Biodiversity Greece

LIFE EL-BIOS
Hellenic Biodiversity Information System
www.biodiversity-greece.gr
Tel: +30 210 5241903 (int.: 129)
Email: info@biodiversity-greece.gr

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State of the art Review - Wireless sensor techniques for biodiversity monitoring

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ΕΥΡΕΤΗΡΙΟ ΠΙΝΑΚΩΝ

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EXECUTIVE SUMMARY

This document aims to describe the cutting-edge technologies that will contribute to designing and implementing a wireless sensor network for biodiversity monitoring. At this phase, we thoroughly investigated existing open-source devices, acoustic sensors and wireless technologies, their characteristics, and techniques to combine them into our sensing device. This study aims to formulate an innovative solution for monitoring acoustic and water quality parameters in the North Pindos National Park during the project

1. INTRODUCTION

1.1 Defining Biodiversity

Biodiversity-ecosystem consists of animals, plants, fungi, and even microorganisms like bacteria that live together in a particular habitat. All these organisms are vital for human sustainability, providing services to maintain balance on our planet. Each species has a specific role in life and collaborates with others to support human wellbeing. In addition, biodiversity is essential for the services provided by nature, such as climate control, flood protection, pollination and food production.

However, it is observed that there has been a dramatic loss of biodiversity in recent years. This continuous waste has severe consequences for human wellbeing and the nature of the planet, such as the destruction of natural habitats due to intensive agricultural production, undisciplined deforestation, overexploitation of water, and increasing global pollution. Given the enormous role that biodiversity plays in the sustainability of the planet and our lives, its continuing loss is becoming increasingly worrying.

Therefore, it is vital to create actions aimed at monitoring biodiversity. By creating tools to monitor habitat environments in real-time, the current situation can be evaluated and the necessary decisions to maintain it can be made.

1.2 Protected Area Management Challenges

Despite the concerted efforts of governments and ecologists to conserve nature, the loss of biodiversity continues at an alarming rate. Thus, protected areas such as NATURA 2000 were developed, which have aimed to preserve nature in their region. However, this task faces various challenges, especially in the past decades when the fields of Wireless Sensor Networks and the Internet Of Things were in their infancy. Here are some of these challenges where technology could help to achieve efficiency and effectiveness:

- **Collection of ecological, environmental and biodiversity data to establish trends, threats and causality.** Obtaining biodiversity data is quite a complex process. Researchers, conservationists, and people who manage a natural habitat must set aside inaccessible areas to observe changes that pose risks. Collecting this traditionally generated data is quite time-consuming as people have to visit the monitoring fields 4-5 times a year to collect as much data as possible. This way of collecting data is often impractical as it is pretty challenging to record illegal activities. In some cases, camera-based or audio-based devices have been developed by various organizations. But, they are not connected to the network to send the gathered data in real-time.

The network of sensors is an innovative solution to monitoring these areas. Distributed devices that feature several sensors are connected wireless to exchange messages to collect helpful information from the field. This approach could significantly increase data collection speed, completeness and accuracy compared to the traditional way of data collection.

- **Surveillance of the Protected Area**. The limited resources of the rangers, the enormous regions of the parks and the limited road access make comprehensive patrolling difficult. In the rainy season, when the animals disintegrate, the patrol becomes even more difficult and may not be accessible in parts of the park for months. Poachers, illegal loggers and ranchers can largely go unpunished. New technology has the potential to transform this challenge by enabling patrolling of these areas with power-autonomous devices that are responsible for real-time notification of threats and illegal activities.

- **Comprehensive analysis of the collective data**. Traditional biodiversity data analysis is a time-consuming process where scientists and ecologists study the data collected, such as photographs, sounds, and environmental measurements, to find a pattern that identifies potential threats and their causality.

  This procedure can be significantly improved by utilising new technologies such as Machine Learning and Artificial intelligence. Foresters, ecologists and local authorities could leap at the chance to use these new technologies for nature protection. For instance, they could know in real-time if there are threats in the forest and what kind they are. The collected measurements can be analysed extremely fast so that we know if you are going for poachers or illegal loggers.

Taking into consideration how to address these challenges, the Wireless Sensor Network architecture is an innovative and efficient solution. The devices take on the role of human resources, providing information from the fields in real-time for long periods.

2. BIOACOUSTIC SENSING DEVICE

A network of wireless sensor devices will be developed at pilot site A in Pindos National Park, in order to monitor the most critical biodiversity risks within the Park. The sensor network will consist of energy-autonomous wireless devices equipped with sound sensing modules cameras and environmental sensors to collect measurements to detect in real-time anthropogenic threats to biodiversity within Valia Calda.

2.1 Acoustic Sensing Devices

In recent years, various integrated devices have entered the market to address biodiversity monitoring. In this section, we enumerate and describe the available solutions that could be useful for implementing a wireless sensor network for biodiversity monitoring.

