NetWare 2021
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Heterogeneous Architecture and Communication Protocol for Irrigation Water Quality Monitoring in Precision Agriculture Solutions

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Laura García

- Bachelor’s degree in Telecommunications Technology Engineering by the Polytechnic University of Valencia in 2015.
- Master’s degree in Digital Postproduction by the Polytechnic University of Valencia in 2016.
- Master’s degree in Business Administration by the Universidad Católica San Antonio de Murcia in 2020.
- Ph.D. degree in Telecommunications by Polytechnic University of Valencia in 2021.
- Ph.D. degree in Computer Science by Haute-Alsace University in 2021.
- Participated in organization committees of international conferences since 2016.
- Research lines focused on precision agriculture, ambient monitoring and water quality monitoring systems and the design of architectures and protocols for the aforementioned purposes.

Why is Precision Agriculture Necessary?

Increase in population → **Higher food needs**

SOLUTION

The use of Precision Agriculture solutions improve the efficiency of the crops and reduces the use of resources such as water and fertilizers.

Why is It Important to Monitor Water Quality?

WHY IS IT IMPORTANT TO MONITOR WATER QUALITY?

The problem of water scarcity is increasing and the 70% of the world's water consumption is due to agriculture

Water quality for irrigation is key to ensure the safety of the produce

In order to improve the water quality for irrigation, it is necessary to employ water treatments. One of the most popular water treatments is Biosorption. It is an ecological and low-cost solution that allows eliminating the presence of heavy metals in the water. That way, the agricultural residues can be reused as biosorption materials to clean irrigation water.

How are the Communications Affected by the Environment?

Communications in Agricultural Environments

Difficulties
- Vegetation
- Activities performed by farmers
- Machinery
- Cost

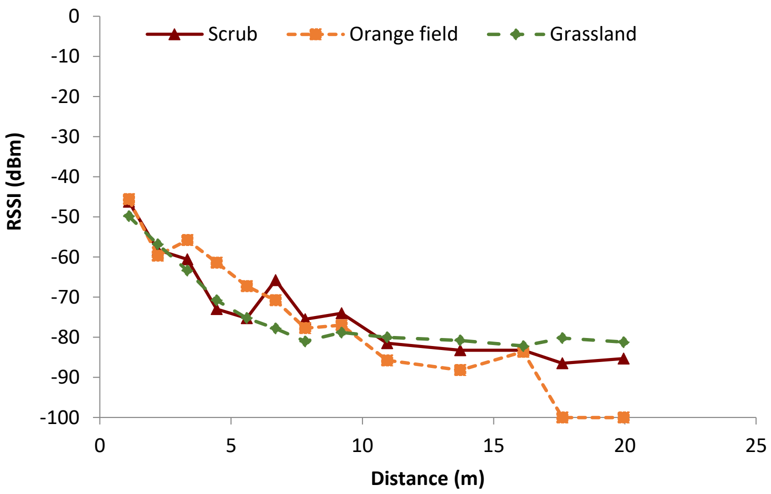
Wireless technologies allow avoiding the possible damages and high costs of wired communication

The network design must consider the losses in signal quality due to the obstructions caused by the vegetation

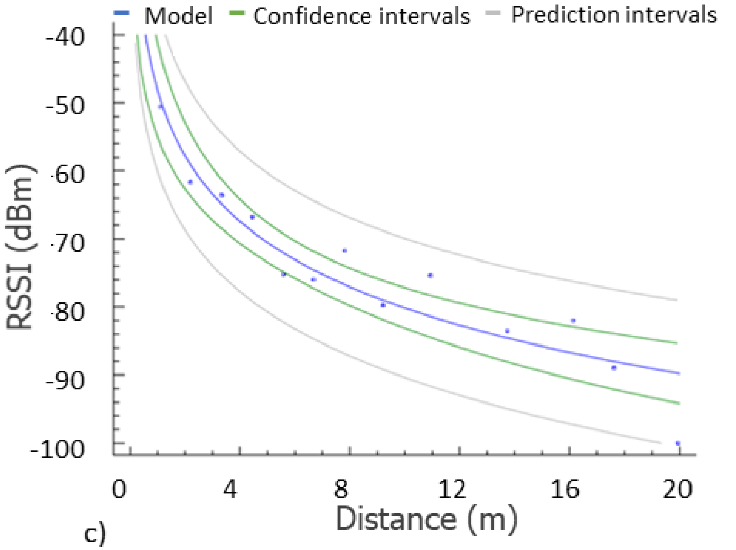
What is the Performance of Low-Cost Devices in Agricultural Environments?

Vegetation obstructions

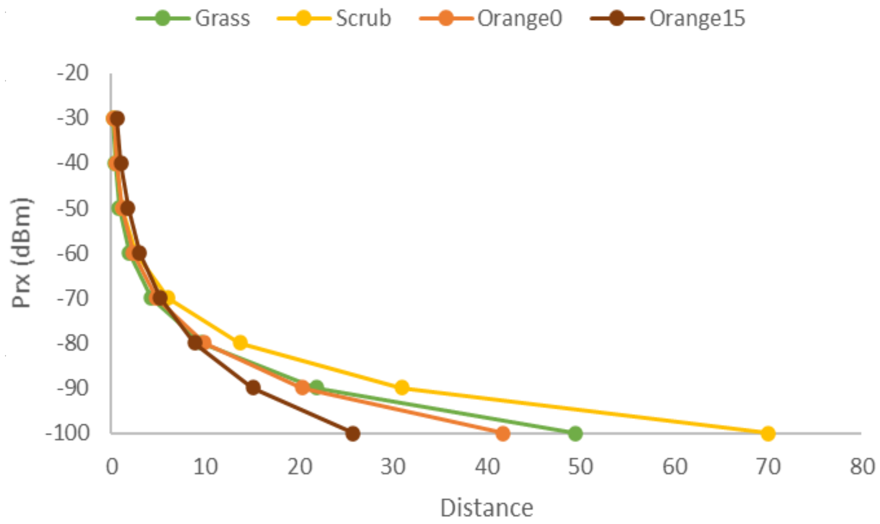
On-ground with varied vegetation types



Coverage



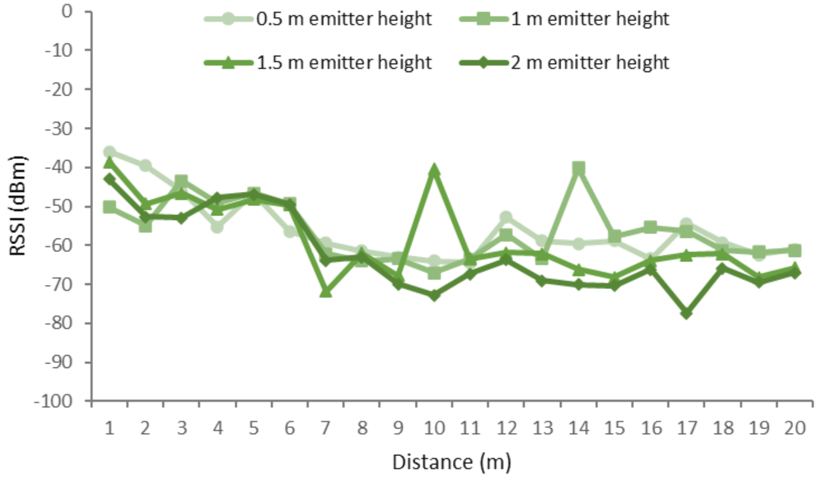
Model



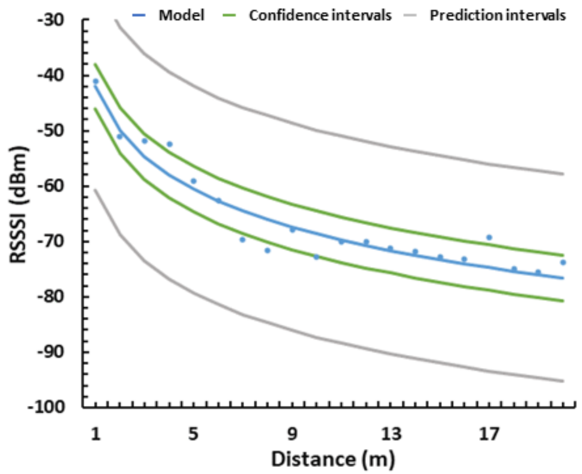
Theoretical distance

Vegetation obstructions

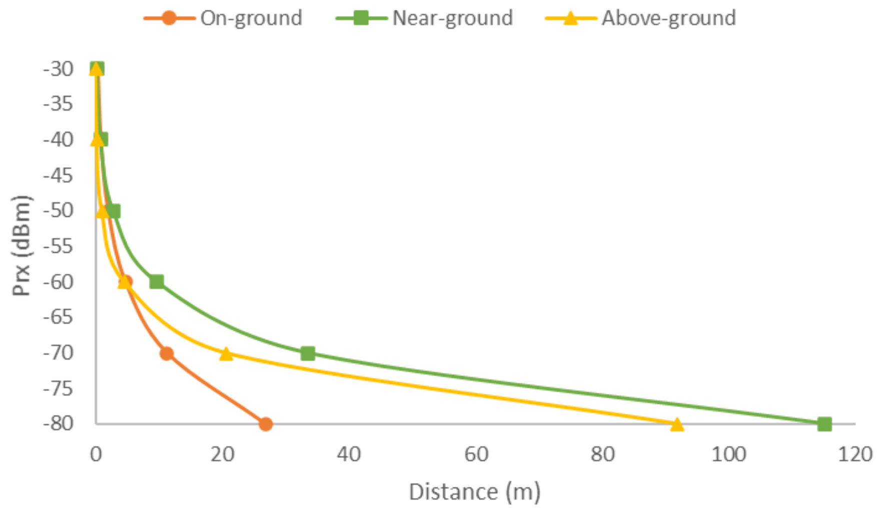
On-ground/ Near ground/Above ground with orange trees



Coverage



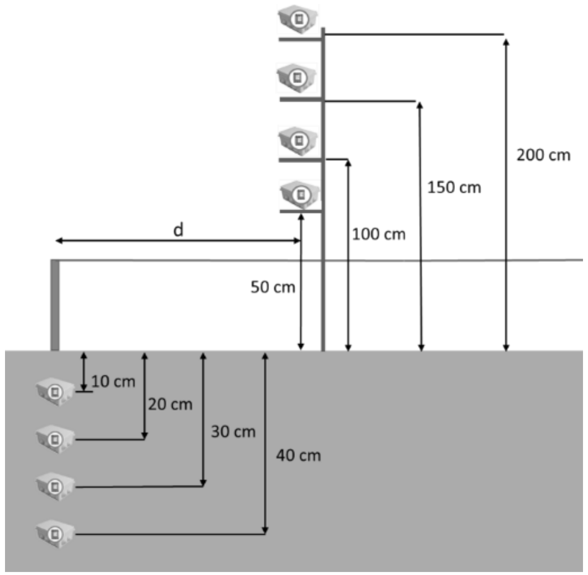
Model

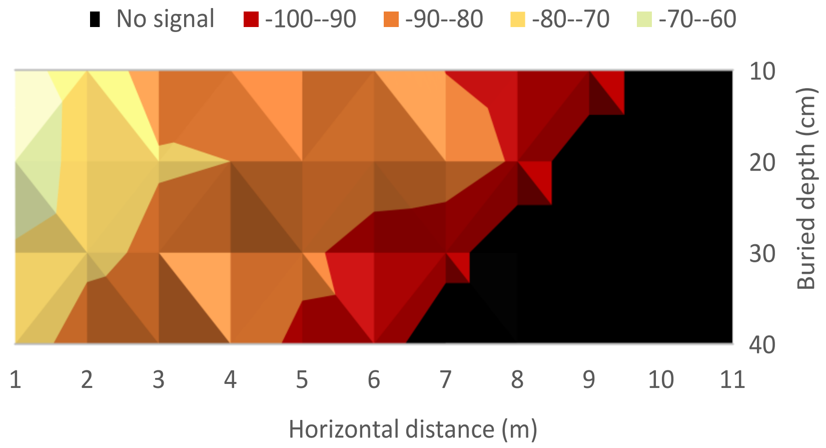


Theoretical distance

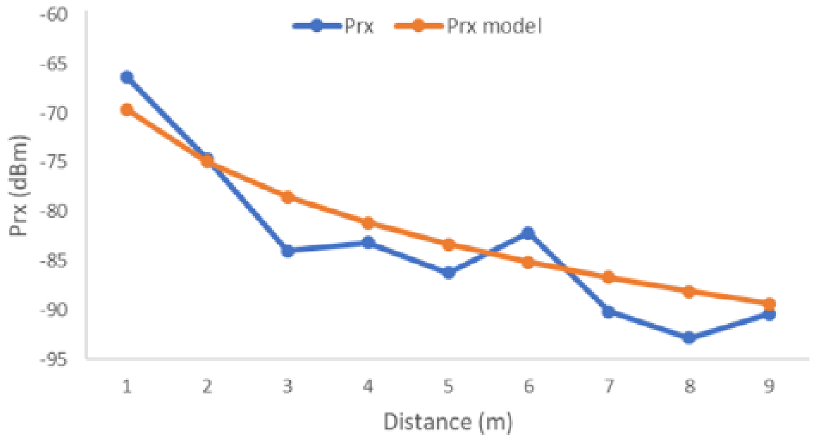
Underground deployments

Height of 50 cm





Coverage

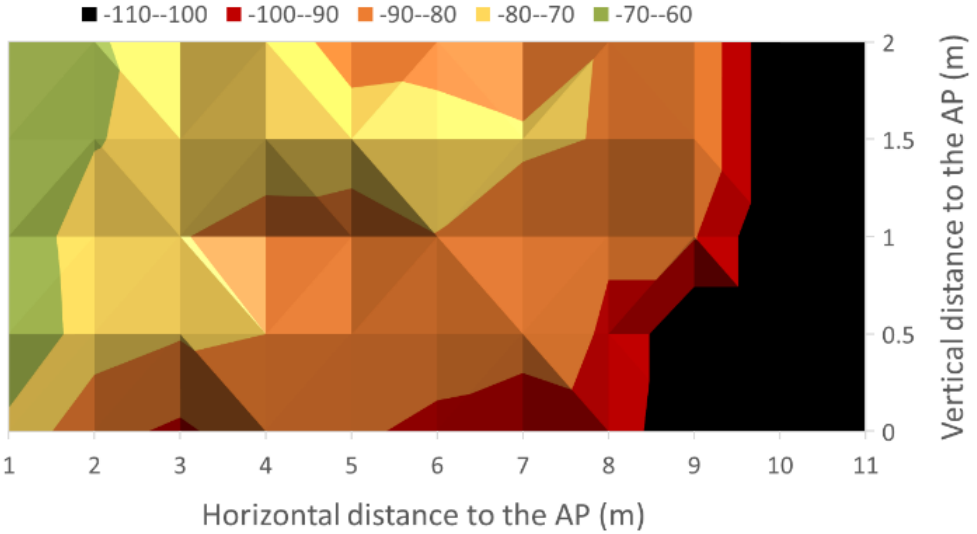


Model 10 cm

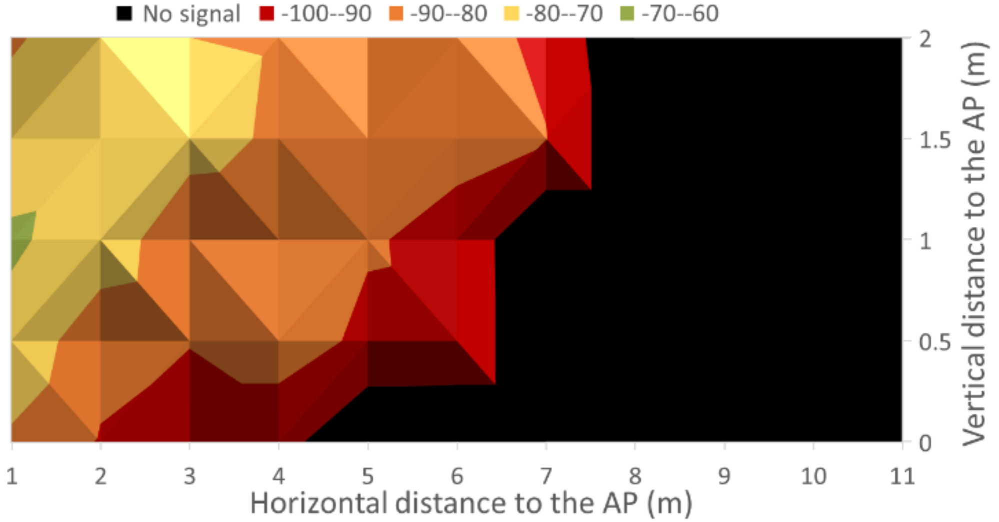
Underground deployments

All heights

Coverage



20 cm



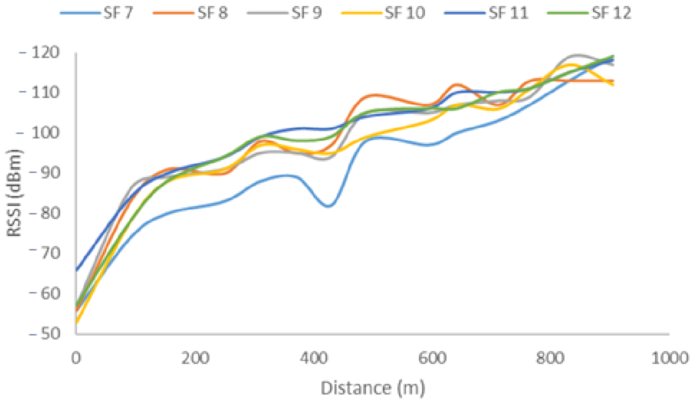
40 cm

LoRa nodes

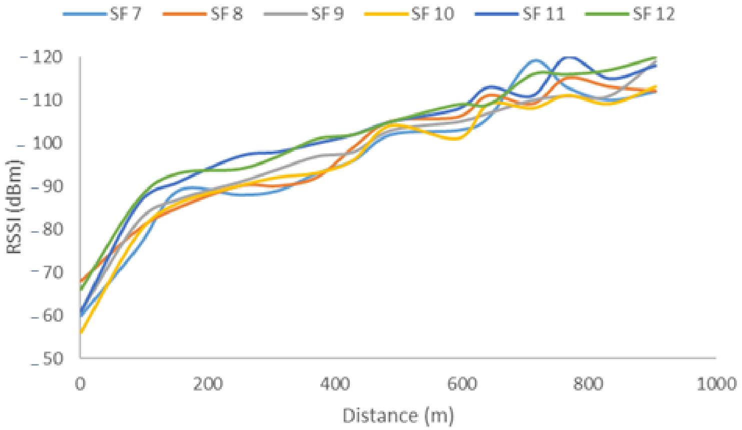
a) b) c)

	Antenna 1	Antenna 2	Antenna 3
Frequency band	433 MHz	433 MHz	868 MHz
Gain	3 dBi	5 dBi	3 dBi
Voltage Standing Wave Ratio	≤ 1.5	≤ 1.5	≤ 1.5
Input impedance	50 Ω	50 Ω	50 Ω
Maximum input power	10 W	50 W	10 W

