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ΤΙΤΛΟΣ ΕΓΓΡΑΦΟΥ:

Best Practice Guide: Autonomous sensor network for the monitoring of biodiversity. Best practices and lessons learned from the deployment of wireless sensor nodes in Pindus National Park

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ACRONYMS & ABBREVIATIONS LIST

IN ENGLISH	
IoT	Internet of Things
WSN	Wireless Sensor Network
3G	3rd Generation
4G	4th Generation
5G	5th Generation
AI	Artificial Intelligence
CNN	Convolutional Neural Networks
DB	Database
DC	Direct Current
GWN	Gateway Node
HaLow	Known as IEEE802.11ah Standard
HAT	Hardware Attached on Top
HTTP	HyperText Transfer Protocol
ID	Identity
JSON	JavaScript Object Notation
LoRa	Long Range
MQTT	MQ Telemetry Transport
NH4+	Ammonium ion
NO3-	Nitrate ion
PH	Potential of Hydrogen
POI	Point of Interest
RTC	Real Time Control
SIM	Subscriber Identity Module
SMA	Sub-Miniature Version A
SQL	Structured Query Language
WiFi	Wireless Fidelity

ΠΕΡΙΛΗΨΗ

Αυτό το έγγραφο παρουσιάζει τις βέλτιστες πρακτικές και τα διδάγματα που αντλήθηκαν από την ανάπτυξη ασύρματων κόμβων αισθητήρων στο Εθνικό Πάρκο της Πίνδου. Είναι το αποτέλεσμα της δράσης B4 και στοχεύει στην περιγραφή της μεθοδολογίας και της επιστημονικής προσέγγισης που εφαρμόστηκε για το σχεδιασμό, την υλοποίηση και την ανάπτυξη ενός Αυτόνομου δικτύου αισθητήρων για την παρακολούθηση της βιοποικιλότητας. Ένας από τους στόχους αυτού του παραδοτέου είναι η καλύτερη κατανόηση των επιμέρους χαρακτηριστικών του σχεδιασμού και της ανάπτυξης ασύρματων δικτύων αισθητήρων σε εξωτερικά περιβάλλοντα. Η ανάπτυξη εξωτερικών δικτύων σε αγροτικές και δασικές περιοχές θέτουν σημαντικές προκλήσεις λόγω της περιορισμένης προσβασιμότητας και της έλλειψης δικτύων και υποδομών ηλεκτρικού δικτύου. Επιπλέον, το αποτέλεσμα αυτού του παραδοτέου θα «τροφοδοτήσει» τις εργασίες στη Δράση B5 και στη Δράση B6, για το σχεδιασμό των αλγορίθμων τεχνητής νοημοσύνης. Για την Δράση B5, αποτελεί το μέσο με το οποίο θα συλλέγονται δεδομένα βιοποικιλότητας και στη συνέχεια θα υποβάλλονται σε επεξεργασία μέσω της τεχνητής νοημοσύνης για την παροχή ενημερωτικών αποφάσεων- στους επιστήμονες και τους σχετικούς ενδιαφερόμενους. Για την Δράση B6 και τις εκπαιδευτικές δραστηριότητες, προσφέρει μια πρώτη περιγραφή της προσέγγισης σχεδιασμού και μεθοδολογίας δικτύου, έτσι ώστε ο ενδιαφερόμενος αναγνώστης να βουτήξει σε περισσότερες λεπτομέρειες τεχνικής σχεδίασης πίσω από την ανάπτυξη και τη λειτουργία του ασύρματου δικτύου αισθητήρων.

EXECUTIVE SUMMARY

This document presents the best practices and lessons learned from the deployment of wireless sensor nodes in Pindus National Park. It is the outcome of action B4 and aims to describe the methodology and the scientific approach conducted for the design, implementation and deployment of an Autonomous sensor network for the monitoring of the biodiversity. One of the goals of this deliverable is the better understanding of the individual characteristics of the design and deployment of wireless sensor networks in harsh habitats. Exterior network deployments in rural and forest areas pose significant challenges due to limited accessibility and the lack of traditional network and power-grid infrastructures. Moreover, the outcome of this deliverable will also drive the work in Action B5 and Action B6, for the design of the AI algorithms (It is the basic foundation where biodiversity data will be collected and then will be processed through AI to provide informative decision-making to the scientists and relevant stakeholder) and the training activities (It offers a first description of the network design and methodology approach so that the interested reader dive into more technical-design details behind the deployment and operation of the wireless sensor network.), respectively.

1. INTRODUCTION

Advances in digital technologies and the Internet of Things (IoT) have been providing scientists with a large number of tools that can be used to effectively monitor biodiversity. Telemetry and sensing from remote wildlife areas can be nowadays feasible using off-the-shelf low-cost equipment utilizing open source software without major limitations on their performance and/or capabilities in comparison to expensive commercial solutions. Advances in battery technology, solar panels, IoT, wide band and cellular networks have enabled the real-time access on a wealth of information about the environment and the animals and facilitate researchers and policy-makers with tools for accurate informative decision making. For the purposes of Action B4, within the reporting period starting from July 2022 till October 2023, UTH managed to design, implement and deploy a multisensory wireless network that is located in the Pindus mountainous area called Valia-Kalda and a dedicated sensing node for water-quality monitoring in Drakolimni lake. Our solutions combined cutting-edge digital communication technologies (4G/5G, LoRA, Wifi) with sensing devices that can capture, record and monitor environmental parameters and allow a user access to that information real-time without the need for the user to be proximate to distant and remote and hazardous areas of harsh environmental conditions. Our solution, has been designed to be:

Agile: The use of the hardware is based on low cost hard-ware devices that can support future modifications and configurations. Those configurations may include software and hardware updates. Considering software configurations, these can be applied remotely, thus allowing the system administrator to re-configure the nodes without the need to be present near the node and prevent him/her from cumbersome effort to uninstall the device from difficult to access points (e.g. tall trees in mountainous remote areas)

Scalable: Our network has been designed to automatically scale its operation without the need from an administrator to reconfigure the networking protocols. It runs with minimal to limited-human intervention and it is able to reconfigure and maintain itself independently, enabling e.g. dynamic connections when a node stops operating due to bad weather conditions or damage.

Energy-autonomous and energy conservative operation: In remote areas where traditional energy source (e.g. power grid) is not present due to lack of the infrastructure of power-grid network, autonomous energy supply and reasonable energy management is essential for increasing the operational lifetime of a node and hence of the network. Nodes are equipped with solar panels and battery that allows for autonomous power supply. Moreover, the use of the battery allows for the storage of the excess energy captured during daylight to be used afterwards during the night or low light conditions. In addition, smart software solutions have been developed to reduce the amount of power consumption of the node, by enabling data transmissions occur every specified period of time or when an outlier or a triggered event occurs and by allowing data preprocessing to occur either at the node or at the cloud based on the power processing demand.

2. DESIGN OF WIRELESS SENSOR NODES FOR BIODIVERSITY MONITORING

2.1 OBJECTIVES

In this Section, we present the design of wireless sensor nodes for biodiversity and sound monitoring (for human presence and fauna monitoring). Below, we present the qualitative characteristics and the requirements of the nodes that can record and transmit biodiversity measurements in harsh environmental conditions.

Wireless Communications: The node needs to support wireless communication technologies for the wireless transmission of the biodiversity data to the remote cloud server. In the forestry environment, cellular network services are not fully supported. There are areas where service is not available and areas where the signal strength is present. The node should be able to utilize the existing communication cellular infrastructure and, in the case, where cellular network signal is not present, the node should be able to utilize wireless networking for extended range and low energy consumption wireless networks supporting the concept of Internet of Things. Therefore, the need for the node to host 4G/5G cellular communication transmission/reception as well as extended-range low-energy consumption wireless protocols such as LoRa, Zigbee, or IEEE802.11ah WiFi HaLow is essential.

