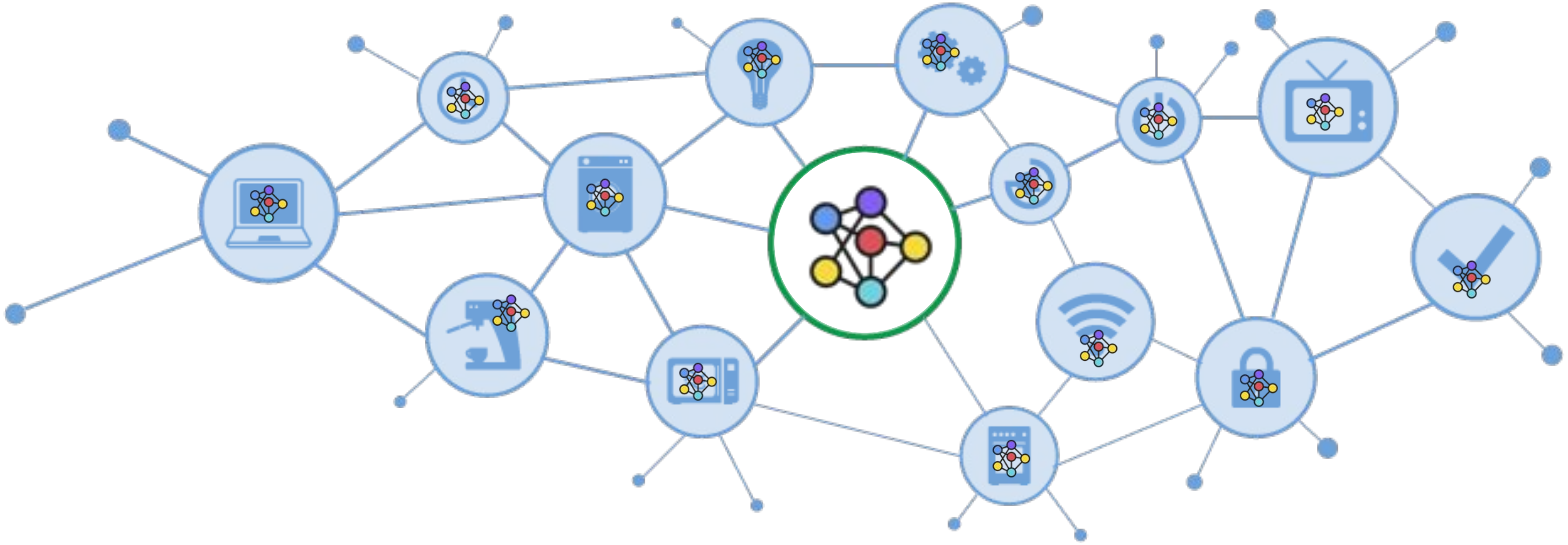
The lamp is turned ON automatically at lower temperatures (around 12°C). Some actuations also appear around 25°C what can be attributed to manual commands.

ArduFarmBot AIoT Project



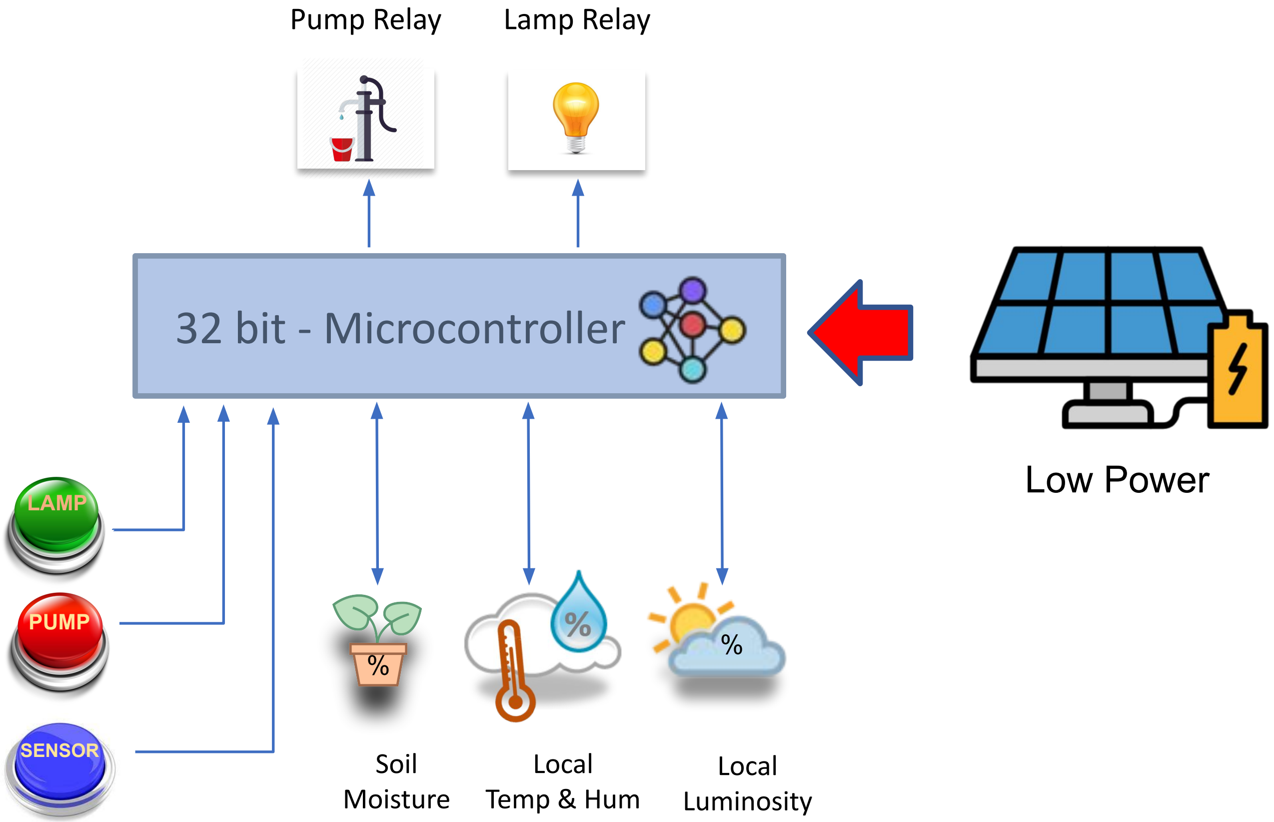
https://github.com/Mjrovai/Python4DS/tree/master/ArduFarmBot_Data_Analysis

