MAI4CAREU | Master programmes in Artificial Intelligence 4 Careers in Europe

University of Cyprus

MAI650 Internet of Things

Vasos Vassiliou

September - December 2023

Co-financed by the European Union
Connecting Europe Facility

This Master is run under the context of Action No 2020-EU-IA-0087, co-financed by the EU CEF Telecom under GA nr. INEA/CEF/ICT/A2020/2267423

CS6xx Internet of Things (8 ECTS)

Course purpose and objectives: The purpose of the course is to provide an overview on IoT tools and applications and to introduce to students hands-on IoT communication concepts through lab exercises.

Learning outcomes: Upon completion of this course, students will be able to explain the definition and usage of the term "Internet of Things" in different contexts. More specifically, the students will know how to apply the knowledge and skills acquired during the course to build and test a complete, working IoT system involving prototyping, programming and data analysis

Teaching methodology: interactive face-to-face lectures, group activities and discussions, in class/lab activities, student presentations and guest lectures or significant recorded public lectures

Assessment: Final exam (50%), midterm exam (20%) and assignments/project (30%).

Main text:

Rajkumar Buyya, Amir Vahid Dastjerdi, Internet of Things Principles and Paradigms, Morgan Kaufmann; 1st edition, 2016

J. Biron and J. Follett, "Foundational Elements of an IoT Solution", O'Reilly Media, 2016.

Other reading:

Jamil Y. Khan and Mehmet R. Yuce, Internet of Things (IoT) Systems and Applications, 2019, ISBN 9789814800297

David Hanes, Gonzalo Salgueiro, Patrick Grossetete, Robert Barton, and Jerome Henry, IoT Fundamentals: Networking Technologies, Protocols, and Use Cases for the Internet of Things, 2016, Cisco Press.

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INTRODUCTION

IoT Communication Technology - Core

CONTENTS

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INTENDED LEARNING OUTCOMES

Upon completion of this introductory unit, students will:

1. have good knowledge of LPWAN technologies
2. have a good knowledge of the types of platforms required for end-to-end application development over various LPWAN technologies
3. have a good understanding of the design principles of edge systems vs the network access method
4. be able to (skills):
    1. Architect a system over a certain type of LPWAN
    2. Make cost assessment related to the selection of equipment for the use of a specific LPWAN
5. be will (competences):
    1. be capable of taking some responsibility in system architecture and business analysis of IoT solutions over LPWAN IoT networks

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Introduction

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Introduction

- By 2020 more than 25 billion devices will be connected through wireless communications
- Great opportunity for new IoT applications in different domains like smart cities, healthcare, agriculture etc.

- IoT applications have specific requirements such as:
  - Low data rate
  - Long range
  - Low energy consumption
  - Low cost
- Success of IoT applications assume the satisfaction of the above requirements

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Introduction

- Current technologies like ZigBee, Bluetooth,3G,4G etc failed to meet all the requirements
- ZigBee and Bluetooth are not adapted for scenarios that require long range communications
- Cellular technologies can provide long range communications but consume more energy

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LPWAN

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Low Power Wide Area Network (LPWAN)

Low Power Wide Area Network (LPWAN) is the wireless communication technology to support IoT applications’ requirements

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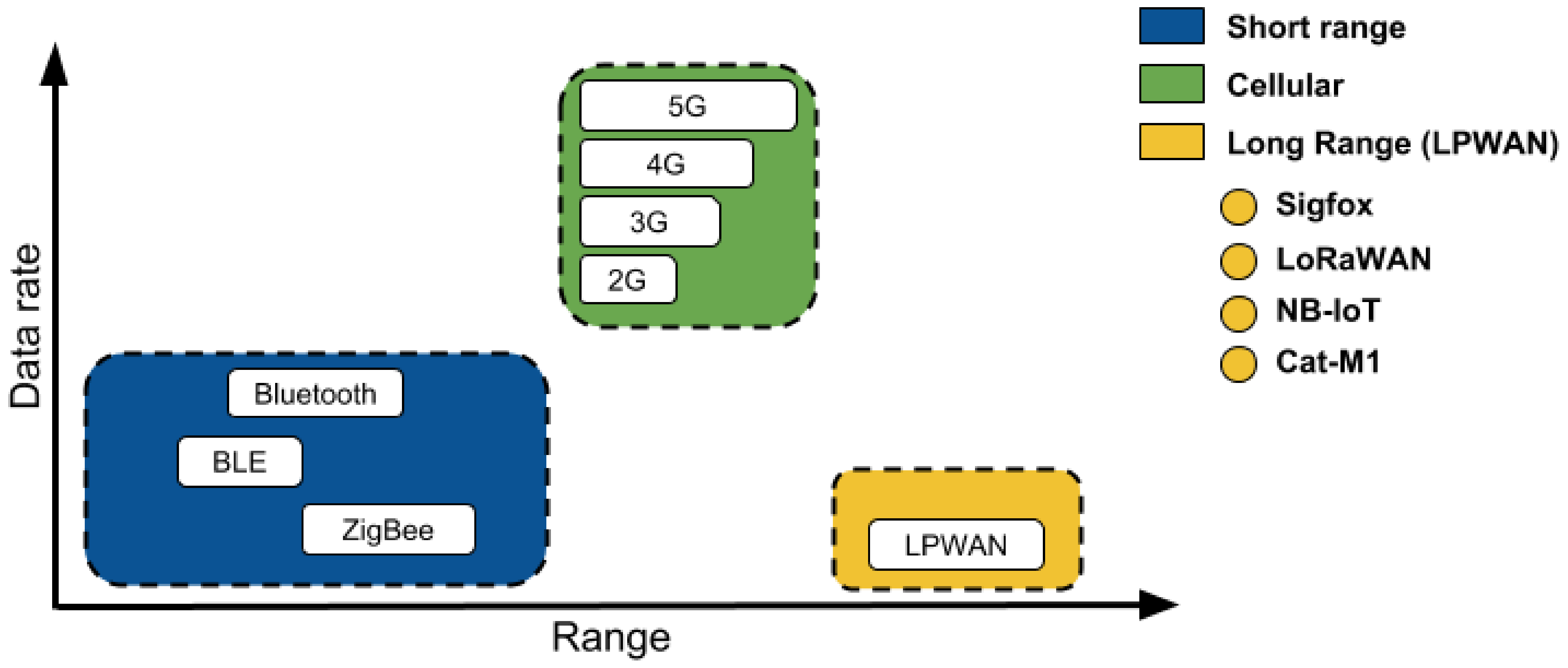
LPWAN Characteristics