2.1.1 AudioMoth

The AudioMoth[1] is a portable ready-to-use device for biodiversity monitoring designed by Silicon Labs. This device is based on a Cortex-M4 microcontroller with 256 kB of flash memory and an onboard MEMs microphone that is able for recording both audible and ultrasonic frequencies. An sd card slot supports external memory for more audio recording space so that it can record sounds for months from the field

Figure 1. AudioMoth deployed (Original picture taken from AudioMoth site)

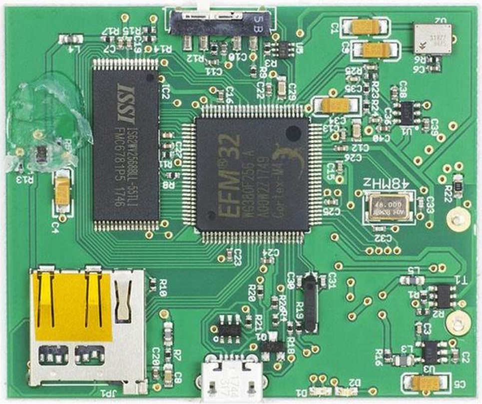

Figure 2. AudioMoth Board (Original picture taken from AudioMoth site)

AudioMoth can be configured through a user-friendly interface where even non-technical users can easily set recording durations, sampling rates, microphone gain and a variety of parameters depending on their development conditions.

[1] "AudioMoth | Open Acoustic Devices." https://www.openacousticdevices.info/audiomoth. Accessed 10 May. 2022.

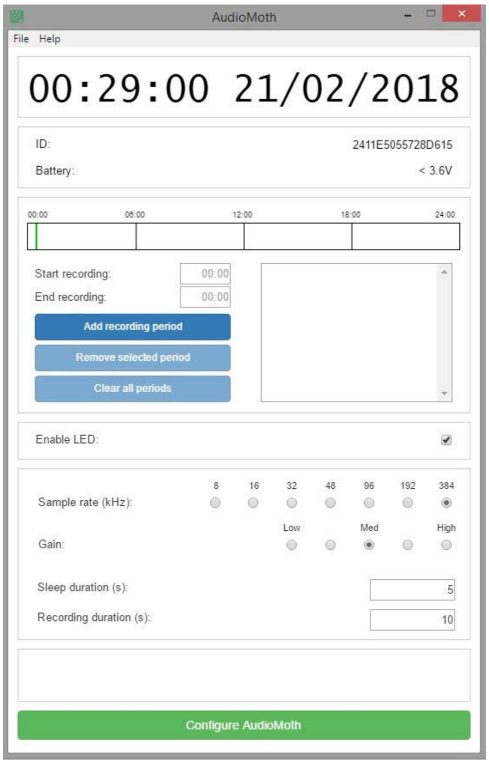

Figure 3. AudioMoth Software Original picture taken from AudioMoth site)

According to Andrew P. Hill[2] the main advantages of AudioMoth over pre-existing devices are its lower cost, lower power usage, small size and ease of use. Its cost, approximately 70,00 € for a single unit, is about 10 times cheaper than pre-existing commercial equivalents. The small size of this device makes it portable and easy to deploy by anyone; there is no need for any additional infrastructure just only a tiny rechargeable battery. In addition, the easy-to-use supporting software makes it possible for users at any skill level to configure a device for multiple applications.

Despite these advantages, AudioMoth present drawbacks for large-scale deployments. First and foremost, it does not have any wireless communication interface build-in to send the gathered information from the field, which means the stakeholders have to retrieve the SD cards and process the data. Moreover, it does not have a solar panel system to charge its batteries. Thus, the maximum recording duration would be 50 days, under specific conditions and configuration (sample rate: 8 kHz, sleep time: 300 s, record time: 30 s)

[2] AudioMoth: A low-cost acoustic device for monitoring biodiversity and the environment https://eprints.soton.ac.uk/432474/2/1_s2.0_S2468067219300306_main.pdf

2.1.2 Song Meter SM4 Acoustic Recorder

The Song Meter SM4[3] is a weatherproof, programmable audio recorder designed for the periodic, seasonal, and long-term monitoring of wildlife bioacoustics in almost any environmental condition. It has two in-built microphones that enable recording sounds from 20Hz - 48kHz and two microphone ports allow you to connect a cabled mic or hydrophone.

It can be scheduled daily recordings to meet a variety of needs, including times that are relative to sunrise and sunset, specific duty cycles with on/off recording patterns, and continuous monitoring all day and all night. The SM4 optimises battery life and memory capacity to record for extended periods of time. Using both memory slots and D-cell alkaline batteries, a typical deployment can record for up to 650 hours spanning several months.

Figure 4. Song Meter SM4 Acoustic Recorder, (Original picture taken from wildlifeacoustics)

The main advantage of the Song Meter SM4 is its dual high-quality microphones. That ensures recording continues – even after one microphone is destroyed by wildlife-incurred damage. Moreover, it has two additional ports where cable microphones could be connected to capture audio from far-off wildlife such as birds in the forest canopy or frogs at a nearby pond. In addition, the ultra-low-power consumption and its ergonomic design enable easy deployments for long periods.