IoT

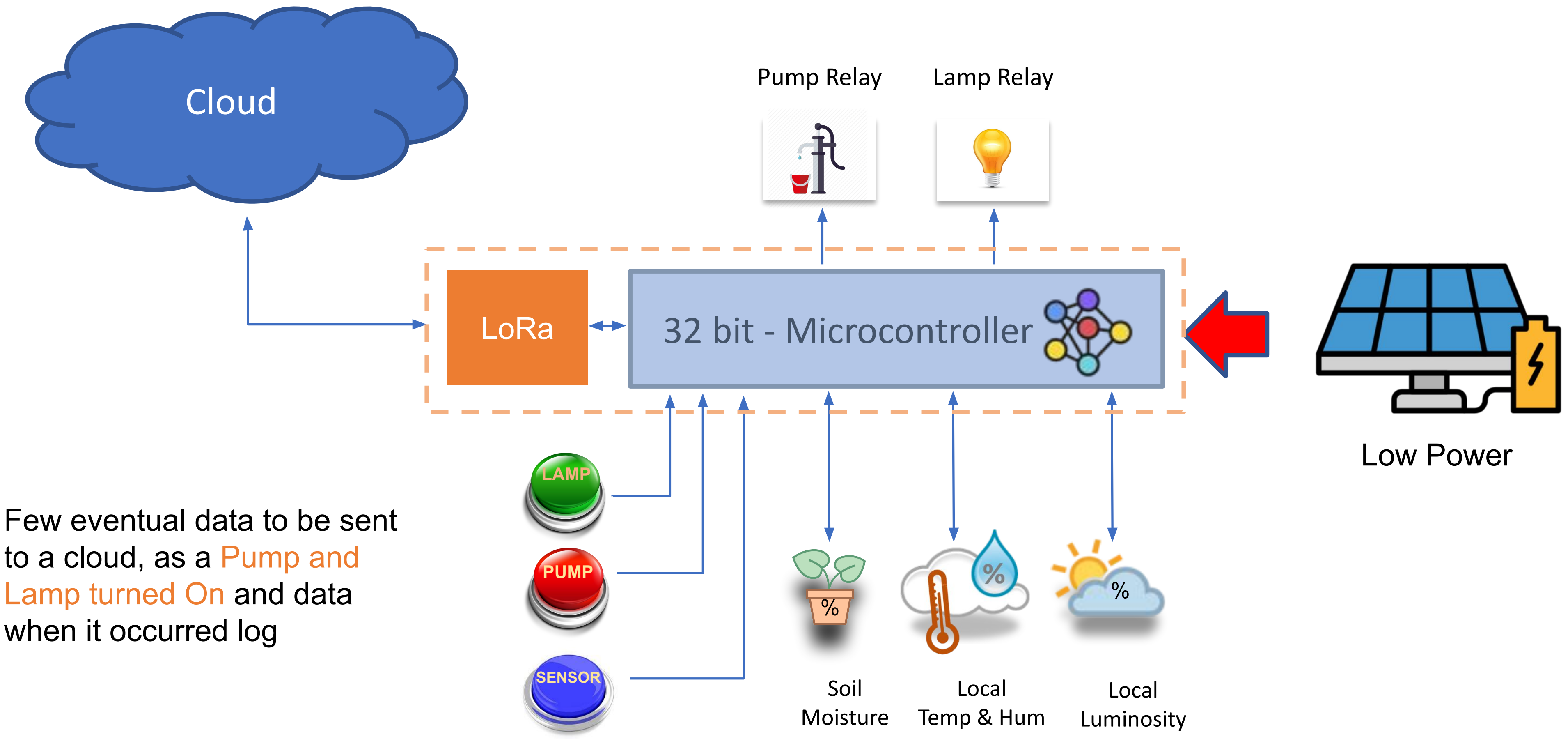


Edge(Tiny)ML

Typical EdgeML (TinyML) Project (offline)



Typical EdgeML (TinyML) Project



Few eventual data to be sent to a cloud, as a Pump and Lamp turned On and data when it occurred log

What is Tiny Machine Learning (**TinyML**)?

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TinyML

Fastest-growing field of **ML**

What is Tiny Machine Learning (TinyML)?

TinyML

Fastest-growing field of **ML**

Algorithms, hardware, software

What is Tiny Machine Learning (**TinyML**)?

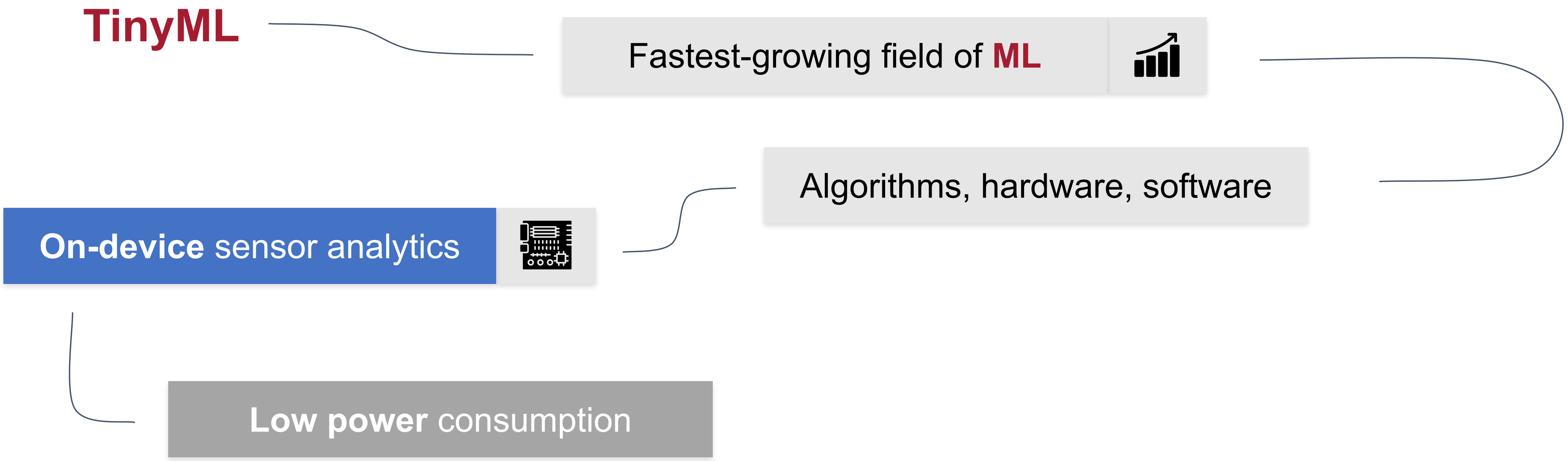
TinyML

Fastest-growing field of **ML**

Algorithms, hardware, software

On-device sensor analytics

What is Tiny Machine Learning (TinyML)?



What is Tiny Machine Learning (**TinyML**)?

TinyML

Fastest-growing field of **ML**

Algorithms, hardware, software

On-device sensor analytics

Low power consumption

Always-on ML

What is Tiny Machine Learning (**TinyML**)?