- **Range**: 10-40km in rural zones and 1-5 km in urban zones
- **Energy efficiency**: more than 10 years lifetime
- **Cost**: few euros ~3€



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LPWAN Important Factors

- Network Architecture
- Communication Range
- Battery Lifetime
- Robustness to interference
- Network capacity
- Network security
- One-way or two-way communication

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LPWAN Technologies

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LPWAN Technologies

- Mostly unlicensed (but regulated) spectrum under 1 GHz (433, 868, 915 MHz)

- Leading technologies

LoRa™ sigfox NB-IoT™

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LoRa

- LoRa Long Range
- The Physical layer or the wireless modulation
- Utilized to create long range communication link
- LoRa is based on chirp spread spectrum modulation (CSS)
- CSS modulation originally developed in 1940
- Traditionally used in military applications because of two characteristics:
  - Long communication distances
  - Interference robustness
- LoRa is the first low cost implementation of CSS for commercial purposes

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LPWAN Technologies

LoRa

- Symbol rate: $RS = BW/2SF$
- SF bits per symbol
- Bit rate: $Rb = \mathrm{SF} BW/2SF$

LoRa

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LoRa

- Main advantages are the long range capability and the long great link budget
- Link budget is the primary factor in determining the range in a given environment
- Link budget typically given in decibels (dB)

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LoRaWAN

- LoRaWAN defines the communication protocol and the system architecture
- Or even simpler: LoRaWAN is the network (WAN = Wide Area Network)
- A protocol standardized by LoRa Alliance
- Current version is v1.03
- LoRaWAN networks typically are laid out in a star-of-stars topology in which gateways (also known as concentrators or base stations) relay messages between end-devices (also known as motes) and a central network server at the backend.

LoRaWAN

- Gateways are connected to the network server via standard IP connections while end-devices use single-hop LoRaTM or FSK communication to one or many gateways.
- All communication is generally bi-directional, although uplink communication from an end-device to the network server is expected to be the predominant traffic.
- Communication between end-devices and gateways is spread out on different frequency channels and data rates. The selection of the data rate is a trade-off between communication range and message duration, communications with different data rates do not interfere with each other.

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LoRaWAN

- LoRa data rates range from 0.3 kbps to 50 kbps.
- Adaptive data rate (ADR) scheme of the end-devices .
- End-devices may transmit on any channel available at any time, using any available data rate, as long as the following rules are respected:
  - The end-device changes channel in a pseudo-random fashion for every transmission. The resulting frequency diversity makes the system more robust to interferences.
  - The end-device respects the maximum transmit duty cycle relative to the sub-band used and local regulations.
  - The end-device respects the maximum transmit duration (or dwell time) relative to the sub-band used and local regulations.

