Environmental Monitoring System

This document outlines hardware requirements, characteristics and cost for this Project. Below you'll find said information.

Stage 1: Environmental sensing node(s)

This section aims to outline the hardware needed for this stage, its characteristics and potential cost.

1. Required Hardware

Here, an outline of hardware components needed for this module are listed.

- Micro controller: Arduino Nicla Sense ME (best option), ESP32 (cost effective)
- Display: OLED Display (such as SSD1351)
- Environmental sensor: seeed Grove SCD41 (only if ESP32 is used)
- Loudness sensor: seeed Loudness sensor (LM2904-based)
- OPTIONAL: Adafruit STEMMA speaker (if audible alarm functionality is needed)
- Alternate communication module: RFM95w LoRa Module

Further Hardware considerations

Considering its primary use in office environments, the necessity of a screen should be evaluated further. It is generally considered best practice to avoid the addition of screens to the nodes to ensure discreetness. Alternative output options should be explored, **such as LED indicators** (Green for good air quality, yellow for moderate air quality and red for poor air quality). This would **significantly reduce the footprint of the nodes and make it more discreet while still communicating data in a very simple way**. The omission of a display would also reduce overall cost of each node.

2. Hardware Characteristics

Here's an outline of hardware specs of the components named above:

- Micro controller:
  - Nicla Sense ME:

Tech specs

Microcontroller	64 MHz Arm® Cortex M4 (nRF52832)
Sensors	BHI260AP - Self-learning AI smart sensor with integrated accelerometer and gyroscope, BMP390 - Digital pressure sensor, BMM150 - Geomagnetic sensor, BME688 - Digital low power gas, pressure, temperature & humidity sensor with AI
I/O	Castellated pins with the following features: 1x I2C bus (with ext. ESLOV connector), 1x serial port, 1x SPI, 2x ADC , programmable I/O voltage from 1.8-3.3V
Connectivity	Bluetooth® 4.2
Power	Micro USB (USB-B), Pin Header, 3.7V Li-po battery with Integrated battery charger
Memory	512KB Flash / 64KB RAM, 2MB SPI Flash for storage, 2MB QSPI dedicated for BHI260AP
Interface	USB interface with debug functionality
Dimensions	22,86 mm x 22,86 mm
Weight	2 g

- ESP32:
    - See ESP32 Datasheet
- Display (may not be needed):
    - Operational Voltage: 3.3V / 5V
    - Resolution: 128 × 96 Pixels
    - communication Interface: 3/4-pin SPI
    - Display Size: 25.708 × 19.28mm
    - Display Panel: OLED
    - Pixel Format: 0.047 × 0.185mm
    - Driver: SSD1351
    - Module Size: 42.2 × 29.0mm
    - More information

- Environmental Sensor (ony for ESP32, Nicla Sense ME has on-board environmental sensors)
    - Operational Voltage: 3.3V / 5V
    - Operational ranges: -10 - +60 °C / 0 - 100% Humidity / 400 - 5000 ppm CO_2
    - SCL clock: 100 kHz
    - Communication interface: I2C (Address: 0×62)
    - Dimensions: 10.1 × 10.1 × 6.5mm
- Loudness Sensor:
    - Operational Voltage: 3.5 - 10VDC (external power likely needed)
    - Dimensions: 24 × 20 × 9.8mm
    - Operational Frequency range: 50 - 2000 Hz
    - Sensitivity: -48 up to -66 dB
    - Signal-to-Noise ratio: >58 dB
    - Output Signal: Analog
- (OPTIONAL) Speaker:
    - Operational Voltage: 3 - 5VDC
- RFM95w LoRa transceiver
    - Frequency range: 868 - 915 MHz
    - Connection: SPI
    - supports wire antennas and uFL or SMA ports (must be soldered on separately)
    - Range: Up to 2 km
    - variable output power (+5 - +20 dBm up to 100 mW)

3. Cost Analysis

Here we evaluate the cost of aforementioned components. All prices include VAT.

