



LUND
UNIVERSITY

Low-Power Wide Area Networks (LPWAN)

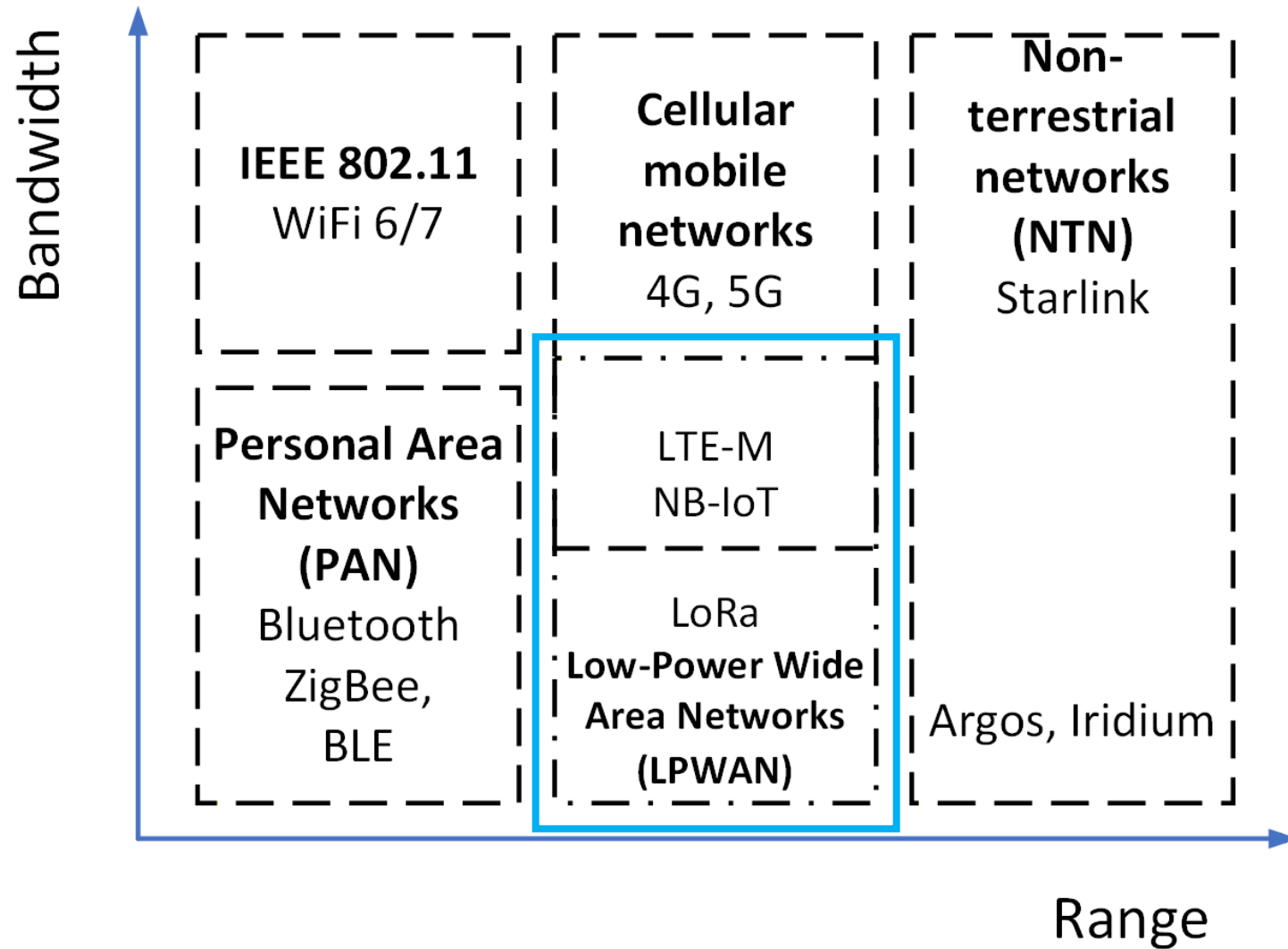
MARIA KIHLM



Literature

- Rashmi Sharan Sinha, Yiqiao Wei, Seung-Hoon Hwang, "A survey on LPWAN technology: LoRa and NB-IoT", ICT Express, Volume 3, Issue 1, pp 14-21, 2017.
- Power saving methods for LTE-M and NB-IoT devices, White paper, Rohde & Schwartz.
 - Pages 1-10.

Lecture today



Today's scenario: The Greenhouse

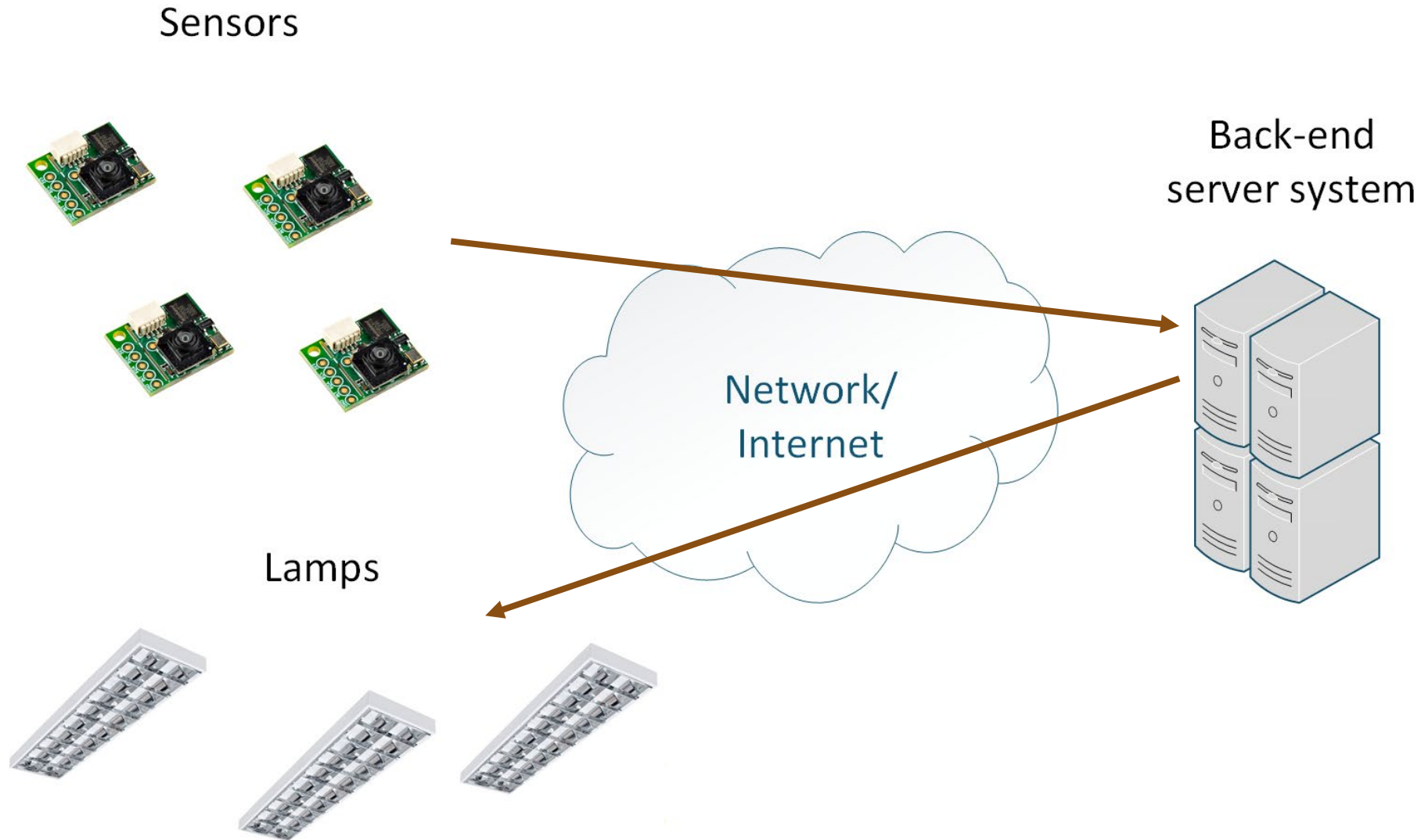
You have been given the task to help a friend that wants to install a smart lighting system for their greenhouse. The system includes about 10 sensors distributed in the greenhouse. Also, the system includes smart lamps that can be controlled via the Internet. The sensors collect and send data to a back-end server system.