TinyML

Fastest-growing field of **ML**

Algorithms, hardware, software

On-device sensor analytics

Low power consumption

Always-on ML

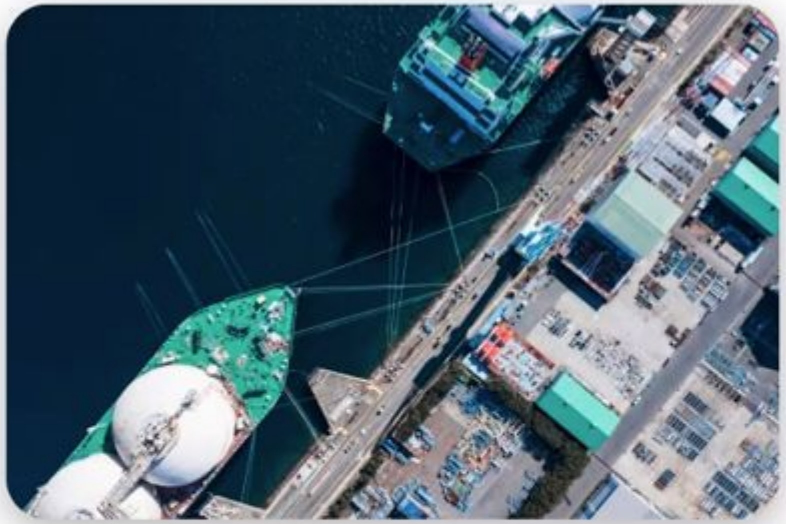
Battery-operated

Predictive Maintenance

Motion, current, audio and camera

- ➔ Industrial
- ➔ White goods
- ➔ Infrastructure
- ➔ Automotive

Asset Tracking & Monitoring



Motion, temp, humidity, position, audio and camera

- ➔ Logistics
- ➔ Infrastructure
- ➔ Buildings
- ➔ Agriculture

Human & Animal Sensing

Motion, radar, audio, PPG, ECG

- ➔ Health
- ➔ Consumer
- ➔ Industrial

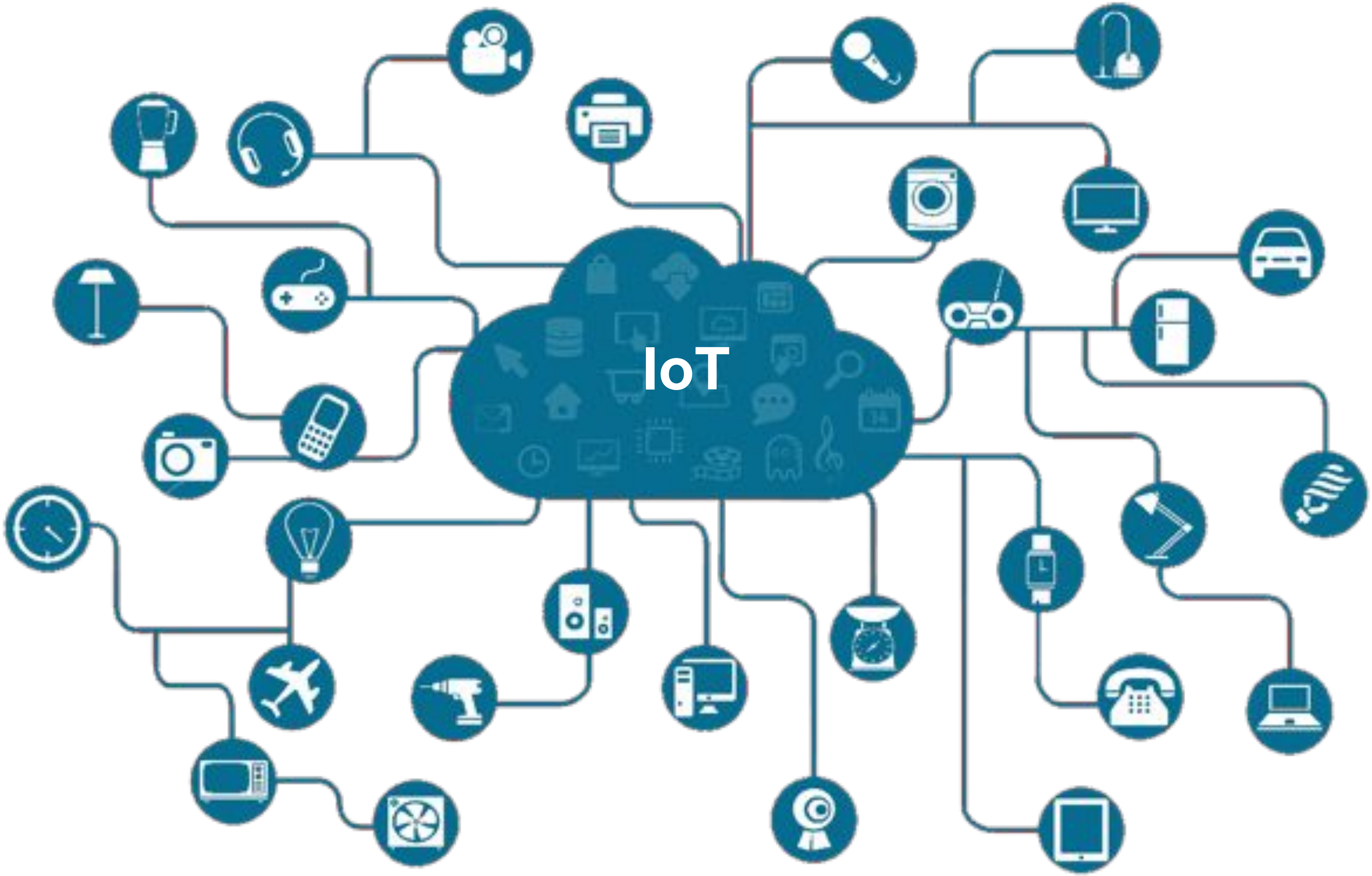
EDGE IMPULSE

Human and Animal Sensing examples

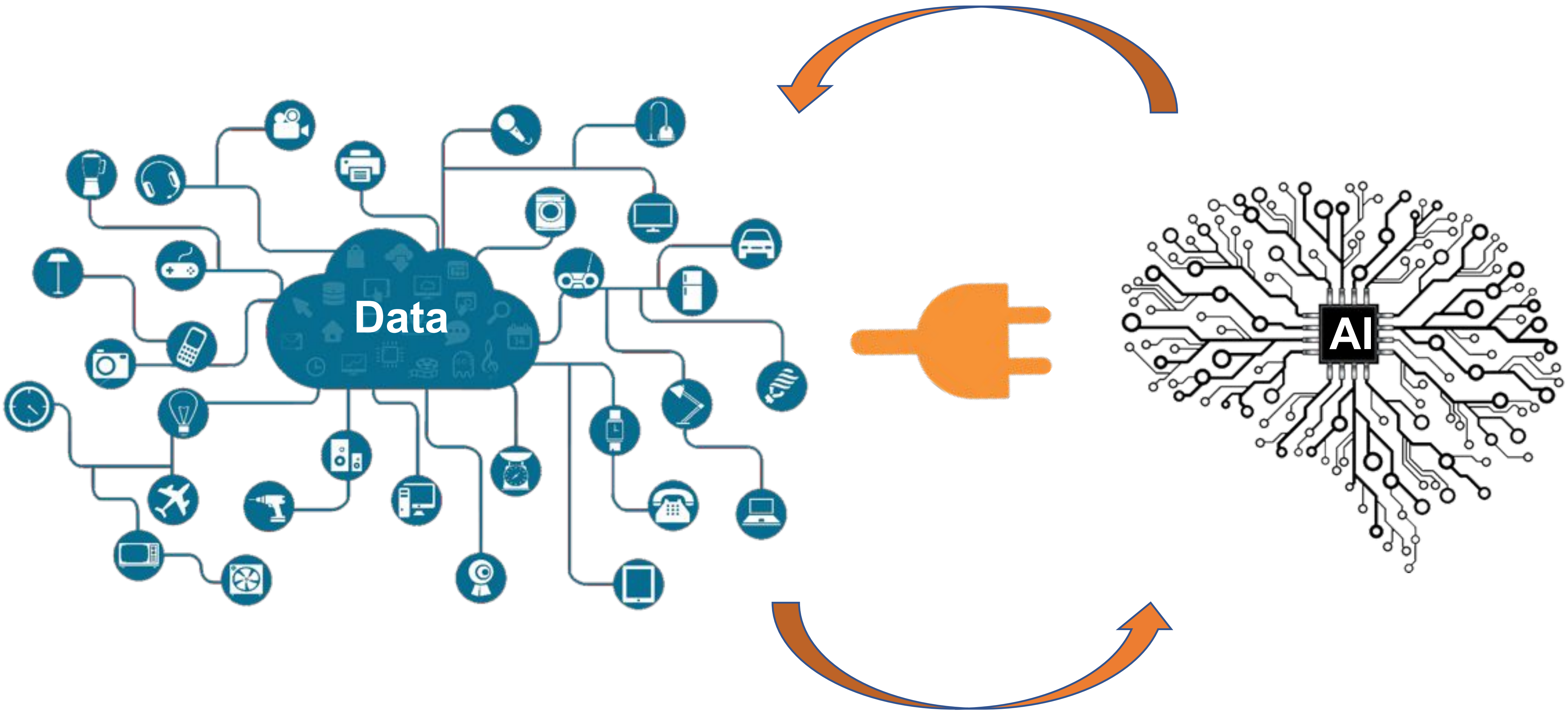
[Atrial Fibrillation Detection on ECG using TinyML
Silva et al. UNIFEI 2021]

[ElephantEdge: A New Neural Wildlife Tracker,
Powered by Edge Impulse]