- ESP32: 0.00 € (already owned, ~5.90 € - 23.30 € if bought new)
- Arduino Nicla Sense ME: 55.30 €
- Display (SSD1351): 21.40 € (may be omitted)
- Environmental sensor (SCD41): 55.60 € (Not needed with Nicla Sense ME)
- Loudness sensor (LM2904): 6.00 €
- (OPTIONAL) Speaker: 6.55 €
- RFM95 LoRa transceiver: 21.95 €

Total cost (ESP32 option, with speaker): **89.55 €**
Total cost (ESP32 option without speaker): **83.00 €**
Total cost (ESP32 option with speaker, no display): **68.15 €**
Total cost (ESP32 option without speaker, no display): **61.60 €**
Total cost (ESP32 option, no speaker, no display, LoRa): **83.55 €**
Total cost (Nicla Sense ME option with speaker): **89.25€**

Total cost (Nicla Sense ME option without speaker): **82.70€**
Total cost (Nicla Sense ME option with speaker, no display): **67.85 €**
Total cost (Nicla Sense ME option without speaker, no display): **61.30 €**
Total Cost (Nicla Sense ME option, no speaker, no display, LoRa): **83.25 €**

As is visible above, the cost difference per node is 30 cents, which may seem minor, but can snowball into considerable savings at scale. with 8 such nodes, overall savings would amount to 2.40 €, 30.00 € with 100 nodes and 300 € with 1000 nodes.

4. Further Considerations

In this section, further considerations pertaining to the choice of micro controller are outlined.

Assuming this project is intended to be production-ready or production adjacent, it is important to consider which of the two micro controller options (Nicla Sense ME or ESP32) is most suitable for this module. While ESP32 is decent for **rapid prototyping purposes** and offers decent performance for the scope of this module, it is not designed for production use and is more tailored to use in conjunction with breadboards and jumper wires, which do not provide a dependable or reliable architecture needed in such mission-critical applications. Jumper wires and breadboards are prone to connection instability over time, which can cause additional monetary or time cost due to more intensive maintenance needs. Even in an office environment, with the additional of a potentially larger footprint in volume due to the ends of jumper wires not being bendable. On the other hand, while more expensive, the Arduino Nicla Sense ME is a **production-ready** micro controller tailored for more permanent and robust applications. As outlined in its specs, it already integrates environmental sensors, eliminating the need of an external sensor. for its size, it provides a sufficiently comprehensive I/O, including SPI communication. Additionally, the more solder-focused design makes it more readily possible to bend cables as needed to achieve as lean of a device as possible. **The use of LoRa over BLE is generally recommended due to better range, reliability and potentially better security. additionally, it can handle more connections, though data would have to be sent in a staggered manner due to poor concurrent airtime, which is an excusable trade-off.**

Break-even analysis: The maintenance cost (in time commitment) for the ESP32 variant (no speaker, no display) would break-even after a total of **approximately 3 hours and 37 minutes of maintenance time, after roughly 5 hours and 17 minutes for the ESP32 variant with all listed additional components**. Assuming frequent maintenance due to connection weakness or other potential issues associated with rapid prototyping approaches, these break even times would likely be reached rather quickly. Please not that the break-even was calculated based on an hourly rate of 17 €. Since wire connections on the Nicla Sense ME are predominantly soldered, while the total break-even time would be similar, the necessity of maintenance would generally be much lower and more infrequent, leading to a much slower break-even due to the more infrequent servicing needs, especially considering reduced potential failure points.

RECOMMENDATION: Due to robustness concerns and the mission-critical nature of said module, it is advised to use production-ready hardware such as the Arduino Nicla Sense ME. Additionally, it is recommended to omit the display to ensure a smaller overall footstep of the nodes and make them more discreet, which is desirable in office environments, which is important to reduce distractions and potential surveillance anxiety among office workers, and foster better productivity and mental health.

Stage 2: The Master Node/Bridge Node

**Next, we evaluate what we need to build the master/bridge node to which the environmental sensing nodes described in Stage 1 connect for real time communication. We will explore which components are likely needed, take a look at technical specifications of those parts and evaluate the cost of the master/bridge node.

1. Hardware

Here, we evaluate what hardware would be needed for the master node.

- Main system: Arduino Portenta X8 or Raspberry Pi 5 (base spec + Micro SD Card and 27W Power supply) or Arduino Portenta H7 or ESP32
- Optionally a display: SSD1351 or other (unless the master node is run in a web server configuration)
- Ethernet interface (Portenta X8/H7 only, already present on RPI5): Portenta Vision Shield - Ethernet
- Storage: Raspberry Pi SSD Kit (256 GiB) or Portenta Max Carrier (includes Ethernet, eliminates need for Portenta vision shield) + mass storage media
- RFM95w LoRa transceiver

Further Hardware considerations

The choice of the right core system and overall necessity of this system should be thoroughly evaluates, since this system is meant to receive data from the environmental Sensing Nodes and aggregate it. An existing server system may also be used, but would necessitate a bridge node that can pass the information from the nodes discussed in Stage 1 to the existing server system. It is not recommended to use an ESP32 due to its more rapid prototyping focus and exclusive support for BLE and WiFi, the latter of which is considered too unreliable for mission critical data transfer. Additionally it is worth considering using LoRa for better reliability, better range and performance.