The back-end server system includes an AI system that processes the data and then adjust the lamps in the greenhouse so that the plants always have optimal light.

Your task is to suggest a solution for the complete networked system.



Basic networked system architecture

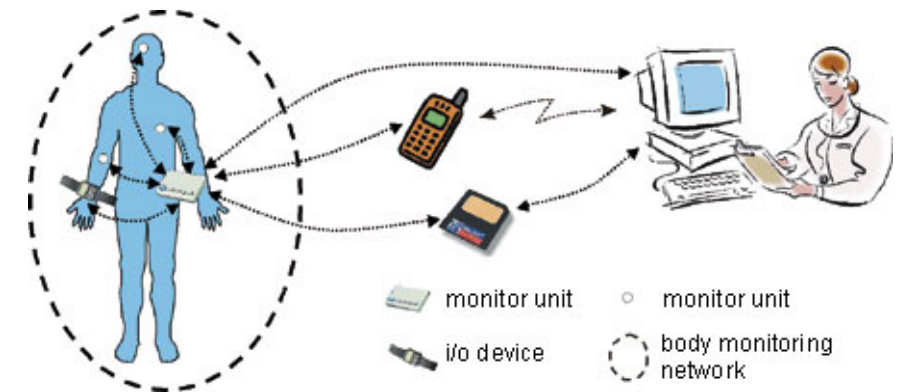
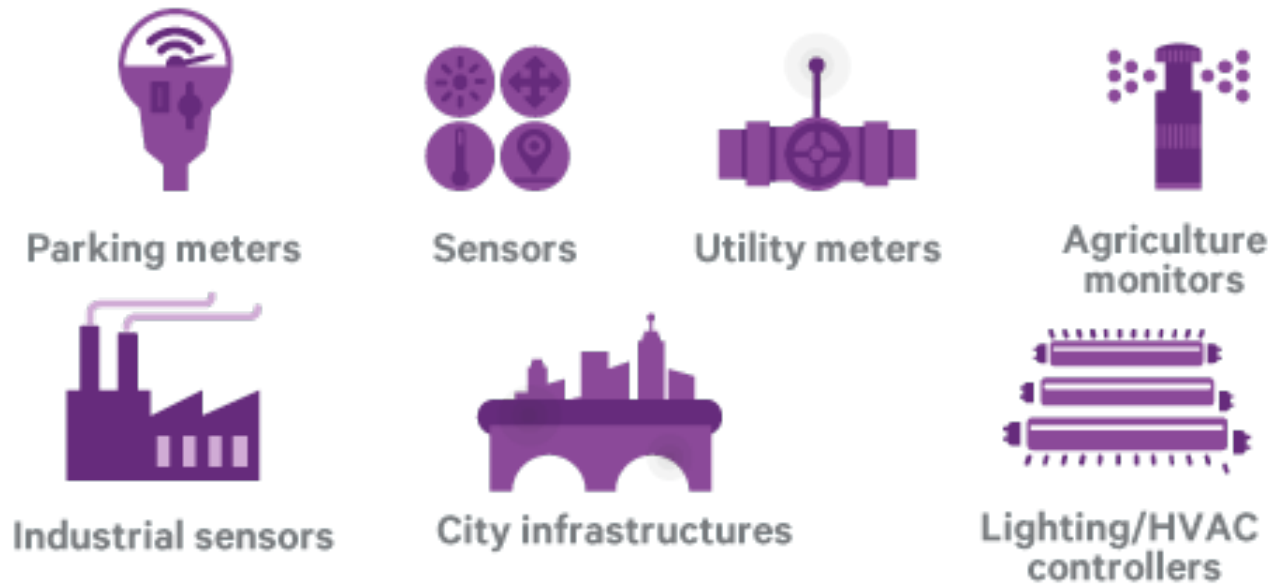


The Greenhouse: Scenario conditions

- About 10 sensors that send data and several lamps that receive data.
- The sensors and lamps should send and receive information to and from a back-end server.
- Good access to electricity in the greenhouse, but we do not know where the greenhouse is situated.
 - Lamps are mains powered.
 - Sensors can be battery-powered or mains powered.

Recap: Internet of Things (IoT)

The Internet of Things (IoT) is the **network of physical objects accessed through the Internet.**



Sources: 5G Wireless Access: an Overview

<https://www.lg.com/my/about-lg/press-and-media/presenting-the-more-effective-accessible-smart-home-with-lg-thing>

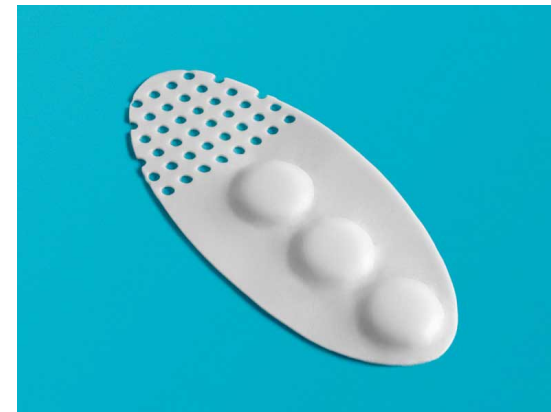
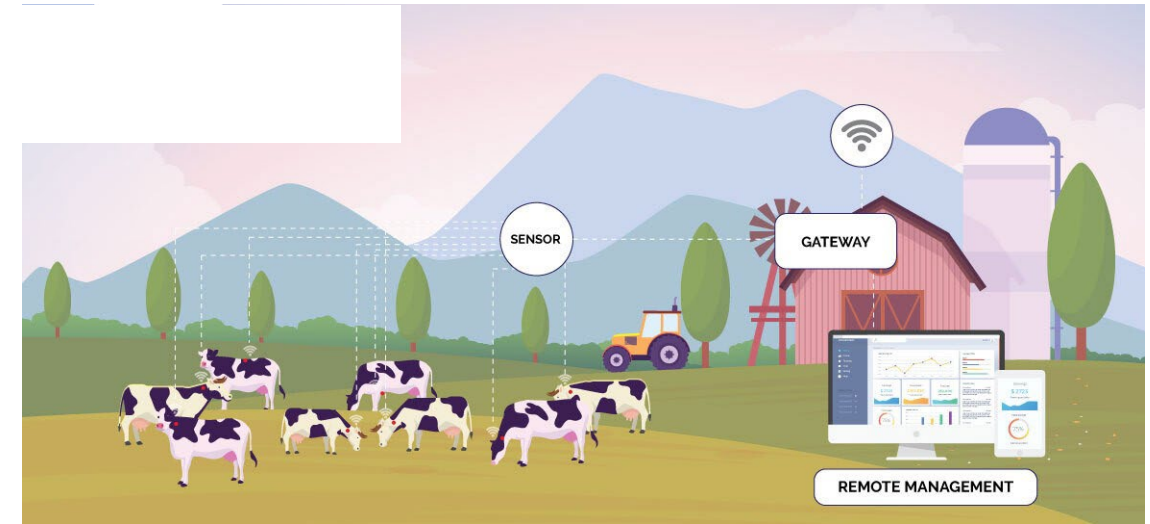
https://www.ercim.eu/publication/Ercim_News/enw51/bielikova.html