However, the cost of the Song Meter SM4 (800,00 €) makes it inefficient for networks with a large number of devices. Moreover, as mentioned for the AudioMoth, the Song Meter SM4 does not have any wireless communication interface build-in to send the gathered information from the field to the cloud.

2.1.3 Comparison

Below, you can find a table showing the specifications of the two described devices. As you can observe, the second device is more expensive than the first. However, it features two high-quality microphones and other peripherals that make it more efficient for long-term deployments. Both of

[3] "Song Meter SM4 Wildlife Audio Recorder." https://www.wildlifeacoustics.com/products/song-meter-sm4. Accessed 10 May. 2022.

these devices appear to have a drawback in data transmission, so it would be necessary to integrate a reliable wireless interface into the desired device.

Table 1. Comparison of Parameters

	AudioMoth	Song Meter SM4
Recording Format	Mono, 16-bit PCM.wav	Two-channel, 16-bit PCM.wav
Sampling Rates	8KHz ~ 48 kHz	8KHz ~ 96 kHz
Built-in Microphones	1	2
Mic. Directional	Omni-Directional	Omni-Directional
Mic. Sensitivity	-38 dB (0 dB=1V/pa@1kHz)	-35 ±4 dB (0 dB=1V/pa@1kHz)
MIc. SNR	63 dB Typ. at 1kHz	80 dB Typ. at 1kHz
Mic. Max Input SL	-	126 dB SPL
Run-Time	1460 hours	510 hours
Storage	Up to 32 GB	Up to 1TB
Dimensions	58mm, 48mm, 15 mm	218mm, 186 mm, 78 mm
Enclosure Material	-	Polycarbonate (Weatherproof)
Operating Temperature	-20°C to 85°C	-20°C to 85°C
Wireless interface	-	-
Price	70,00 €	800,00 €

2.2 Open-Source Platforms

Besides the available ready for use acoustic sensing devices, plenty of open-source platforms could be a feasible solution for implementing an energy-autonomous sensing node. These platforms allow access to its source code to any other users or developers to customize its operation according to their needs. Therefore, we can choose from various existing low-sized, low-power platforms that enable us to build simple, portable sensing nodes or larger platforms that will allow us to create advanced, energy-demanding sensing nodes.

2.3.1 Simple, low-sized solutions

- **Raspberry Pi**[4] is the most popular development device with a large support community. It has the size of a credit card with the performance of a home computer. Its latest version, Raspberry pi 4 model B, features quite powerful CPU and memory modules up to 8 GB.
- **BeagleBone Black**[5] The BeagleBone Black is another device that belongs to the family of computers with a board. It has similar capabilities to Raspberry Pi platforms, except that it has a large number of Input/Output pins (GPIO) for integrating sensors and several peripherals.
- **Arduino Yun**[6] is a low-power microcontroller board based on the ATmega32uA and the Atheros AR9331. It features a built-in Wi-Fi module for wireless communication with sensors or other devices and supports Linux OpenWrt operated system.
- **Intel Galileo**[7] is a microcontroller board based on an Intel CPU and is hardware and software compatible with Arduino shields. It features a miniPCI Express slot.

Figure 5.- Raspberry Pi, Original picture taken from Raspberry Pi Foundation)

Figure 6.- BeagleBone Black Board Original picture taken from beagleboard.org)

Figure 7. Arduino Yun, Original picture taken from arduino.cc

Figure 8.Intel Galileo (Original picture taken from generationrobots,com)

[4] "Teach, Learn, and Make with Raspberry Pi." https://www.raspberrypi.org/. Accessed 10 May. 2022.
[5] "BeagleBone Black - BeagleBoard.org." 11 Nov. 2021, https://beagleboard.org/black. Accessed 10 May. 2022.
[6] "Arduino Yún | Arduino Documentation | Arduino Documentation." 11 Apr. 2022, https://www.arduino.cc/en/Main/ArduinoBoardYun. Accessed 10 May. 2022.
[7] "Intel Galileo - Wikipedia." https://en.wikipedia.org/wiki/Intel_Galileo. Accessed 10 May. 2022.