Energy Efficiency: The node must be characterized by energy-efficiency. Its operation (biodiversity data sensing, recording, processing and transmitting, receiving) requires a limited amount of energy since power supply in remote forestry and rural areas is not present. This is directly related to the appropriate choice of the hardware components that the node is composed of, which must be characterized as low-energy, as well as it is related with the design and configuration of the software for the sensing, recording, analysis and processing of the data (computing) and the networking protocols for the transmission of the data. Moreover, the node must be energy autonomous equipped with autonomous power-source such as a solar panel and a battery for energy storage.

Computing and Processing of the data: The node must be able to process and filter the recorded data locally when the volume of the data is so large that the wireless transmission is too costly in terms of energy-consumption demand or in terms of financial cost when the 4G/5G communication service is the only available option. Smart software solutions must be able to assess whether computing and processing of the data should be taken place locally or it is preferable by means of computing and processing power needed and transmission cost required, to be held by a remote server.

Security and minimal nuisance to the hosting environment: The exterior design of the node must create the minimum nuisance to the environment. The coloring of the node should fit to the environments coloring conditions, so that animals should not be able to identify its presence and got distracted or annoyed and cause damages to the node and potential harm themselves. This also means that the node installation must not be reachable by wild animals neither humans and the node could be potentially vandalized or damaged.

Installation barriers against harsh weather conditions: Valia Kalda and Pindus mountains where Drakolimni lake is located present a diverse geography of mountainous regions, rocky terrain, and hazardous weather conditions that can change any time and are very intense especially during winter. Installing and deploying nodes in such challenging environment requires the node casing to be "tamper proofed "against harsh weather and environmental conditions.

Programmable and reconfigurable hardware allowing components extensibility and updates: Researchers and engineers should be able to reprogram and reconfigure on-the-fly the node after the installation. The access to the nodes in such remote mountainous areas is difficult and requires time and effort to approach the deployment field. Therefore, the ability to monitor remotely the health status of the node and the operational status of the sensing devices is critical. Researchers and engineers must be able to re-configure and reprogram the hardware on-the-fly and observe whether something is going wrong and can be corrected remotely or it requires in-the-field service maintenance. This reduces the number of "undesirable" visits in the field. Moreover, adopting a modular structure approach for the node design, where the hosting device (main node component) can support various type of sensors allows for easy maintenance and easy hardware updates when for example one or more sensing device(s) fail and stop working while the rest of the hardware continuous to operate. This offers flexibility and reduces costs and allows the engineer (installer in the field) to change the defective hardware with less effort. On the other hand, the engineer-administrator located in the lab, is in the position to assist the installer remotely and consult him/her whether the new modifications are operating well or not.

2.2 NODE DESIGN METHODOLOGY

This Subsection presents the methodology that we have followed to design and create the wireless sensing nodes. Two different type of nodes are considered. The first type refers to the wireless sensing node that is used to form a wireless sensor network to monitor biodiversity measurements in the National Park of Valia Kalda in Northern Greece. The other type of nodes consists of a single entity that is equipped with various sensors for monitoring the water quality of the lake Drakolimni.

Wireless Sensor Node for Biodiversity Monitoring in Forestry Areas – The Valia Kalda Case.

The wireless nodes created for monitoring of the biodiversity in the Valia Kalda forest areas are a thought-out combination of hardware and software tailored to meet the needs of the project. This subsection provides an overview of the approach and important factors considered during the design process. The initial design of these nodes and their associated data communication network has been meticulously planned to address the following aspects.

Adapting to Challenging Weather Conditions: Valia Kalda is known for its weather conditions, including temperatures and precipitation. The wireless nodes have been engineered to withstand these challenges ensuring collection and transmission of data.

Overcoming Limited Availability of Electricity: Due to the nature of the forest areas access, to a power source is limited. Therefore, the node design incorporates energy components and strategies to effectively manage power consumption maximizing operation with limited battery capacity.

Low light environment: Forested areas pose challenges for nodes in terms of battery recharging. To address this the nodes are equipped with batteries that have capacity to sustain operations during extended periods of low light. Additionally, power efficient components are carefully chosen to minimize energy consumption and prolong battery life.

One of the goals of these nodes is to collect sound data and transmit it to databases. To optimize node efficiency and conserve battery life, data collection and transmission are managed with care.

Data Transmission: In forest environments direct point to point communication encounters obstacles. Therefore, data transmission relies on 4G connectivity that can be maintained in remote forested areas.

On-Node Data Processing: To reduce both the time required for data transmission and associated costs the nodes are equipped with onboard data processing capabilities. This allows initial data processing to occur within the node itself thereby reducing the amount of data that needs to be transmitted and alleviating the burden on the database.

Battery Dependency: The nodes operate in a mode where their activity's dependent, on battery power and synchronized with sensor functionality. This approach maximizes battery lifespan while extending the duration of each node.

The wireless devices created for monitoring biodiversity in Valia Kalda are an effective solution that is specifically designed to address the difficulties faced in forest environments. These devices take into account factors such, as weather conditions, limited power availability, lighting conditions and challenges related to transmitting data.

Wireless Sensor Node for Water Quality Monitoring– The Tymphi – Drakolimni Lake Case

The device we used, specifically tailored for monitoring the biodiversity in Lake Drakolimni, demonstrates its adaptability in this setting. We successfully overcame the challenges of data transmission conducted measurements and prioritized integration with the surrounding environment.

Challenging Environment. When setting up a node near Lake Drakolimni we encountered some obstacles. The lake is known for its weather conditions, including freezing temperatures and heavy snowfall. Although we didn't build the node from scratch, we made modifications to ensure it can withstand these conditions and collect data without interruptions.

Data Transmission Difficulty. Due to Lake Drakolimnis location, transmitting data posed a challenge. We identified two spots in the area where 4G signal was available. To overcome this issue, we carefully calculated the placement of the node to ensure data transmission.

Minimal Environmental Impact. Our deployment strategy emphasizes into minimizing any impact on the environment. Our team has ingeniously designed the node to blend seamlessly into its surroundings so that it doesn't attract attention and has as less impact as possible on the environment. From the beginning of the installation and ongoing maintenance we have taken care to minimize any disturbances and protect the untouched condition of Lake Drakolimni.

2.3 BLUEPRINT DESIGN OF THE WIRELESS NODES

In this Subsection we present the blueprints of the wireless sensing nodes. We present the designs considering the hardware components used to build the devices, as well as the software development for the collection, recording, storage, processing and analysis of the monitored metrics.

System Hardware - Wireless Sensor Node for Biodiversity Monitoring in Forests – The Valia Kalda Case.

The design of the trap can be categorized into five groups:

1. Casing-Mounting
2. Sensors
3. Communication
4. Controllers
5. Energy

Emphasis has been given in the selection of the casing. Weather conditions that would affect the electronics and sensors should be considered and mitigated. Thus, the box containing the electronics is IP 68 rated. Additionally, to ensure minimal footprint, the exterior is painted in discreet colour which combined with the hight of the installation, it is almost unnoticeable. Furthermore, sensors and electrical panels have been placed strategically to combine functionality and discreet.

The node is equipped with the *Bosh BME 280*[1] temperature, humidity and barometric sensor which has an operational temperature range of -40 to 85 °C with accuracy of ±1.0°C, ±3% and ±1 hPa respectively. Sound is captured by the Rode Video Micro Ultracompact Camera-

Mount Shotgun Microphone which is a compact and powerful microphone with 100Hz - 20kHz frequency range and -33.0dB re 1 Volt/Pascal sensitivity.