<https://www.cablefree.net/wirelesstechnology/internet-of-things-iot/>

LPWANs

Recap: Resource-constrained networking

Resource-constrained networking includes all types of network technologies where **low energy consumption** is important.



Sources: <https://www.hudsonmedicalinnovations.com/body-sensors>
<https://psiborg.in/livestock-monitoring-using-iot/>
<https://www.tern.org.au/news-standards-assist-conservation-decision-making/>

Low Power WANs (LPWAN)

- **Low Power WAN (LPWAN)** is a type of wireless network designed to allow **long-range communications at low bit rates and low energy consumption**.
- **Long range:** The operating range of LPWAN technology varies from a few kilometers in urban areas to over 10 km in rural settings.
- **Low power:** LPWANs are designed for low power consumption, LPWAN transceivers can run on small, inexpensive batteries for up to 20 years.
- **Low cost:** LPWAN devices should have low costs to allow for networks with many devices.

Standards for LPWAN

There are several standards for LPWAN. We will discuss:

- **Long Range WAN (LoRa)**
 - **Public LoRa networks** are in operation in several Swedish cities (and in other countries), for example Lund Open City Sensor Network.
 - There are commercial solutions for **Private LoRa networks**.
- **Narrowband IoT (NB-IoT) and LTE-M**
 - NB-IoT and LTE-M are available in Sweden via the 4G/5G operators.
- Other standards are SigFox, mioty, Weightless etc.

Note: All commercial services come with different fees, and they usually also have limitations in the data transmission (for example, maximum number of bytes per day per sensor).

LoRa

Long Range WAN (LoRa)

- **Long Range WAN (LoRAWAN, usually called LoRa)** is an international standard for LPWAN. LoRaWAN defines the communication protocol and the system architecture, while LoRa defines the physical layer.
- LoRa operates on **license-free frequency bands** on VHF and UHF. In Europe: 169MHz (VHF) and also 433 and 868 MHz (UHF).
- Devices has a **physical address of 64 bits** (Extended Unique Identifier, EUI-64)
- LoRa can achieve **data rates between 0.3 kbit/s and 27 kbit/s**, depending upon the configuration.
- **Maximum payload size of 256 bytes**. For a long battery life, the data transmissions must be very limited with a low payload.

LoRa – basic network architecture

Network elements in a LoRa network:

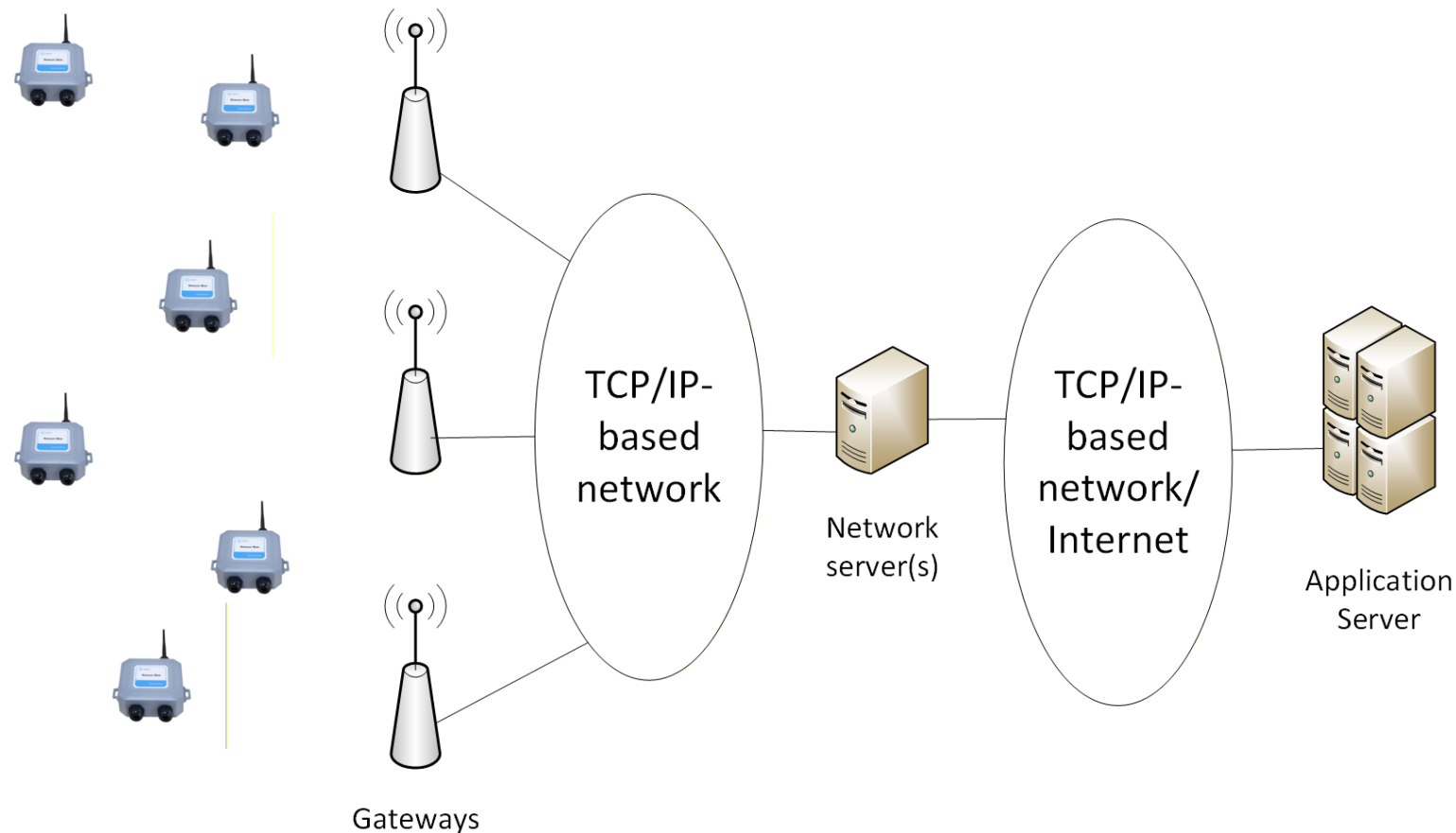
- **End devices:** End devices send or receive information through LoRaWAN, these can be sensors, actuators, trackers.
- **Gateways:** The devices to which the nodes are connected by LoRaWAN and allows the communication of these with the Network Server(s).
- **Network Server(s):** The software that controls the network and the logic of communications between the nodes and the Gateways.
- **Application Server:** It is the software that will process the data that is communicated through LoRaWAN, this software is completely independent of the LoRaWAN network.