2. Hardware Characteristics

Here, we take a look at Hardware specs of the hardware listed above.

- Core System:
  - Arduino Portenta X8:
    - See Arduino Portenta X8 Datasheet
  - Raspberry Pi 5:
    - 2.4 GHz Quad-core Arm Cortex A76 CPU (64 bit)
    - Dual-band 802.11ac WiFi support
    - Bluetooth 5.0/BLE
  - Arduino Portenta H7:

The Arduino Portenta H7 is based on the STM32H747 microcontroller, XI series.

Microcontroller	STM32H747XI dual Cortex®-M7+M4 32bit low power Arm® MCU (datasheet)
Radio module	Murata 1DX dual WiFi 802.11b/g/n 65 Mbps and Bluetooth® (Bluetooth® Low Energy. 5 via Cordio stack, Bluetooth® Low Energy 4.2 via Arduino Stack) (datasheet)
Secure Element (default)	NXP SE0502 (datasheet)
Board Power Supply (USB/VIN)	5V
Supported Battery	Li-Po Single Cell, 3.7V, 700mAh Minimum (integrated charger)
Circuit Operating Voltage	3.3V
Display Connector	MIPI DSI host & MIPI D-PHY to interface with low-pin count large display
GPU	Chrom-ART graphical hardware Accelerator™
Timers	22x timers and watchdogs
UART	4x ports (2 with flow control)
Ethernet PHY	10 / 100 Mbps (through expansion port only)
SD Card	Interface for SD Card connector (through expansion port only)
Operational Temperature	-40 °C to +85 °C
MKR Headers	Use any of the existing industrial MKR shields on it
High-density Connectors	Two 80 pin connectors will expose all of the board's peripherals to other devices
Camera Interface	8-bit, up to 80 MHz
ADC	3× ADCs with 16-bit max. resolution (up to 36 channels, up to 3.6 MSPS)
DAC	2× 12-bit DAC (1 MHz) available, only one is accessible by the user through the external A6 pin
USB-C	Host / Device, DisplayPort out, High / Full Speed, Power delivery

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    - ESP32 See Hardware Characteristics in Stage 1 (Not recommended)
- Display (Optional):
    - See Hardware Characteristics in Stage 1
- Communication Module (only for Arduino Portenta, Raspberry Pi has on-board Ethernet)
    - Portenta Vision Shield - Ethernet:
        - Includes a camera and Microphone, Can be omitted in code

- Portenta Max Carrier

Connectors	• High-Density connectors compatible with Portenta products • 2x USB-A female connectors • 1x Gigabit Ethernet connector (RJ45) • 1x FD-Can on RJ11 • 1x mPCIe • 1x Serial RS232/422/485 on RJ12
Audio	• 3x audio jacks: stereo line-in/line-out, mic-in • Speaker connector
Memory	• Micro SD
Wireless modules	• Murata CMWX1ZZABZ-078 LoRa® • SARA-R412M-02B (Cat.M1/NB-IoT)
Operating temperatures	• -40 °C to +85 °C (-40° F to 185 °F)
Dimensions	• 101.60 mm x 101.60 mm (4.0 in x 4.0 in)
Debugging	• Onboard JLink OB / Blackmagic probe
Power/Battery	• Power Jack for external supply (6-36V) • On-board 18650 Li-ion battery connector with battery charger (3.7V)

- Storage: (Portenta Max Carrier has that covered for the Portenta family)
  - Raspberry Pi SSD Kit:
    - Includes 256 GiB M.2 NVMe SSD
    - Has GPIO pass through
    - 16mm Stacking header
- RFM95w LoRa transceiver
  - Frequency range: 868 - 915 MHz

- Connection: SPI
- supports wire antennas and uFL or SMA ports (must be soldered on separately)
- Range: Up to 2 km
- variable output power (+5 - +20 dBm up to 100 mW)