Data transmission is achieved by the *HUAWEI 4G Dongle E3372 h153*[2] which provides reliable 4G connectivity. The Blade Dipole Swivel Antennas, with SMA connectors are specifically created to boost signal strength guaranteeing data transmission in challenging or distant environments. These antennas are crucial, for maintaining uninterrupted communication. Furthermore, the SIM card is vital for establishing a secure network connection by enabling a link between the 4G dongle and the Internet Service Provider. It ensures data exchange making it an essential component, in maintaining a network connection.

The node relies on a central control unit called *Raspberry Pi 4 Model B 2GB*[3]. This high-tech processor effectively handles all the sensors, peripherals and communication tasks. Supporting its functionalities is the *WaveShare Power Management HAT*[4] which includes a Real Time Clock (RTC) and precise power control features to ensure energy usage. The Raspberry Pi acts as the core of the e trap running algorithms and logical operations to manage its functions.

[1] https://www.bosch-sensortec.com/products/environmental-sensors/humidity-sensors-bme280/
[2] https://consumer.huawei.com/za/routers/e3372/specs/
[3] https://www.raspberrypi.com/products/raspberry-pi-4-model-b/
[4] https://www.waveshare.com/power-management-hat.htm

For power supply, the system is packed with the *Battery Lithium NCR18650B* 3350mAh[5] which is responsible for providing power to the parts of the e trap allowing it to function continuously. These rechargeable lithium batteries are designed to be reliable and long lasting in environmental conditions. The Waveshare Solar Power Manager (C). 3x 18650 utilizes energy to recharge three NCR18650B lithium batteries. This ensures a power supply enabling the trap to operate for extended periods of time. With its panels, the e trap efficiently captures solar energy supporting uninterrupted operation. The solar panel is an eco-sustainable energy solution suitable, for remote deployment areas. Finally, to enhance functionality the DC step up converter 5-35V 2A ensures a supply of 10V to specific components. This converter optimizes power efficiency and extends battery life. The following figure shows the blueprint layout of the wireless sensing node.

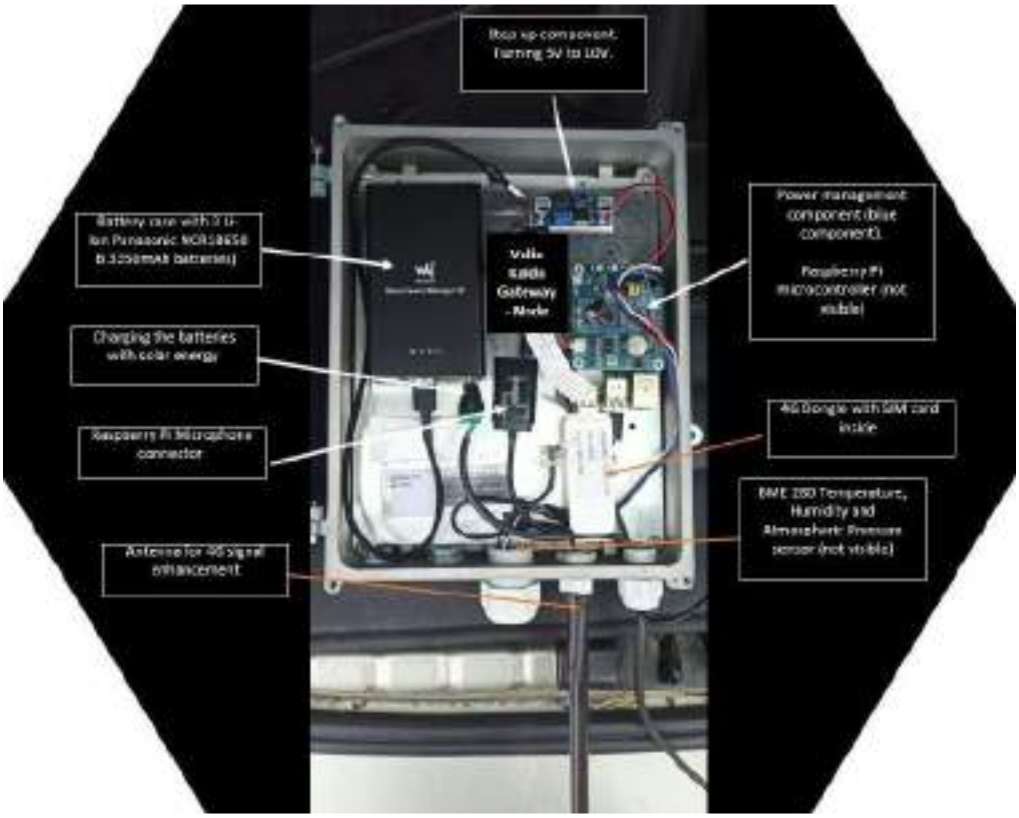


Figure 1. Blueprint Layout of the Wireless Sensing Node.

System Hardware - Wireless Sensor Node for Water Quality Monitoring– The Tymphi – Drakolimni Lake Case

In this subsection, we discuss our methodology for the design of a sensing node that accommodates various sensors in the lake 'Drakolimni' located in the mountain of Tymfi, in the northwestern Greece Epirus region. The aim of this installation was to enable the capability of real-time monitoring of the water quality measurements. The

[5] https://eu.nkon.nl/panasonic-ncr18650b-made-in-japan.html

The design included a procurement of specialized commercial 'off-the-shelf' sensor solution, the development of the device's software configuration, the development of a server infrastructure to handle the measurements and the metrics, the hardware development pertaining to the device's power management, and the deployment operation itself to the lake.

Wireless Sensing Node: Due to the rugged requirements necessary for this project, a sole homemade solution was rejected, and a commercial product was deemed necessary. The device chosen is a Rika *Sensors RK900-1 (RK900-1, n.d.)* automatic weather station, a specialized sensors package from Rika Sensors, a weather sensors and environmental sensor manufacturer out of Changsha, China. The particular package included a core communications and logging hub terminal, and water quality sensors, specifically for PH, Air Temperature, Liquid Temperature, Electric Conductivity, Turbidity, Dissolved Oxygen, Chlorophyll concentration, and NH4+ & NO3- concentrations, for a total of 9 measurements taken from the body of water and environment. The selection of the type of the sensing devices were proposed by EKBY. EKBY provided its expertise and indicated the type of the sensing devices as well as their sensitivity and operational requirements.

Table 1. Indicative Expected Values for Water Quality Measurements.

Measurement	Ind. Exp. Value	Range	Accuracy	Resolution
Ph	Neutral	0-14PH	±0.05PH	0.01PH
Air Temperature	N/A	-40-+60℃	±0.5℃	0.1℃
Water Temperature	Low	-40-+80℃	±0.5℃	N/A
Electrical Conductivity	N/A (mS/cm)	0-20mg/L (ppm)	±0.5%FS	0.01mg/L
Turbidity	N/A	0-4000NTU	±1%FS	0.1%
Chlorophyl	0.3 mg/lt	0～400ug/L (Temp 0-50℃0)	±3% ±0.5℃	0.1 ug/L， 0.1℃
Dissolved Oxygen	N/A			
Ammonium ion NH4+	0.024 mg/lt (low) 0.253 mg/lt (high)	0-100mg/L	±10%FS	0.1mg/L
Nitrate ion NO3-	0.09 mg/lt (low) | 0.27 mg/lt (med) 2.5 mg/lt (high)	0.1-14000ppm	±1%FS	0.001ppm

Figure 2. The touch screen interface of the RK900-1 terminal device.

Communication: The communications & logging hub terminal, running a custom Android operating system, serves to gather all the sensor metrics, optionally display them on a touch screen on the terminal, and transmit them over the network as needed. The sensors themselves are connected to the hub terminal through cabling, communicating over Modbus (a common client/server data communications protocol in the application layer). At the opposite site, the sensor heads are sub-merged into water.