The LoRa standard specifies the communication protocols between these network elements.

LoRa network architecture - illustration

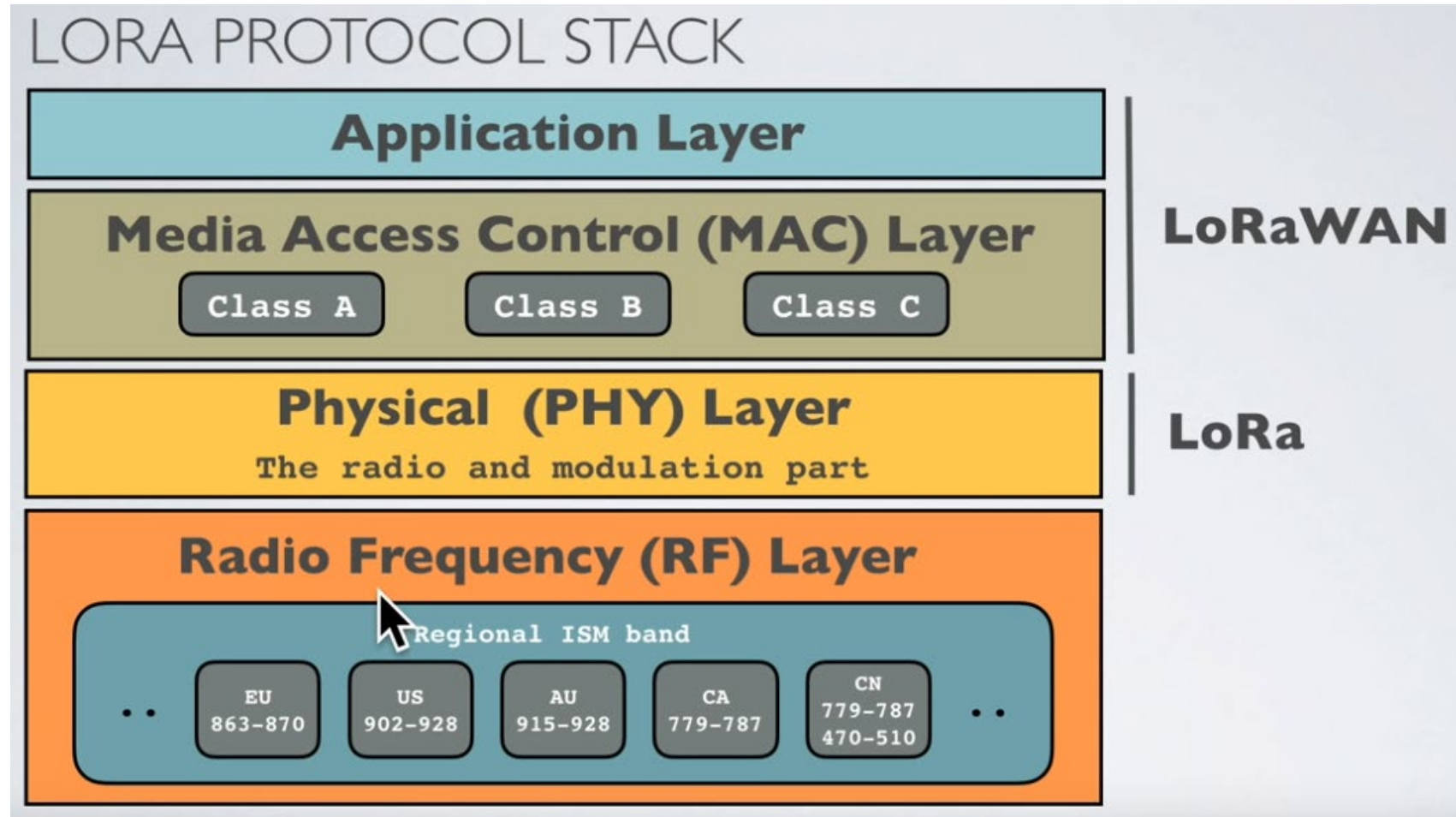
LoRa uses a centralized network architecture.

The End devices connect with the gateways. The gateways are connected with the Network server(s). The Network server is connected with the Application server.

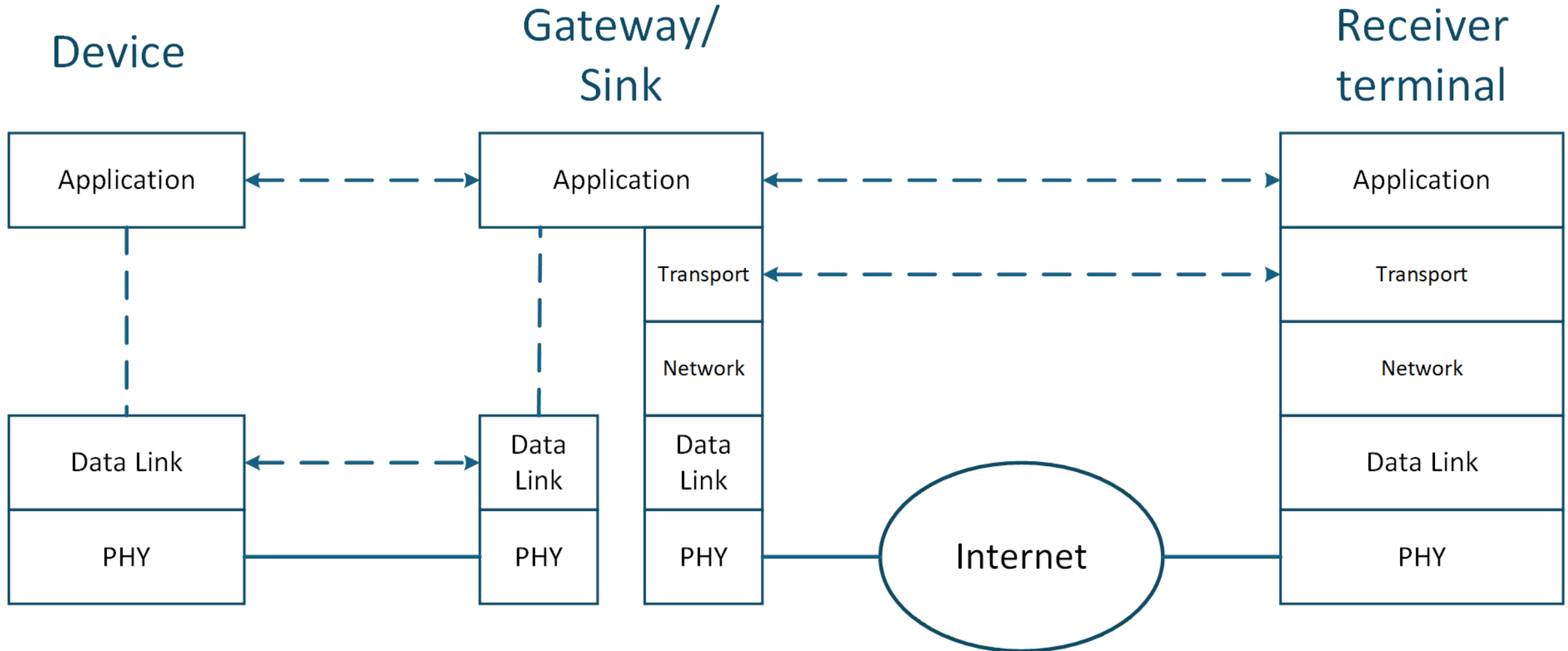


Protocol stack for End devices

The End devices can only communicate within the LoRa network (i.e they are not connected to the Internet).