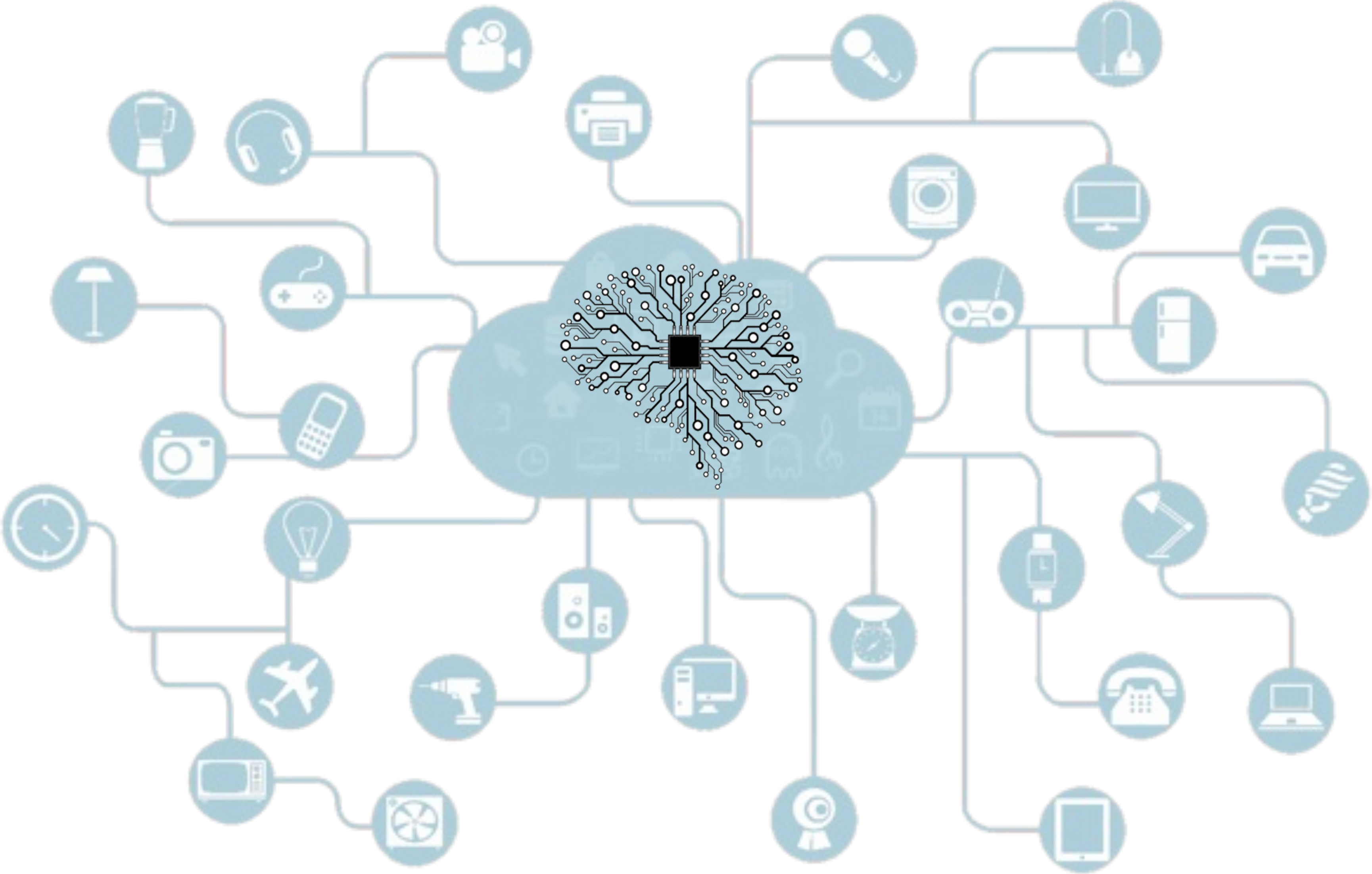
IoT - Architecture



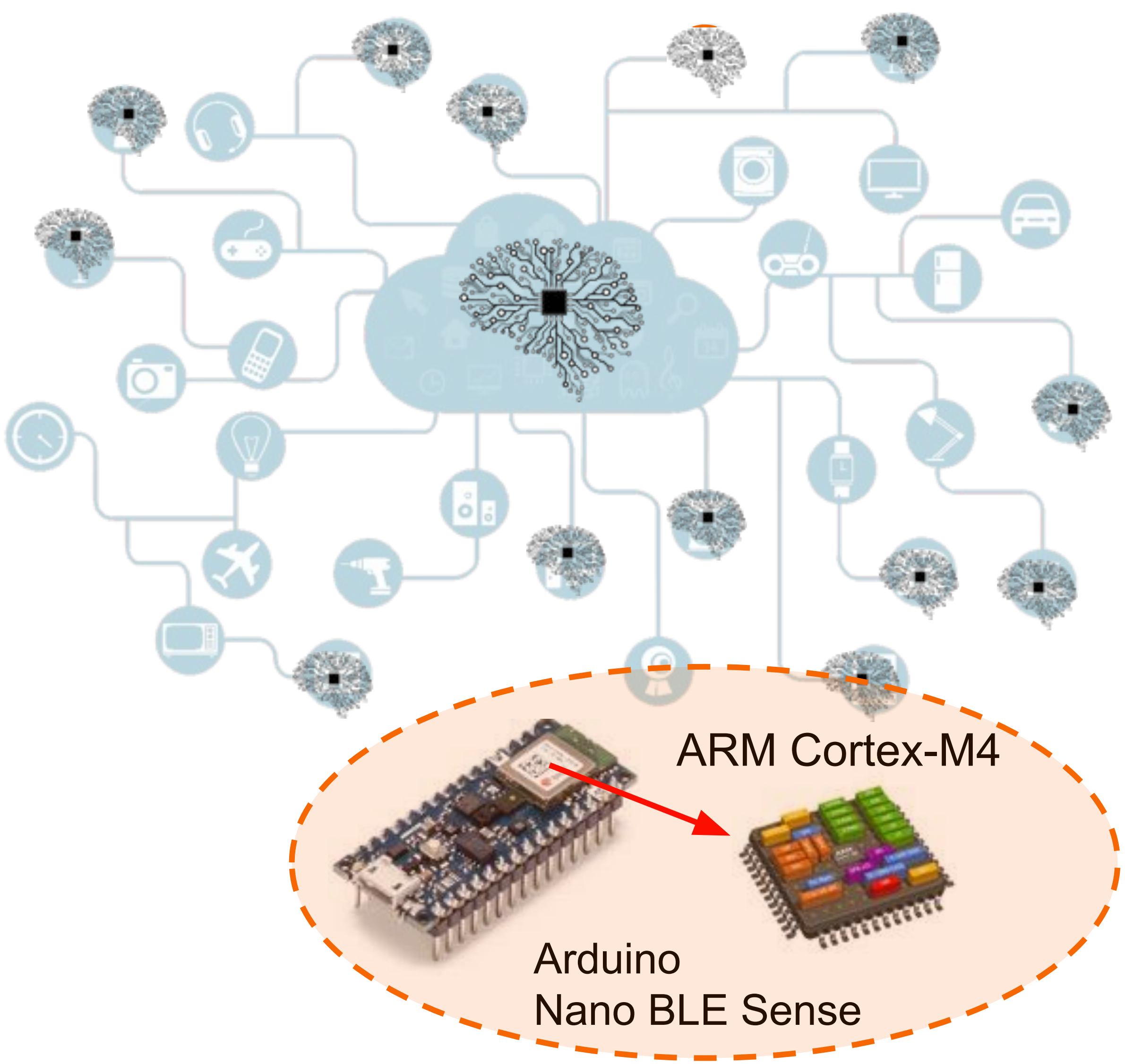
Endpoints devices ⇨ Data + AI ⇨ Value



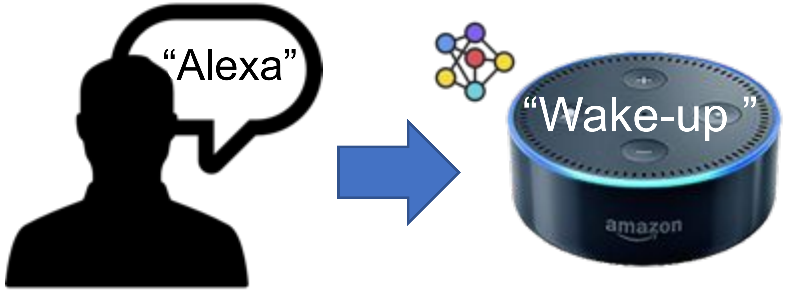
AI + IOT = AIoT



ML (AI) at the “edge of the edge”⇨TinyML

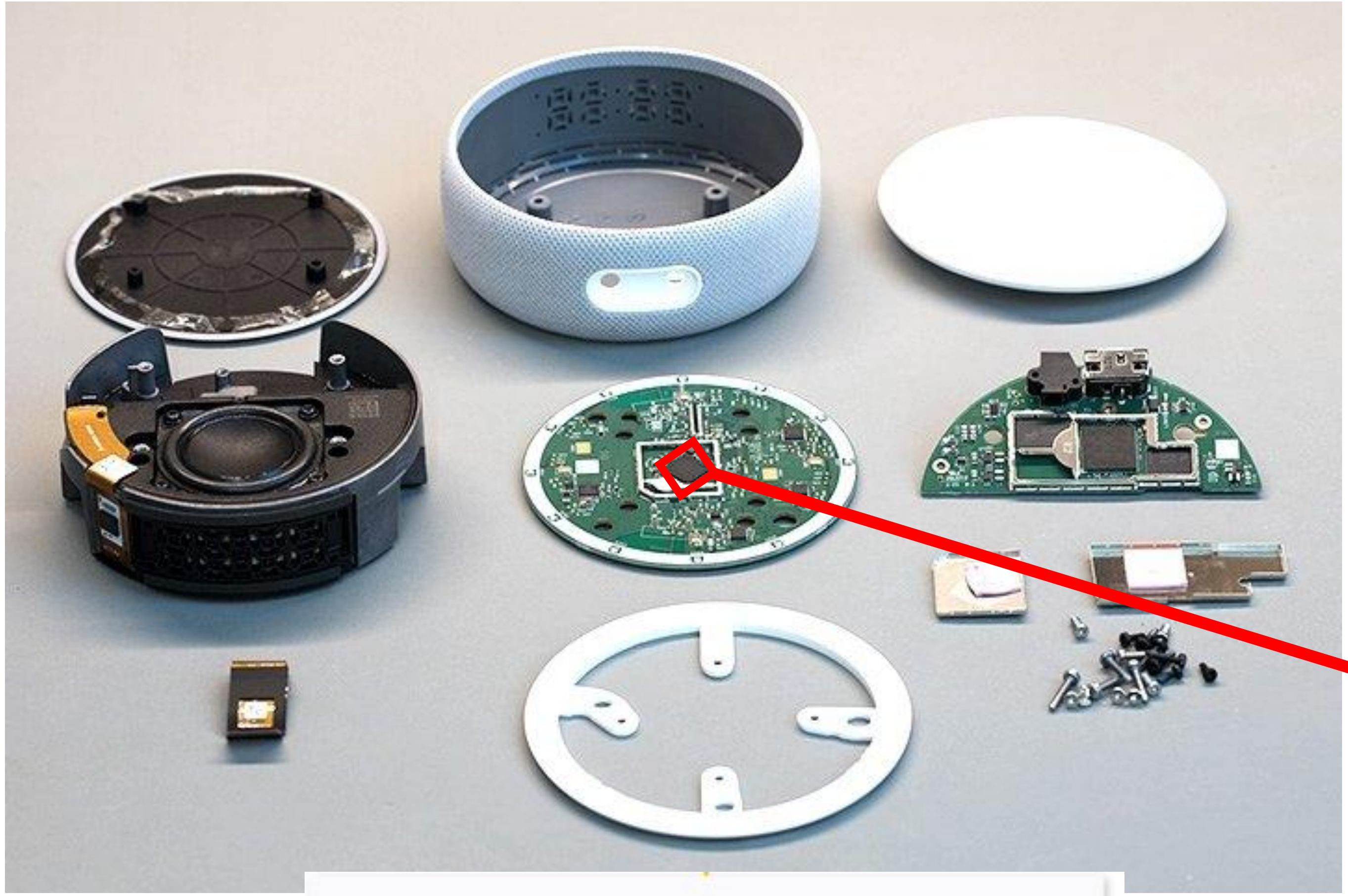


TinyML enables machine intelligence right next to the physical world



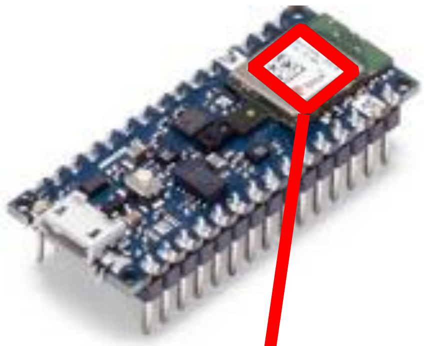
ML at microprocessor level avoid issues as Latency, Power Consuming, and Security

Echo-Dot Teardown vs Arduino Nano BLE Sense



MediaTek 7658CSN: Wi-Fi +ARM® Cortex-R4

Nordic nRF52840-M4