Figure 3. Two example Rika sensors shown, RK500-04 Dissolved Oxygen (DO) & RK500-11 Liquid Temperature.

The hub terminal supports both WiFi and 4G mobile data communications. UTH confirmed through an expedition (field study) prior to deployment that mobile network signal strength was at a serviceable level in the target location (though not always at full reliability), sending the metrics with 4G data over HTTP was selected as the transfer method to store these data to a cloud-based database. Other methods such as the MQTT protocol were considered but rejected for ease of implementation and error handling interfaces availability.

Due to the deployment's specialized needs, the device's default configuration that was targeting continuous operation was not fitting our tight power availability, and communication with the manufacturer regarding the device's software configuration was required and undertaken, patching device firmware and software for a variety of encountered problems, including manufacturer software bugs, the data-format of metrics send from the device, and customization of the measurements pickup interval by the sensors to allow us to implement a more power-efficient power management strategy. The power management approach chosen involves an autonomous setup with batteries and a solar panel. Two 12V batteries, wired in parallel, were used for the purpose, recharged from the solar panel. Moreover, an add-on Arduino microcontroller, implemented and programmed by our team, handles the supply & cutoff of power to the device – in the deployed configuration, powering the device up for 15 minutes every 6 hours (taking metrics every 5 minutes), before powering it down, and cycling.

System Software - Wireless Sensor Node for Biodiversity Monitoring in Forests – The Valia Kalda case.

Flow of the monitored data (Temperature, Humidity, Atmospheric Pressure, Sound) - From the field to the server

The operational workflow for the ELBIOS node encompasses the following steps:

1. **Power Management HAT:** This component is responsible for overseeing power consumption on the Raspberry Pi. It activates the Pi during predefined hours each day. Communication between the Power Management HAT and the Raspberry Pi is facilitated through the i2c protocol, employing a custom communication code.

2. **Clock Calibration (if required)**: The initial interaction between these two devices involves calibrating the clock on the HAT if necessary.

3. **Waiting for Pi Actions to Complete**: Following clock calibration, the Power Management HAT awaits the completion of actions on the Raspberry Pi.

4. **Raspberry Pi Tasks:**

   - **BME280 Sensor Reading**: The Raspberry Pi maintains a task list, which includes reading data from the BME280 sensor. This sensor is designed to measure air temperature and humidity.

   - **Sound Recording**: Another task involves recording environmental sounds for a predetermined duration. In our scenario, this duration is set at 15 minutes.

   - Upon completion of each task outlined above, the Raspberry Pi transmits the gathered data to a MQTT server. This server features three distinct topics, each corresponding to a specific type of measurement. The topic format is structured as follows: deploymentID/gatewayID/interface/dataType, where dataType represents temperature, humidity, pressure, image, and sound, respectively. The data is transmitted in the following sequence: initial transmission of air measurements, followed by the image, and concluding with segmented portions of the audio, captured within a 15-minute window and limited to a maximum of 4 seconds per segment. Within the server environment, a dedicated MQTT Client is subscribed to all topics associated with each device. Whenever a new measurement is received via MQTT, this Client captures the data and subsequently integrates it into the databases.

In our system, we utilize two distinct databases for efficient data management:

- **InfluxDB**:
  - Type: Time series database.
  - Description: InfluxDB is an open-source solution explicitly designed for handling and retrieving time series data. It serves various domains such as operations monitoring, application metrics, IoT sensor data, and real-time analytics.
- **MongoDB**:
  - Type: Document-oriented, cross-platform database program.
  - Description: MongoDB is a source-available NoSQL database program. It utilizes JSON-like documents with optional schemas, providing flexibility in data representation.

Air measurements are stored in the InfluxDB, while the metadata for images and sound is managed in MongoDB. Additionally, the actual image and sound segments are stored in the filesystem. Each file is named after the respective capture date. This nomenclature enables easy retrieval using metadata from the database, which is linked to these file names. This comprehensive approach ensures efficient storage and retrieval of all relevant data types.

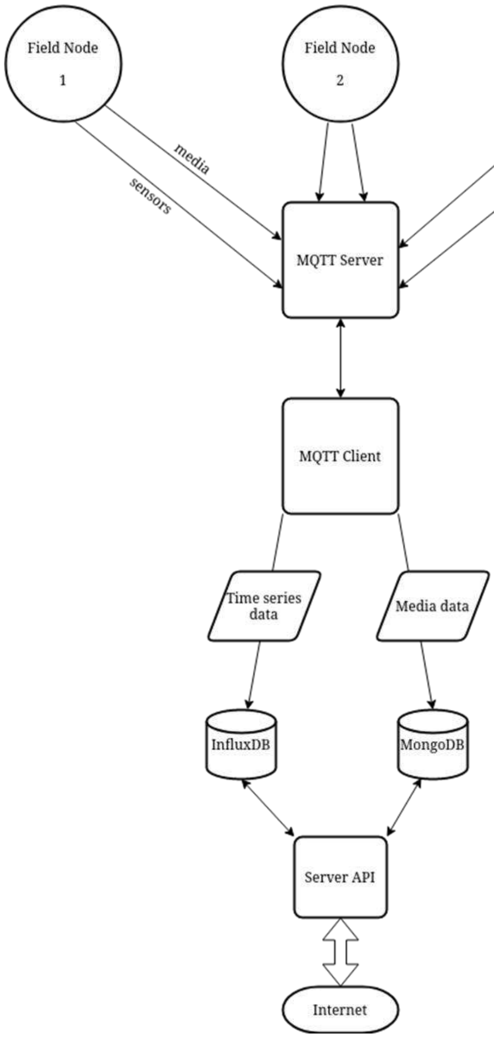


Figure 4. Data Flow Diagram for measurement Storage.