Recap: Protocol stack for non-critical applications



LoRa Network options

A LoRa network can be deployed in two basic ways:

- **Public LoRaWAN network**

- You make a subscription to a public LoRaWAN operator.
- The operator provides the Network server and the Application server.
- The operator may also have public LoRa gateways.
- Easy to install a new network and application.
- **Fees for the subscription and for the data transmission** (or with a strict cap on the allowed bit rate).

- **Private LoRaWAN network**

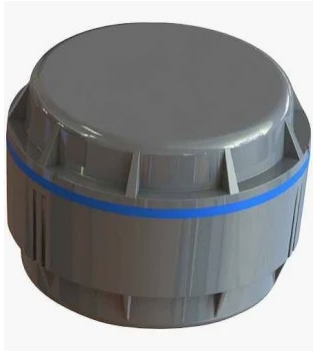
- You deploy a self-hosted private network, with your own network server and application server.
- There exists open-source software for network and application servers.
- You need to have technical skills to deploy and configure the whole network with application software.
- **(High) installation costs for the equipment, but no other fees.**

Examples of LoRa end devices and Gateways

Microphone



Gateways



Sensors

Cameras

Node association / Initial access

All entities in a LoRa network are pre-configured, so there are **no dynamic procedures for node association**.

- All entities are configured regarding security and communication parameters.
- A Gateway only accepts data transmissions from End devices that the Gateway has been paired with (part of the network setup).
- A Network server only handles registered Gateways.
 - If you use a public LoRa network operator, you register your Gateways and End devices with this network operator.

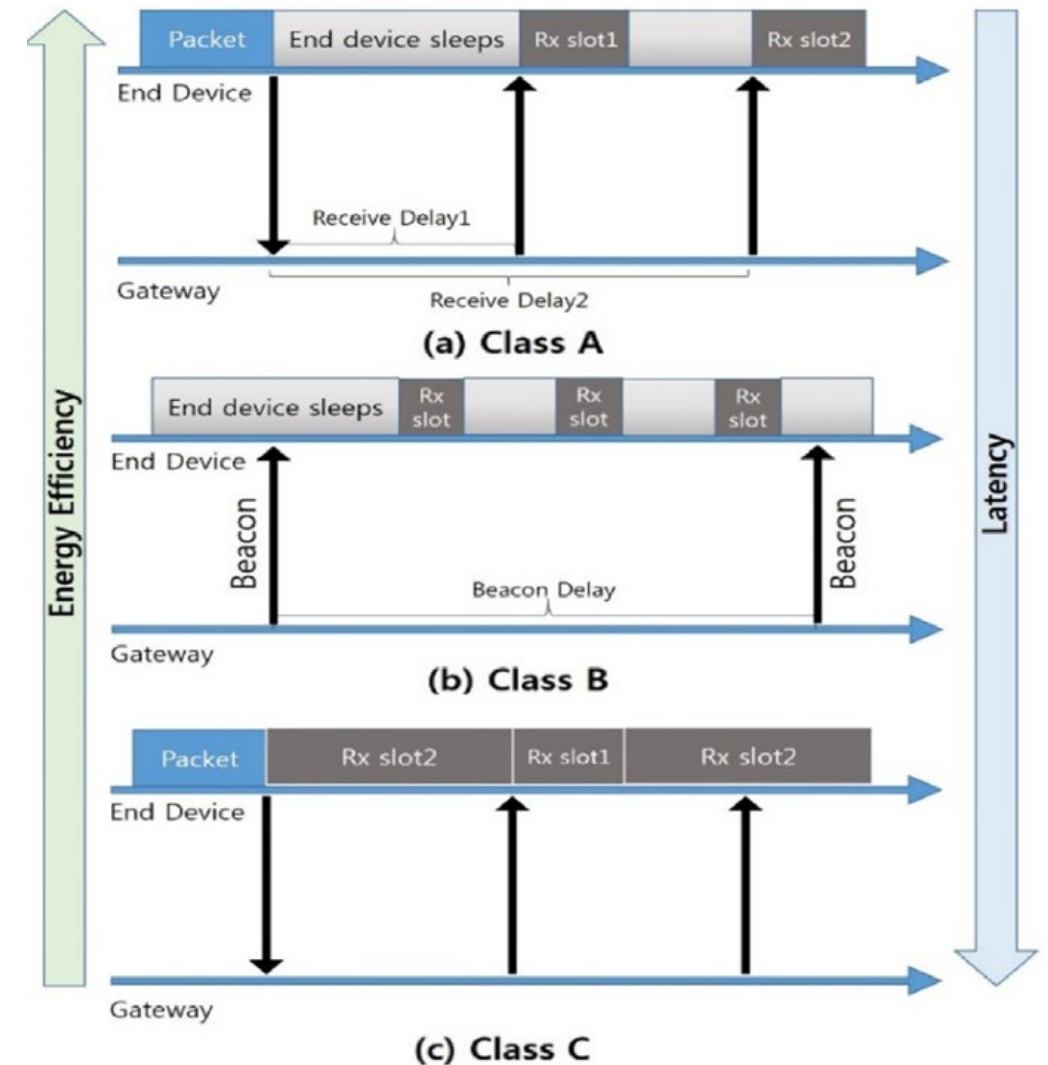
Types of LoRa devices

LoRa defines three types of devices:

- **Class A** devices are battery-powered sensors (that **send data**).
- **Class B** devices are battery-powered actuators (that **receive data**).

(A device can switch between Class A and B)

- **Class C** devices are mains powered actuators. These devices never sleep.