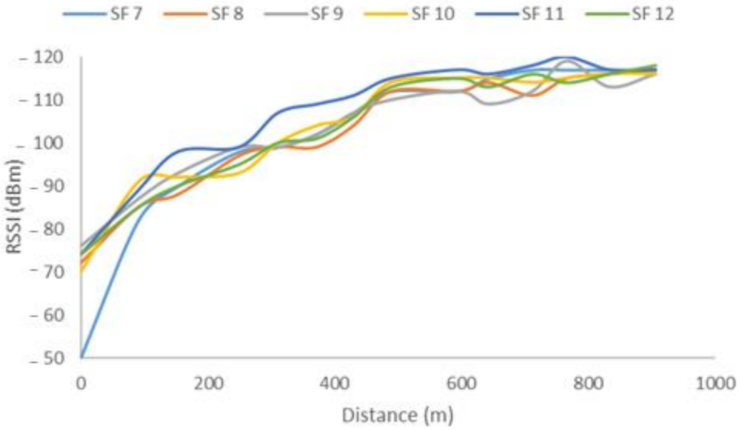
Coverage Antenna 1



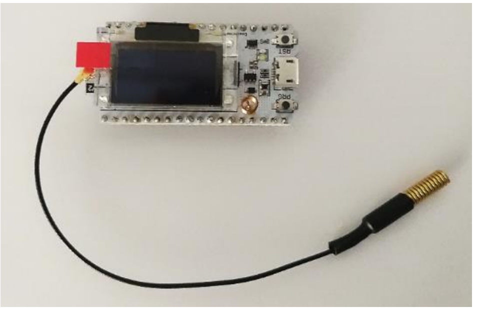
Coverage Antenna 2



Coverage Antenna 3



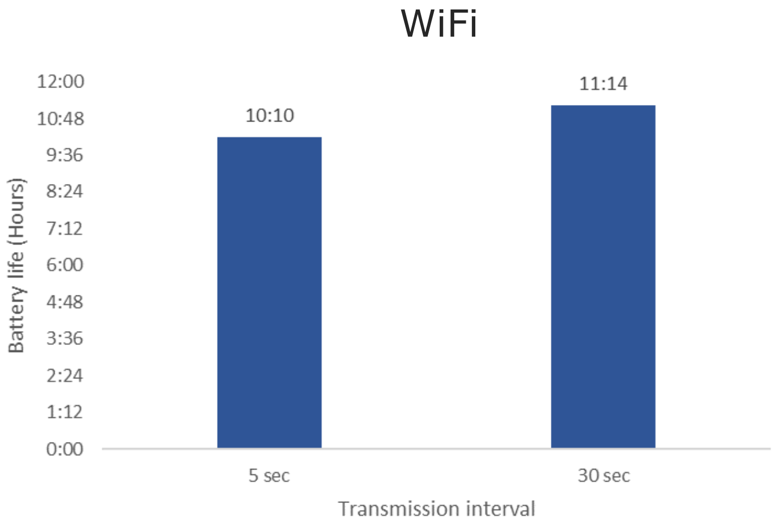
PERFORMANCE OF LOW-COST DEVICES IN AGRICULTURAL ENVIRONMENTS

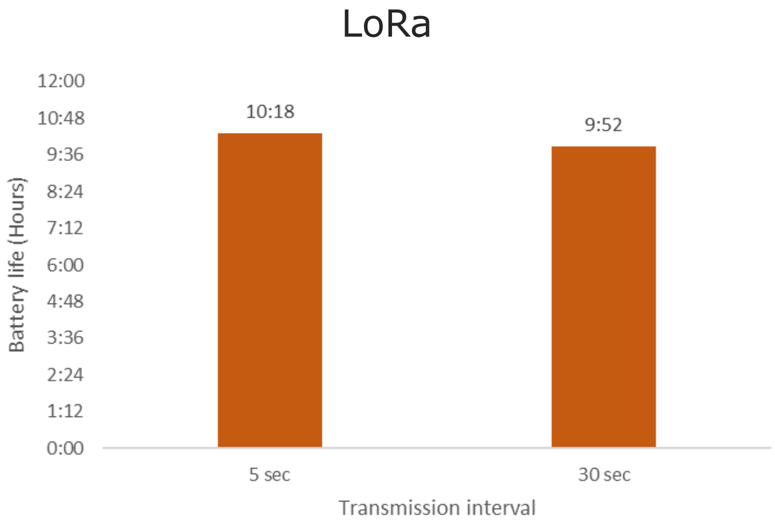


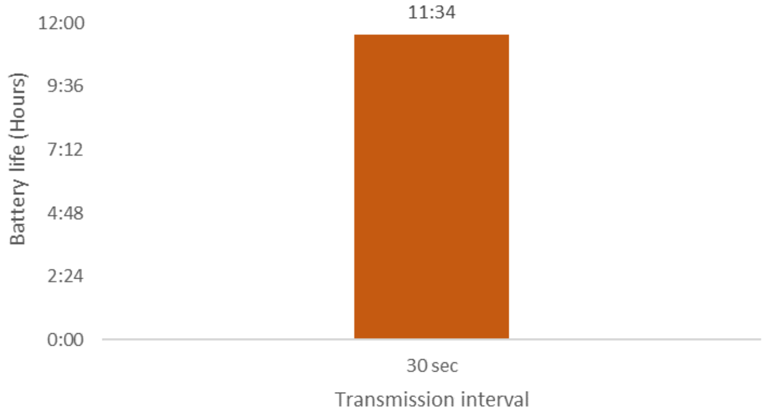
Mode	Energy consumption
LoRa 10 dB tx power	50 mA
LoRa 12 dB tx power	60 mA
LoRa 15 dB tx power	110 mA
LoRa 20 dB tx power	130 mA
WiFi AP mode	135 mA
WiFi scan mode	115 mA

LoRa settings

Tx Power	17 dB
Frequency	433 MHz
SF	7
Signal Bandwidth	125 KHz
Coding rate	4/5
Preamble length	8 Symbols

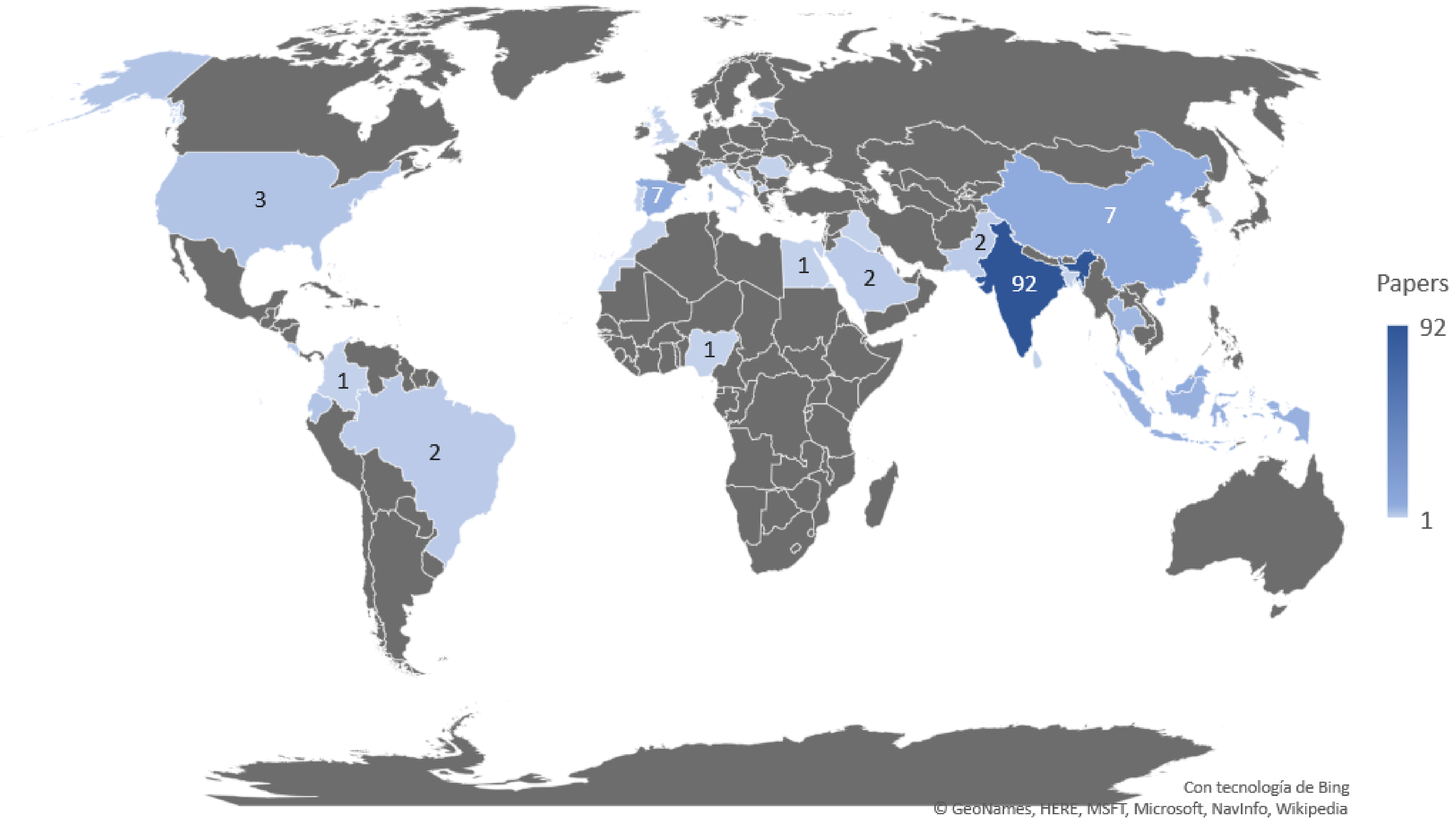






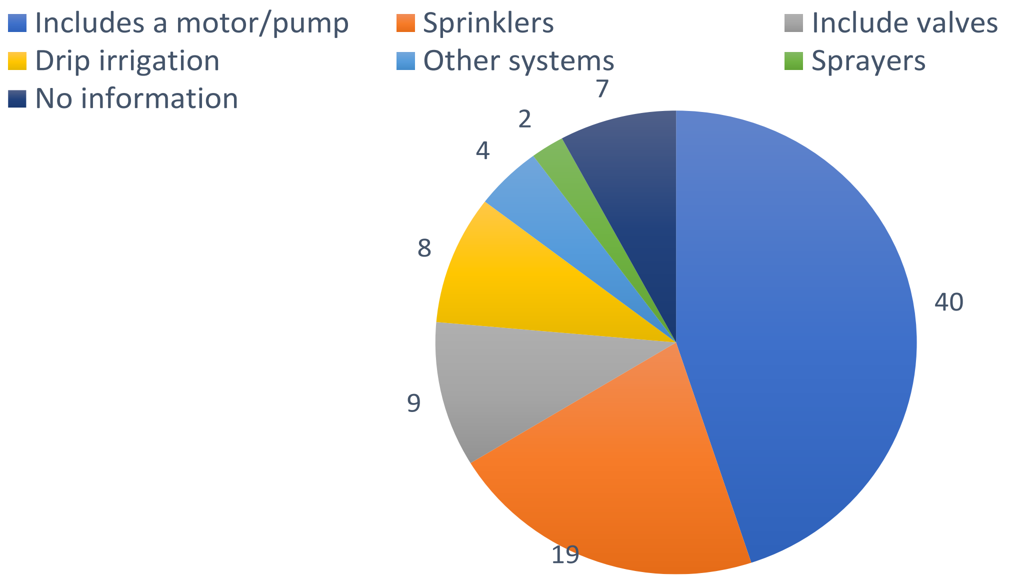
What is the Current State of Smart Irrigation Systems for Precision Agriculture?