MCUs enable **TinyML**

SIZE

LOW POWER

LOW COST

MCUs enable **TinyML**

SIZE

LOW POWER

LOW COST

< 140 µW

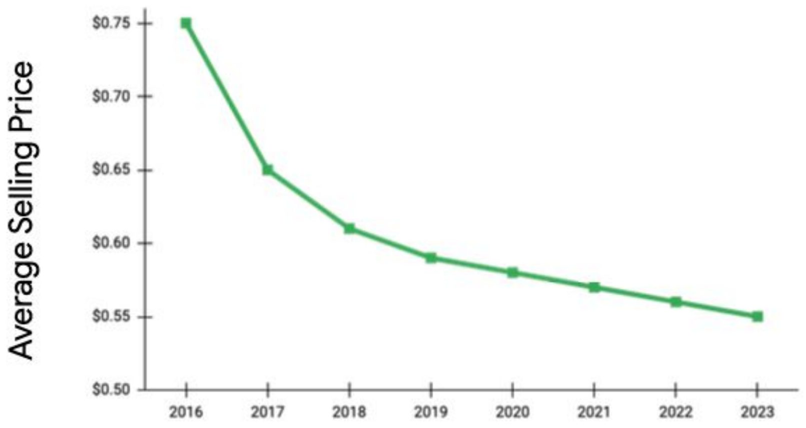
Syntiant NDP100

MCUs enable **TinyML**

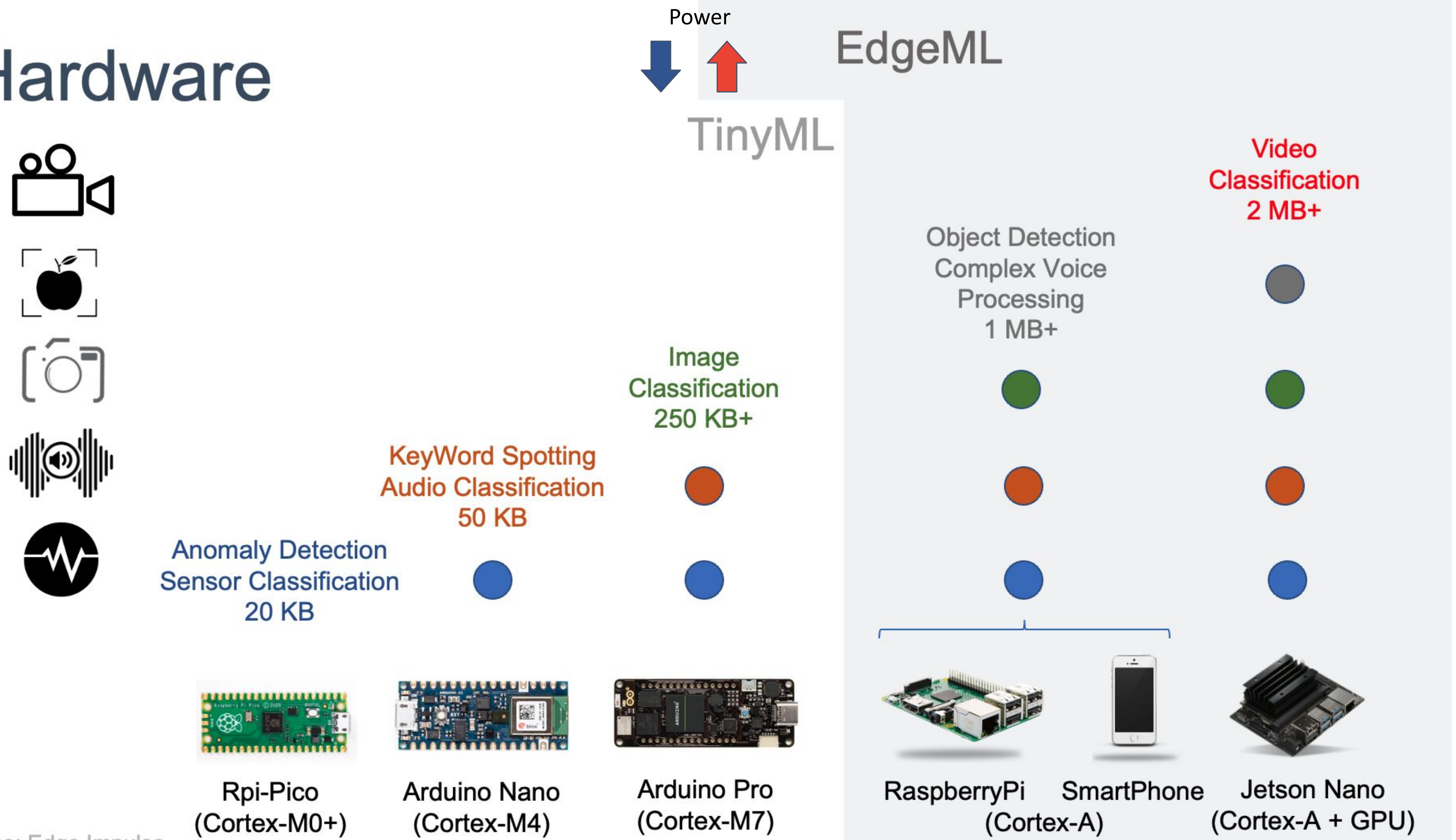
SIZE

LOW POWER

LOW COST



Hardware



Source: Edge Impulse

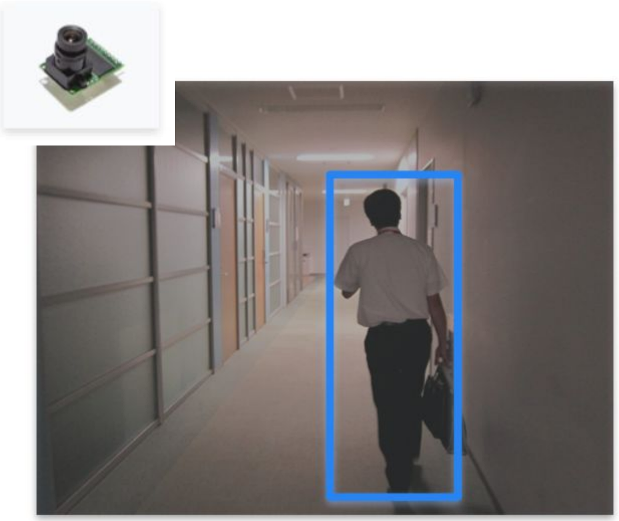
TinyML Application

Examples

Sound

Vibration

Vision



Sound

Vibration

Vision


amazon


amazon


amazon

More than just voice

- Security (Broken Glass)
- Industry (Anomaly Detection)
- Medical (Snore, Toss)
- Nature   (Bee*, Mosquito sound)