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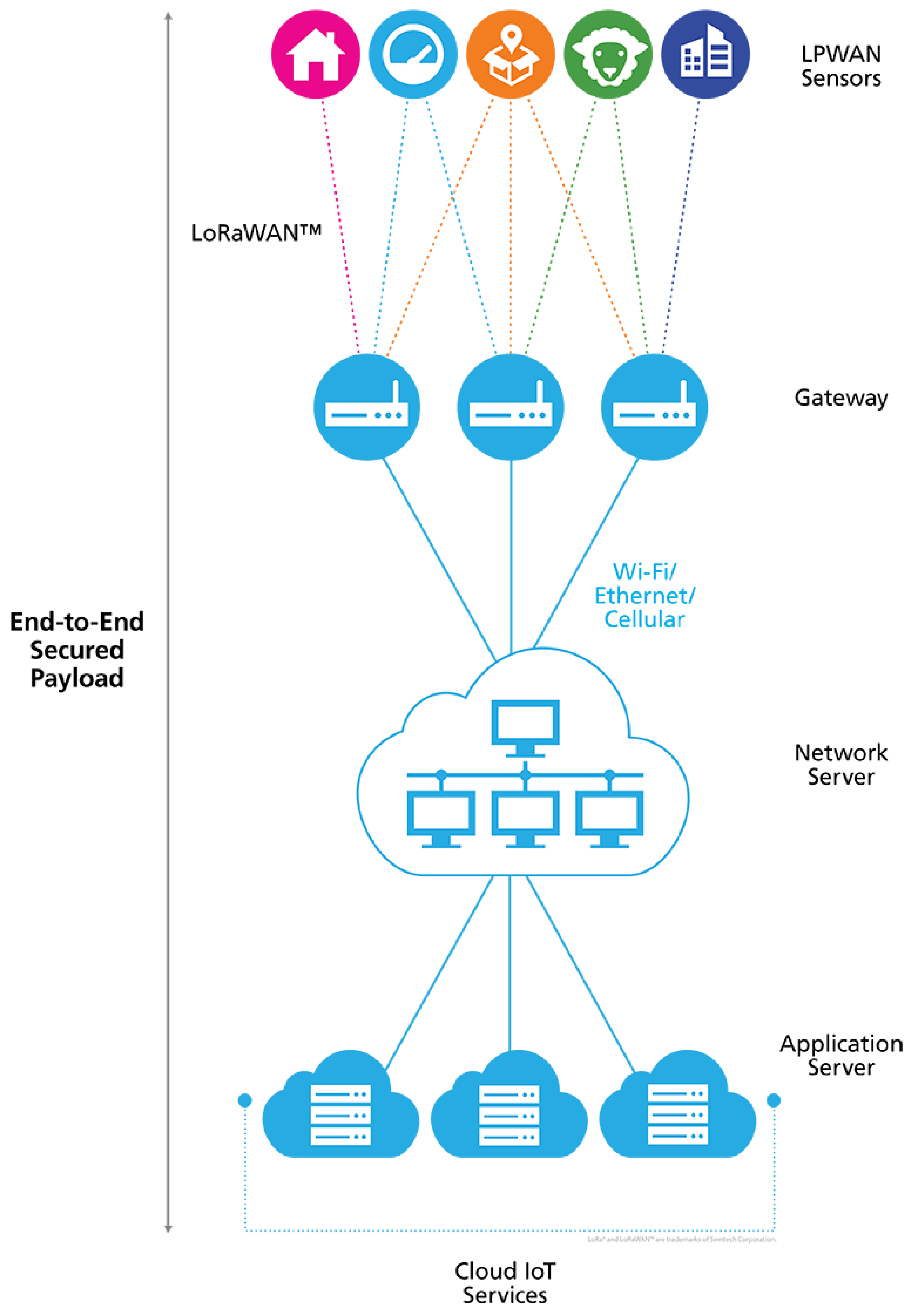
LPWAN Technologies

LoRaWAN



Source: Semtech

LoRaWAN

- All LoRaWAN devices implement at least the Class A.
- They MAY implement options named Class B, Class C
- In all cases, they must remain compatible with Class A.

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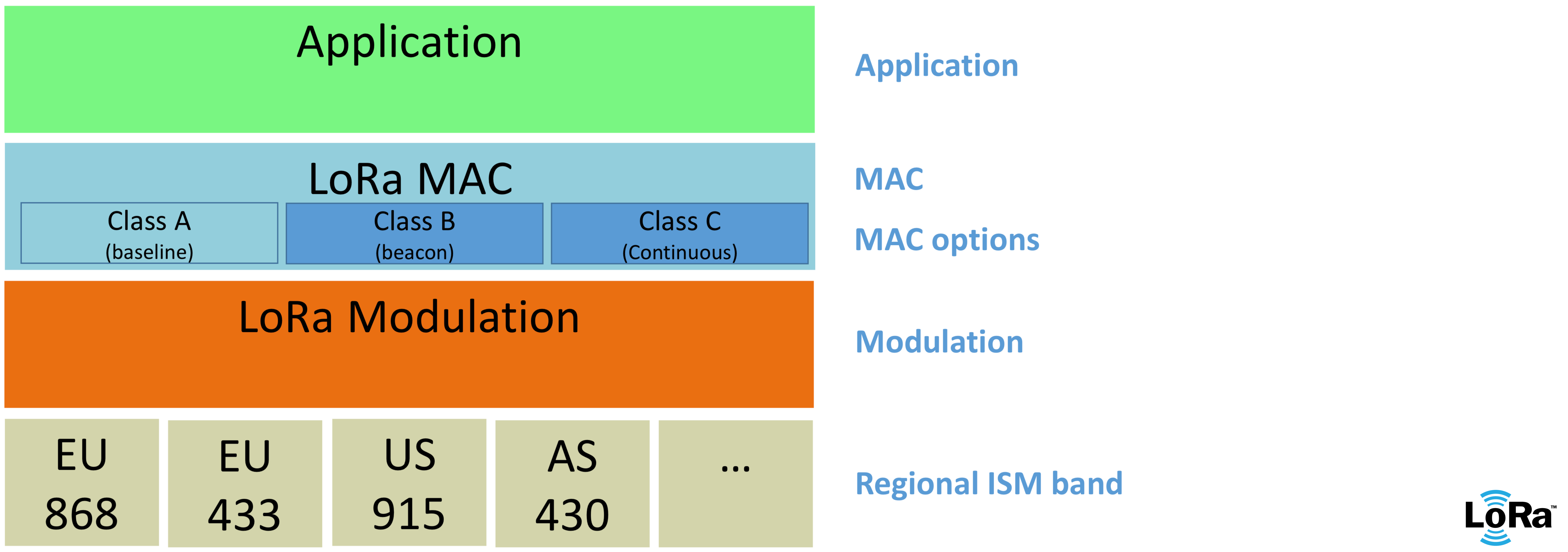
LPWAN Technologies