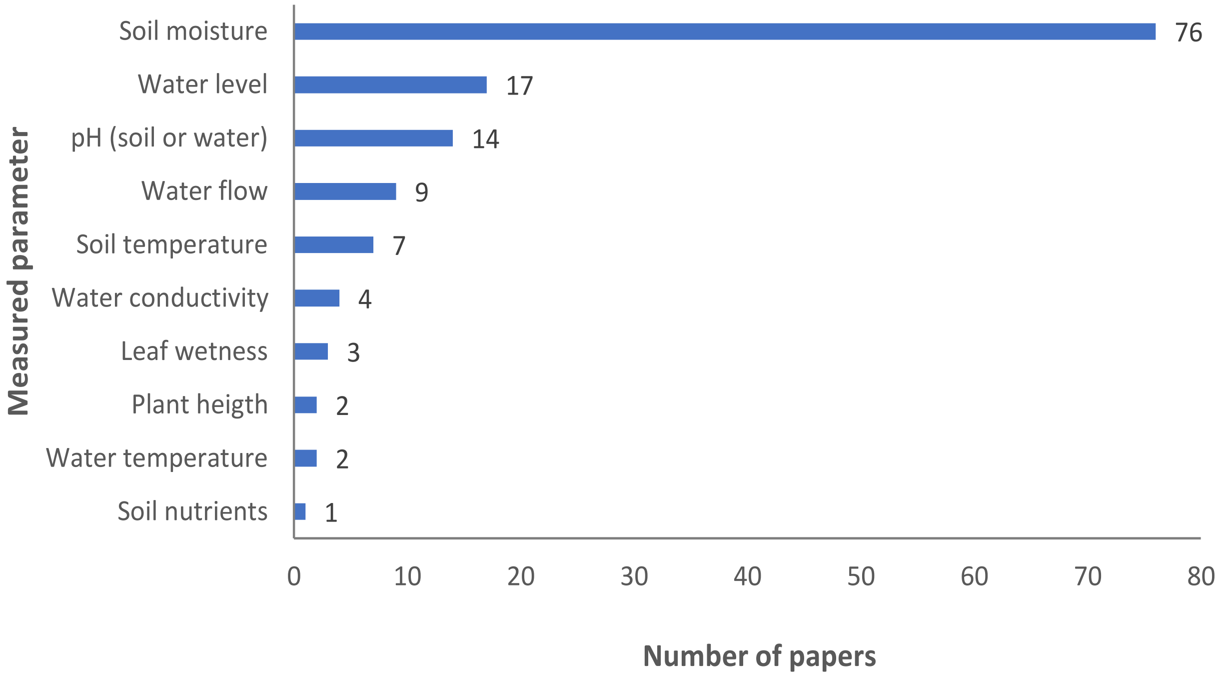
Number of studies on Smart irrigation



Own study

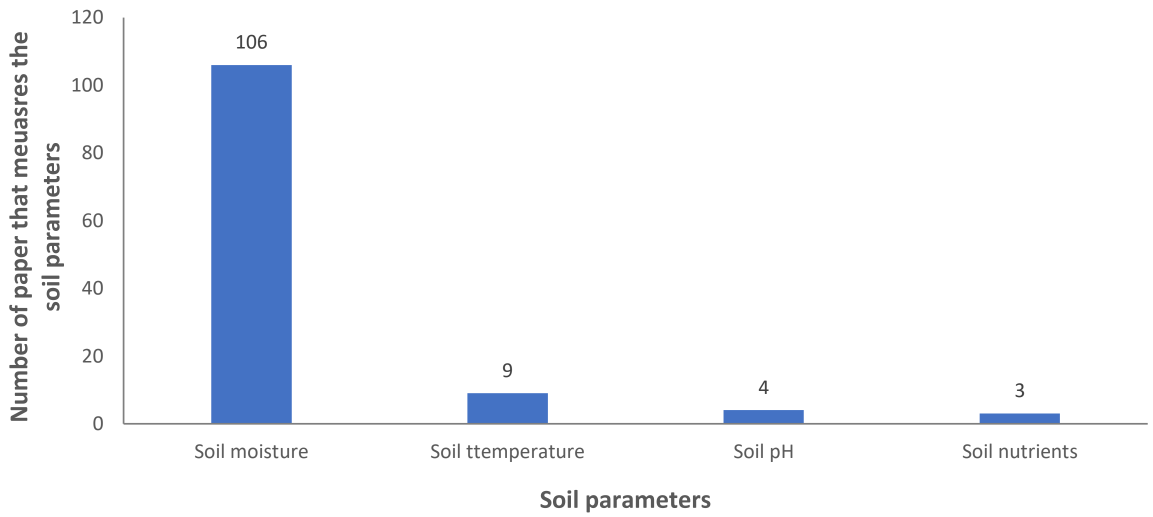
Water Management

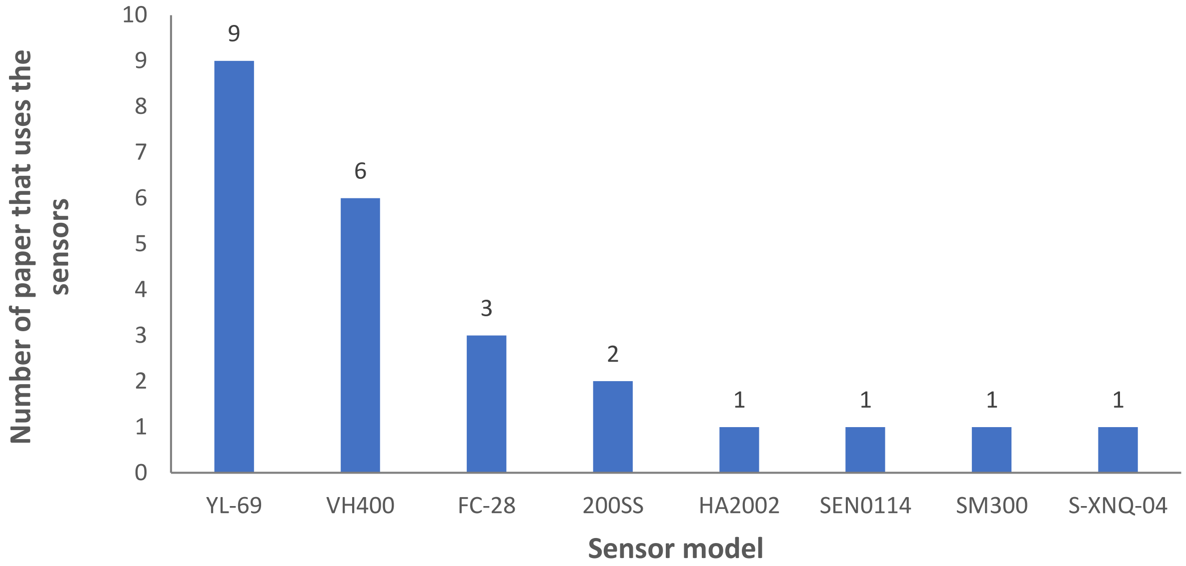




Own study

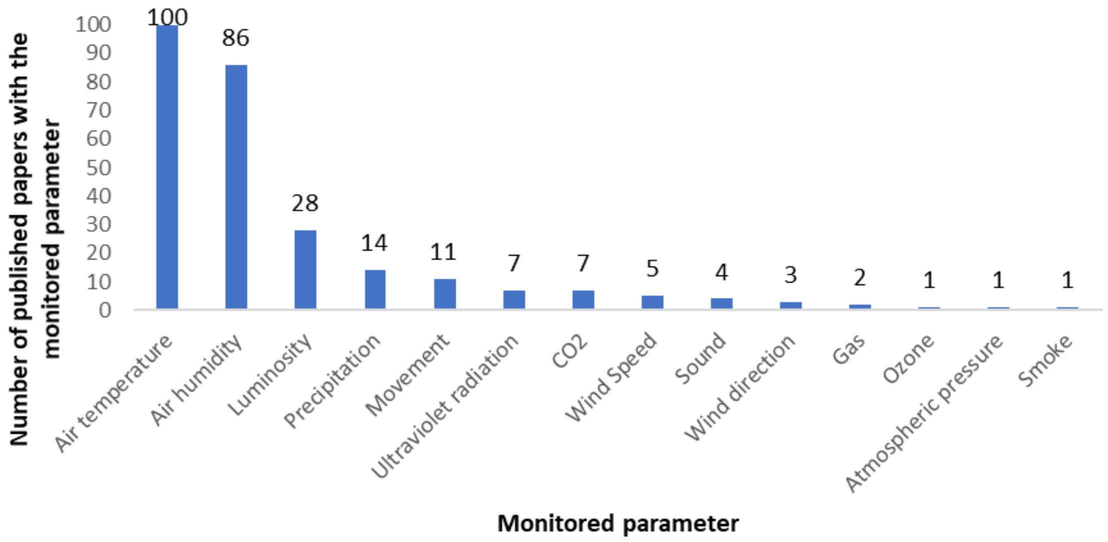
Soil monitoring

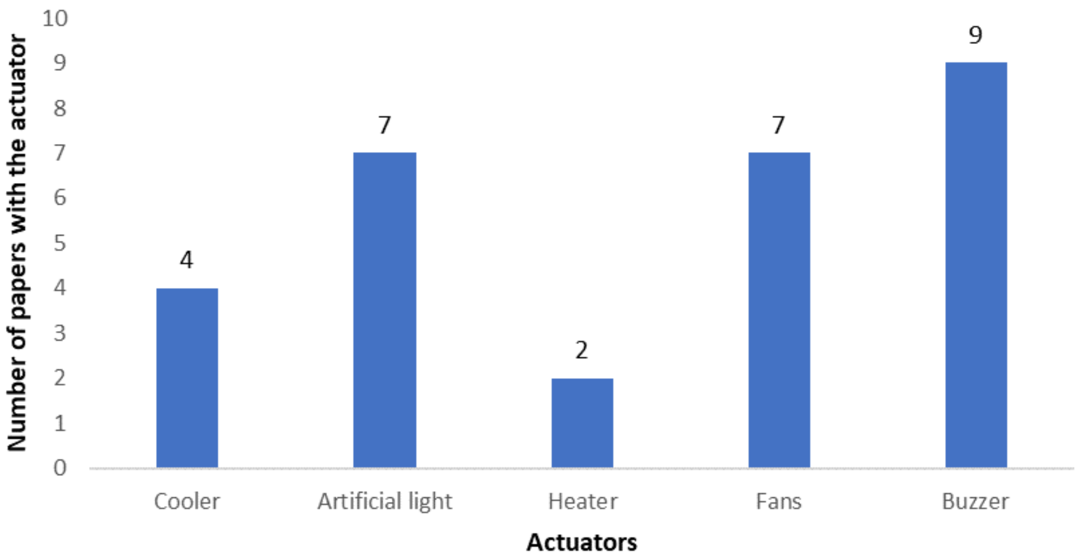




Own study

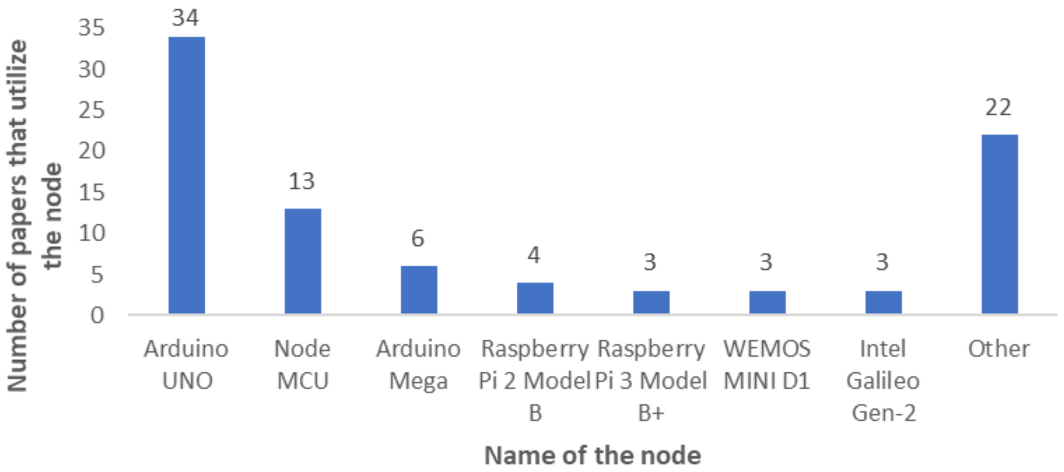
Weather monitoring

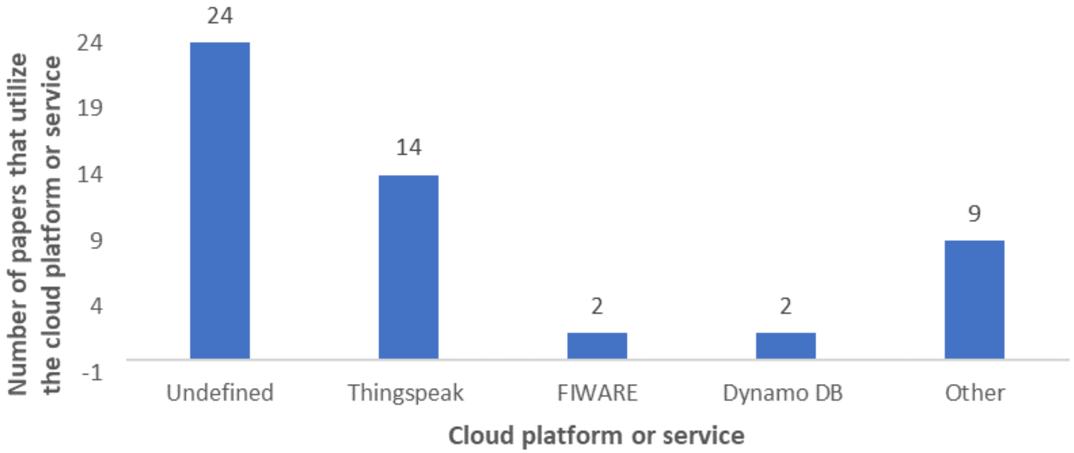


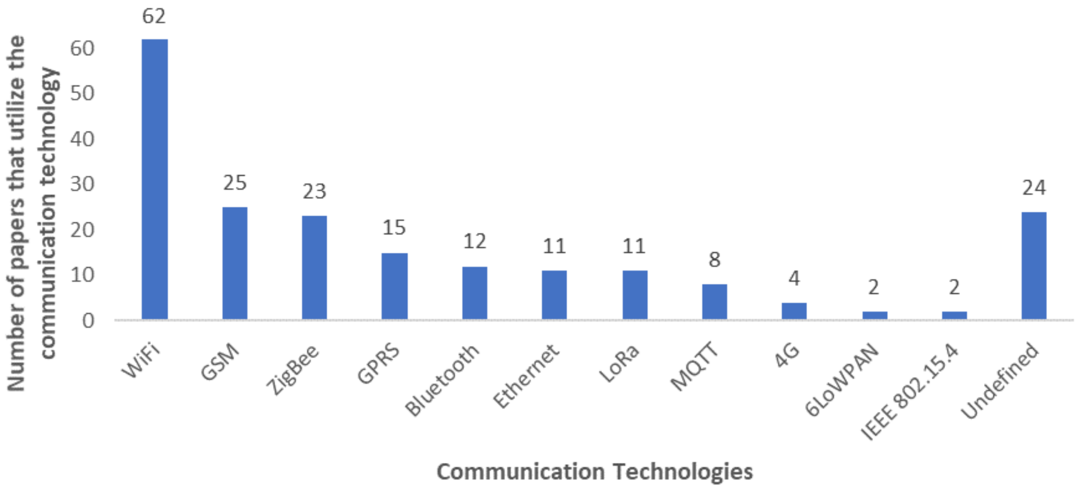


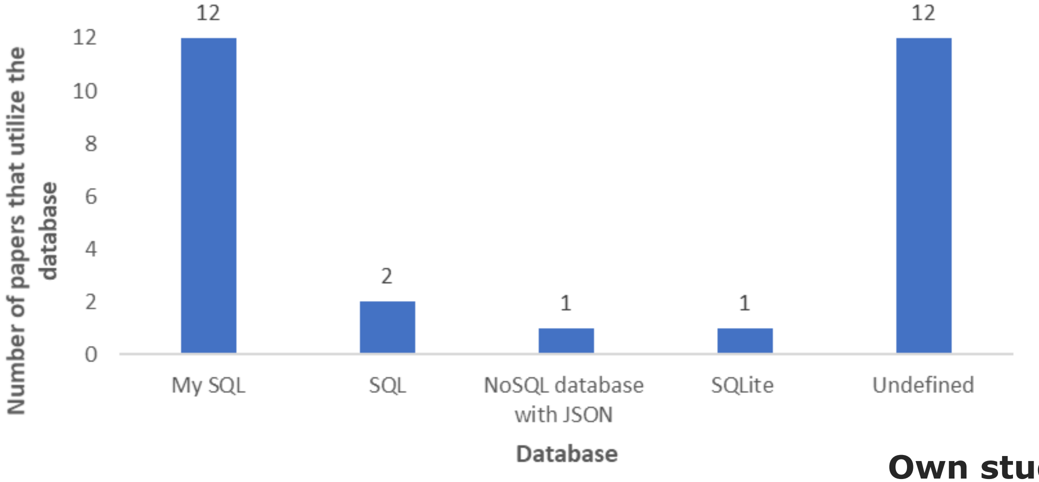
Own study

Sensor networks for irrigation systems

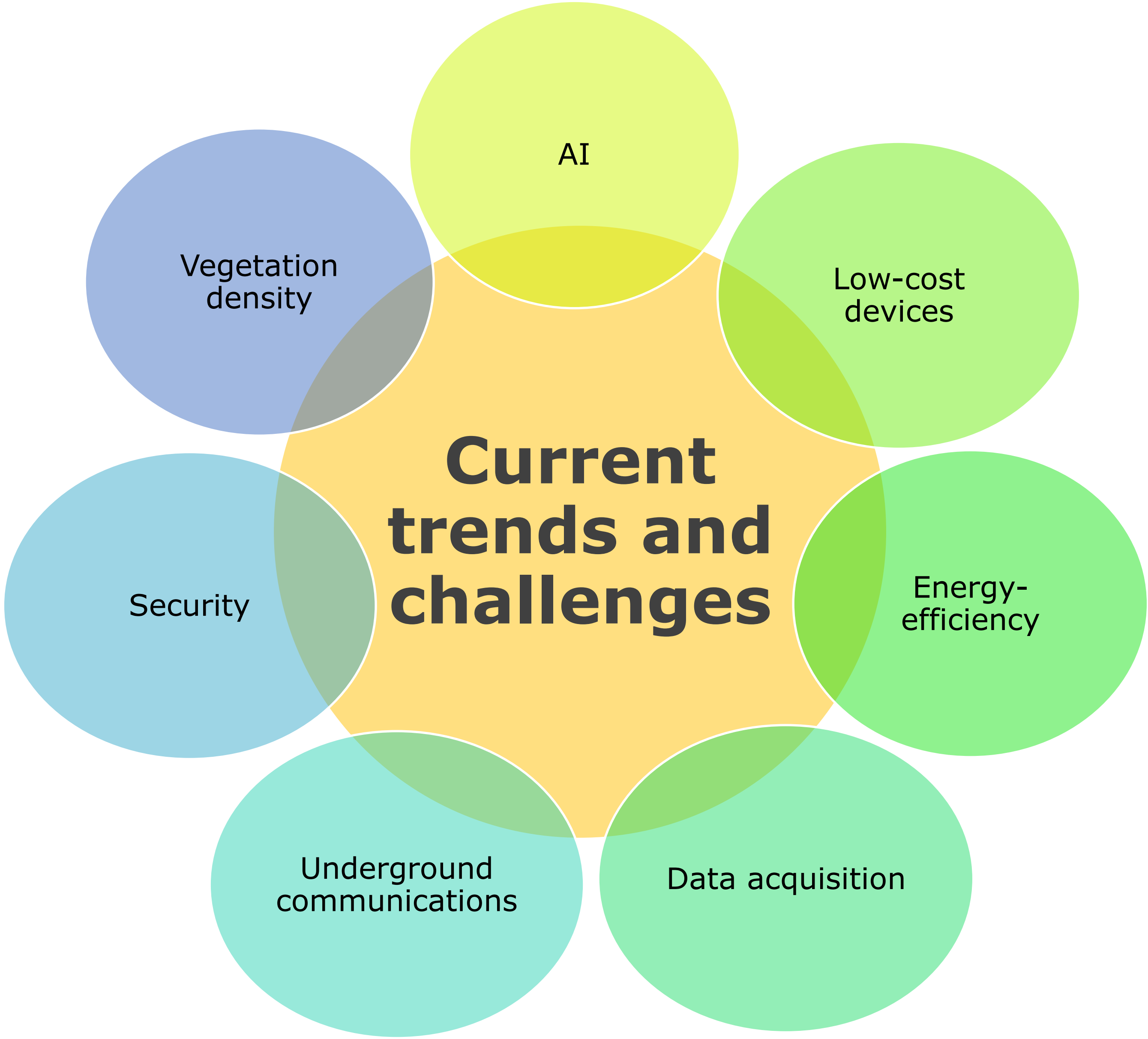








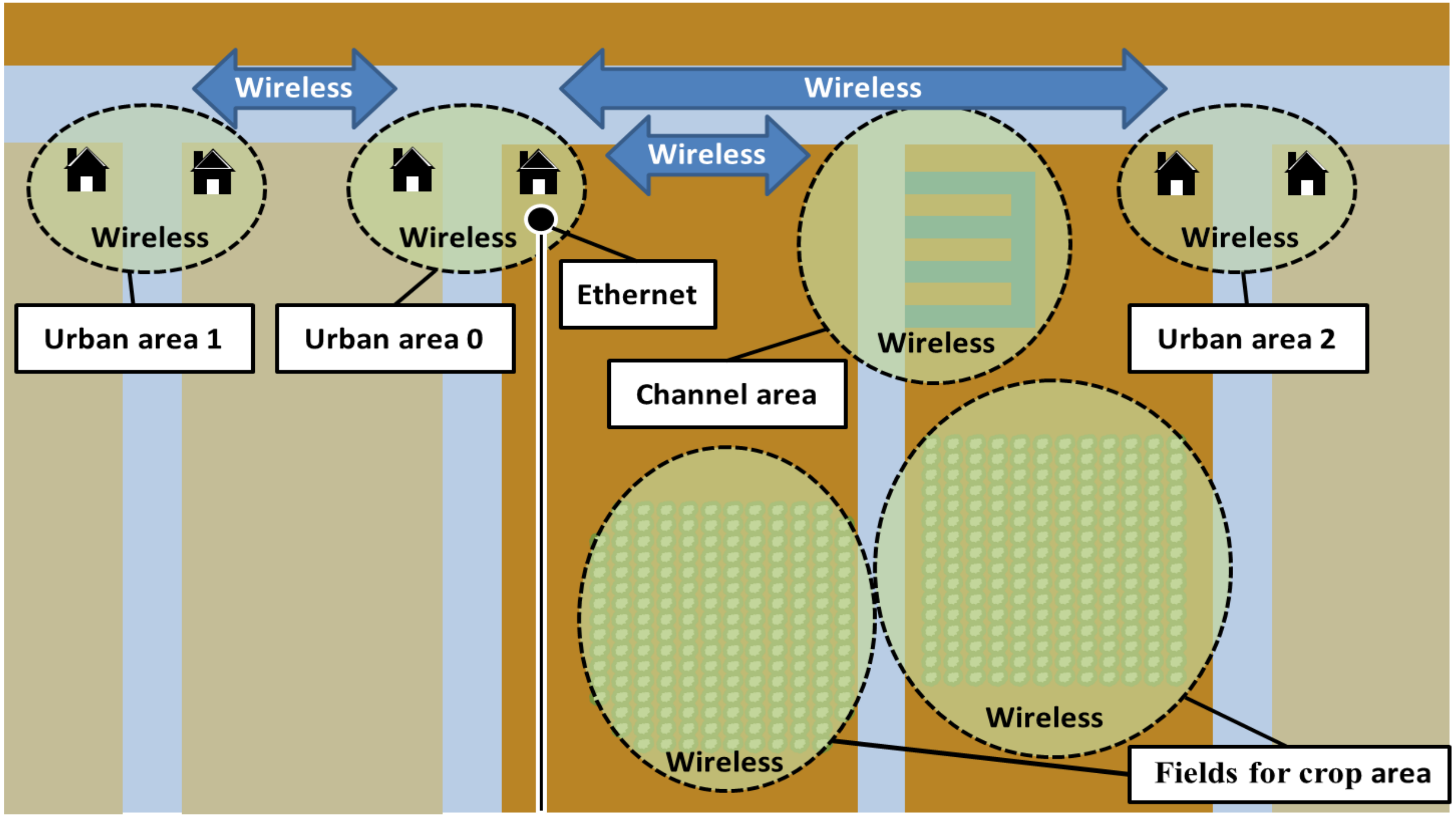
Own study


AI
Vegetation density
Low-cost devices
Current trends and challenges
Security
Energy-efficiency
Underground communications
Data acquisition