Table 2. Comparison of Parameters

	Raspberry Pi 4 mode B	Raspberry Pi 3 model A+	BeagleBone Black	Arduino Yun (OpenWrt)	Intel Galileo
CPU	1.5Ghz 64-bit Quad-core Cortex-A72	1.4Ghz 64-bit Quad-core Cortex-A53	1Ghz ARM CPU	400mhz (AR9331) and 16mhz (ATmega)	Intel 400mhz
RAM	1GB / 2GB / 4GB / 8GB	512 MB	512MB	64MB (AR9331) and 2.5KB (ATmega)	256MB
USB	4	1	1	1	1
HDMI	yes	yes	yes microHDMI	no	no
Digital GPIO pins*	40	40	2x46	20	14
Ethernet	yes	No	yes	yes	yes
Wi-Fi	yes	yes	no	yes	no
Bluetooth	yes	yes	no	no	no
Storage	External SD card	External SD card	Internal 4Gb Flash	External microSD	External microSD
Power Consumption	540 mA	80 mA	250 mA	50 mA	800 mA
Price	80,00 €	30,00 €	80,00 €	75,00 €	90,00 €

2.2.2 Advanced solutions

- **NVIDIA® Jetson Nano™ Developer Kit**[8] is a powerful development device with a graphics card capable of performing complex calculations. The combination of 128-core Maxwell CPU and Quad-core ARM A57 @ 1.43 GHz allows it to run neural network algorithms for applications such as image classification, object detection, segmentation, and speech processing.
- **Nvidia Jetson Xavier NX Developer Kit**[9] is the Nvidia Foundation's flagship edge AI device. Compared to the Jetson nano, it has a CPU with more cores at a faster speed, plus it has the NVIDIA Volta GPU with 384 cores, making it more than ten times more efficient than other Ai edge devices. However, it consumes about 10 watts in normal conditions.

[8] "NVIDIA Jetson Nano Developer Kit." https://developer.nvidia.com/embedded/jetson-nano-developer-kit. Accessed 10 May. 2022.
[9] "Jetson Xavier NX Developer Kit." https://developer.nvidia.com/embedded/jetson-xavier-nx-devkit. Accessed 10 May. 2022.

- **Icarus**[10] node has been designed and developed by the NitLab, the research laboratory of the University of Thessaly. This node provides experimental capabilities to researchers worldwide who want to evaluate their protocols on a real-world testbed. It features multiple state-of-the-art wirelesses and wired networking technologies and a powerful central processing unit. It can support applications such as video streaming, processing, data analysis and streaming.

Figure 9. Icarus Node (Original picture taken from [NitLab](#))

Figure 10. Nvidia Jetson Xavier NX

(Original picture taken from [Nvidia Developer](#))

Figure 11. Nvidia Jetson Nano

(Original picture taken from [Nvidia Developer](#))

[10] "Icarus Nodes - NITlab." http://nitlab.inf.uth.gr/NITlab_old/index.php/hardware/wireless-nodes/icarus-nodes. Accessed 10 May. 2022.

Table 3. Comparison of Parameters

	NVIDIA® Jetson Nano	Nvidia Jetson Xavier NX	Icarus wireless nodes
CPU	Quad-core ARM A57	6-core Denver & A57 (2x) 4MB L2	i7-2600 Processor, 3.40GHz
RAM	4GB	16 GB	8 GB
GPU	128-core Maxwell	384-core Volta 21 TOPS (INT8)	
USB	4	4	4
HDMI	yes	yes	yes
Digital pins*	40	40	optionally
Ethernet	yes	yes	2
Wi-Fi	no	yes	802.11a/b/g/n cards
Storage	microSD	microSD	Soild state drive
Power**	2000 mA	2500 mA	2500 mA
Price	167,00 €	378,00 €	-

2.3.3 Comparison

Below you can find a chart showing the current drawn by each platform. This current is measured in mA and does not include the current of any additional peripherals that will be attached to the platform, like Wi-Fi interfaces, cameras, sensors etc.

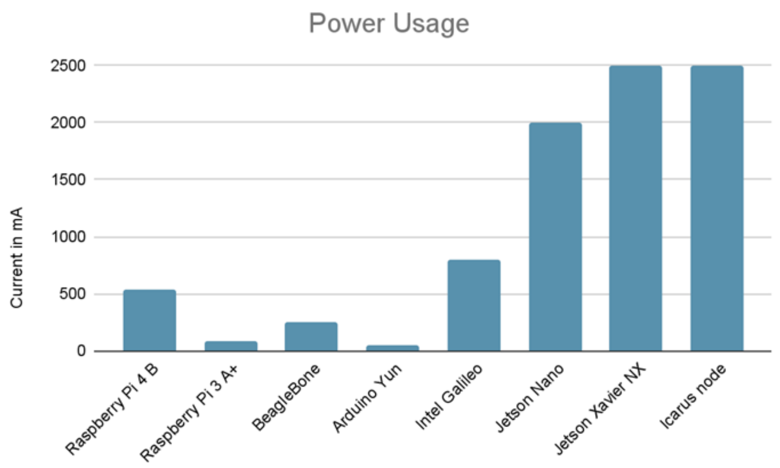

Figure 12. Current Usage per Platform

2.4.1 Microphone Polar Patterns

- **Omni-directional**[11] - An omni-directional microphone captures sound from all sides and all directions. Whether the sound is in front, behind, or on one side of the mic, it picks up the signal equally.
- **Cardioid**[12] – So named because the pick-up pattern of the audio is somewhat heart-shaped. The mic picks up sound mostly from the front and sides of the microphone and also a bit from behind.
- **Uni-directional**[13] - This sound pattern is excellent for focusing on a specific sound and blocking out ambient noise. For example, this is a great microphone if you only want to receive one target sound in a noisy environment. Uni-directional microphones are highly directional and should be aimed directly at the subject to record the best sound quality