LoRaWAN



LoRaWAN – Class A

- End-devices allow for bi-directional communications whereby each end-device's uplink transmission is followed by two short downlink receive windows.
- The transmission slot scheduled by the end-device is based on its own communication needs with a small variation based on a random time basis (ALOHA-type of protocol).
- This Class A operation is the lowest power end-device system for applications that only require downlink communication from the server shortly after the end-device has sent an uplink transmission.
- Downlink communications from the server at any other time will have to wait until the next scheduled uplink.

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LoRaWAN – Class B

- End-devices of Class B allow for more receive slots.

- In addition to the Class A random receive windows, Class B devices open extra receive windows at scheduled times.

- In order for the End-device to open it receive window at the scheduled time it receives a time synchronized Beacon from the gateway. This allows the server to know when the end- device is listening.

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LoRaWAN – Class C

- End-devices of Class C have nearly continuously open receive windows, only closed when transmitting.

- Use more power to operate than Class A or Class B but they offer the lowest latency for server to end-device communication.

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SigFox

- Reliable and low-power solution to connect sensors and devices.
- Unlicensed 868 MHz bands with only a single operator per country.
- Coverage of 30-50 km (rural), 3-10 km (urban) and up to 1,000 km (line-of-sight).

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SigFox

- Binary phase-shift keying (BPSK) radio transmission meth
- Bi-directional functionality
- Lightweight messages (8-12 bytes, excluding payload headers)
  - Uplink 150 messages of 12 bytes per day
  - Downlink 4 messages of 8 bytes per day
- SigFox supports “spatial diversity” which means that a message sent by an object is received by any base station nearby.

sigfox

SigFox

- The protocol focus on:
  - Autonomy
  - Simplicity
  - Cost efficiency
  - Small messages
  - Complementarity

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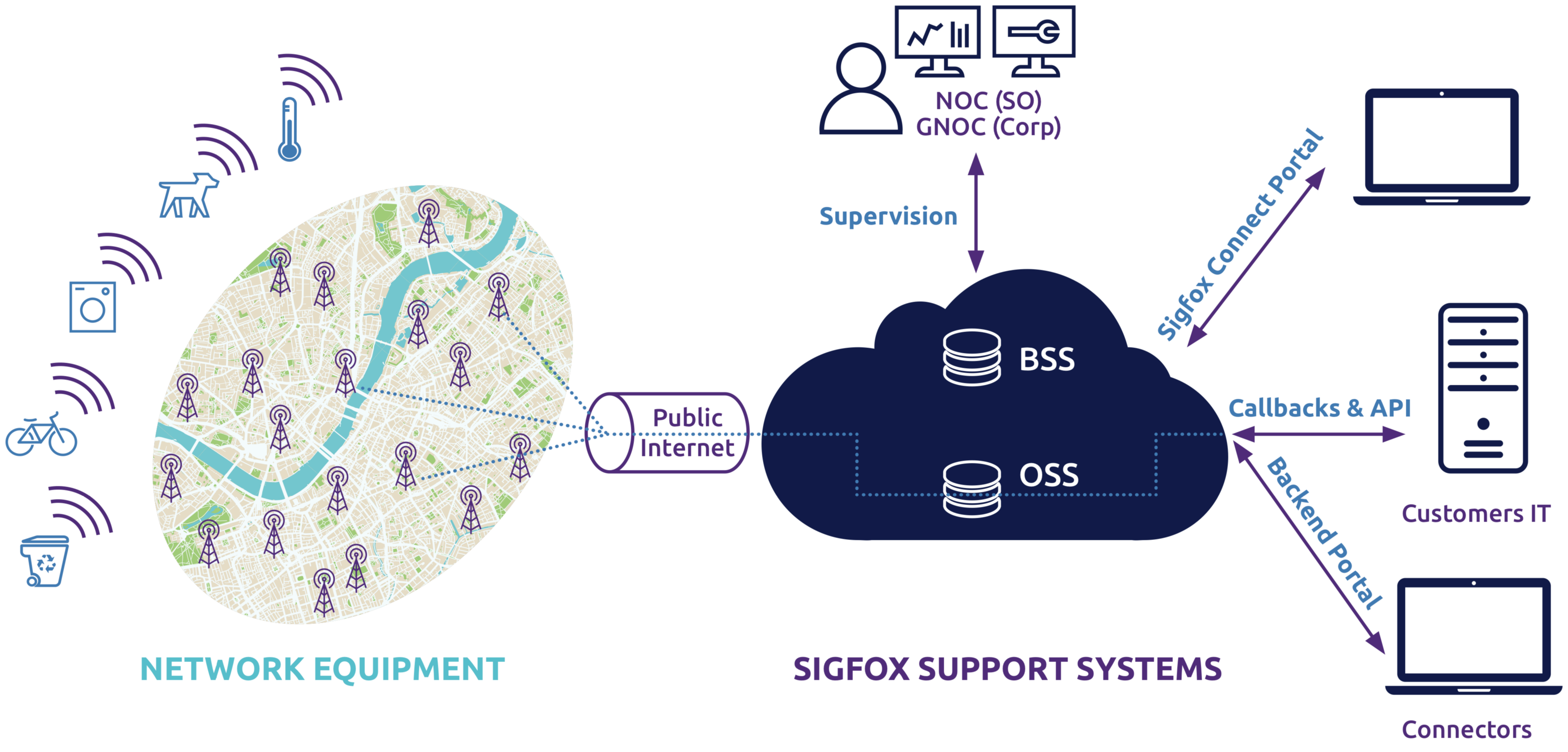
LPWAN Technologies