3. Cost Analysis

In this part, we take a look at the cost of the Master/Bridge node, and its components. all prices include VAT, exclude shipping cost

- Arduino Portenta X8: 223.00 €
- Arduino Portenta H7: 120.80 €
- Raspberry Pi 5 (Base spec: 4 GiB RAM): 62.90 €
- Portenta Vision Shield - Ethernet: 55.00 € (Vision Shield - LoRa: ~65.80 €)
- Portenta Max Carrier: 340.00 €
- Raspberry Pi SSD Kit: 44.90 €
- RFM95w LoRa transceiver: 21.95 €

Configurations

- Portenta X8 + Portenta Max Shield (web server configuration): **563.00 €**
- Portenta X8 + Vision Shield - Ethernet (BLE/WiFi to Ethernet bridge): **278.00 €**
- Portenta X8 + Vision Shield - Ethernet + RFM95 (LoRa to Ethernet bridge): **299.95 €**
- Raspberry Pi + SSD kit (web server configuration): **107.80 €**
- Raspberry Pi + SSD kit + RFM95 (web server configuration): **129.75 €**
- Portenta H7 + Vision Shield - Ethernet (BLE/WiFi to Ethernet bridge): **175.80 €**
- Portenta H7 + Vision Shield - Ethernet + RFM95 (LoRa to Ethernet bridge): **197.75 €**

Maintenance Considerations

In terms of maintenance, the configurations listed above all generally have rather low maintenance needs, however the type of maintenance would be different depending on the configuration. The BLE/WiFi or LoRa to Ethernet bridges have minimum maintenance needs, since they only act as a simple relay between the Environmental Sensing Node(s) and the Data Aggregation Server (assumed already present), therefore virtually no additional maintenance needs would be added. On the other hand, the web server configurations may add a bit more maintenance needs in form of up-time assurance, but also rather minimal, beyond potential system updates.

Choice of Configuration

It is recommended to choose the BLE/WiFi or LoRa to Ethernet bridge configurations, if existing server infrastructure will be used for data aggregation and visualization. If a standalone Master Node with web server capabilities is preferred, the web server configurations are recommended. It is generally recommended to use BLE or LoRa for better reliability, especially if the WiFi connection in the environment is known to be less than optimal. The BLE/WiFi or LoRa to Ethernet bridge configuration based on the Arduino Portenta H7 is the most cost effective if existing server infrastructure is used for data processing. Otherwise, the Raspberry Pi-based web server configuration is more cost effective (and most cost effective overall).

4. Additional Considerations

One downside of BLE is that it only supports up to 8 simultaneous incoming connections in BLE Central mode. It's worth considering using multiple BLE/WiFi bridge nodes to support more than 8 environmental Sensing Nodes. another option is using LoRa, especially due to its range, efficiency and better security, if LoRaWan is implemented on the micro controller via its firmware. However, using multiple BLE/WiFi to Ethernet bridges would also come with the benefit of spreading workload across multiple nodes, reducing strain on the individual Bridges, even if data is only sent every 30 - 60 minutes as key data points. A trade off with LoRa would be the requirement to send sensor data in a staggered manner, which, however is not of real concern, since data variation is unlikely to be large enough to affect accuracy.

Additional Overall Considerations

Power Delivery

The power delivery for both the Environmental Sensing Nodes and Master/Bridge Nodes would generally rely on mains power through small power bricks, similar to phone chargers. However, when considering the potential for a power outage, which may compromise the system, cause data loss or even damage components, adding a backup battery (continuously charged by the main power source) could be added in the future, to give the Environmental Monitoring System transitional power to safely shut down.

Data Security

Here, several options are available:

- MAC Address Obfuscation
- Use a custom service UUID
- Pairing and Bonding with encryption
- Use a Whitelist on the Master/Bridge Node (Central)
  These options improve communication security and prevent unauthorized devices from connecting, preventing potential Man in the Middle attacks or other kinds of

eavesdropping or injecting bad data.
If LoRa is used, LoRaWAN should be implemented in the firmware through libraries like LMiC, LoRaMAC-node or RadioLib, alongside the libraries for the RFM95w.

Maintenance (updates)

To push updates, the Master Nodes (in case of BLE/WiFi or LoRa bridges, that would be the server connected to it) would be used to distribute the firmware updates to all sensing nodes and/or BLE/WiFi or LoRa bridges, depending for which of them the firmware update is intended.