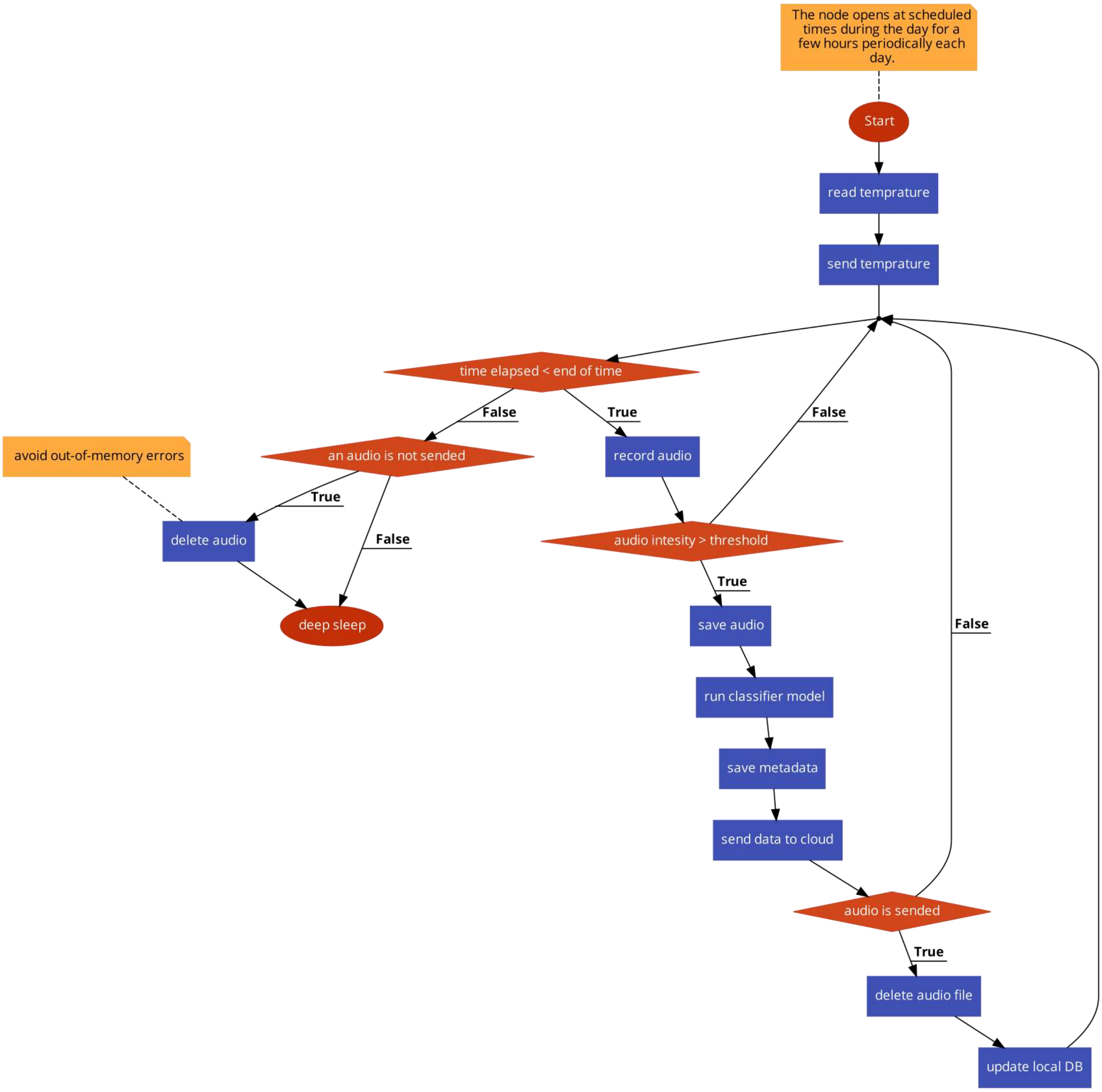


Figure 5. Operational Diagram of the Sensing Node.

Recorded Sound Analysis Software

The application we have developed serves to recognize unexpected activities within the forest and categorising them as abnormal events. A critical component of this implementation involved the integration of an additional sensor, a high-quality microphone, into the constructed nodes. This microphone is adept at capturing a broad spectrum of audio.

The underlying concept is to train our system using sounds that are commonly heard within urban environments. This training allows the system to recognise sounds that are similar to those of the city but will have been recorded by our nodes in the forest, helping us then to detect potentially suspicious activity. As an illustrative example, the application can effectively identify the distinct sound of an engine, a clear indicator of unwarranted human presence, or it can detect the presence of music, indicating the unauthorised presence of campers during restricted periods.

Various methodologies for sound analysis were considered, and we opted the sound classification based on a Convolutional Neural Network (CNN)[6] and Linear Classifier model[7]. This approach entails training the system to classify sounds and predict their respective categories. Leveraging deep learning techniques eliminates the necessity for traditional audio processing methods, streamlining the data preparation process without the need for extensive manual or customised feature engineering. The fundamental approach involves converting recorded audio data into an image problem, which then through the CNN architecture undertakes feature extraction.

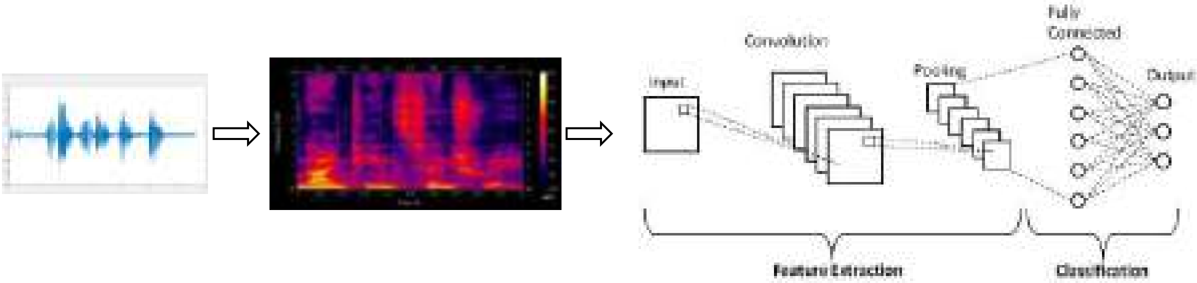


Figure 6. Audio Classification Tests.

The initial step carried out the transformation of sound files into spectrograms. These spectrograms are subsequently fed into a CNN and Linear Classifier model, resulting in predictions regarding the classification of the sound. A spectrogram is a visual representation of the spectrum of a signal over time and is unique to each signal. By looking at the vertical slices of the spectrogram we can see the spectrum of the signal, from which we can understand the power of the signal distributed over all frequencies in time.

It offers an elegant means of encapsulating the essential characteristics of audio data within an image. With this image data, we leverage standard CNN architectures to process it and extract feature maps that serve as an encoded representation of the spectrogram image. The subsequent phase involves generating output predictions based on these encoded representations. Feature maps are passed through a classifier, comprising several fully connected linear layers, culminating in the final classification output. The node was designed to operate for a few hours during the day. While the node is active, it continuously records small audio segments and constantly checks if any of them surpass a predefined sound intensity threshold. This is done to decide whether to store the audio segment in a file for further analysis. The node was engineered to capture real-time changes and make decisions promptly. Immediately after storage, the classifier function is invoked in parallel, which assigns the category with the highest score. All of these metadata are recorded in a database and transmitted to our laboratory's cloud via 4G technology. The following Figure shows the System

[6] Alzubaidi, L., Zhang, J., Humaidi, A.J. et al. Review of deep learning: concepts, CNN architectures, challenges, applications, future directions. J Big Data 8, 53 (2021). https://doi.org/10.1186/s40537-021-00444-8

[7] Theodoridis, S. and Koutroumbas, K., 2006. Pattern recognition. Elsevier.

Architecture Diagram and how the gateway node communicates with a 4G communication link with the server.

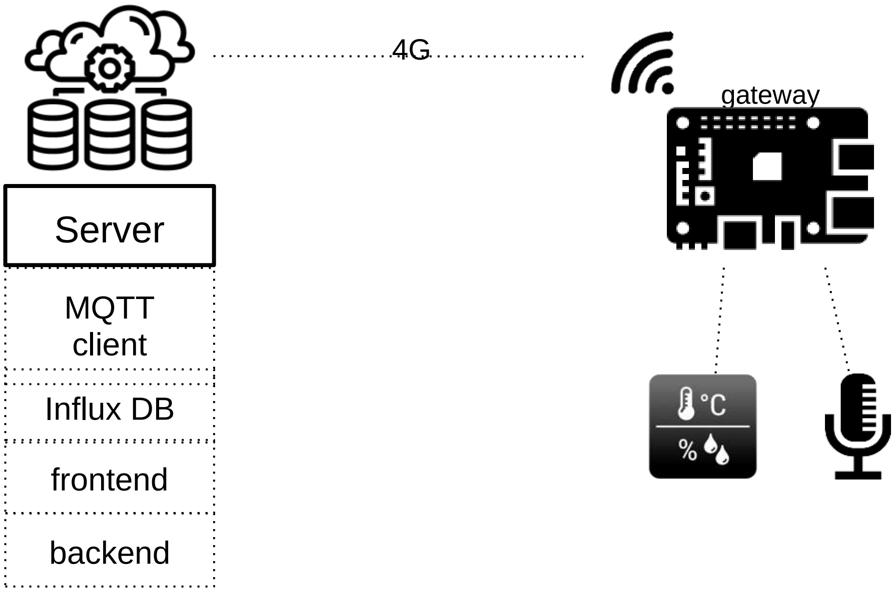


Figure 7. System Architecture Diagram.