SigFox

LPWAN Technologies

SigFox



sigfox

SigFox

- High Network capacity:
  - Ultra-narrow band modulation
  - Spatial diversity
  - Frequency and time diversity

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SigFox

- High Energy efficiency:
  - Low chips consumption during transmission
  - High idle state – more than 99%
  - No pairing is needed thus less overhead
  - Idle consumption very low

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SigFox

- Apply security-by-default in all components

- Security support:
  - Authentication and integrity on messages
  - Cryptography
  - Payload encryption
  - Data privacy
  - more …

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LPWAN Technologies

SigFox

DEVICE

- Crypto capabilities
- Subscription management
- Device management

DATA

- Data Integrity
- Data Encryption: confidentiality
- Data privacy

RADIO

Protect DATA IN MOTION

- UNB radio robustness
- Authentication & Integrity

CLOUD

Protect DATA IN REST

- Secured hosting
- Backhaul security
- Corrupted message detection

Source: sigfox.com

sigfox

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NB – IoT

- Open Standard based on LTE
- Developed by 3GPP and standardized as part of 3GPP Release 13 in June 2016
- Licensed spectrum on a range of possible bands
- Offer 20dB coverage improvement versus GSM
- 12-15 years operation on a single battery charge

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NB – IoT

- Options of operations:
  - Stand-alone operation
  - Operation in LTE “guard band’
  - Operation within wider LTE carrier (aka inband)

NB-IoT

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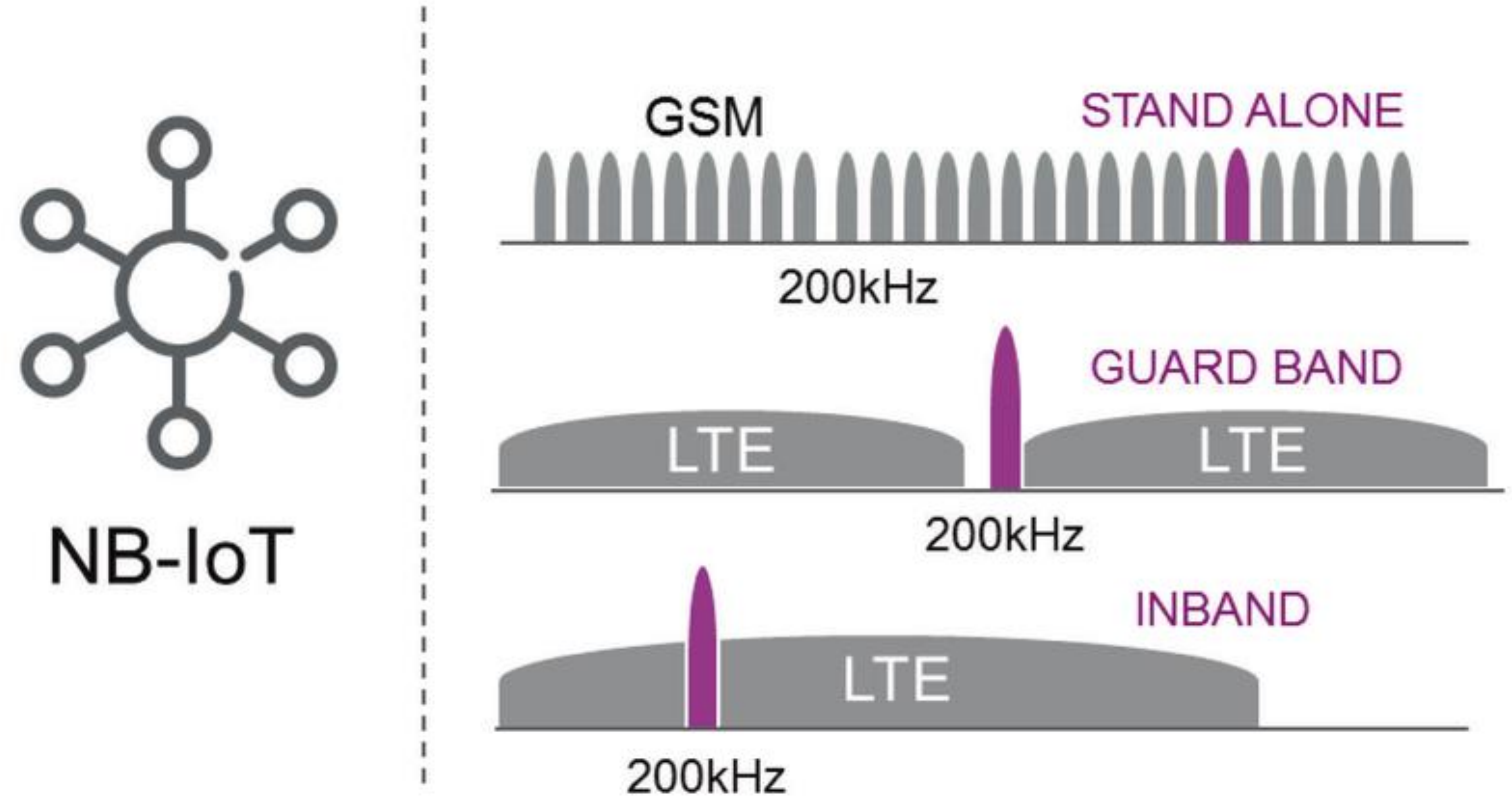
LPWAN Technologies