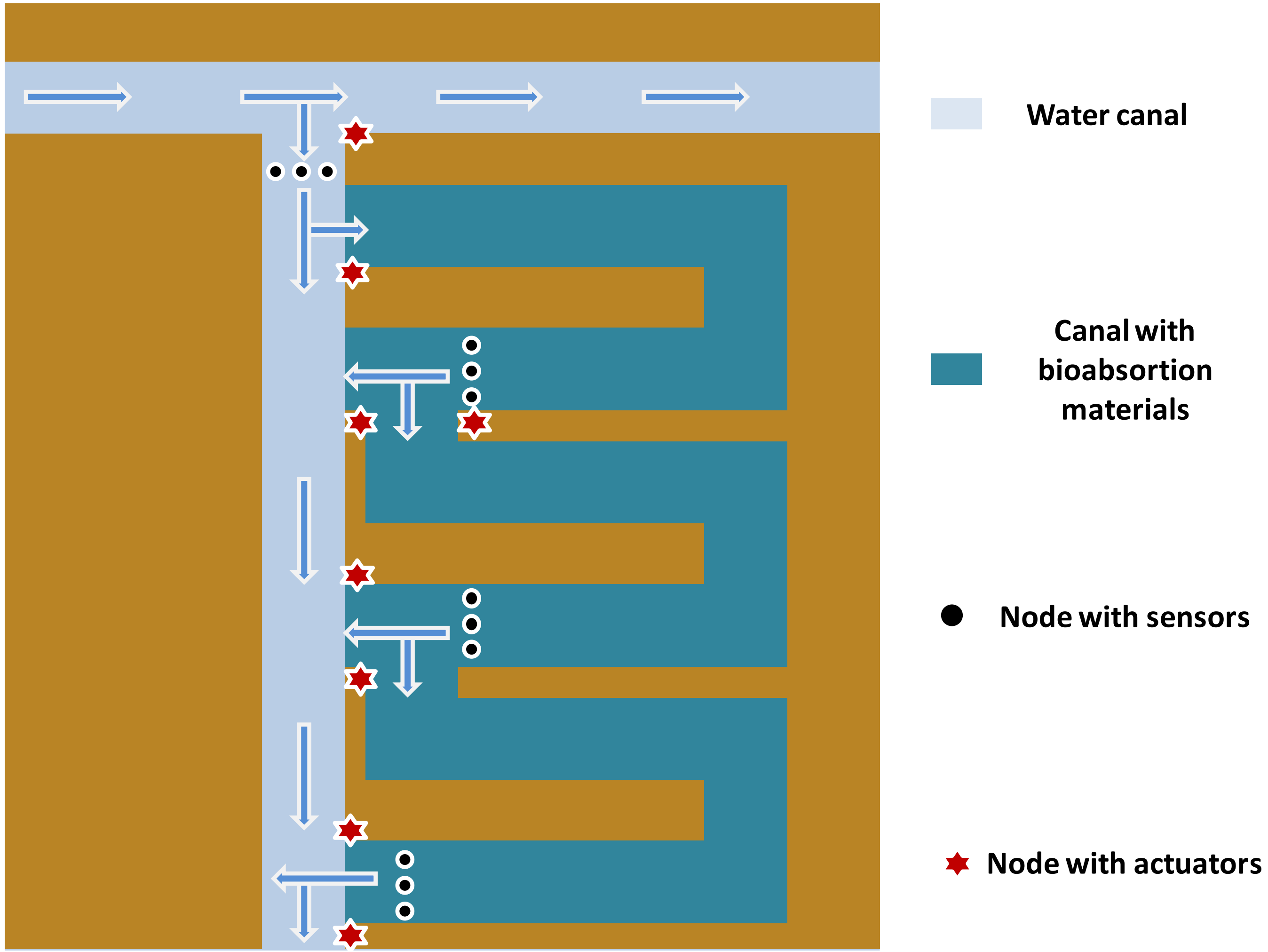
Own study

Heterogeneous Architecture for Irrigation

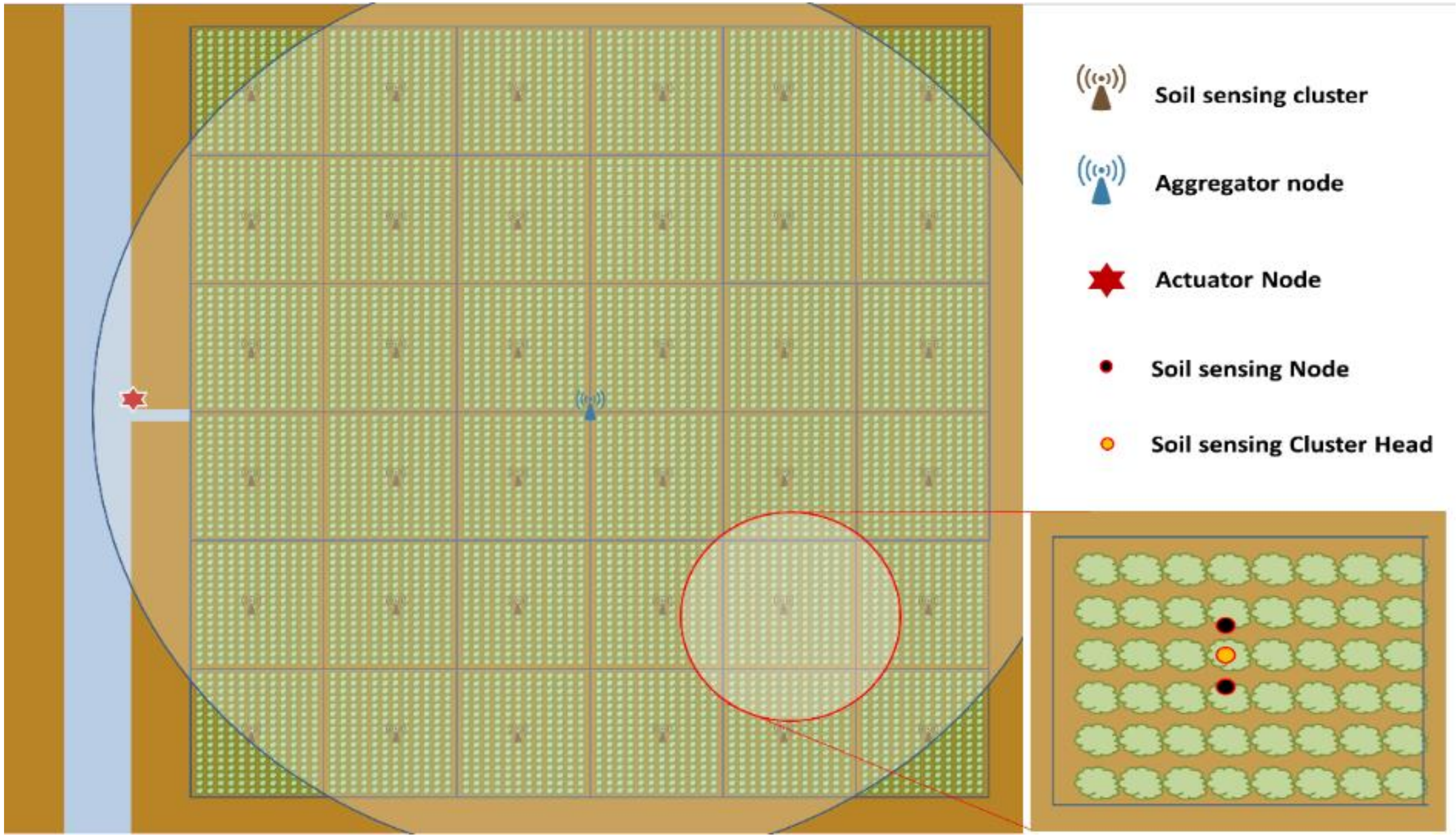
Monitored areas



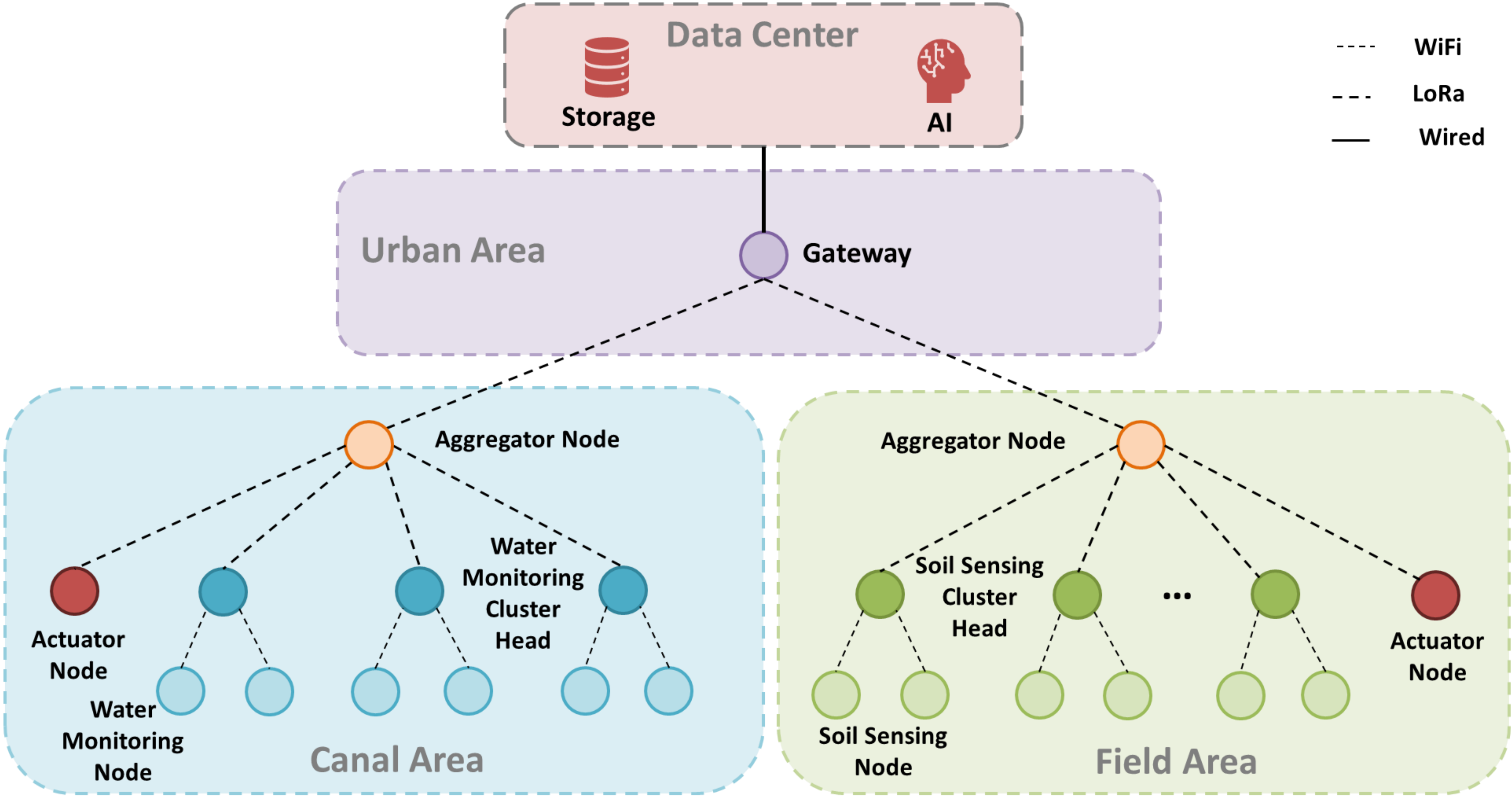
Monitored areas



Monitored areas

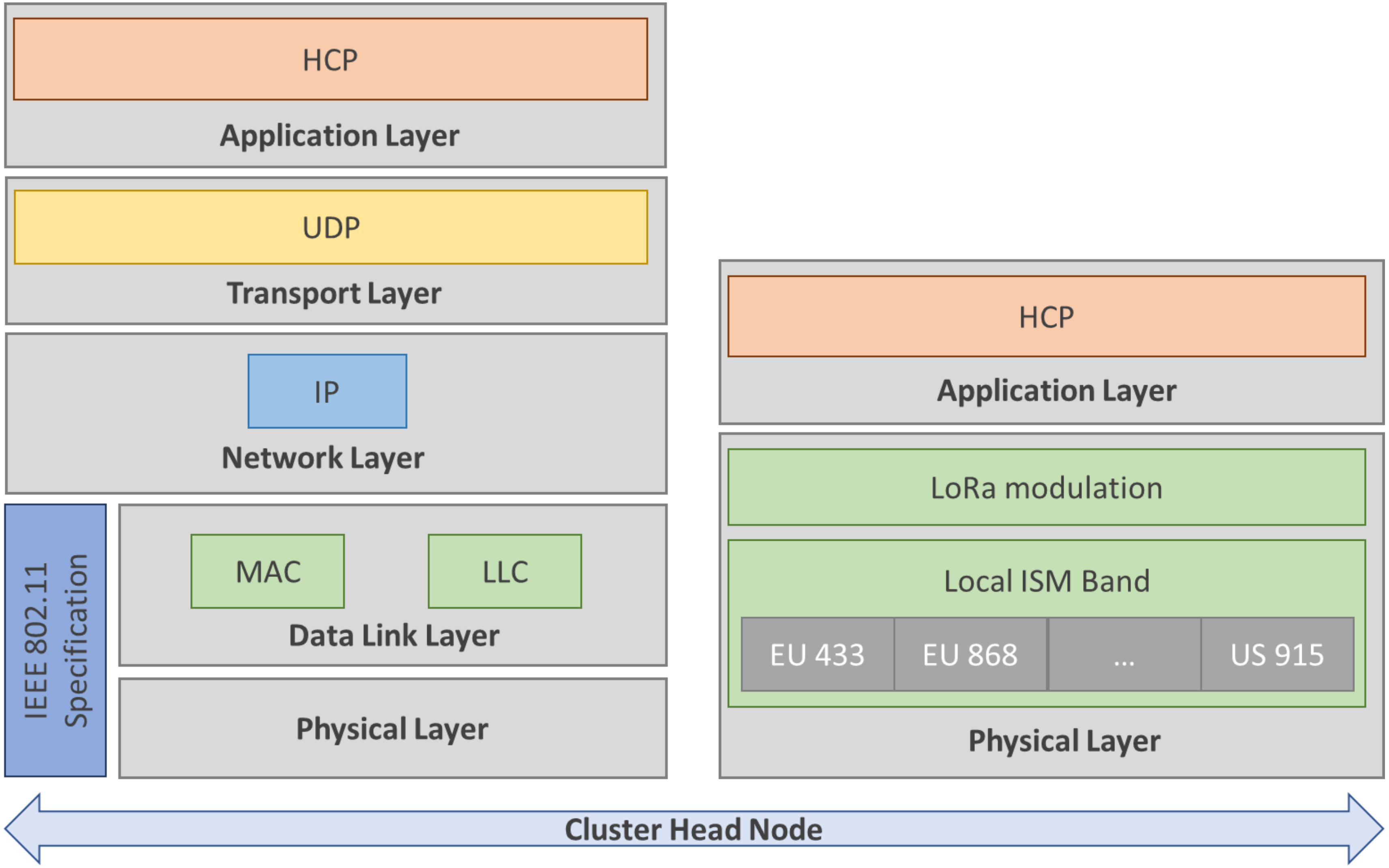


Topology

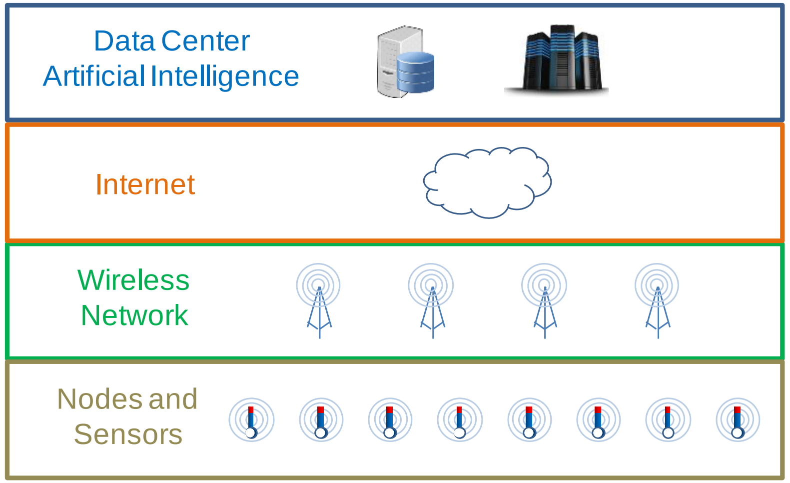


Data Center
Storage
AI
WiFi
LoRa
Wired
Urban Area
Gateway
Aggregator Node
Aggregator Node
Water Monitoring Cluster Head
Soil Sensing Cluster Head
Actuator Node
Water Monitoring Node
Actuator Node
Soil Sensing Node
...
Canal Area
Field Area

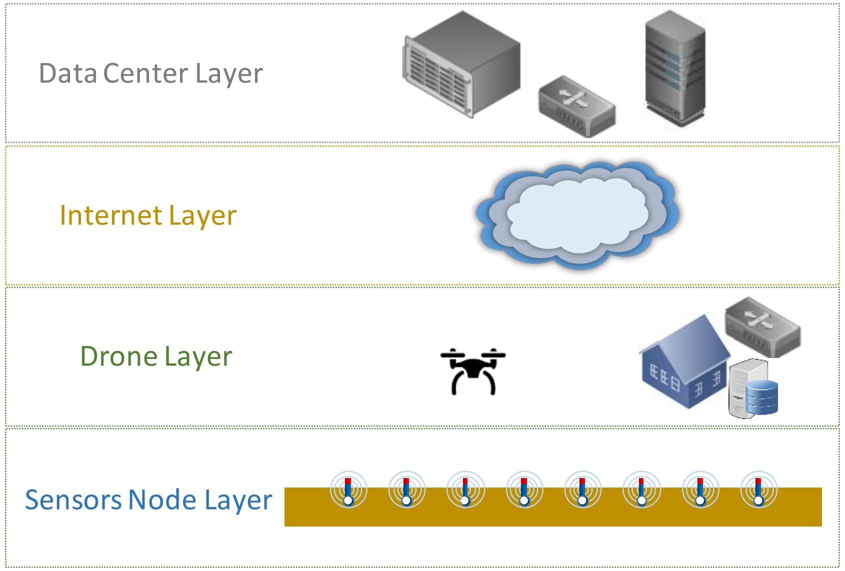
Protocol stack



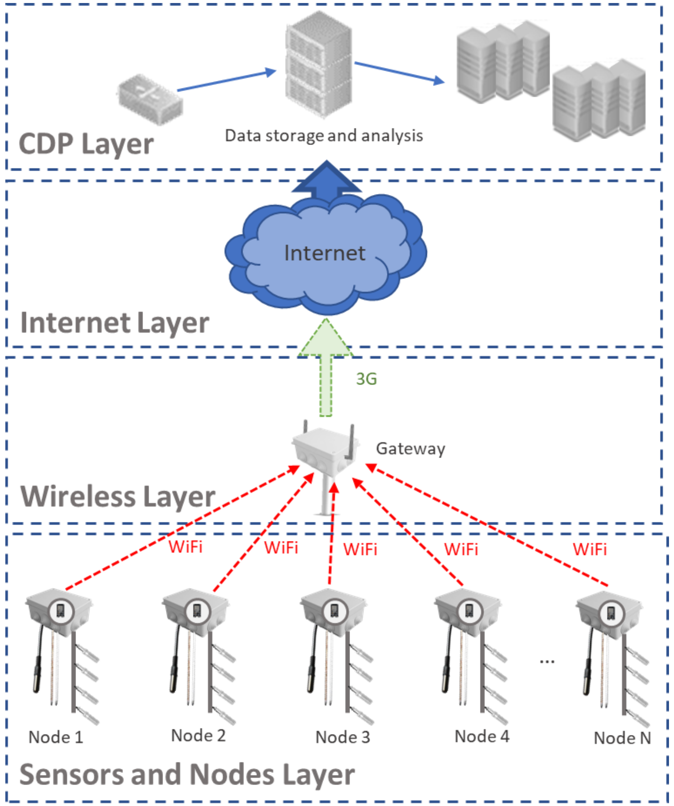
Architecture for IoUT functionalities



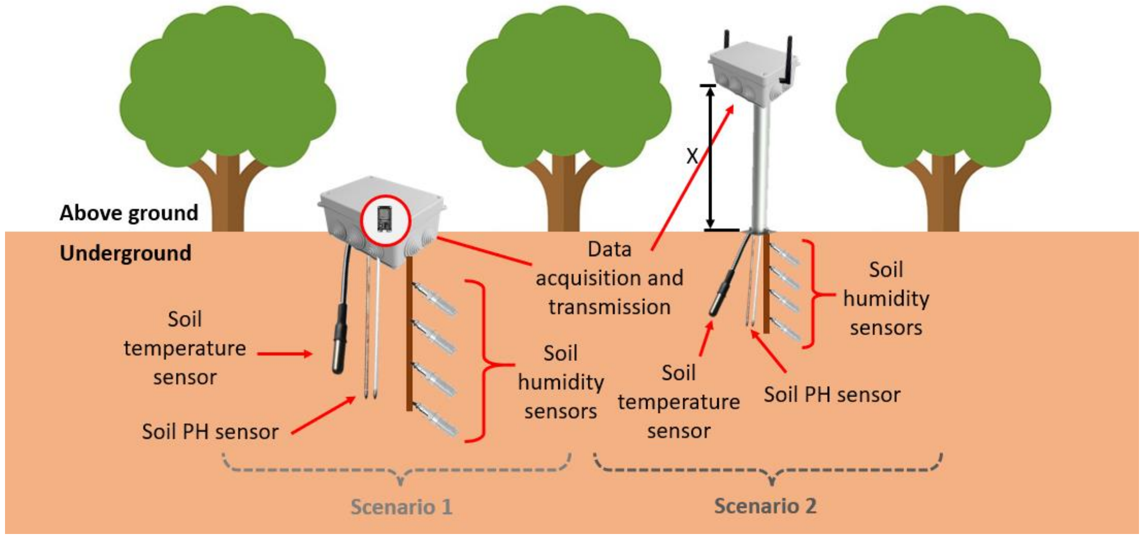
Architecture for the use of drones for data acquisition



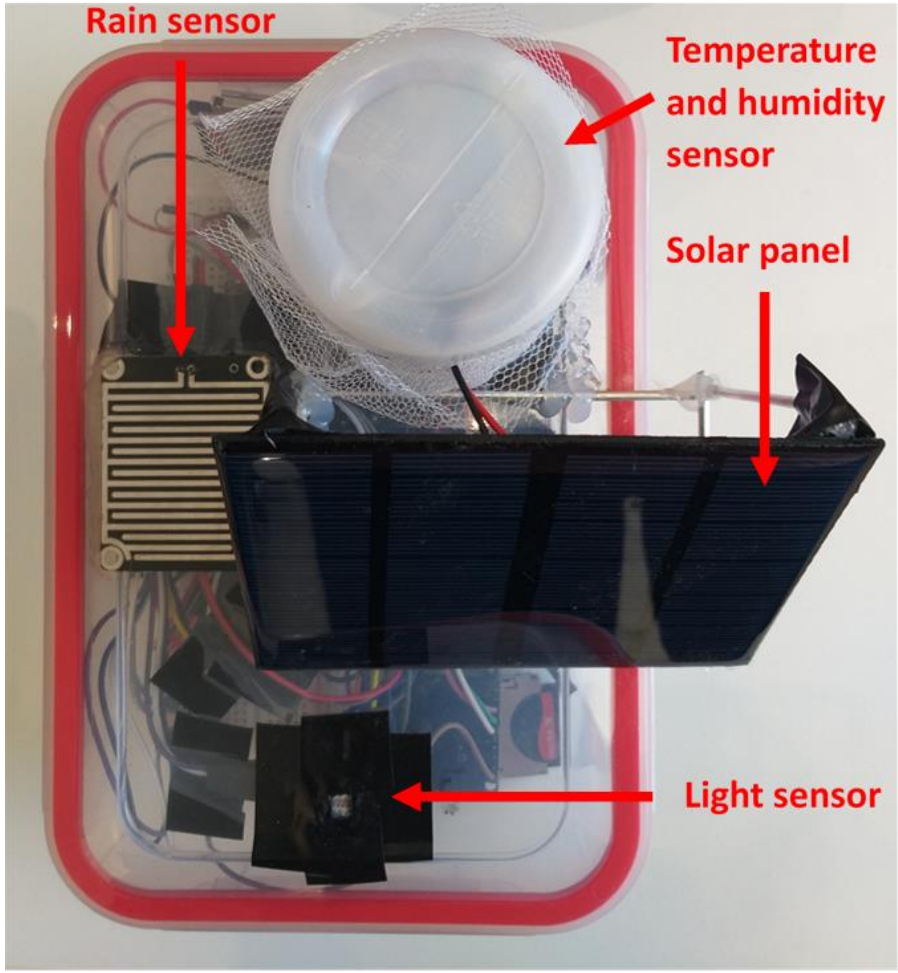
Architecture for remote fields with cellular connection