The next improvement steps to follow will involve the qualitative analysis of both the data and algorithms used, as the open forest environment poses a significant challenge. Additionally, we will modify the communication between our nodes to allow them to communicate with each other in cases where the 4G network fails to find a signal in a specific location. In such instances, nodes will search for a node with better signal strength to establish a connection. In such instances, nodes will actively seek out a neighbouring node with a stronger signal. In this design, we will incorporate the WiFi Halow communication protocol. In the accompanying image, you can observe the distinctive configuration of two novel node types enriched with the latest communication technologies.

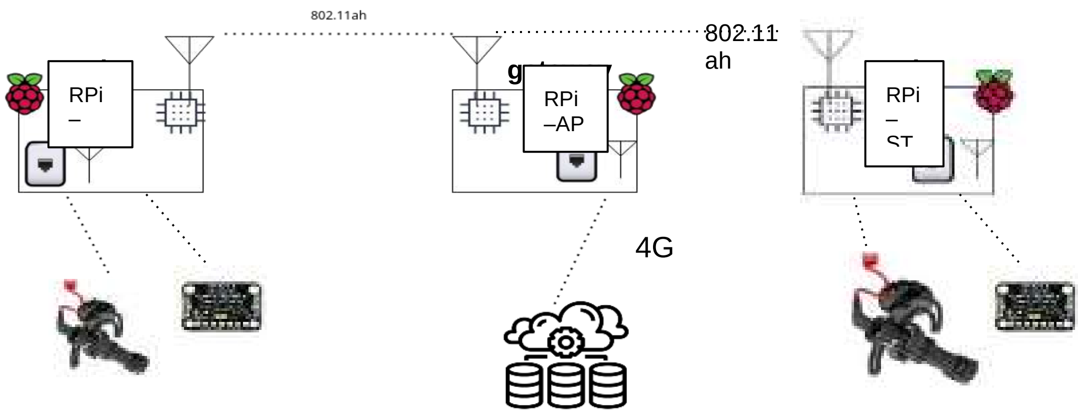


Figure 8. New System Design.

System Software - Wireless Sensor Node for Water Quality Monitoring– The Tymphi – Drakolimni Lake case

Since the node for water quality monitoring was based on a commercial "off-the-shelf" solution, the software development in that case focused on the capture and storage of measurement data on the remote server that is located in our premises. For the metrics data storage, the InfluxDB time-series database was chosen for the purpose. A network database proxy service was implemented in the Go language, receiving the data over the network in a POST HTTP request, performing some necessary post-processing (for the most part, workarounds regarding data formats and value key bugs, as well as some sensor calibration timing issues, that the manufacturer was unable to fix in time, by implementing data correctness filters etal.), and writing them in the database, timestamped & tagged.

As EL-BIOS necessitated the conduct of the deployment before winter season (the harsh path to the lake typically closes down due to snow), requiring a deployment at the latest in the mid of October, a backup temporary network server was setup by the team on a Raspberry Pi single-board computer in our laboratory, to handle our server functions, and allow the project to deploy. At this point, the device was tested for function at length locally in our lab, in a mock water container.

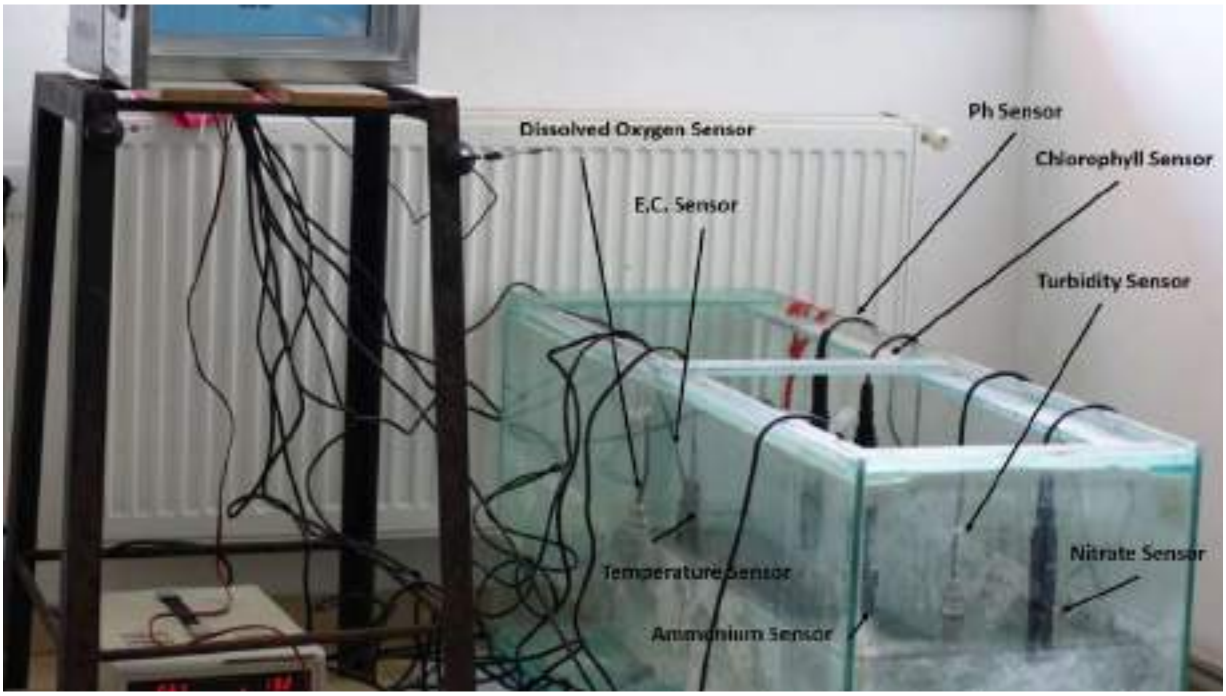


Figure 9. Laboratory experimental evaluation of the operational performance of the water quality sensing device. The device is equipped with various sensors for measuring for PH, Air Temperature, Liquid Temperature, Electric Conductivity, Turbidity, Dissolved Oxygen, Chlorophyll concentration, and NH4+ & NO3.

3. DESIGN AND DEPLOYMENT OF A WIRELESS SENSOR NETWORK FOR BIODIVERSITY MONITORING

3.1 OBJECTIVES

Designing efficient and reliable wireless sensor networks in exterior environments such as rural or forestry areas requires the consideration of the uncertainty and the changing dynamics and conditions. The requirements for the hardware and the software design and the development for wireless sensor nodes had been analyzed on the previous section. The main objective of this section is to present our rationale for enabling connectivity and service-extended coverage in a remote mountainous area so that information routing through the deployed network topology can take place and the quality of the collected data be sufficient for the scientists in order to have access and perform analytics real-time. Other aspects such as equipment cost, energy limitations, installation barriers, programmability and reconfigurability have been extensively discussed in the context of the wireless sensor node design. Implicitly, the appropriate design choice for the nodes affects the network operation as well.

The network deployment in the field of Valia Kalda was strategically chosen after visiting the terrain and conducting a field study by making observations and collecting data in the natural environment. Our observation and data collection included measurements of the signal strength of the cellular networks, the ability to approach the potential installation spots using forestry roads, the need to establish communication links between at least two points using extended range low power consumption communication technologies, the need to select an installation spot that can be as less distracting as possible to the animals and their habitat, the need to be non-easily detected and/or easy to be accessed and potentially vandalized or damaged by humans and the need to have non-obstracted access to direct sunlight for power-sourcing our equipment due to the dense vegetation of the area.

The installation of the network nodes followed and incremental deployment approach where 02 of the 10 nodes were initially placed and installed and in sequence at a second phase the rest of the nodes 08 finally installed in the selected points. This approach gave us the opportunity to observe the operation of our initial setup and conduct an operational assessment of the “initial small-scale” wireless sensor network, identifying possible problems that would be avoided during the second phase of the deployment. The selected points formed a network topology that allows for a multi-hop mesh networking when using the IEEE8022.11ah WiFi HaLow protocol and a cellular networking approach for accessing 3G/4G public networks. This design selection for supporting two different wireless communication technologies allows for increased connectivity and redundancy in communication channels and guarantees network robustness in harsh environments.