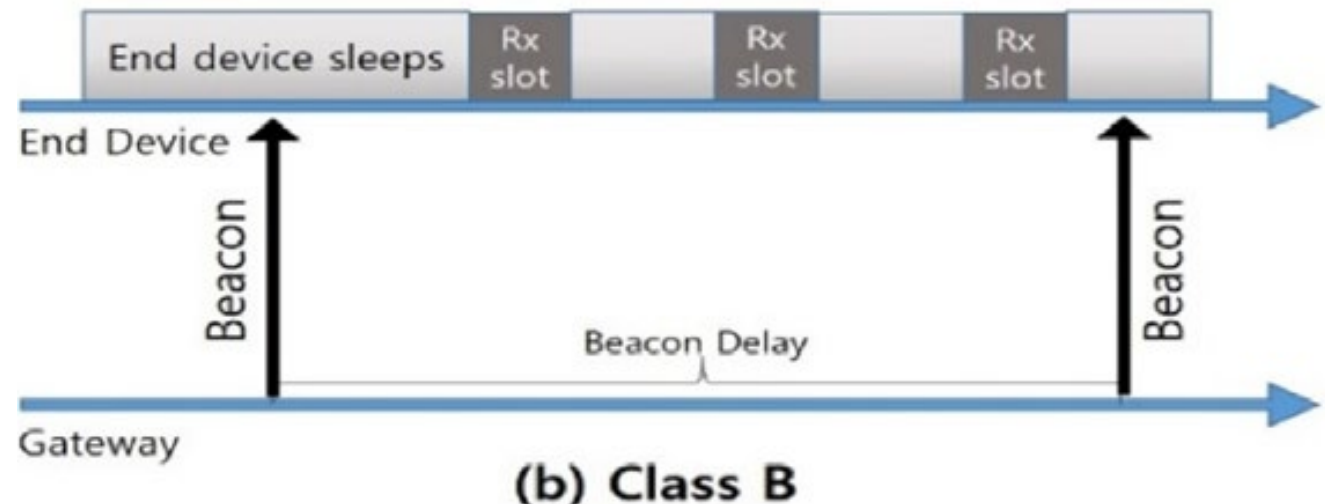
MAC-protocol for Class A devices

- **A Class A device (sensor) wants to send data.**
- The MAC protocol for LoRa Class A devices is **contention-based and similar to ALOHA.**
- A sensor that want to transmit data, does this at any time
- When data is sent, the device opens two receive windows, at 1 and 2 seconds.
- A Gateway can send a reply in one or both of the receive windows.
- If more than one Gateway receives the data packet, the Network server decides which base station will send the ACK.



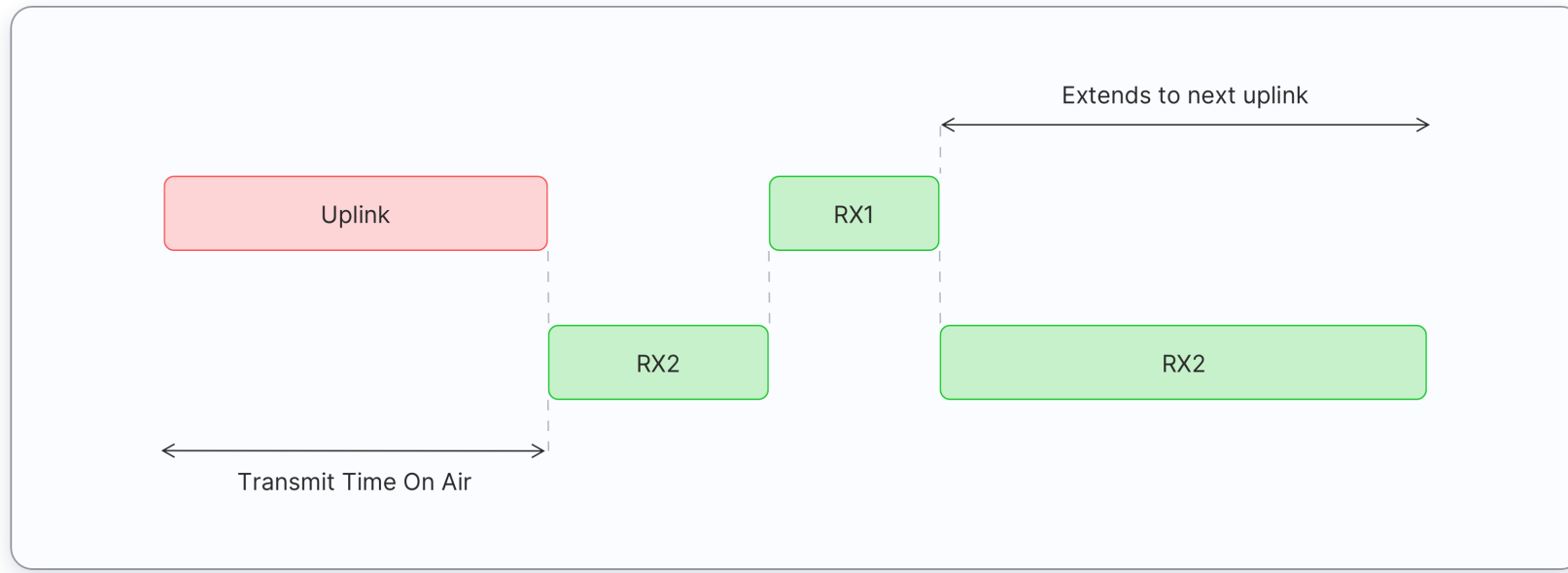
MAC protocol for Class B devices

- **A Class B device (actuator) waits for data.**
- The MAC protocol for Class B devices is contention-free and similar to **Polling**.
- The Gateway sends a beacon on a regular beacon delay to synchronize all the devices in the network.
- When an end device receives the beacon, it can open a short reception window called “ping slot” predictably during a periodic time slot.
- If the Gateway has data to send to the device, it sends this data during the predefined time slots.
- In between of these time slots, the device sleeps.



MAC protocol for Class C devices

- Class C devices extend Class A capabilities by keeping the receive windows open unless transmitting an uplink.
- Therefore, Class C devices can receive downlink messages at almost any time, thus having very low latency for downlinks.



Uplink information flow

- An **End node** transmits a data packet.
- All **Gateways** that receive the data packet forwards it to the **Network server**.
 - The Gateway adds information about the connection quality in the message.
- The Network server decides which Gateway will **acknowledge the packet** (and may add data to be sent to the end device).
- The Network server forwardes the data to the **Application server**.

This will increase the reliability of the system.

- A data packet has a higher probability to be correctly transmitted, since it is enough that the data packet reaches **one** of the Gateways.

Downlink information flow

- The **Application server** initiates the data transmission to an **End device** by sending the data message to the Network Server.
- The **Network server** chooses the Gateway with the best previously reported connectivity conditions to the intended End device. The Network server then sends the data message to this Gateway,
- The **Gateway** puts the data message in its queue and **waits** until the End device has a scheuled receive window.
- The Gateway sends the data message to the **End device** using the agreed downlink MAC protocol.

LoRa?

You have been given the task to help a friend that wants to install a smart lighting system for their greenhouse. The system includes about 10 sensors distributed in the greenhouse. Also, the system includes smart lamps that can be controlled via the Internet. The sensors collect and send data to a back-end server system.

The back-end server system includes an AI system that processes the data and then adjust the lamps in the greenhouse so that the plants always have optimal light.

Your task is to suggest a solution for the complete networked system.



Greenhouse - Solution suggestions - LoRa

- LoRa can be a suitable technology, but depends on how often the sensors and lamps must send and receive data. You have to choose if you want to deploy a Public or a Private LoRa Network solution (you always need to describe 1 solution).
- Sensors are Class A and lamps are Class B or C devices.
- If you choose a Private LoRa network, you need to describe how you deploy the Network and Application servers, and where these are placed.
 - Also, you need a network solution for the communication between Gateways, Network server and Application server.
- A solution using a Public LoRa network must include an argumentation about that a Public LoRa operator is available in the area (available in 100+ countries, but not everywhere).
 - Also, you need a solution for the backhaul between Gateways and the Internet.