Soil monitoring



Meteorology monitoring

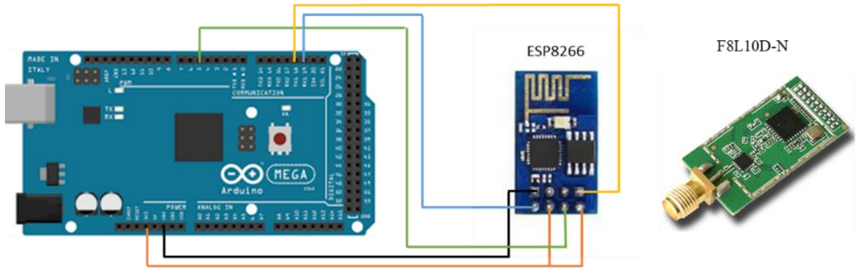


Water monitoring

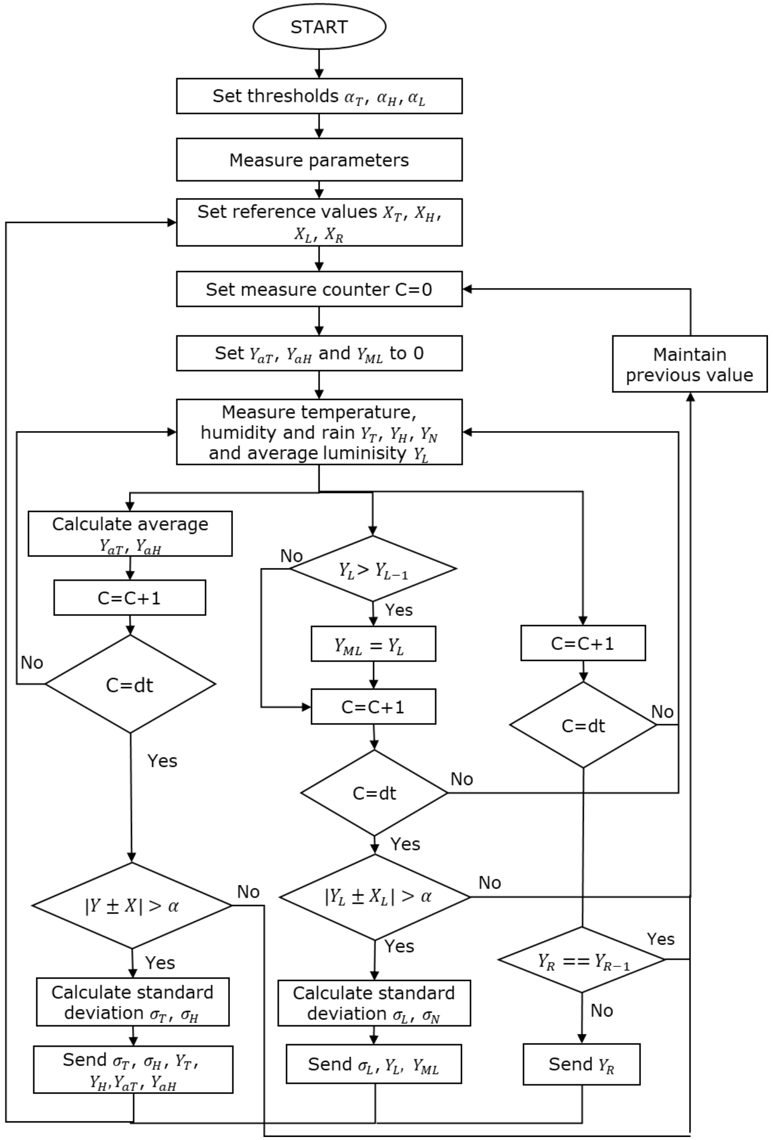
SENSORS

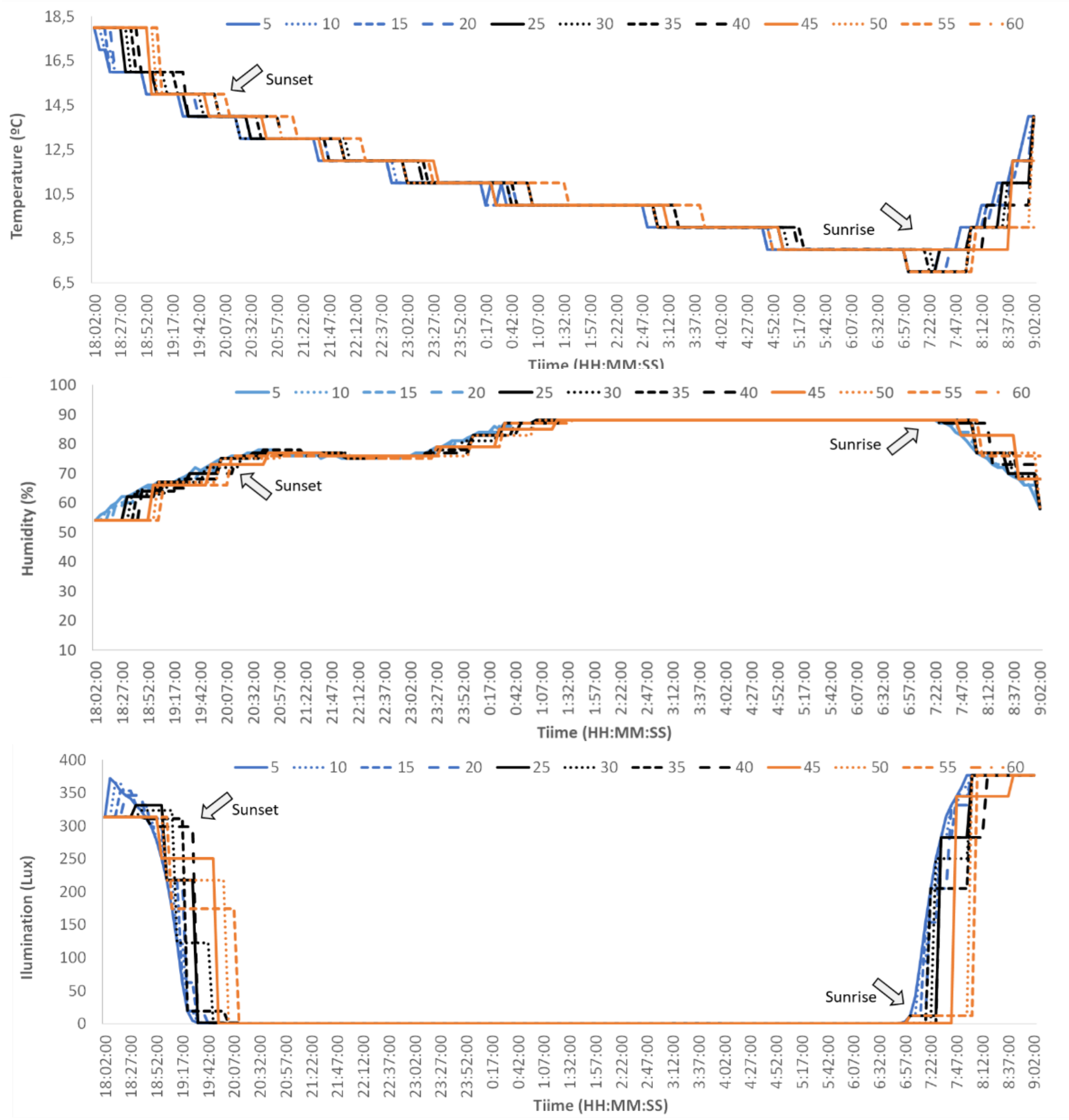
Turbidity

Conductivity



Data acquisition algorithm



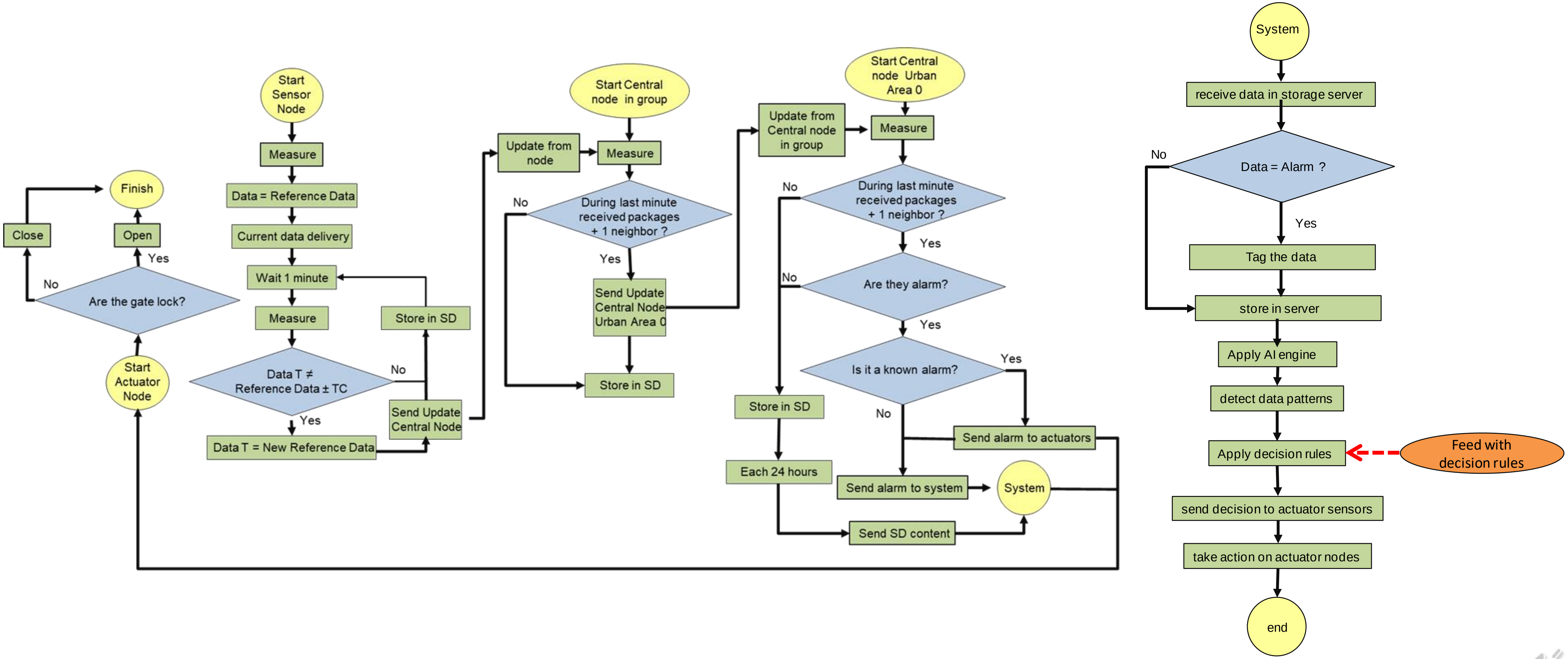


25 min

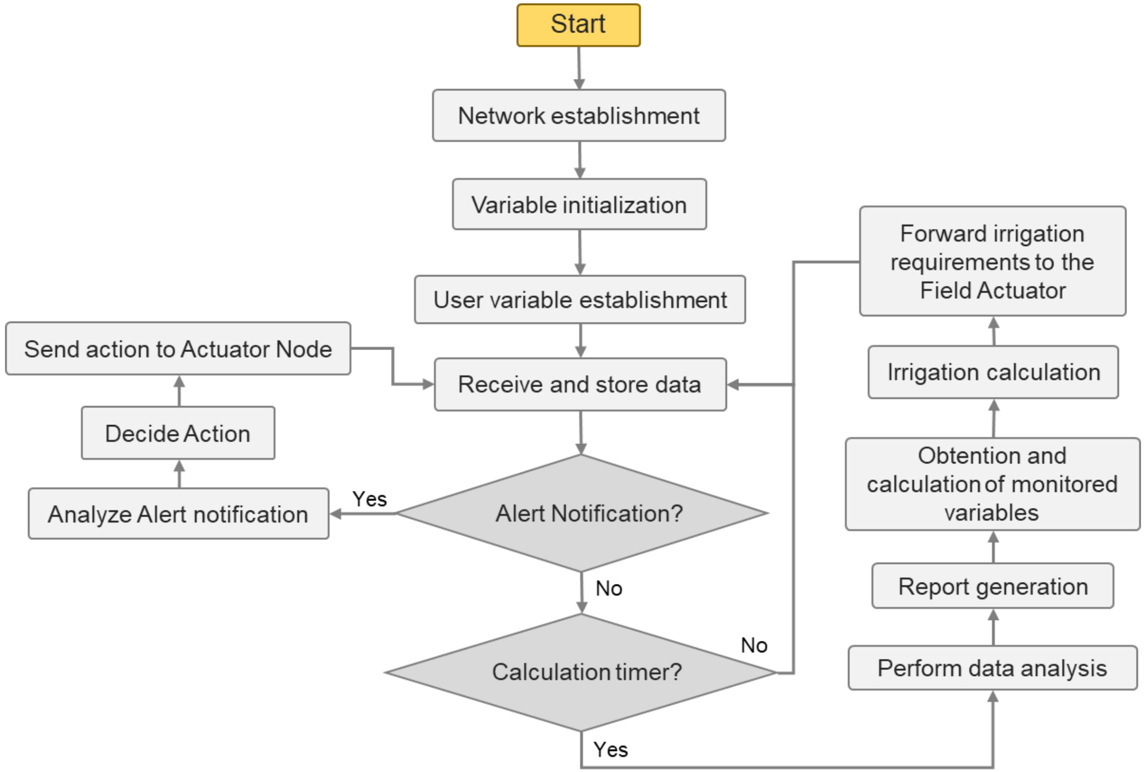
45 min

15 min

System operation algorithms



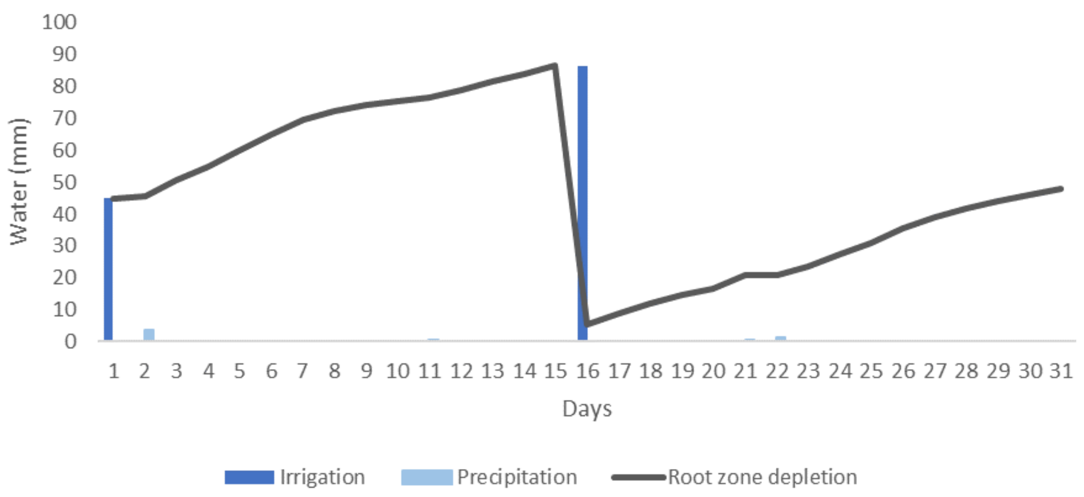
Flow chart data center



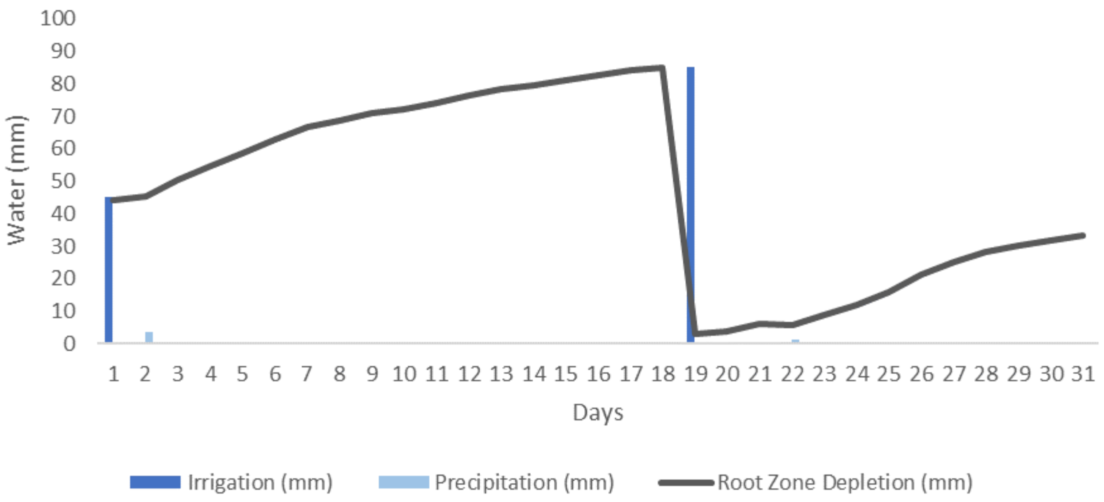
Algorithm 3.1. Irrigation algorithm

1) Variable initialization
2) User parameter initialization
3) ETo calculation
4) Determination of the Crop Stage
5) **If** Water stress **then**
6)   Calculate irrigation adjustment due to water stress
7) **end if**
8) **If** High salinity levels **then**
9)   Calculate irrigation adjustment due to salinity
10) **end if**
11) **If** Precipitation **then**
12)   Determine the precipitation amount
13)   Determine the hour of the precipitation
14)   Calculate irrigation adjustment due to precipitation
15) **end if**
16) Calculate ETc
17) Calculate Irrigation requirements of the crop
18) **End.**