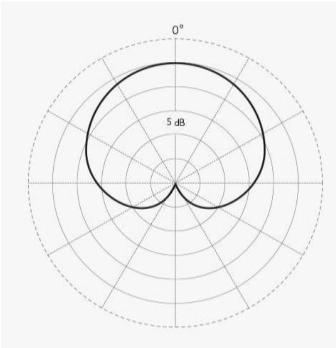

Figure 13. Cardioid Pattern
(Original picture taken from wikimedia)

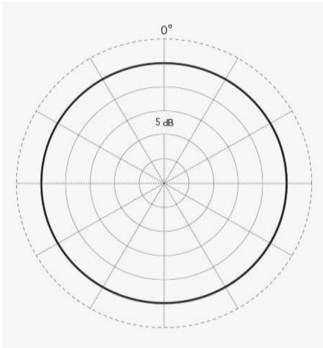

Figure 14. Omni-directional Pattern
(Original picture taken from MyNewMicrophone)

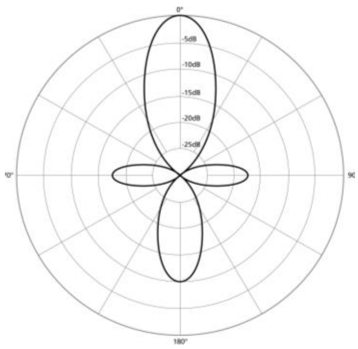

Figure 15. Uni-directional Pattern
(Original picture taken from Discmakers)

[11] "Microphone - Wikipedia." https://en.wikipedia.org/wiki/Microphone. Accessed 10 May. 2022.
[12] "Microphone - Wikipedia." https://en.wikipedia.org/wiki/Microphone. Accessed 10 May. 2022.
[13] "Microphone - Wikipedia." https://en.wikipedia.org/wiki/Microphone. Accessed 10 May. 2022.

2.2.2 External Microphones

- **Rode VideoMicro**[14] - It is a compact microphone with a cardioid polar pattern capable of recording sounds in high quality from the field. It comes with a luxurious fur windshield to isolate environmental noises. It is usually used on top of a wide range of cameras, although it can be adapted to single-board computers using an external USB sound card.
- **Rode VideoMic GO**[15] - The VideoMic GO is a unidirectional microphone from Rode. Its pattern makes the recording process easier when you want to isolate surrounding sounds, focusing on a specific subject in front of the microphone. It can be integrated to any single-board computer using an external sound card.
- **Rode Lavalier Go**[16] - This microphone has an omnidirectional pattern capable of capturing sounds from any direction from the environment. The 3.5mm TRS jack it has makes it compatible with various devices.

Figure 16. Rode Lavalier Go (Original picture taken from Rode.com)

Figure 17. Rode VideoMic GO (Original picture taken from Rode.com

Figure 18. Rode VideoMicro (Original picture taken from Rode.com)

[14] "RØDE VideoMicro | Ultra-compact On-camera Microphone." https://rode.com/microphones/on-camera/videomicro. Accessed 10 May. 2022.
[15] "RØDE VideoMicro | Ultra-compact On-camera Microphone." https://rode.com/microphones/on-camera/videomicro. Accessed 10 May. 2022.
[16] "RØDE Lavalier GO | Professional Lavalier Microphone." https://rode.com/microphones/lavalier-wearable/lavalier-go. Accessed 10 May. 2022.

Table 4.Comparison of Parameters

	Rode VideoMicro	Rode VideoMic GO	Rode Lavalier Go
Acoustic Principle	Pressure Gradient	Pressure gradient electret condenser	Permanently Polarised Condenser
Polar Pattern	Cardioid	Uni-directional	Omnidirectional
Frequency Range	100Hz - 20kHz	20Hz - 20kHz	20Hz - 20kHz
Signal-to-Noise Ratio	-	79 dBA	67 dB
Equivalent Noise	20dBA	15 dBA	27 dB Typical
Maximum SPL	140dB SPL	110 dB SPL	110 dB
Sensitivity	-33.0dB re 1 Volt/Pascal (22.00mV @ 94 dB SPL) +/- 2 dB @ 1kHz	-31dBV(28.78mV @ 94dB SPL) ± 1dB @ 1kHz	-35dB (17.8mV @94dB SPL)
Power Requirements	2V-5V DC	2 - 5V DC	Powered from plug-in power TRS socket (2.7V)
Output Connection	3.5 mm	3.5 mm	3.5 mm
Price	47,00 €	55,00 €	52,00 €

3. WATER QUALITY

Besides the WSN of Valia Calda, a network of sensing devices should be deployed in the ecosystem of Tymphi Drangolake. This network will monitor water quality-related parameters and detect abnormal changes in the lake, a relic of the ice age, located within Aoos Canyon Nature Reserve Area. This unique ecosystem faces significant threats due to livestock waste and illegal human activities.