3.2 DESIGN & DEPLOYMENT METHODOLOGY OF A WIRELESS SENSING DEVICES

The Deployment of a Wireless Sensor Network in Valia Kalda – Brainstorming

Having agility in the core of our design principles, all the electronics components are placed in such a way that 40% of the node space is empty. As a result, working (i.e., soldering, wiring, etc.) and maintenance are made easier for the field engineer, while we can upgrade or add more sensors if needed.

Working in such a physical environment, while hanging from a branch of a tree, ten meters above ground can be tricky to say the least, so we made a tweak to the node casing. In order to avoid any unnecessary openings for level one checking, we removed ¼ of the metal front-end part of the case and replaced it with glass. Field engineers can make a basic visual inspection of the node (water inside, broken cases of components, LED lights that are turned off or flashing when they shouldn't, etc.).

Having agility again in our mind, both solar panel and microphone sensor are connected independently to the node case, with a 5m long cable, each. If deemed necessary, we can easily move one of them to a new position, without affecting the other parts of the system.

Valia Kalda covers approximately 1500 Km^2 and has dense forests, rocky ridges and rapid streams. Monitoring the whole area with ten Gateway-Nodes (GWN) is not feasible, so we identified several points of interest (POIs) and strategic places on the map. For the purpose of biodiversity monitoring we looked for places at different altitudes and for human activity monitoring, at specific POIs and areas of interest.

The Deployment of a Wireless Sensing Device for Water Quality Monitoring in the lake Drakolimni - Brainstorming

Our design methodology for the deployment in the lake of Drakolimni is based on three parameters. The sensing node can only be placed on the shore of the lake (individual sensors have 5m long cables). Only two points have a serviceable 4G signal (35m and 60m respectively, away from the shore). The wider area of the lake Drakolimni is stressed by a lot of visitors during the summer and autumn months.

Our methodology relied on a "played it by ear" approach where we tested and assessed the signal measurements in various points. We were equipped with sufficient (in meters) cabling for electrical and networking connections and conducted our field study. When conducting a field study, we identified a concentration of rocks at the shore of the lake, making the perfect spot for our installation. The sensing node is visible only when someone is in close proximity, and sensors could be immersed easily into the water. One of the two identified spots with serviceable 4G signal was close to the node allowing the deployment of the transmission antenna.

3.3 DEPLOYMENT OF THE WIRELESS SENSOR NETWORK

The Deployment of a Wireless Sensor Network in Valia Kalda – Lessons Learned

On August 2023 the second phase of the project was completed. From the ten GWN that were deployed, one of them didn't work from the very beginning and another one sent biodiversity monitoring related data and none of human activity related data.

Although our team of field engineers were equipped with spare parts and all the necessary tools to act on any issue, the GWN didn't operate as designed. The malfunctioned nodes were replaced afterwards with fully functional ones. To avoid such unexpected and time-costly issues in the future, we decided to have complementary GWNs at our disposal when in the field, making a full replacement when a problem or technical issue arises, investigating the causes afterwards, when in the lab.

As far as the GWN that sent only biodiversity monitoring data, we concluded that although the 4G signal strength was deemed serviceable, it wasn't enough to support audio related data. To fix such an issue we decided to lift the threshold of what is accepted as serviceable 4G signal strength.

The following picture presents a map of the Valia Kalda network deployment, while the next table presents the actual coordinates where each node is located.

Figure 10. EL-BIOS: Valia Kalda - Map of the WSN Deployment.

Table 2. Coordinates of the wireless nodes deployment and check control during installation of the sound and biometric measurements monitoring system.

Node No	Coordinate X	Coordinate Y	Location	Sound file check	Biometric data file check
100	39.86913	21.16872	Entrance of Valia Kalda, next to Milia Village	OK	OK
101	39.90005	21.14045	1 Km far from the end of the road to Arkoudorema	OK	OK
102	39.90839	21.14674	200 m far from the main crossroad	OK	OK

103	39.92198	21.13093	400m far from the road to Arkoudorema	OK	OK
104	39.92368	21.13349	250m far from the road to Lakes	OK	OK
105	39.90580	21.14203	100m far from the main crossroad, Vovusa Perivoli	OK	OK
106	39.90328	21.14644	50m from the road that is in parallel aligned with the small river of Arkoudorema	OK	OK
107	39.91118	21.13818	In the middle of the route to Arkoudorema	OK	OK
108	39.91854	21.13880	60m far from the main entrance of Valia Kalda	OK	OK
109	39.89565	21.14562	Lakes next to Arkoudorema	OK	OK

The following Figures constitute a sample of the deployment photobook and present the setup of specific nodes which are mounted up in trees of the Valia Kalda Pindus National Park.

Figure 11. Node 100 (39.86913, 21.16872), Node and mic installation up in a tree.

Figure 12. Node 101 (39.90005, 21.14045): Node and mic Installation up in a tree.

Figure 13. Node 103 (39.92198, 21.13093): Node and mic Installation up in a tree.

The Deployment of a Wireless Sensing Device for Water Quality Monitoring in the lake Drakolimni – Lessons Learned

Our expertise mainly in rural and agricultural field deployments allowed us to plan and organize our work proactively and minimize the risks during deployment while operating in the field. Nevertheless, the forest deployment in remote areas poses challenges that require creativity to address unexpected issues during deployment.

The following picture presents the map of the lake Drakolimni deployment.

Figure 14. Map of the Drakolimni Lake.

Zooming in, the picture reveals the point of deployment.

Figure 15. Map of the Drakolimni Lake and Point of the Wireless Node for Water Quality Monitoring.

The following Figures constitute a sample of the deployment photobook and present the setup of the sensing node and its components.

Figure 16. The Sensing Node equipped with its Sensors Fully Operational.

Figure 17. Immersing the sensors in the lake.

Figure 18. Solar Panel for power sourcing the device.

Figure 19. Connecting the solar panels with the batteries.