NB – IoT



Idowu-Bismark, Bode & Idachaba, Francis & Atayero, Prof. (2017). A Survey on Traffic Evacuation Techniques in Internet of Things Network Environment. Indian Journal of Science and Technology

NB – IoT

- 180 kHz UE RF bandwidth for both downlink and uplink.
- Downlink of NB-IoT:
  - OFDMA with the same 15 kHz subcarrier spacing as LTE or 3.75KHz subcarrier spacing
  - Slot, subframe, and frame durations are 0.5 ms, 1 ms, and 10 ms.
- Uplink of NB-IoT:
  - FDMA with GMSK modulation, and
  - SC-FDMA (including single-tone transmission as a special case of SC-FDMA).

NB – IoT

- Downlink physical signals and channels:
  - Narrowband Primary Synchronization Signal (NPSS)
  - Narrowband Secondary Synchronization Signal(NSSS)
  - Narrowband Physical Broadcast Channel(NPBCH)
  - Narrowband Physical Downlink Control Channel(NPDCCH)
  - Narrowband Physical Downlink Shared Channel(NPDSCH)

- Uplink physical channels:
  - Narrowband Physical Random Access Channel(NPRACH)
  - Narrowband Physical Uplink Shared Channel(NPUSCH)

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NB – IoT

- Peak Data Rate:
  - NDSCH peak data rate 226.7 kbps
  - NPUSCH peak data rate 250 kbps

- Power Consumption
  - 10-year battery life with 200-byte data a day on average

- Capacity
  - one PRB supports more than 52500 UEs per cell

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NB – IoT

- As of March 2019 GSA had identified:
  - 149 operators in 69 countries investing in one or both of the NB-IoT and LTE-M network technologies
  - 104 of those operators in 53 countries had deployed/launched at least one of the NB-IoT or LTE-M technologies of those, 20 operators in 19 countries had deployed/launched both NB-IoT and LTE-M
  - 22 countries are now home to deployed/launched NB-IoT and LTE-M networks
  - 29 countries are home to deployed/launched NB-IoT networks only
  - Two countries are home to deployed/launched LTE-M networks only
  - 141 operators in 69 countries investing in NB-IoT networks; 90 of those operators in 51 countries had deployed/launched their networks
  - 60 operators in 35 countries investing in LTE-M networks; 34 of those operators in 24 countries had deployed/launched their networks

NB-IoT

Comparison

- **LoRa:** Unlicensed sub-GHz spectrum. Chirp Spread Spectrum (CSS) modulation. Can define packet size. Transceiver chip is available only from Semtech Corportion. LoRaWAN the Medium Access Control (MAC) layer for managing communication between LPWAN devices and gateways.

- **Sigfox:** Proprietary. Unlicensed 868 MHz or 902 MHz bands with only a single operator per country. Coverage of 30-50 km (rural), 3-10 km (urban) and up to 1,000 km (line-of-site). Uplink 150 messages of 12 bytes per day. Downlink 4 messages of 8 bytes per day.

- **NB-IoT:** Licensed bands including unused 200 kHz bands previously used for GSM or CDMA. Based on LTE resource blocks.

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LPWAN Use Cases

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LPWAN Use Cases

- Agriculture
- Utilities
- Auto Manufacturing
- Asset Tracking
- Smart Cities
- Industry
- Logistics
- Smart Buildings