Results



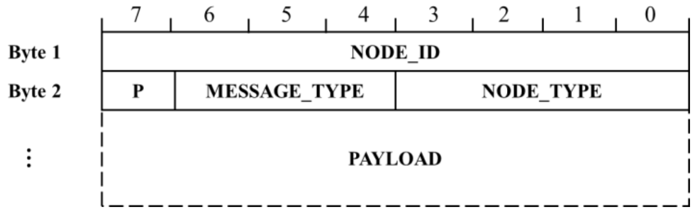
Murcia



Gandía

Protocol Design

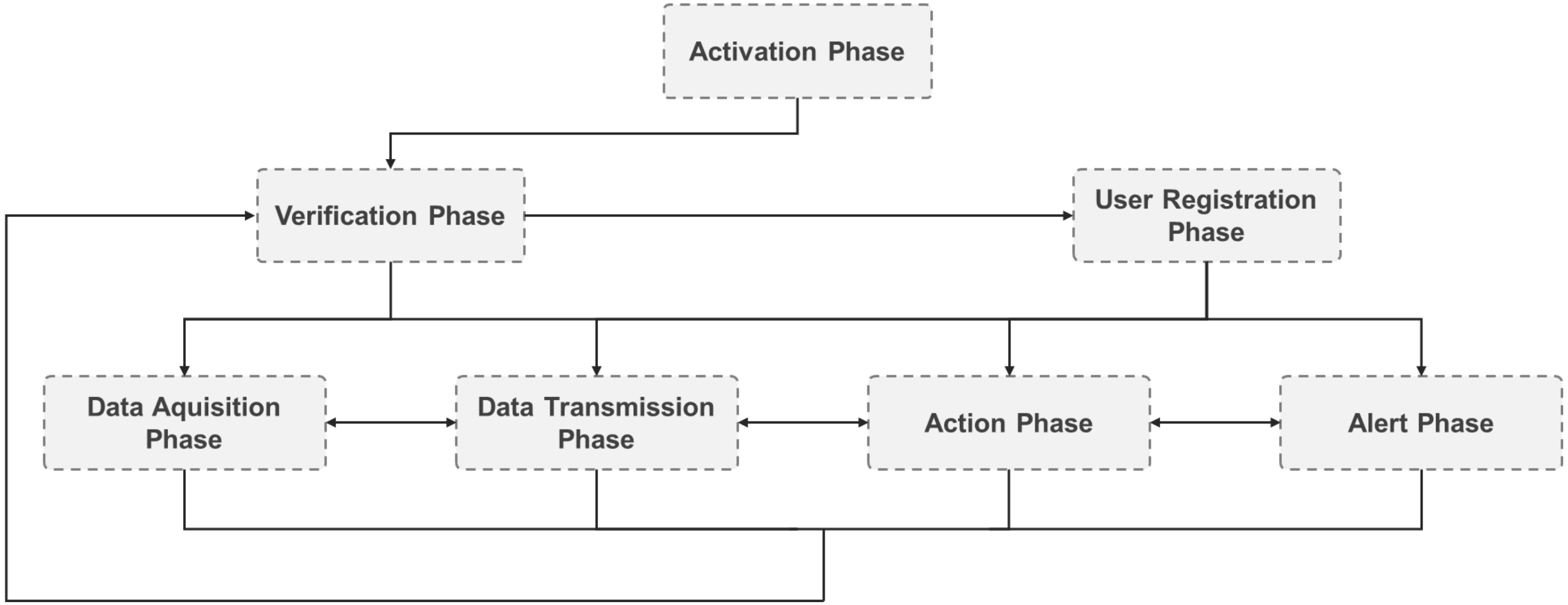
Message format



Value	Node Type	Bit			
		3	2	1	0
0	Data center	0	0	0	0
1	Gateway	0	0	0	1
2	Aggregator Node of Canal Area	0	0	1	0
3	Aggregator Node of Field Area	0	0	1	1
4	Actuator Node of Canal Area	0	1	0	0
5	Actuator Node of Field Area	0	1	0	1
6	Water Monitoring CH	0	1	1	0
7	Water Monitoring Node	0	1	1	1
8	Meteorology Monitoring Aggregator Node	1	0	0	0
9	Soil Sensing CH	1	0	0	1
10	Soil Sensing Node	1	0	1	0
11	Farmer User	1	0	1	1
12	Hydrographic Confederation User	1	1	0	0

Value	Message Type	Bit			Description	Priority
		6	5	4		
0	REGISTER	0	0	0	This message is sent when creating the topology for the node to be assigned an ID.	Yes
1	DATA	0	0	1	This is the message format to forward data.	Both options
2	ACTION	0	1	0	This is the message that is sent to the actuators with the actions they have to perform.	Yes
3	MALFUNCTION	0	1	1	This is an Alert message that is forwarded to the Data Center when a malfunction in one of the elements of a node is detected but the node is able to perform other activities.	Yes
4	IS_DOWN	1	0	0	This is an Alert message that is forwarded to the Data Center to notify that a node is not functioning.	Yes
5	LOW_BATTERY	1	0	1	This is an Alert message that is forwarded to the Data Center to notify that a node has a low battery and thus, there is a problem with the energy-harvesting functionality.	Yes
6	POLLUTION	1	1	0	This is an Alert message forwarded to the Data Center by the nodes in the Canal Area to notify that pollution has been detected.	Yes
7	SALINITY	1	1	1	This is an Alert message forwarded to the Data Center by the nodes in the Canal Area to notify that high levels of salinity have been detected in the water.	Yes

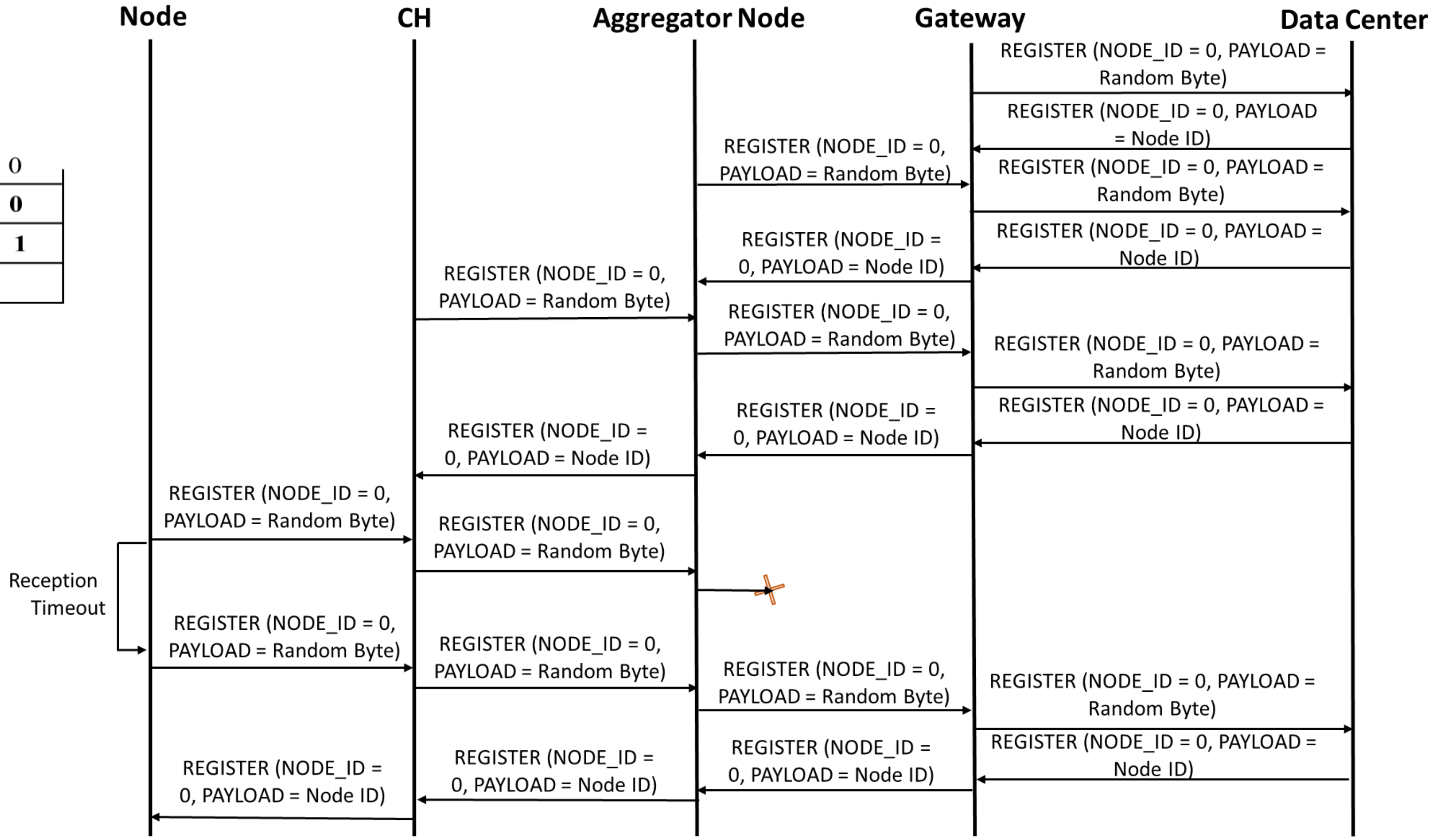
System diagram



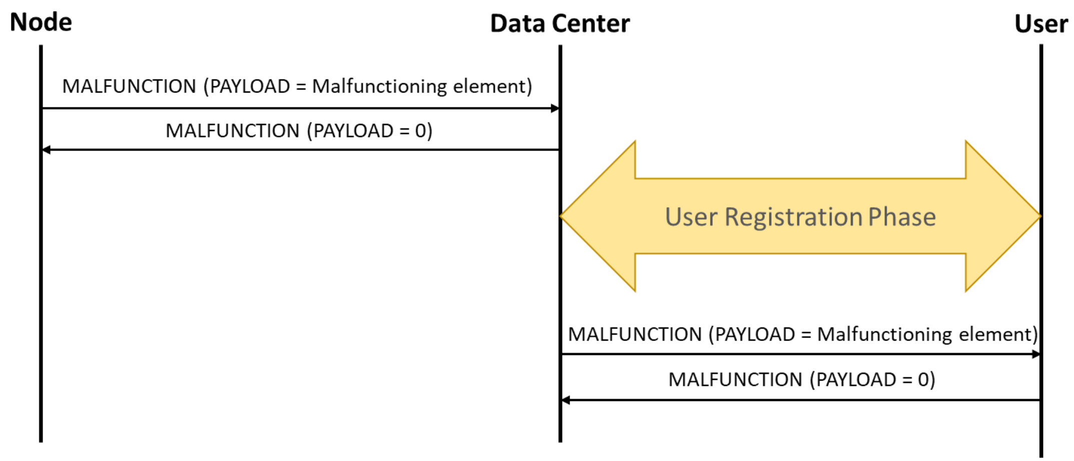
Activation phase

Register message

	7	6	5	4	3	2	1	0
Byte 1	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Byte 2	**1**	**0**	**0**	**0**	**0**	**1**	**1**	**1**
Byte 3	**Random**							

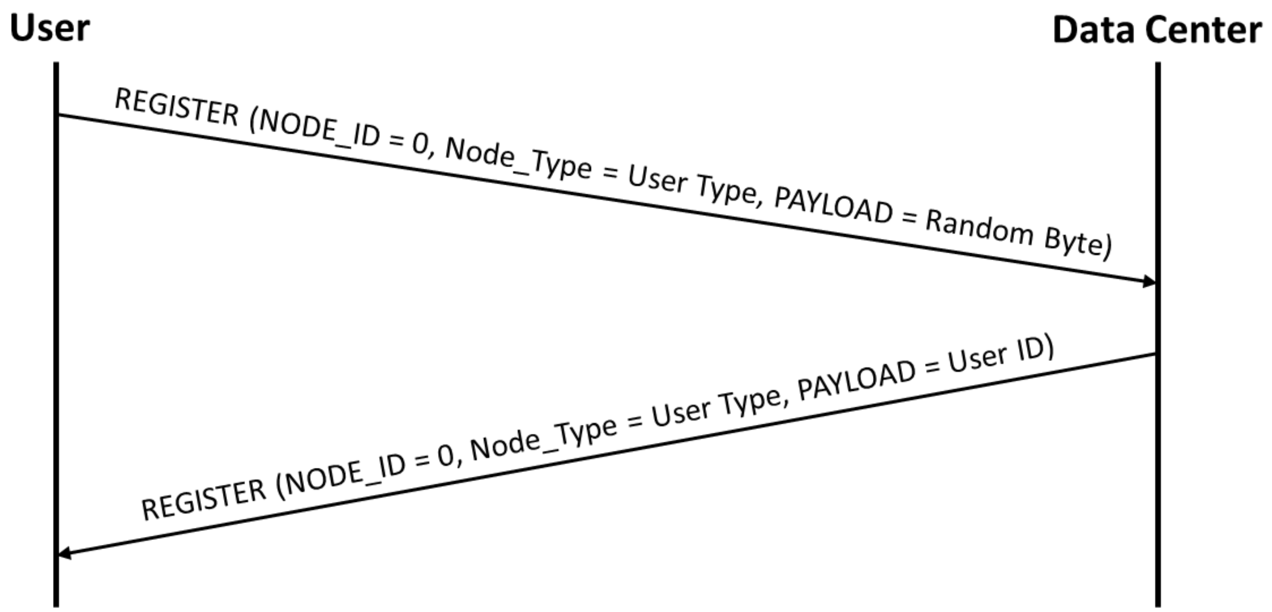


Verification phase



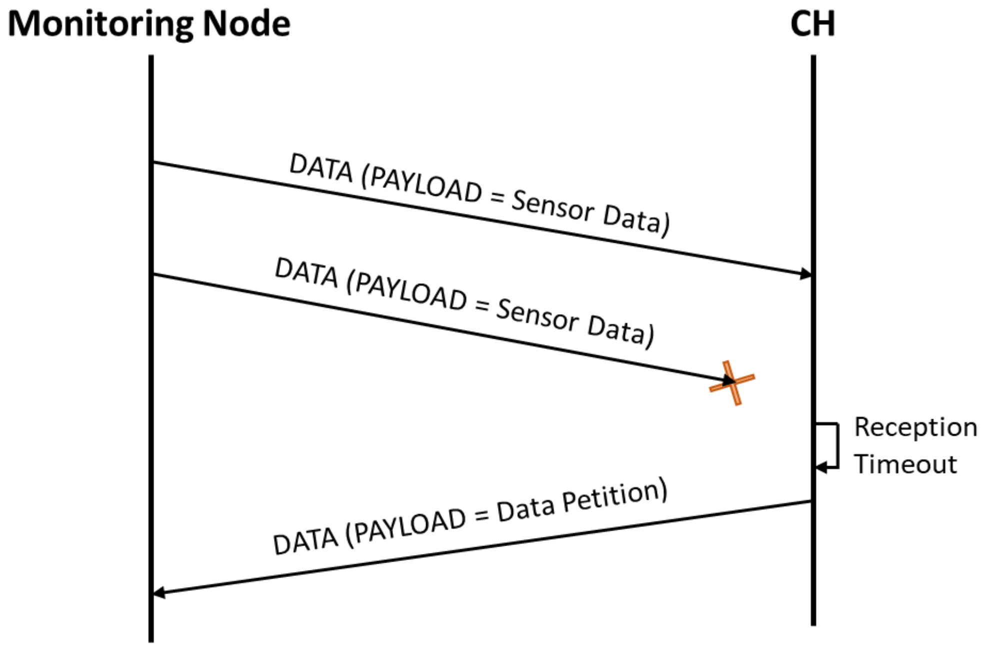
Node Type	Bit				
	4	3	2	1	0
Actuator Node of Canal Area	-	-	-	Gate 2	Gate 1
Actuator Node of Field Area	-	-	-	Flux sensor	Gate
Water Monitoring CH/Node	-	-	Oil sensor	Turbidity sensor	Salinity sensor
Meteorology Monitoring Aggregator Node	Wind sensor	Luminosity sensor	Rain sensor	Humidity sensor	Temperature sensor
Soil Sensing CH/Node	pH sensor	Temperature sensor	Humidity sensor 3	Humidity sensor 2	Humidity sensor 1

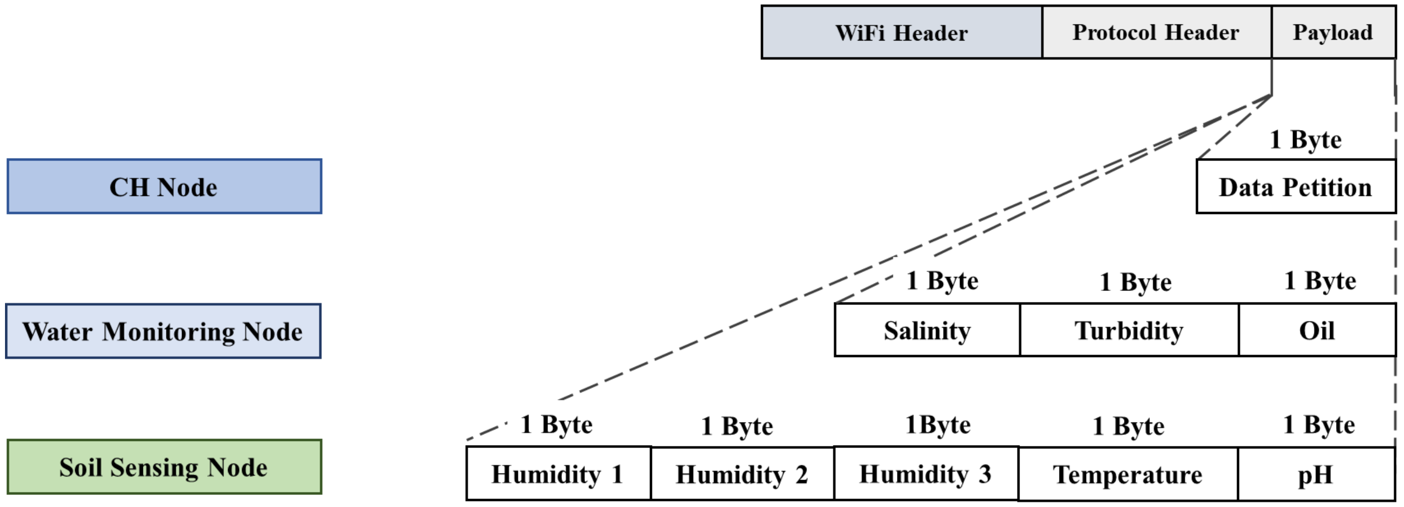
User registration phase



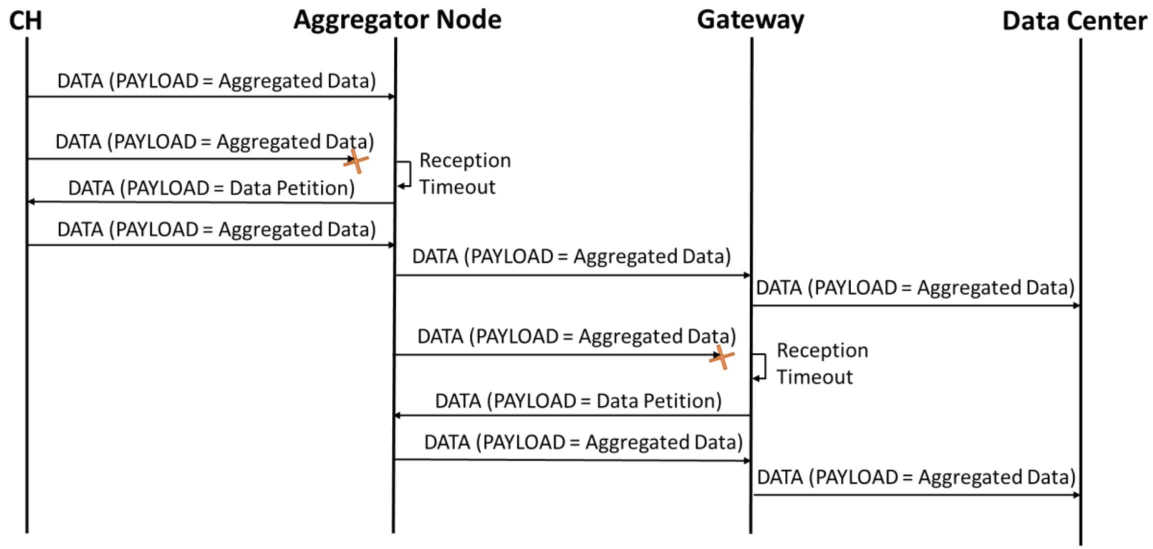
User Type	Node Type
Farmer User	Meteorology Monitoring Aggregator Node, Aggregator Node of Field Area, Actuator Node of Field Area, Soil Sensing CH, and Soil Sensing Node
Hydrographic Confederation User	Aggregator Node of Canal Area, Actuator Node of Canal Area, Water Monitoring CH, and Water Monitoring Node.