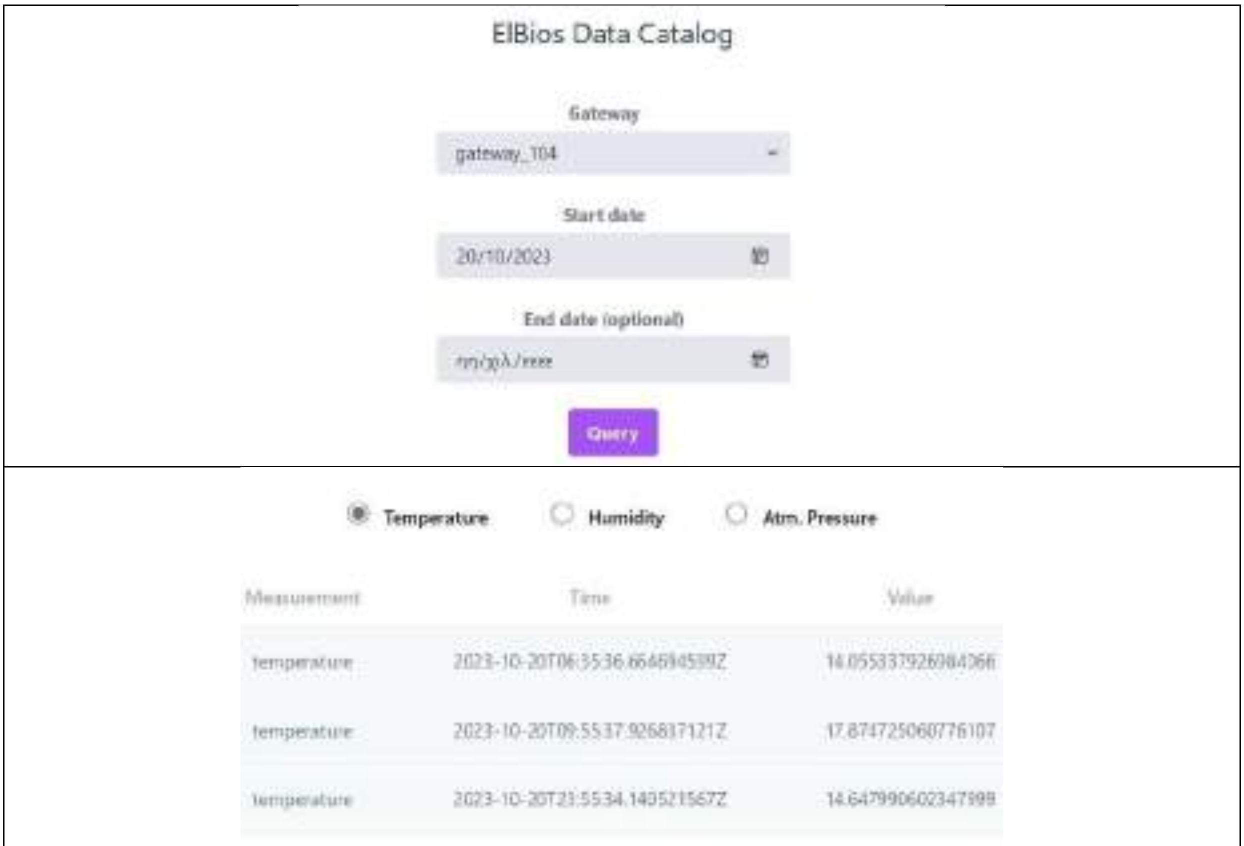
Figure 20. The antenna installation.

4. FIRST RESULTS – PERFORMANCE EVALUATION OF THE WSN

4.1 Valia Kalda Wireless Sensor Network – First Results

In this Section, a small indicative selection of the data that had been recorded and transmitted in the cloud infrastructure is presented. This data is visualized through an experimental dashboard that has been designed and developed in our laboratory. The purpose of this dashboard is to provide the reader with a user-friendly environment to navigate and monitor the biodiversity datasets that are stored in UTH's database repositories. The data will be available for integration with the EL-BIOS Information Platform using a rest API[8].

In Figure 20, the dashboard menu is displayed, enabling users to explore the data. The first box is equipped with a dropdown list containing the names of the devices, while the other box permits users to specify the range of days they are interested in. At the end of the menu, there is a "Query" button that users can click after making their selections to display the relevant data. In the other figures, examples of the query request results are displayed.



Elbios Dashboard - Temperature in degrees Celsius (°C)

[8] This is an ongoing work that will be completed in the next months of the project.

○ Temperature ◉ Humidity ○ Atm. Pressure

Measurement	Time	Value
humidity	2023-10-20T06:35:36.665151873Z	52.90387298689767
humidity	2023-10-20T09:55:37.927944209Z	40.802443173832096
humidity	2023-10-20T23:55:34.140839236Z	44.95637691766 79

Elbios Dashboard - Humidity in percentage (%)

○ Temperature ○ Humidity ◉ Atm. Pressure

Measurement	Time	Value
pressure	2023-10-20T06:35:36.665145734Z	838.26058053832 78
pressure	2023-10-20T09:55:37.927082272Z	838.888026336592
pressure	2023-10-20T23:55:34.140827292Z	839.2006300403555

Elbios Dashboard - Atmospheric Pressure in Millibar Pressure Unit (mBar)

1. 1697978906.mp3

▶ 0:03 / 0:05

Classifier results	Value
gateway	gateway_104
timestamp_created	2023-10-22 15:15:06
timestamp_evaluated	2023-10-22 15:15:06.611326
interpreter_class	dog_bark
interpreter_certainty	96
interpreter_class2	gun_shot
interpreter_certainty2	0
threshold	1000
avg_intensity	-1
classify_duration	0:00:00.150926
certainty_threshold	75

Audio Data metadata

Figure 21. Dashboard of the ELBIOS Biometrics and Sound Monitoring System.

Considering the quality assessment of the recorded sound files, the plan within the next months is to conduct experimentation with an aim to improve the developed software and apply potential updates or reconfigurations on the hardware.

The recorded data is significantly affected by wind, resulting in noise in the audio. It's essential to address these environmental conditions to enhance the quality of the audio data. This will improve the performance of the classifier and ensure more reliable results. The data should be categorized based on the classifier's output within a maximum duration of four seconds per file.

The objective is to confidently identify recurring categories in consecutive audio files, providing a higher level of certainty that the identified category is accurate. The ultimate goal is to create a real-time system capable of alerting a responsible person to any unusual forest activity while maintaining a historical record of events and generating daily reports.

4.2 Biodiversity node installed in Drakolimni Lake

At the time of writing, the device and server components are successfully writing data in our database, though network signal weakening at times could be expected. The accumulated data can be viewed & analyzed through plethora of visualization & analysis tools available over the time-series database (Grafana, etc.). This refers to a future work that is expected to provide with data the dashboard of the EL Bios portal. The following table presents a small sample of the recorded measurement.

Table 3. Recorded Values from the sensing node deployed in the Drakolimni Lake.

Date / Values	pH	Temperature (°C)	Liquid Temperature (°C)	Turbidity (NTU)	Electric Conductivity (mS/cm)	Dissolved Oxygen (mg/l)	NO3- (ppm)	NH4+ (ppm)	Chlorophyll (µg/l)
2023/10/21 04:55:00	7.11	7.3	6.7	12.89	0	7	0.1	0.09	0
2023/10/21 05:00:00	7.13	7.3	6.7	13.51	0	7.1	0.1	0.09	0
2023/10/21 05:05:00	7.12	7.3	6.7	11.44	0	7	0.1	0.09	0
2023/10/21 10:57:20	7.38	7.8	7.2	2.37	0	7.7	0.1	0.09	0
2023/10/21 11:02:20	7.40	7.8	7.3	2.29	0	7.7	0.1	0.09	0

2023/10/21 11:07:20	7.40	7.8	7.2	2.47	0	7.7	0.1	0.09	0
2023/10/21 17:04:40	7.82	9.4	8.9	1.27	0	7.8	0.1	0.09	0
2023/10/21 17:09:40	7.84	9.4	8.9	1.31	0	7.8	0.1	0.09	0

A further special showcase of a metrfic picking up a rare Chlorophyll measurement is shown below: This might be indicated as an outlier, but it falls within the range of the values that sensor supports.

Table 4. Recorded Values from the sensing node deployed in the Drakolimni Lake.

Date / Values	pH	Temperature (°C)	Liquid Temperature (°C)	Turbidity (NTU)	Electric Conductivity (mS/cm)	Dissolved Oxygen (mg/l)	NO3- (ppm)	NH4+ (ppm)	Chlorophyll (µg/l)
2023/10/21 04:55:00	7.11	7.3	6.7	12.89	0	7.3	0.1	0.09	359.5

5. CONCLUSION

The aim of this deliverable is to present the work conducted in the context of ELBIOS Action B4 and to offer a thorough understanding to the interested reader about the rationale and the methodology that we have followed for the design and deployment of a wireless sensor network for Biodiversity monitoring in the Valia Kalda National Park and of a water quality wireless sensing device in the lake Drakolimni. A major challenge to overcome was the remoteness of the area that required a very thorough preparation and extensive performance and operational evaluation of the sensing devices in the laboratory. That would minimize the risk of misconfiguration that would require in turn human intervention and presence in the field in order to re-install or/and re-configure the network and the devices. This deliverable will be used by Action B5 and B6 for the implementation of the designated activities