NB-IoT and LTE-M

Narrowband IoT (NB-IoT) and LTE-M

Narrowband Internet of Things (NB-IoT) and **LTE for Machines (LTE-M)** are Low Power Wide Area Network (LPWAN) radio technology standards developed by 3GPP.

- NB-IoT and LTE-M are **services in the 4G/5G networks**, and the solution for the 5G mMTC application scenario.
 - Therefore, NB-IoT and LTE-M use **licensed frequency bands** (exact frequencies differ between regions, but frequency bands below 1 GHz are supported).
- Devices are identified by its **SIM (Subscriber Identity Module)** as in all cellular mobile networks.
 - eSIM and iSIM are new technologies for IoT.

Sources: A survey on LPWA technology: LoRa and NB-IoT

<https://blog.nordicsemi.com/getconnected/the-difference-between-sim-esim-isim>

https://en.wikipedia.org/wiki/SIM_card

<https://business.teliacompany.com/internet-of-things/iot-connectivity/lpwa-iot>

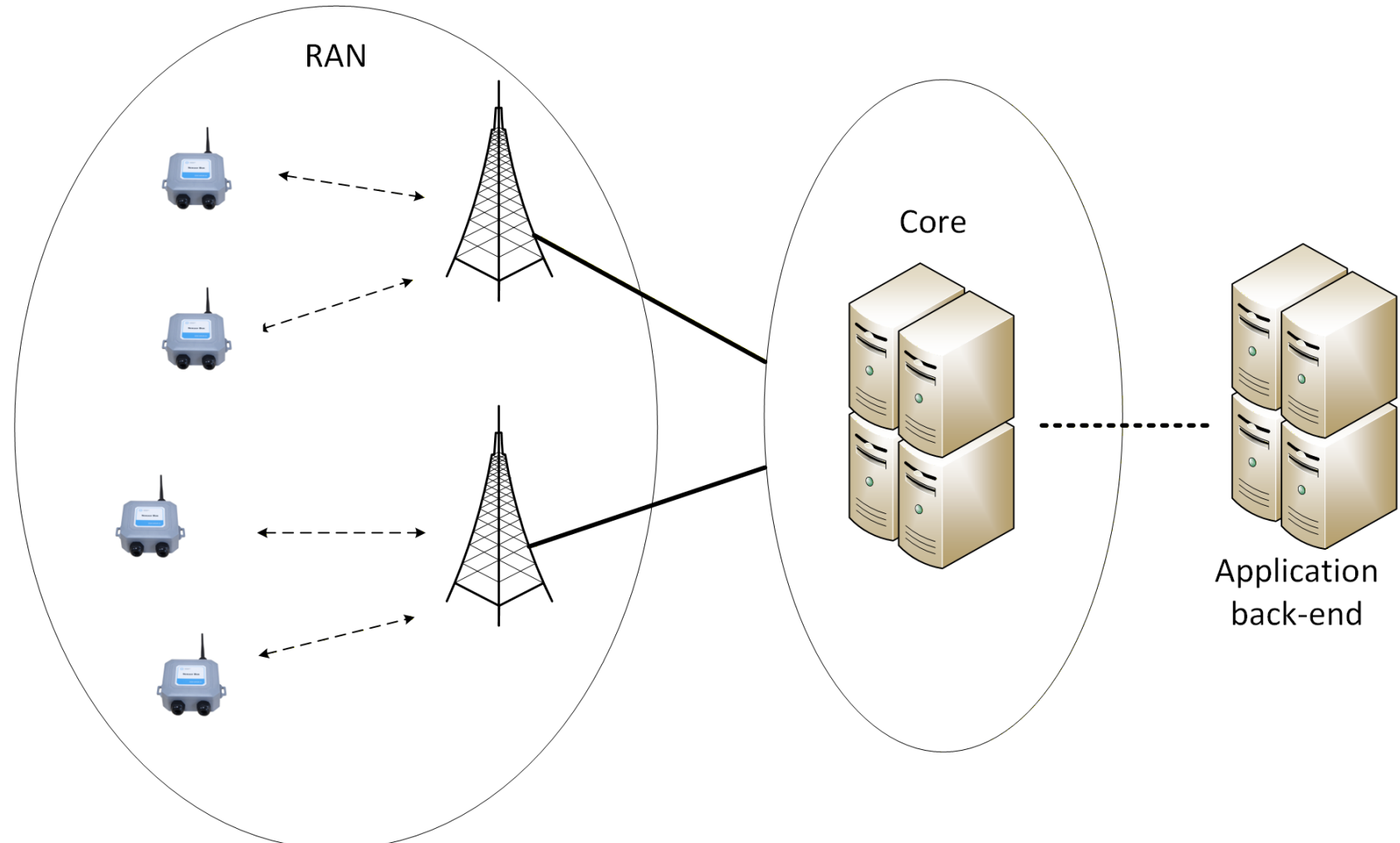
<https://en.wikipedia.org/wiki/LTE-M>

NB-IoT / LTE-M infrastructure

An end device **connects with the closest cellular base station** (where closest can mean the base station with the best connectivity), as ordinary UEs in cellular mobile networks.

The mobile operator provides the Application back-end (IoT platform).

The users connect with the IoT Platform.



Characteristics of NB-IoT

- Aimed at **stationary devices** that infrequently **send small amounts of data**.
 - Uplink data rate up to 159 kbps, which works well for infrequent data transmissions.
 - Downlink data rate up to 127 kbps.
 - **Mobility is not supported.**
- Specifically designed for **low power with deep penetration**
 - Devices can run for more than 10 years on a single small battery.
 - Strong signal penetration indoor, underground, garages, and thick buildings.
- **Cheap subscription and data transmission rates, but only for low data rates and stationary devices.**



Characteristics of LTE-M

- **Simplified version of LTE (4G)**, which reduces hardware complexity and cost.
- **Can support moving devices** without losing data sessions at speeds of up to 200kmh.
- Supports both uplink and downlink data transfer, where devices have a data rate of up to 1 Mbit/second.
- Up to 10 years of battery using Power Saving Mode (PSM) and extended Discontinuous Reception (eDRX), but this means much lower data rates and longer latencies.
- **More expensive than NB-IoT, but can be a good alternative for mobile devices. Cheaper than an ordinary 4G subscription.**



Use case for LTE-M: Maersk

Maersk have deployed private 4G networks on 450 vessels, where they use a hybrid private/public connectivity solution (using software-defined network solutions).

The containers are equipped with LTE-M devices, and a container can be globally tracked in real-time.