3.1 Water Quality Parameters

In this section, we enumerate and describe the fundamental water quality-related parameters. The following parameters are essential to life within aquatic systems. Impairments of these can be observed as impacts on the flora and or fauna.

- **Water Temperature** - This parameter quantifies the kinetic energy of the atoms or molecules of water. The scale of measurement is degrees Celsius or Fahrenheit and is quite important for the sustainability of flora and fauna of an ecosystem.
- **Dissolved Oxygen** - It is the most critical parameter of underwater life. It represents the value of oxygen dissolved in water. Dissolved oxygen is essential for aquatic organisms to survive and grow, such as fish that

require 5 mg/L DO. When this measurement reaches the lower limit of 2 mg/L DO death is caused to most aquatic organisms

- **PH** - pH is a measurement that determines the acidity or alkalinity of a liquid. Its scale is logarithmic and has values from zero to 7 where values that are close to seven express acidic liquids while those that are close to zero are alkalic.

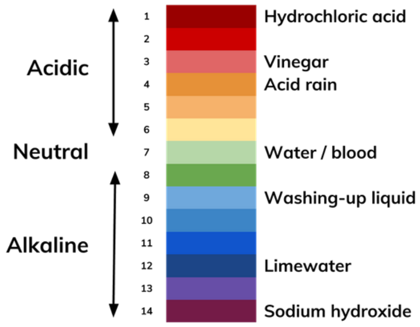

Figure 19. pH scale
(Original picture taken from Seneca)

- **Electrical Conductivity** - Electrical conductivity expresses the ability to conduct electricity underwater. This phenomenon is observed when the elements of water are broken down by chemical reactions into positively and negatively charged ions. Some of the most common positively charged ions are sodium, (Na+) calcium (Ca+2), potassium (K+) and magnesium (Mg+2). The major negatively charged ions are chloride (Cl-), sulfate (SO4-2), carbonate (CO3-2), and bicarbonate (HCO3-).

3.2 Water Quality Sensing Device

The considered devices (nodes) will compose of open-source and reconfigurable modules. They will be based on a modular architecture that allows flexible soft/hardware upgrades to feature various sensing modules. The devices also will host different communication technologies (ZigBee, LoRa WiFi, 4G-LTE).

3.3 Smart Water Sensor Libelium

The Smart Water sensor board[17] has been designed to facilitate the measurement of the most important chemical parameters that allow the remote monitoring of water quality in different scenarios, which includes contamination surveillance in natural environments such as rivers and lakes, control of the appropriate conditions of water in pools or fish farms and observation of industrial sewage from industries. Among these parameters are included water temperature, conductivity, pH, dissolved oxygen, oxidation-reduction potential (ORP) and turbidity.

[17] "Smart Water Sensor Guide - Development Libelium." https://development.libelium.com/smart_water_sensor_guide/waspmote-plug-amp-sense. Accessed 10 May. 2022.

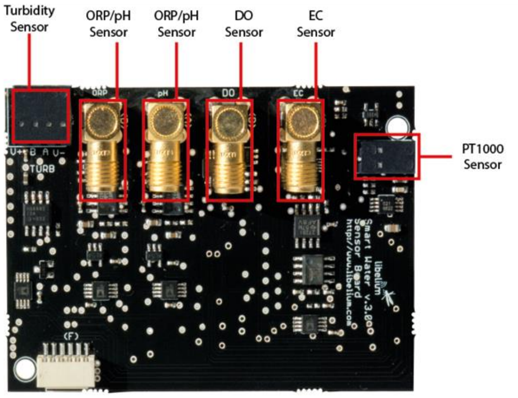

Figure 20. Smart Water Sensor Libelium (Original picture taken from Libelium)

In the following table, we can see the main features of the sensors that are compatible with the Smart Water Sensor device Libelium.

Table 5. Comparison of Parameters

	Measurement range	Accuracy	Resistance	Temperature of operation	Response Time	Cable length
Temperature sensor	0 ~ 100 ºC	DIN EN 60751	1000 Ω	0 ~ 100 ºC	-	~500 cm
Dissolved Oxygen sensor	0~20 mg/L	±2%	-	0 - 50 ºC	2 minutes for 2 mV	~500 cm
pH sensor	0~14 pH	-	0~80 ºC	0~80 ºC	<1 min	~500 cm

3.2.2 Smart Water Ions Sensor Libelium

The Smart Water Ions Sensor Board[18] has been designed to facilitate the measurement of the most important chemical parameters that allow the remote monitoring of water quality in different scenarios, which includes contamination surveillance in natural environments such as rivers and lakes, control of the appropriate conditions of water in pools or fish farms, agriculture, hydroponics and observation of industrial sewage from industries.