* [Smart Beehive monitoring systems]

Sound

Vibration

Vision

Cow Monitoring

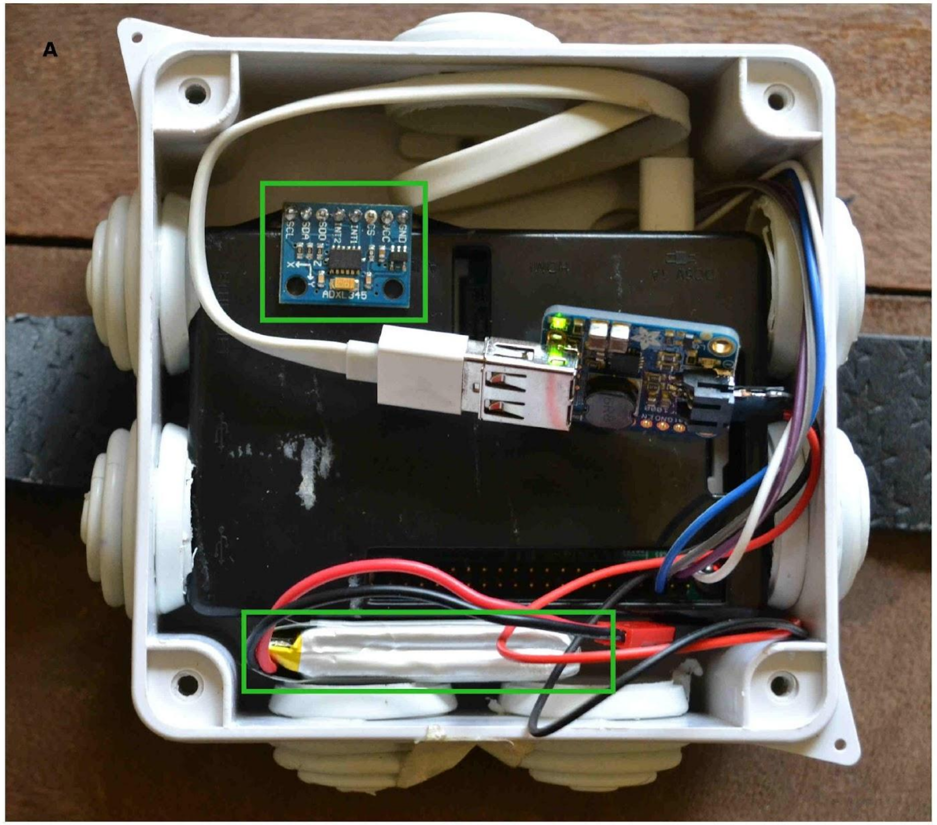
Using the Internet of Things for Agricultural Monitoring

“We aim to deploy a variety of sensors for agricultural monitoring. One of the projects involves using accelerometer sensors to monitor activity levels in dairy cows with a view to determining when the cows are on heat or when they are sick.”

Ciira wa Maina, Ph.D.

Senior Lecturer
Department of Electrical and Electronic Engineering
Dedan Kimathi University of Technology
Nyeri Kenya
Email: ciira.maina@dkut.ac.ke

Kenia



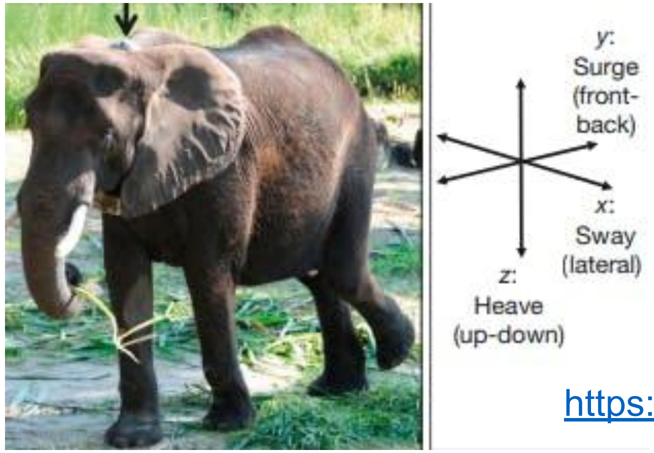
https://sites.google.com/site/cwamainadekut/research

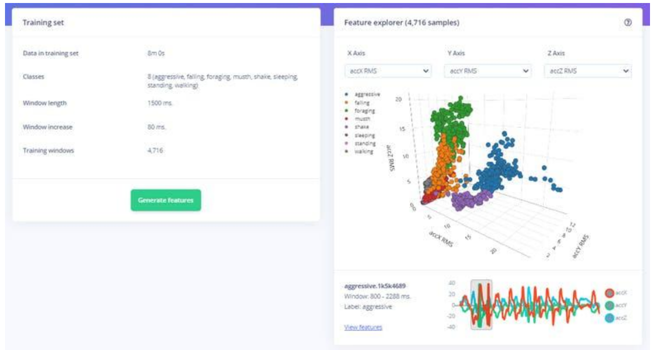
Predict and classify common Elephant behavior