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LPWAN Use Cases

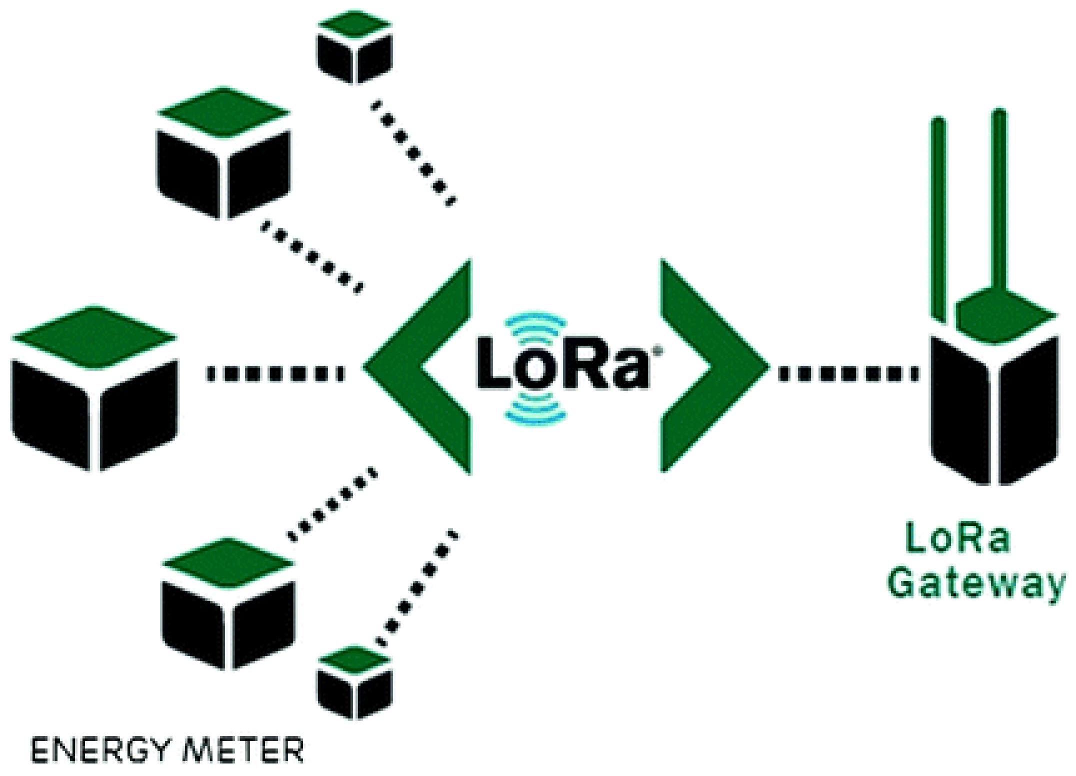
Agriculture

- Monitor weather conditions
- Virtually fence, track and manage herds
- Collect soil condition data
- Monitor silo and tank levels
- Monitor food temperatures
- and more …

LPWAN Use Cases

Utilities

- Remote Monitoring & Predictive Maintenance
- Transmission Line and Tower Surveillance
- Fault Detection & Location
- Smart meters



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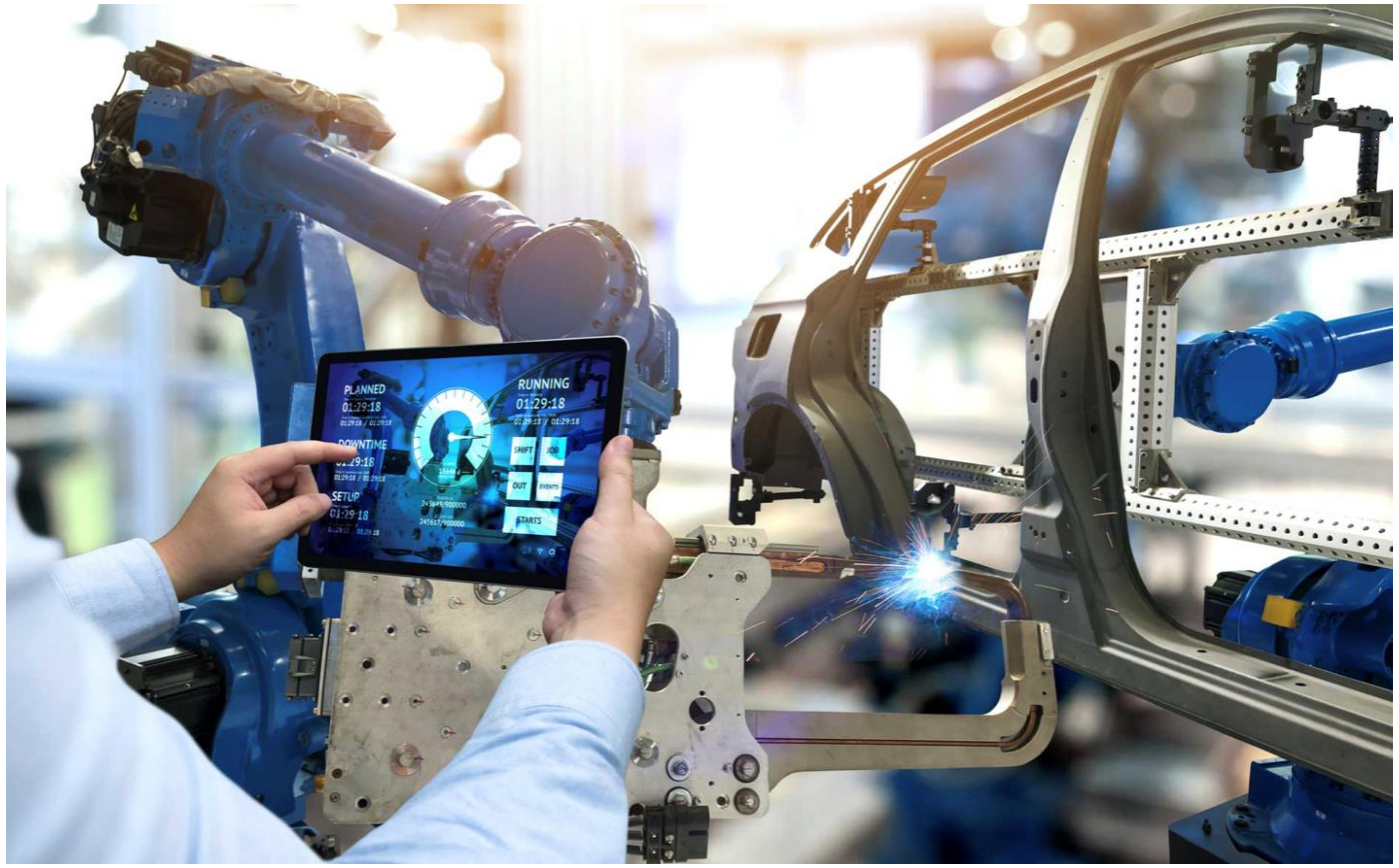
LPWAN Use Cases