Data acquisition phase

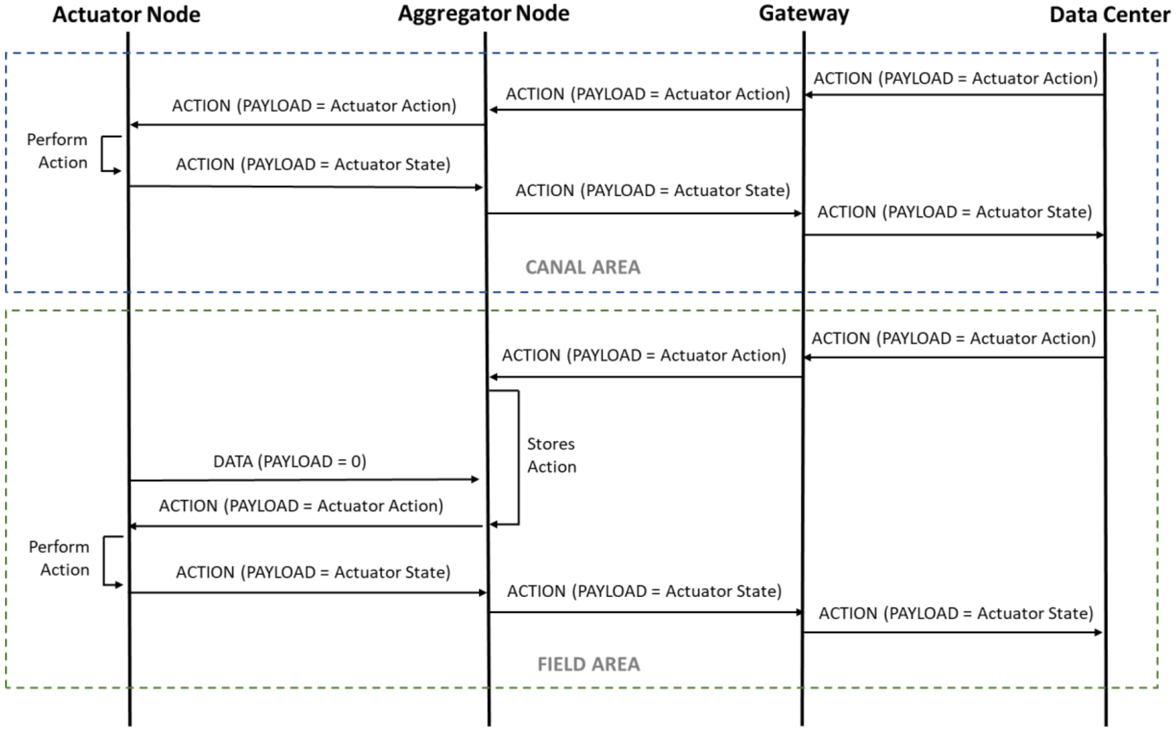




Data transmission phase



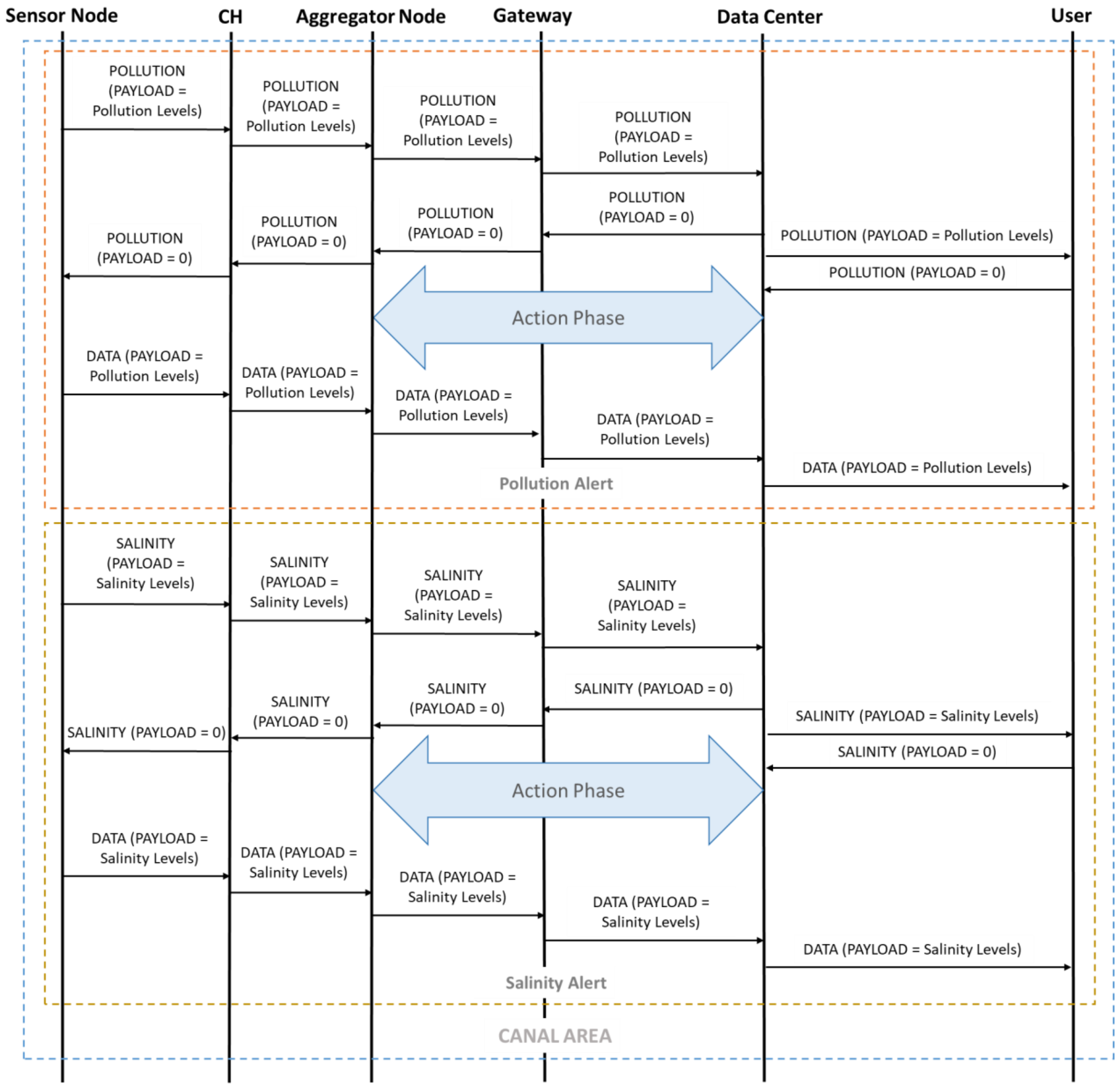
Action phase



Alert phase

- Pollution detected

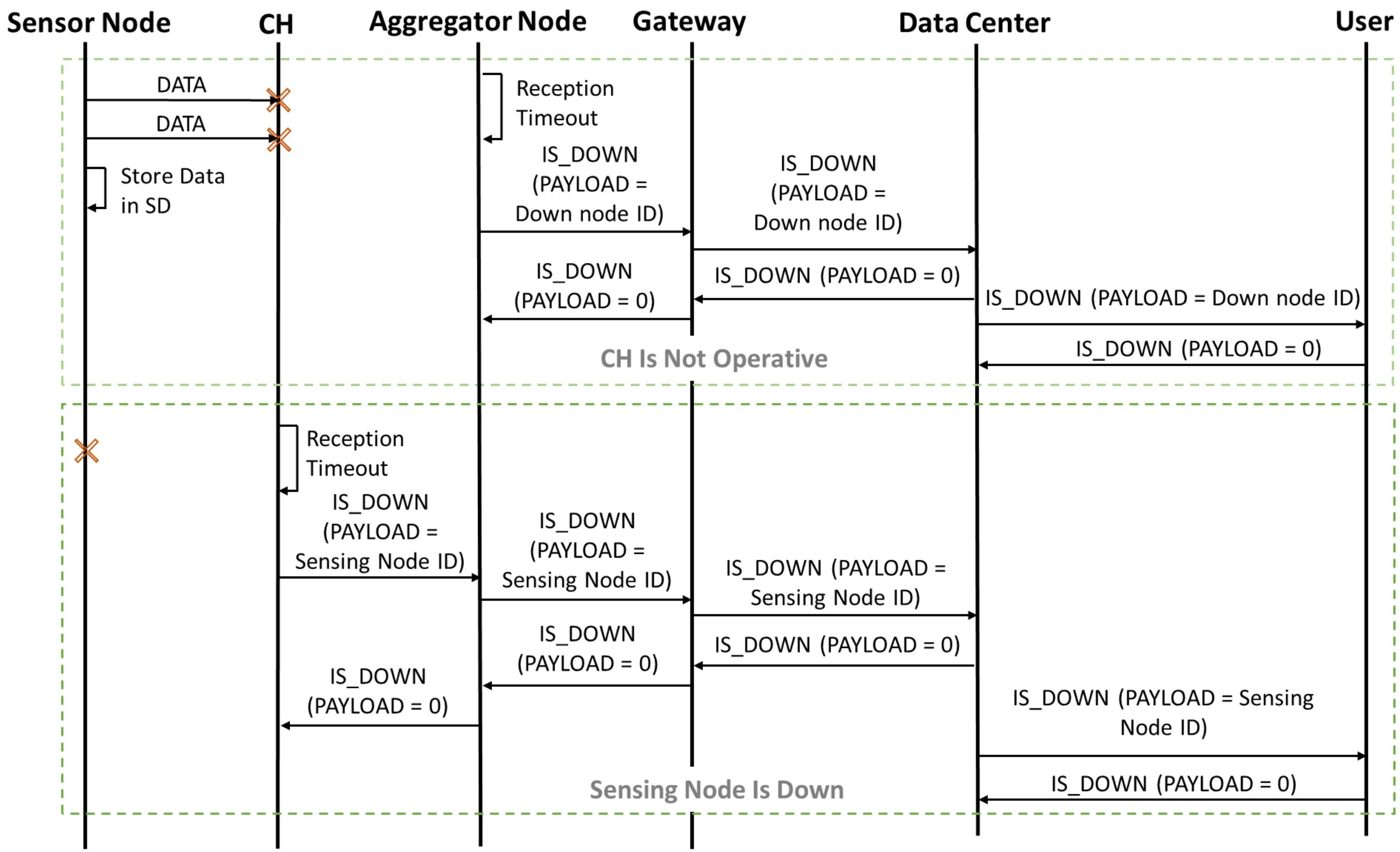
- High salinity levels detected



Alert phase

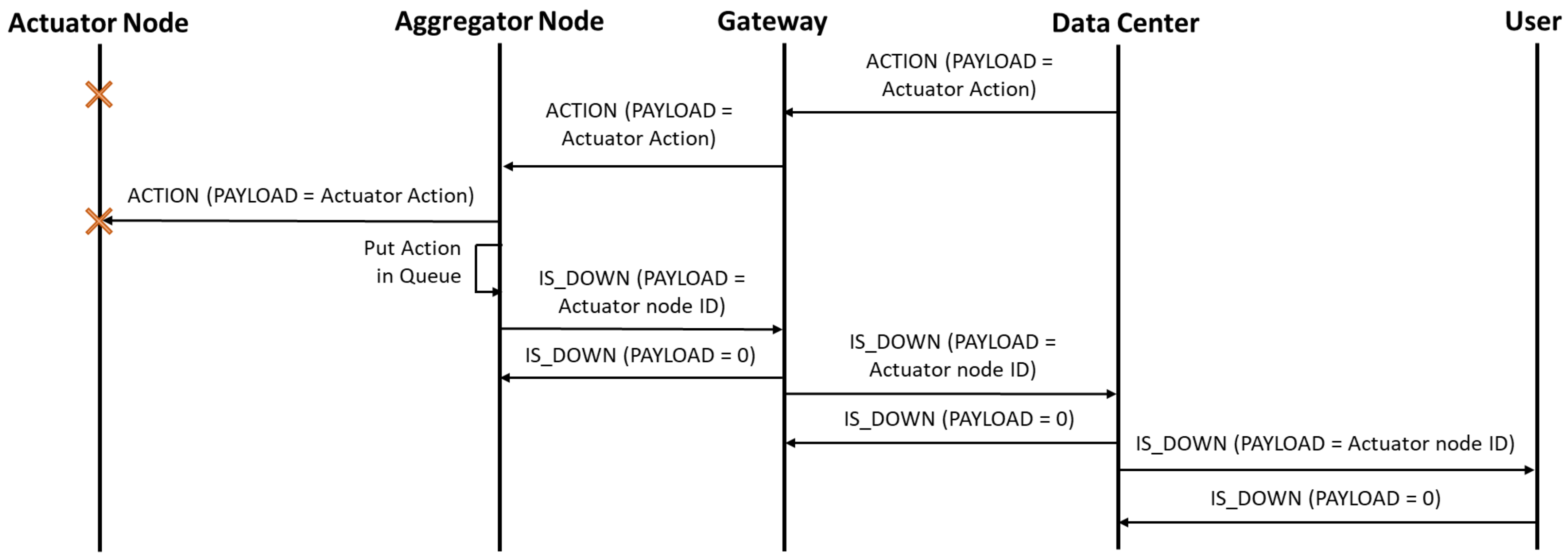
- Cluster head is not operative

- Sensing node is not operative



Alert phase

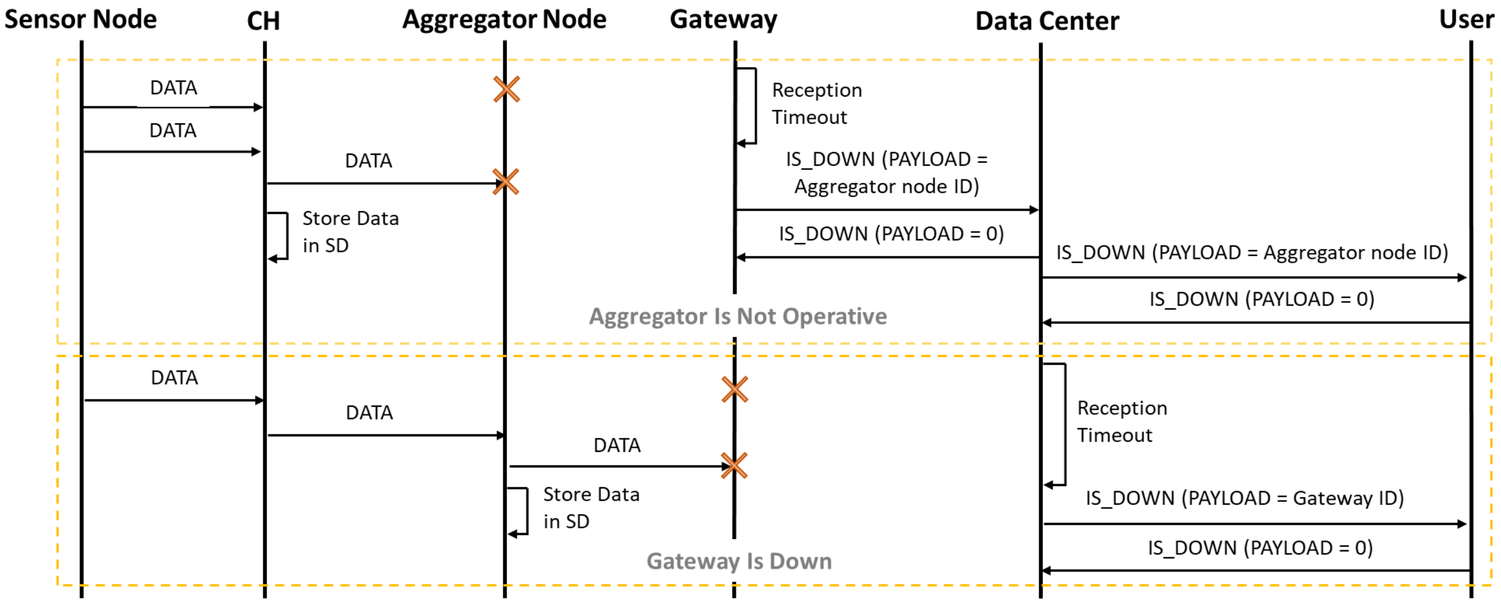
- Actuator node is down



Alert phase

- Aggregator node is down

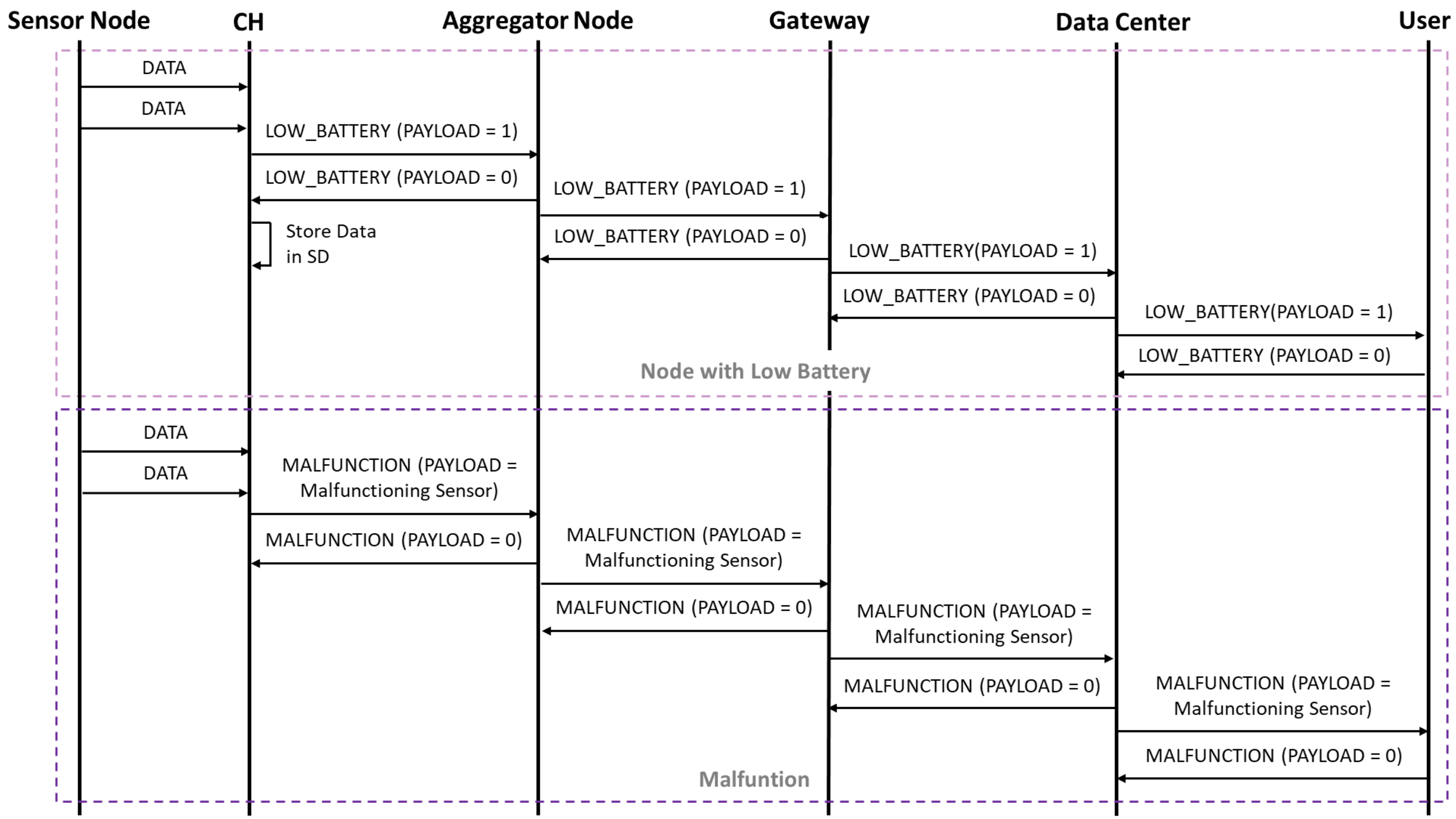
- The gateway node is down



Alert phase

- Node with low battery

- Malfunction detected



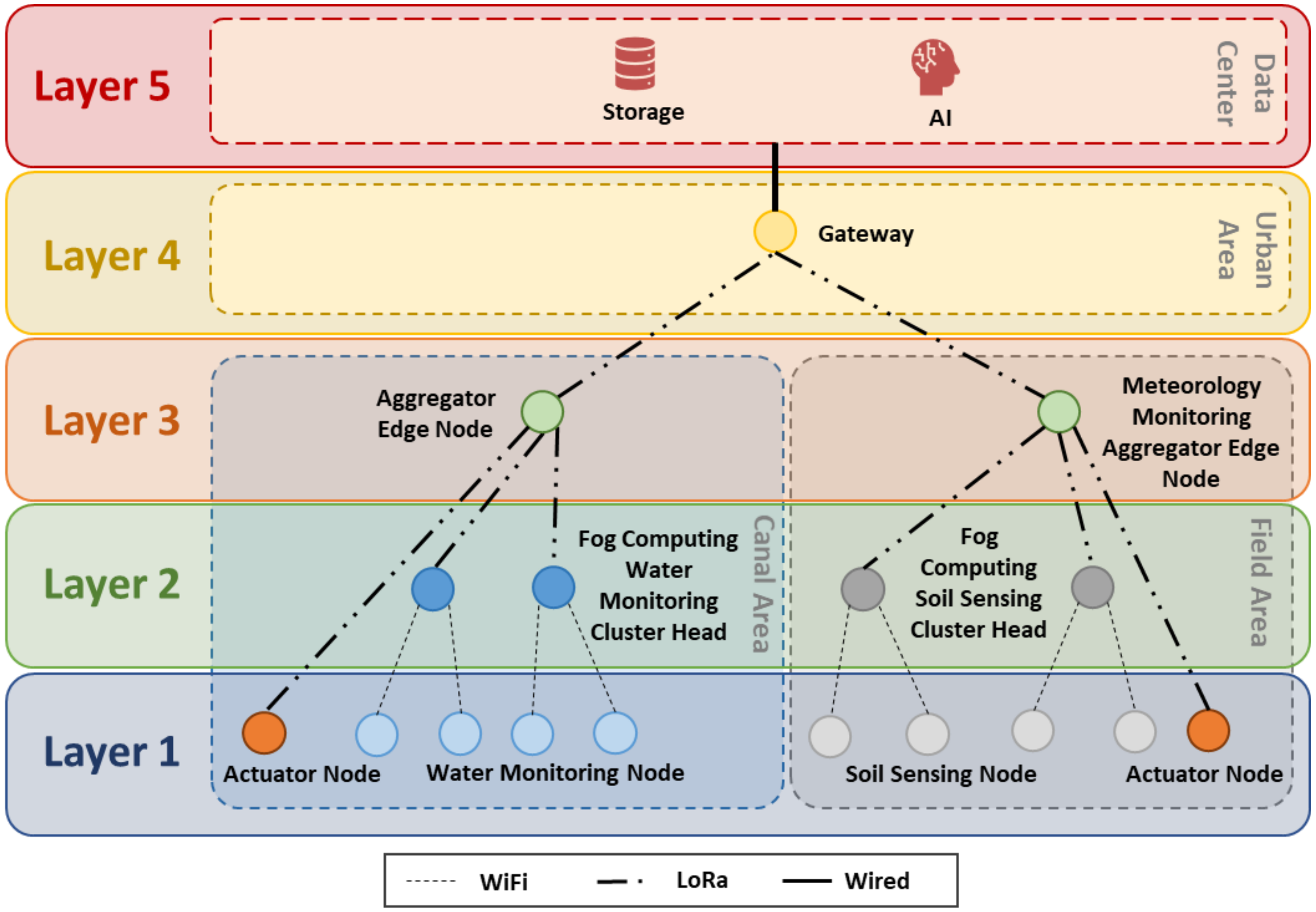
Alert phase

- Data center is down

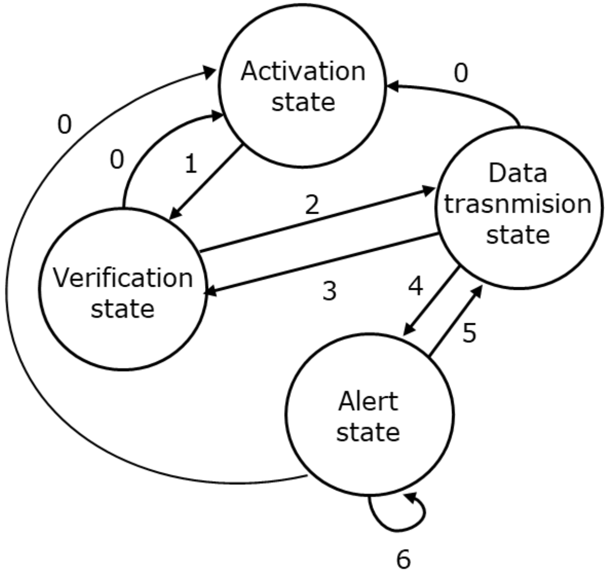
  - Notification in the user application
  - The aggregator node performs fog computing

- User not available → - Autonomous operation of the system.

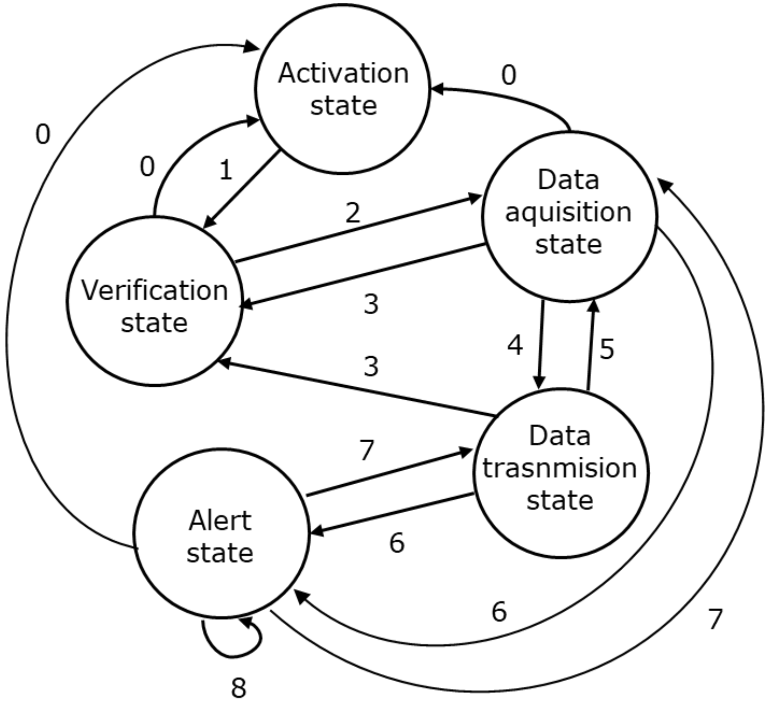
Multi-layer fog computing framework for constrained LoRa networks



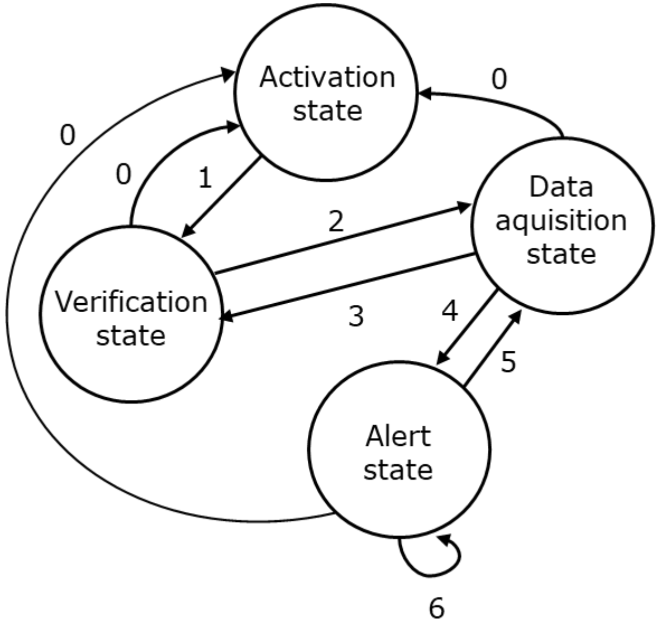
Gateway and Aggregator node



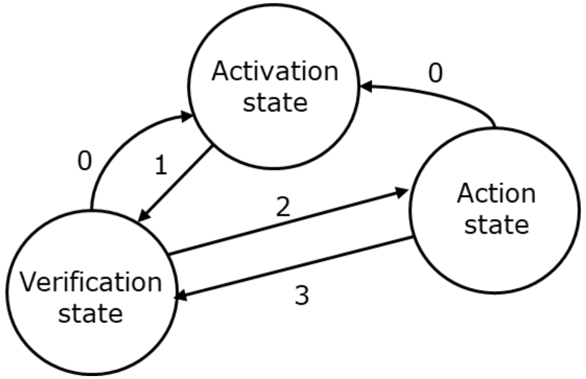
CH node and meteorology monitoring aggregator node



Sensing node

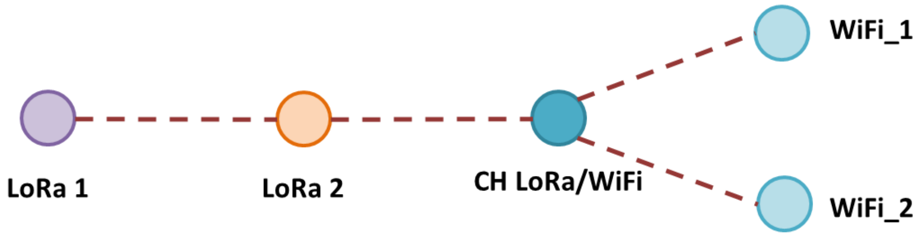


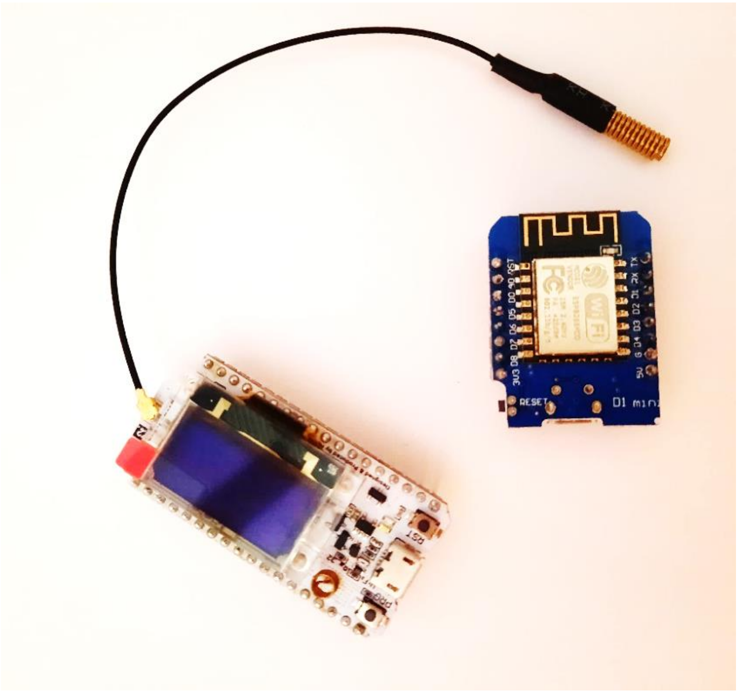
Actuator node



Performance Results

PERFORMANCE RESULTS OF THE PROTOCOL

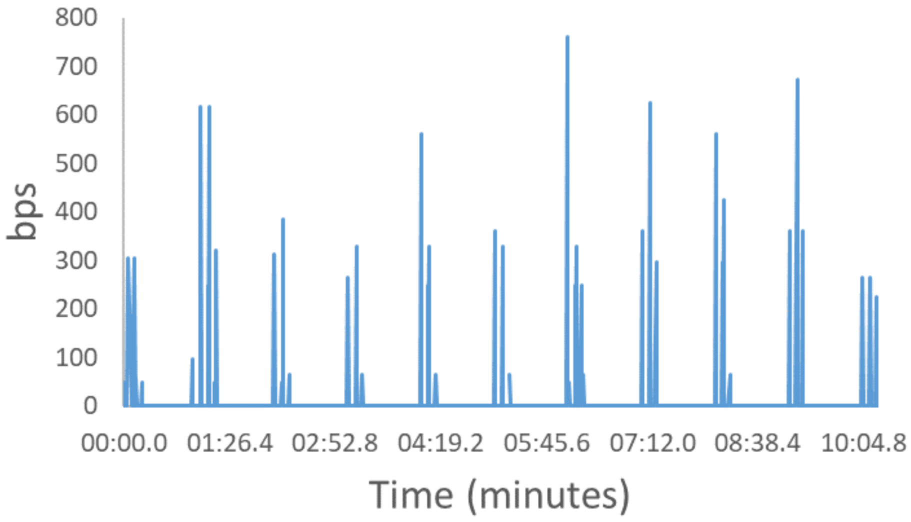




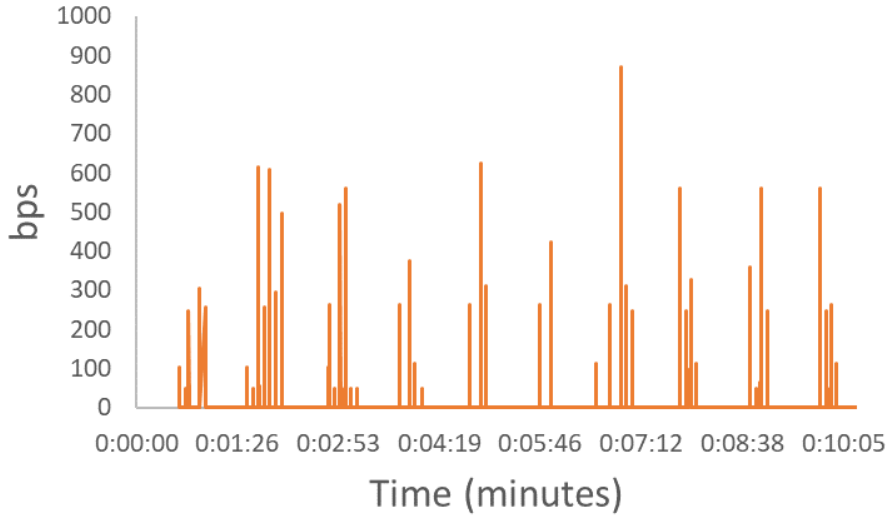
a) b) c)

d) f)

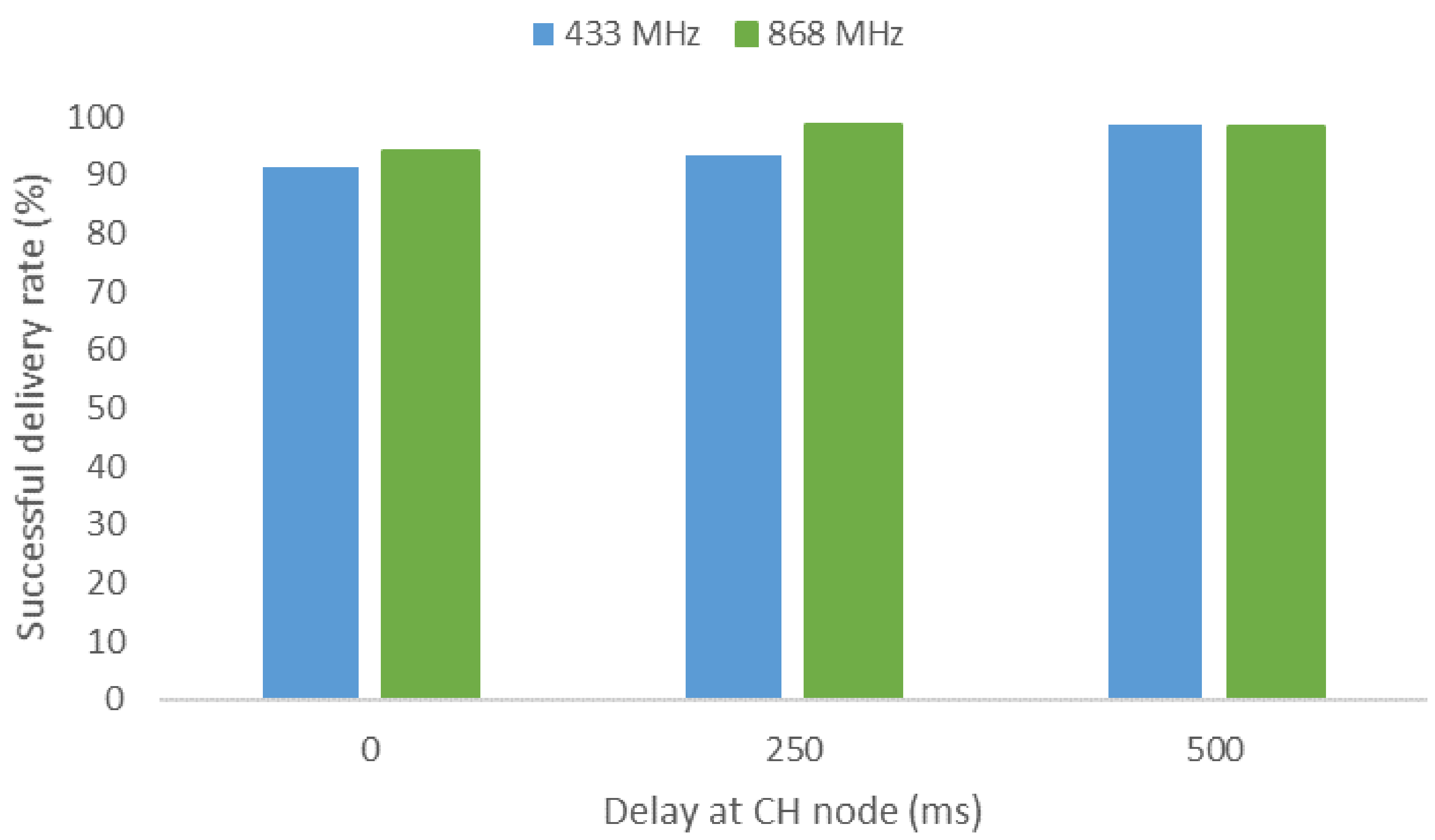
Consumed bandwidth



433 MHz and transmission delay at the bridge of 0 ms for the complete network