[18] "Smart Water Ions Sensor Guide - Development Libelium." https://development.libelium.com/smart-water-ions-sensor-guide/sensors. Accessed 10 May. 2022.

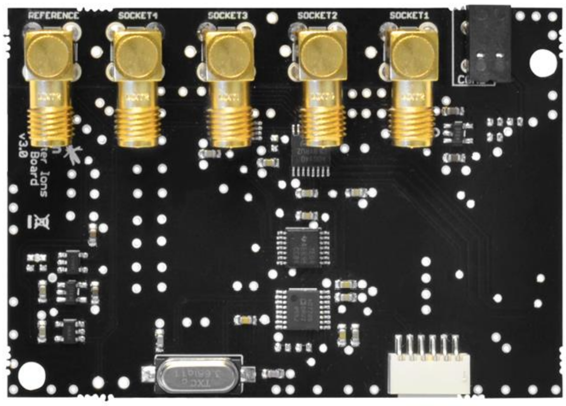

Figure 21. Smart Water Ions Sensor Libelium

(Original picture taken from Libelium)

In the following table, we can see the main features of the Ions sensors that are compatible with the Smart Water Ions Sensor device Libelium.

Table 6. Comparison of Parameters

Ion	Sensitivity	Temp(ºC)	pH	Lineal Range	Interferences
Ammonium NH4+	-54 ± 5	5 - 50	4 - 8.5	0,09 - 9000 mg/L	K (-0,8); Na (-2,7); Mg (-3,2); Ca (-4)
Chloride Cl-	-54 ± 5	5 - 50	2 - 12	1,5 - 35000 mg/L	Error presence of Ag or S
Nitrate NO3-	-54 ± 5	5 - 50	2 - 11	0,6 - 31000 mg/L	Br (-1,2); NO2 (-1,7); OH (-1,8); AcO (-2,2)
Perchlorate ClO4-	-54 ± 5	5 - 50	1 - 11	1 - 10000 mg/L	SCN (-1,7); NO3 (-1,7); I (-1,7)
pH Sensor	-54 ± 5	5 - 50	0 - 14	0 - 14	-

4. NETWORK

In recent years, wireless sensor networks have become increasingly popular in research and industrial applications —a device equipped with different types of sensors such as temperatures, microphones, cameras etc., collects valuable data from the field. These data are transmitted to the decentralised cloud infrastructure through a low-power communication interface for storage and further processing.

A Wireless sensor network can be defined as a network of devices that can communicate the information gathered from a monitored field through wireless links. The data is transmitted from the distributed sensor nodes to the one gateway device, using RF interfaces for power saving and extensive coverage. After that, the gateway device is responsible for transmitting these data through the appropriate communication protocol related to the deployment terrain.

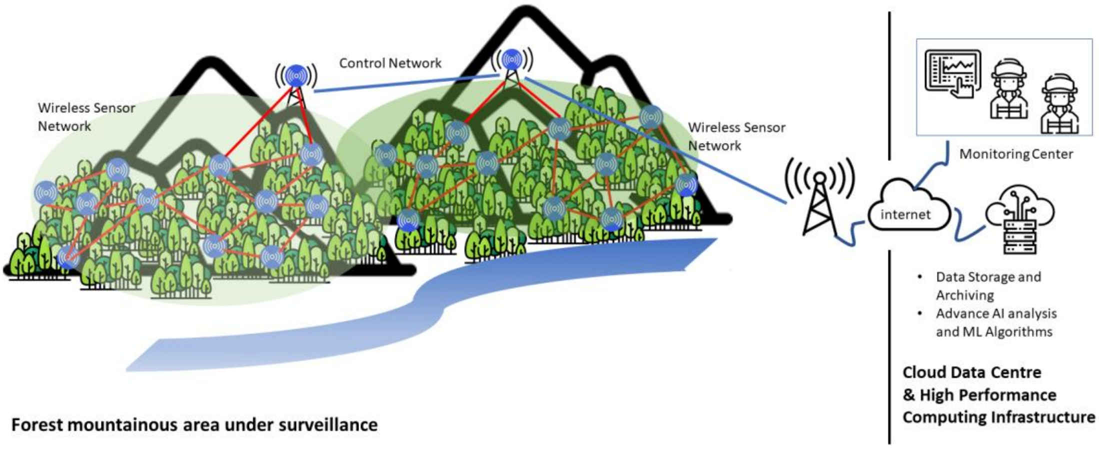

Figure 22. Wireless Sensor Network

4.1 Network Topologies

The sensor nodes are deployed at predefined positions to create the desired topology that addresses each scenario's needs. Below are described the most common topologies of a wireless sensor network.