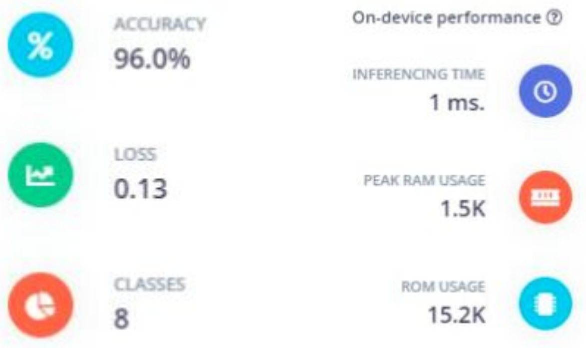
Aggressive

Standing

Sleeping

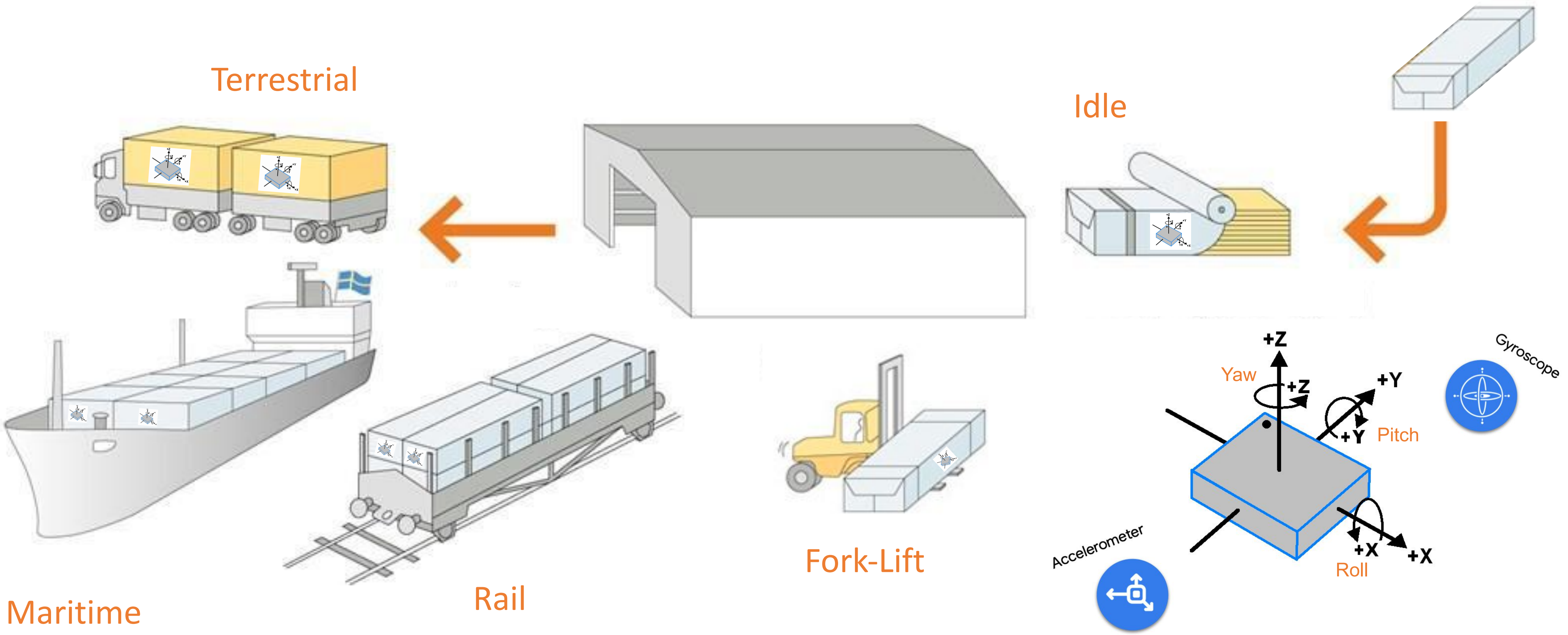






https://www.hackster.io/dhruvsheth_/eletect-tinyml-and-iot-based-smart-wildlife-tracker-c03e5a

Mechanical Stresses in Transport



[ICTP SciTyniML 21 - Hands on Embedded ML - Motion/Anomaly Detection and Scientific Applications]

Application: Factory machinery

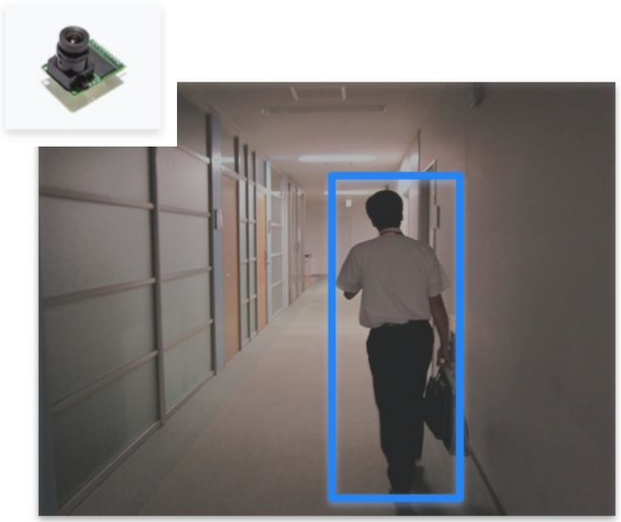
Ball Bearings

Accelerometer

Sound

Vibration

Vision



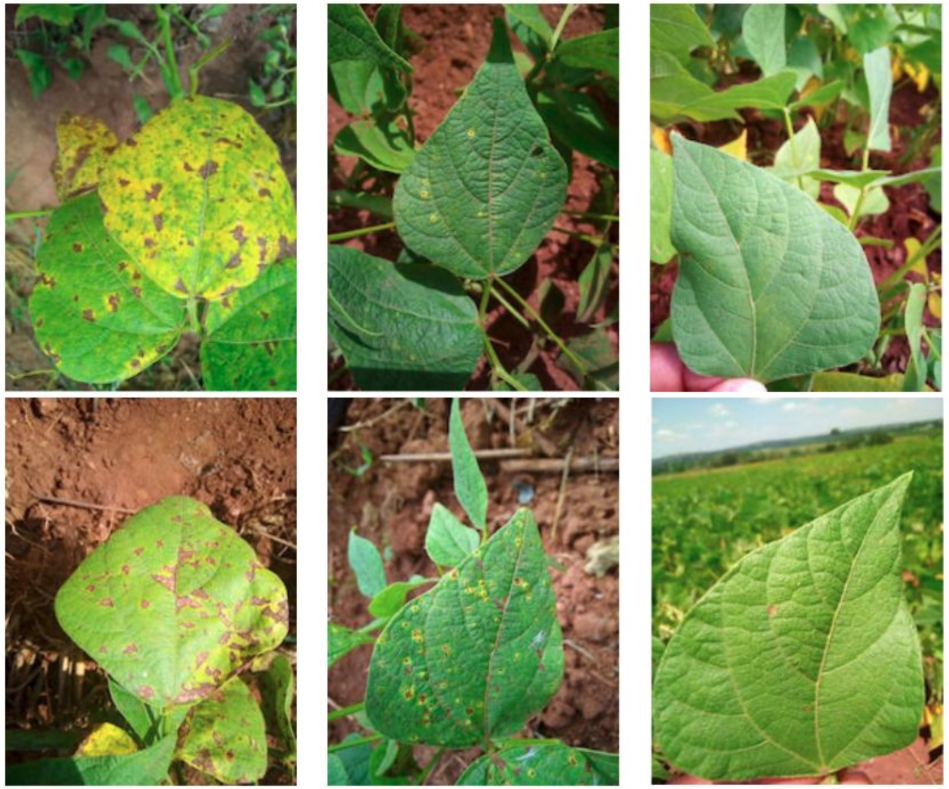
Forest Fire Detection

[TinyML Aerial Forest Fire Detection]

[IESTI01 - Forest Fire Detection – Proof of Concept]

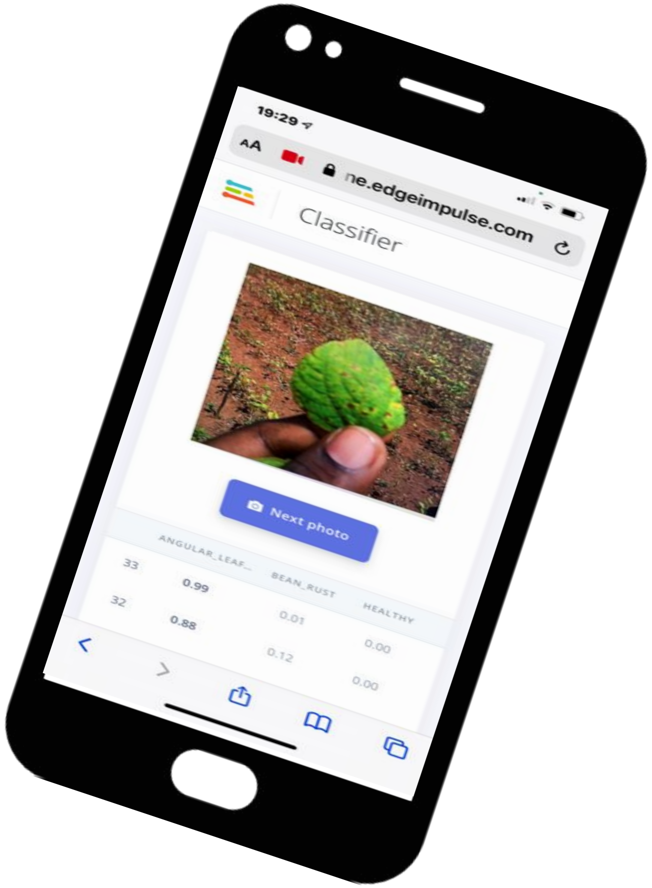
Detecting Diseases in the Bean plants

AIR Lab Makerere University
UGANDA



Angular Leaf Spot | Bean Rust | Healthy

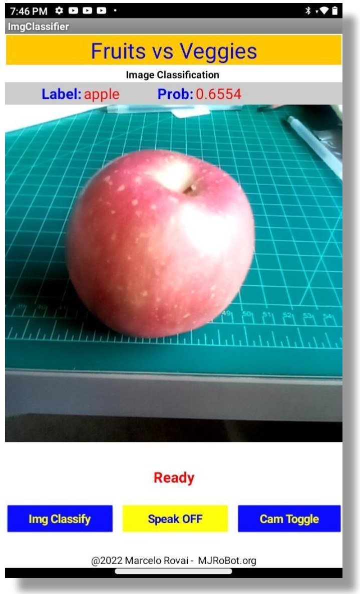
Dataset: https://github.com/AI-Lab-Makerere/ibean/