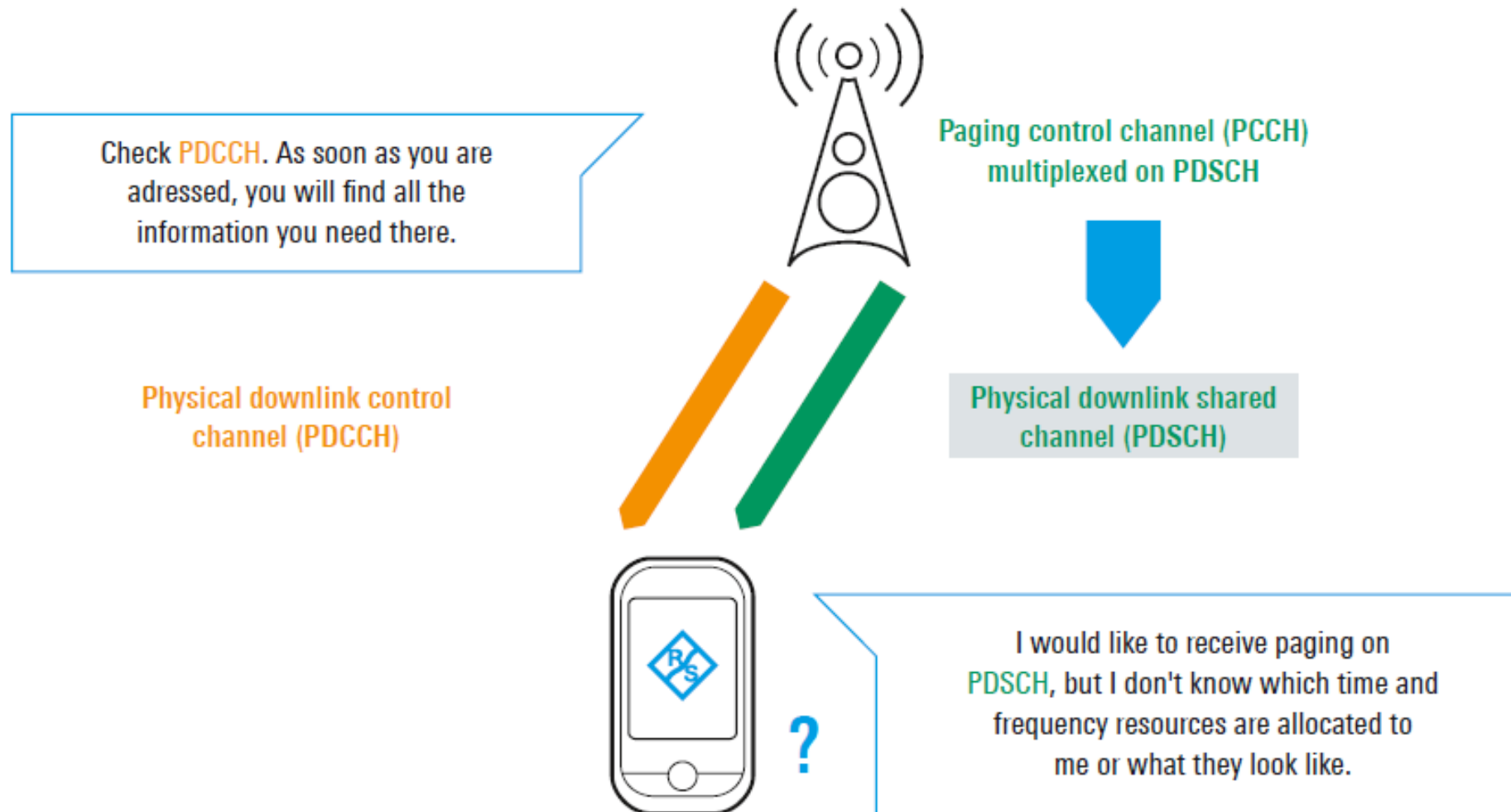
<https://onomondo.com/case-story/maersk/>

<https://onomondo.com/blog/onomondo-ships-worlds-largest-private-lte-network-at-sea-with-maersk/>

Cellular network based IoT

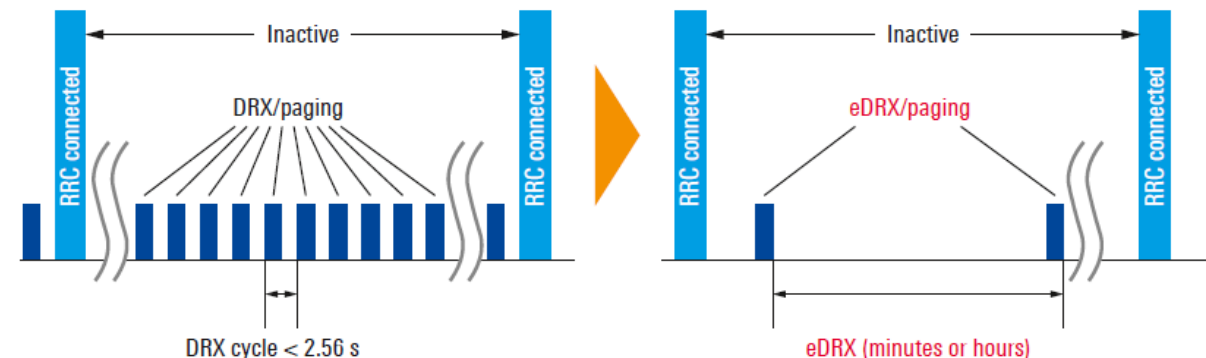
- In a cellular network, each connected device must receive paging information so that it knows when and how to send data (due to the contention-free MAC).
- A device connected to a cellular network must be in one of two so called **Radio Resource Control (RRC)** states:
 - Connected mode, allowing transmission and reception of user data over an established connection.
 - Idle mode or camping on a cell
- In the latter mode, **the device has to periodically update its knowledge about system information broadcast by the network.**
 - The device has to monitor the physical downlink control channel for paging messages and decode the paging message on its allocated physical downlink shared channel.
 - This **consumes energy**.

Illustration: Cellular network based IoT



Power saving technique: DRX

- **Discontinuous reception (DRX)** is a mechanism that allows the device to stop monitoring the radio channel and enter low power consumption mode or sleep mode for a certain period of time.
 - A device operating in DRX mode only monitors the channel at defined time intervals. The device will enter sleep mode the rest of the time.
- **Extended discontinuous reception (eDRX)** is a power saving optimization feature specifically aimed at **resource-constrained IoT**.
 - The device can request the use of idle eDRX during the initial attach procedure.
 - The network entity accepts the request from the device by providing the eDRX parameters.
 - The device will then use the received eDRX parameters for the subsequent procedures.



NB-IoT or LTE-M?

You have been given the task to help a friend that wants to install a smart lighting system for their greenhouse. The system includes about 10 sensors distributed in the greenhouse. Also, the system includes smart lamps that can be controlled via the Internet. The sensors collect and send data to a back-end server system.

The back-end server system includes an AI system that processes the data and then adjust the lamps in the greenhouse so that the plants always have optimal light.

Your task is to suggest a solution for the complete networked system.



Greenhouse - Solution suggestions – NB-IoT/LTE-M

- A solution using NB-IoT or LTE-M requires that there is cellular mobile network coverage in the area where the greenhouse is situated.
- **NB-IoT:** Both sensors and lamps are stationary, so NB-IoT can be a good alternative.
 - However this depends on the required data rates and the accepted latencies.
 - If the sensors are battery-powered, NB-IoT has a low energy consumption.
- **LTE-M:** LTE-M can also be a good alternative if there is a need for higher data rates with lower latencies.
 - Higher data rates means higher energy consumption, so it could require that the sensors are mains powered.
- In either case, your friend needs to get a subscription with a mobile operator.



LUND
UNIVERSITY