868 MHz LoRa notes and transmission delay at the bridge of 0 ms for the complete network


433 MHz
868 MHz
100
90
80
70
60
50
40
30
20
10
0
Successful delivery rate (%)
0
250
500
Delay at CH node (ms)

Conclusion

- **Over 280 papers were studied** and classified to obtain an overview on the current trends of Precision Agriculture (PA) systems for irrigation. In this analysis, the **main parameters** to be monitored have been detailed.

- An **architecture** that allows establishing a heterogeneous network and presents a tree topology with multiple hops for the LoRa part of the network, in contrast to the usual point-to-point implementation of LoRa connections, has been designed.

- A **heterogeneous protocol** has been developed:
    - It has a reduced header of 2 Bytes.
    - Includes the WIFi/LoRa bridge.
    - Considers multiple alerts.

- The **algorithm** that determines the irrigation requirements has been presented as well.

- **Practical experiments** have been carried out to evaluate the performance of the proposed solutions.

- More types of technologies such as ZigBee or BLE could be added to the system in order to provide new functionalities.

- More elements can be added to the architecture such as vehicles and machinery.

- Creating a routing protocol for multi-layer LoRa networks would allow providing more scalability to our proposal.

- The performance of other wireless technologies such as LoRa and ZigBee for IoUT applications could be studied to expand on the knowledge of the performance of these technologies in underground environments.

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Thank you for your attention