- **Star Topologies -** The star network topology consists of one gateway device and multiple edge devices. In this topology, there are communication links between the gateway and edge devices where they can exchange messages. However, it is not permitted to communicate with two-edge devices directly; all messages have to pass through the gateway. This allows low-latency communications between the remote node and the gateway.

  The limitation of this topology is its dependence on a single gateway device. So, the network size depends on the coverage of the wireless interface it uses and the geo-relief of the field.

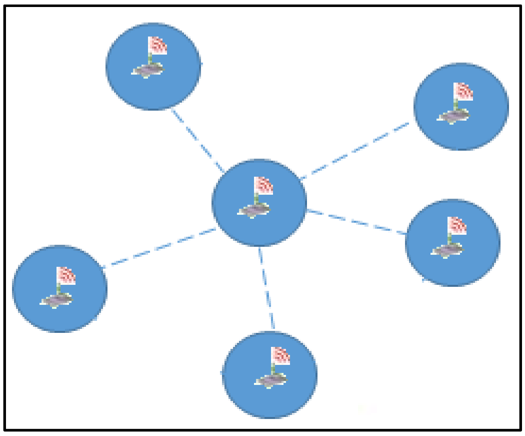

Figure 23. Star Topology

(Original picture taken from researchgate)

- **Tree Topologies -** In the tree topology, each device is connected to the one node placed higher in the tree and with several lower nodes. The communication messages are transmitted from the bottom to the top, where is located the gateway device. This topology is used in scenarios where it is necessary to extend the coverage of the network. However, the entire network may collapse if certain communication links are lost.

- **Mesh Topologies -** In mesh topologies, each edge device can communicate directly with anyone in its coverage. The communication between two nodes that are out of coverage is performed by relay nodes that are placed between them. The most critical advantage of this topology is its tolerance for problems that may occur between communication links. If a communication link is broken, the relay node will reroute messages to the gateway using a different path.

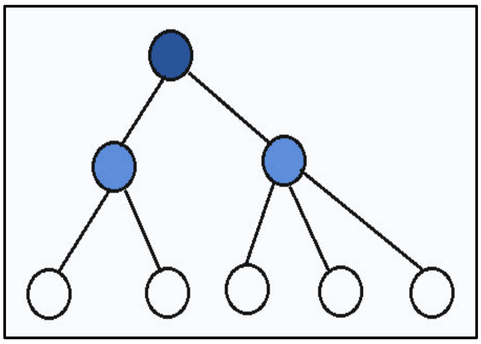

Figure 24. Tree Topology

(Original picture taken from iot4beginners)

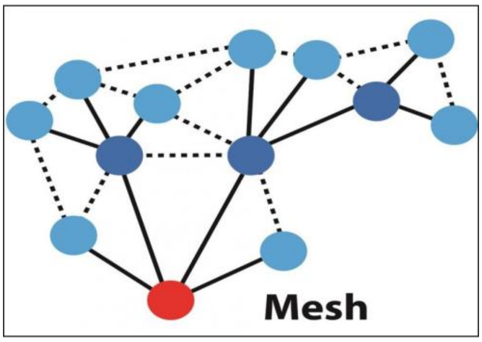

Figure 25. Mesh Topology

(*Original picture taken from* [*Spacmeter*])

4.2 Gateway Device

The gateway device is responsible for the data transmission between the monitoring fields and the NITOS Cloud. It features several communication protocols, such as XBee, LoRa, 4G, e.t.c. to create a local wireless network for the edge sensing devices. These devices are deployed strategically to receive data from as many nodes as possible constantly. Due to this property, they have to be fully operational 24/7.

The research laboratory NITLab of the UTH-DECE has already developed a gateway[19] device based on the single board computer BeagleBone Black. It has a PCB hut that can drive several communication interfaces, and a solar panel system powers this device to be energy autonomous and independent from any electrical infrastructure.

[19] "LoRa Agricultural Testbed - NITlab." https://nitlab.inf.uth.gr/NITlab/nitos/lora/lora-testbed-2. Accessed 10 May. 2022.

Figure 26. Gateway

5. CONCLUSION

Based on the state of the art technologies described in this document, the UTH-DECE will develop innovative nodes of wireless sensors for pilot testing in Northern Pindus National Park during the project. These nodes will be equipped with the sensors mentioned above, depending on the monitoring field. In addition, we will provide access to the backbone network and connects the WSN with the end-users through the Internet by utilising Getaway devices.

With this review, UTH-DECE has covered a wide range of cutting-edge technologies that will contribute to the design of the sensing node, forming three different solutions. These are related to the main platform of the device where we will use. The trade-off between these devices' performance and power consumption has to be studied to choose the best available solution. Some platforms can perform complex computations at high speeds but are energy-demanding, while others are energy efficient with low performance. The energy consumption of the devices is an essential feature of them, as they should be designed to be energy autonomous.

The selection of the main platform will be made after a complete mapping of the characteristics of the installation field. Factors such as tree shading, node distances and network coverage will significantly contribute to this choice.