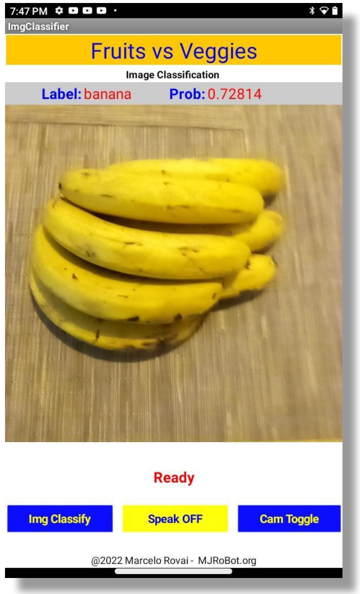


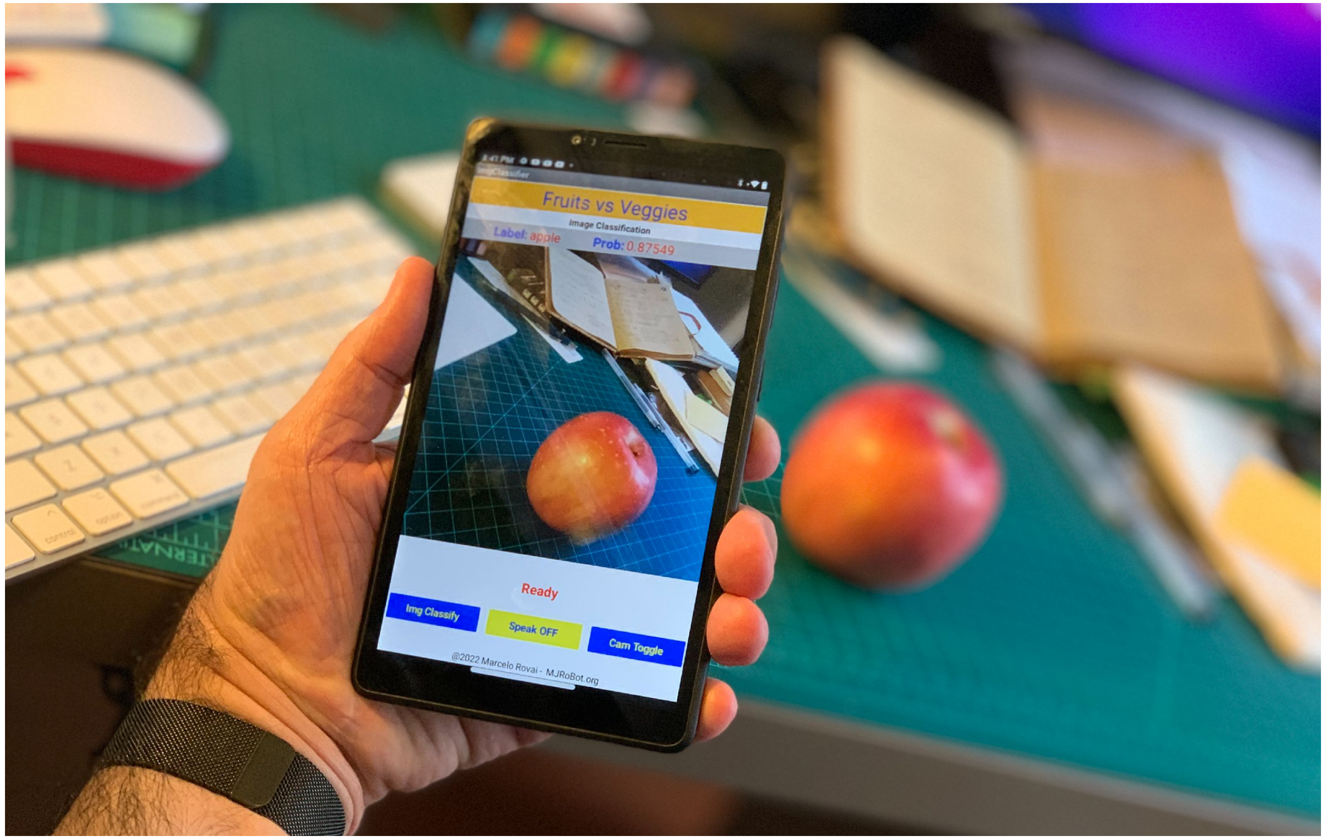
[Learn the steps to build an app that detects crop diseases]() (Android Studio)

Classifying Images using Smartphones

AI WITH APP INVENTOR







https://github.com/Mjrovai/APP_Inventor-ML_Projects

TinyML Projects – UNIFEI / MJRovai

Vision

- Coffee Disease w/ Seeed Maix Bit [Doc]
- Image Classification w/ ESP32-CAM [Doc]

Sound

- Listening Temperature w/ Nano 33 [Doc]

Vibration

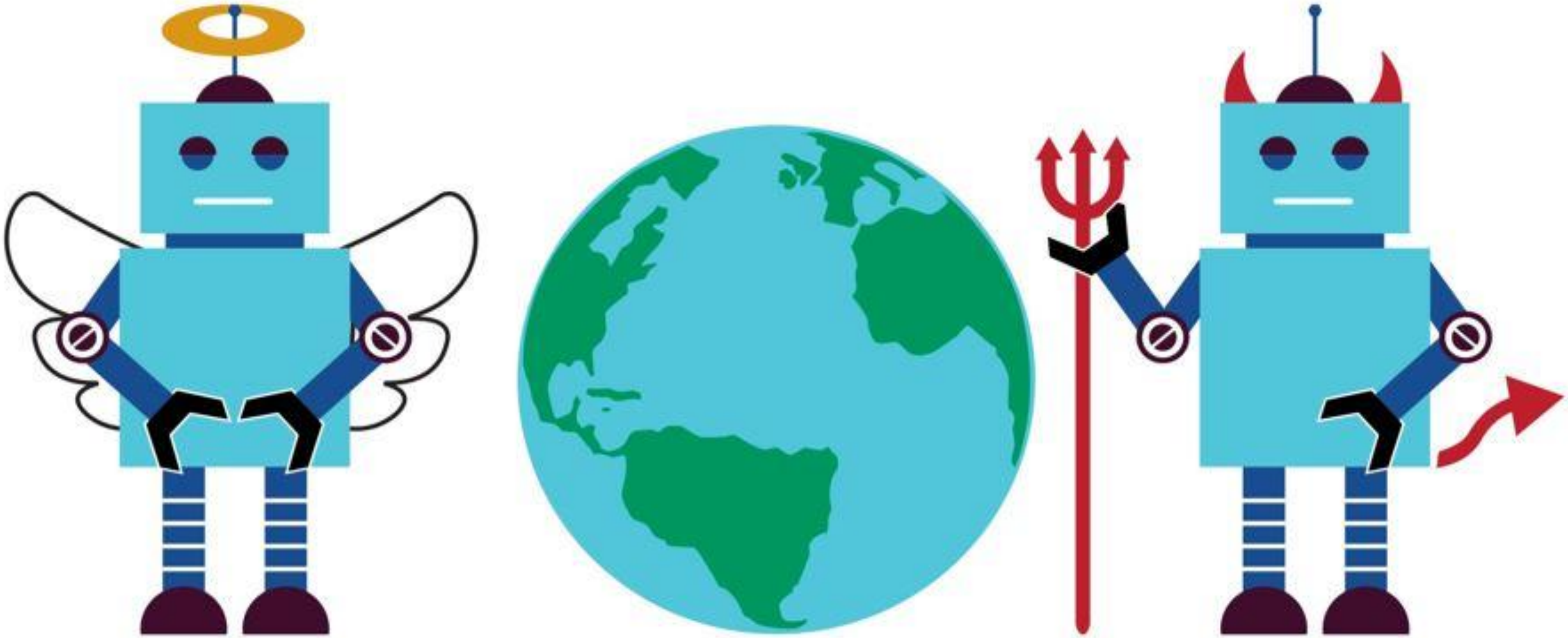
- Motion Recognition with RPi Pico [Doc]
- Gesture Recognition with Wio Terminal [Doc]

General AI <u>does not exist</u> (yet)

Dedicated TinyML Applications

- Image Classification
- Object Detection
- Sound Recognition
- Gesture / Motion Recognition
- Anomaly Detection
- …

Responsible AI



Thanks

And stay safe!

ICTP

UNIFEI