Auto Manufacturing

- Process optimization with environmental monitoring (e.g. temperature, air quality…)
- Condition-based monitoring and predictive maintenance
- Safeguarding worker's health and safety



Asset Tracking

- Insurance: recover stolen vehicles
- Logistics: track assets along the supply chain
- Construction: fight equipment robberies and assess usage trends
- Agriculture: virtually fence, track and manage herds

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LPWAN Use Cases

Smart Cities

- Streetlights control
- Smart Grids
- Waste collection monitoring
- Road signs connection
- Public transport systems
- Traffic monitoring and management
- Public alarms and intercoms management

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LPWAN Use Cases

Industry

- Monitor vital parameters, leaks and ruptures in pipes
- Monitor employee attendance remotely

- Worker safety
- Notification when tanks are running low
- Improved warehouse security
- Predictive Maintenance

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LPWAN Use Cases

Logistics

- Monitor transport conditions throughout the entire supply chain
- Improving food safety
- Real-time traceability
- Improved warehouse security

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LPWAN Use Cases

Smart Buildings

- Building automation system
- Collect consumption data
- Smoke and fire alerts
- Energy efficiency
- Making operational improvements
- Establishing a more sustainable environment

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Best wireless technology for IoT use case

Key IoT Verticals	LPWAN (Star)	Cellular (Star)	Zigbee (Mostly Mesh)	BLE (Star & Mesh)	Wi-Fi (Star & Mesh)	RFID (Point-to-point)
Industrial IoT	●	○	○			
Smart Meter	●					
Smart City	●					
Smart Building	●		○	○		
Smart Home			●	●	●	
Wearables	○			●		
Connected Car					○	
Connected Health		●		●		
Smart Retail		○		●	○	●
Logistics & Asset Tracking	○	●				●
Smart Agriculture	●					

● Highly applicable ○ Moderately applicable

Criteria for choosing the best LPWAN technology

Source: https://behrtech.com

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Criteria

- Reliability
- Security
- Network Capacity
- Battery Life
- Mobility Support
- Public vs Private Network

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Criteria

Reliability

- Really important especially in mission-critical applications
- High reception rate and minimal packet loss required
- Enhance power efficiency if you achieve high reliability
- Interference resilience (increasingly congested medium and license-free spectrum) is a prerequisite to ensure high reliability
- Avoid interferers or packet collisions when the traffic is high, thereby improving overall reception rate.

Criteria

Security

- Message confidentiality, authentication, and integrity are essential elements of network security.
- Encryption should be natively embedded in the network
- 128-bit AES can be used to establish network-level security for data communications
- Transport Layer Security (TLS) protocol to protect IP-based data transfer to the cloud.
- Message authentication mechanisms to confirm message authenticity and integrity.

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Criteria

Network Capacity

- A large network capacity requires to achieve the required scale.
- Quality-of-Service assurances
- Optimization of the radio spectrum usage is important factor to achieve a large network capacity.
- An ultra-narrowband approach with minimal bandwidth usage provides a very high spectrum efficiency
- LPWAN systems employing asynchronous communication need a mitigation scheme to prevent packet collisions (i.e. self-interference)

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Criteria

Battery Life

- Devices are generally programmed to go into deep sleep mode when not transmitting messages, maximizing battery life.

- When the system is active and transmitting, power consumption is kept at a trickle.

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Mobility

- LPWAN technologies must be able to maintain the connectivity in the presence of moving devices or base stations

- Increased packet losses when not able to support use cases with mobile entities as for the example in the case of the fleet management.

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Criteria

Public vs Private Network

- Advantages Public:
  - The biggest advantage of public LPWANs run by network operators is saving infrastructure costs.
- Disadvantages Public:
  - be dependent on the provider’s network footprint
  - Public LPWANs leave coverage gaps in many areas

- Advantages Private:
  - allow for rapid deployments by end users with flexibility in network design and coverage based on their own needs.
- Disadvantages Private:
  - data privacy concern over the centralized back-end and cloud server.

Criteria

Network Capacity

- A large network capacity requires to achieve the required scale.
- Quality-of-Service assurances
- Optimization of the radio spectrum usage is important factor to achieve a large network capacity.
- An ultra-narrowband approach with minimal bandwidth usage provides a very high spectrum efficiency
- LPWAN systems employing asynchronous communication need a mitigation scheme to prevent packet collisions (i.e. self-interference)

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Criteria

- Proprietary vs Standard
- Operating Frequency
- Data Rates
- Variable Payload Size

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Summary

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- ❑ LWPaN Technologies
- ❑ What is LWPAN
- ❑ LWPAN technologies and standards
  - ❑ LoRAWAN
  - ❑ NB-IoT
  - ❑ Sigfox
- ❑ LWPAN use cases

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