Large-scale EXecution for Industry & Society

Deliverable D7.7

Field Deployment of a Smart Gateway for collecting, pre-processing and transmitting in-situ observations

Co-funded by the Horizon 2020 Framework Programme of the European Union
Grant Agreement Number 825532
ICT-11-2018-2019 (IA - Innovation Action)

DELIVERABLE ID | TITLE	D7.7 | Field deployment of a Smart Gateway for collecting, pre-processing and transmitting in-situ observations
RESPONSIBLE AUTHOR	Marco Ferretti (TESEO)
WORKPACKAGE ID | TITLE	WP7 | Weather and Climate Large-scale Pilot
WORKPACKAGE LEADER	CIMA
DATE OF DELIVERY (CONTRACTUAL)	31/05/2021 (M29)
DATE OF DELIVERY (SUBMITTED)	30/06/2021 (M30)
VERSION | STATUS	V1.0 |Final
TYPE OF DELIVERABLE	DEM (Demonstrator)
DISSEMINATION LEVEL	PU (Public)
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DOCUMENT VERSION

VERSION	MODIFICATION(S)	DATE	AUTHOR(S)
0.1	Table of contents	13/05/2021	Marco Ferretti (TESEO); Paolo Ferretti (TESEO)
0.2	Deliverable drafting	28/05/2021	Marco Ferretti (TESEO); Paolo Ferretti (TESEO)
0.3	Refinements	04/06/2021	Marco Ferretti (TESEO); Paolo Ferretti (TESEO)
0.4	Review of the deliverable	18/06/2021	Antonio Parodi (CIMA); Alberto Scionti (LINKS)
0.5	Update according to the reviewers´ comments	21/06/2021	Marco Ferretti (TESEO); Paolo Ferretti (TESEO)
0.6	Review of the deliverable	28/06/2021	Martin Golasowski (IT4I)
0.7	Update according to the reviewer´s comments	29/06/2021	Marco Ferretti (TESEO)
1.0	Final check of the deliverable	30/06/2021	Katerina Slaninova (IT4I)

GLOSSARY

ACRONYM	DESCRIPTION
ADC	Analog-To-Digital Converter
API	Application Program Interface
ARM	Advanced RISC Machines
BSEC	Bosch Sensortec Environmental Cluster library
CMSIS	Cortex Microcontroller Software Interface Standard
COTS	Commercial Off The Shelf
DAQ - NI	Data Acquisition (DAQ) - NI - National Instruments
CORTEX	ARM processor core type
EMC	Electro Magnetic Compatibility
ROM	Read only memory
FIX	GPS position acquired
FLASH	Non-volatile computer memory
(E)GPRS	(Enhanced) General Packet Radio Service
GSM	Global System for Mobile communications
IC	Integrated Circuit
I2C	Inter-Integrated Circuit
IAQ	Internal Air Quality
IoT	Internet Of Things
JSON	JavaScript Object Notation
LPWA	Low Power Wire Area network
LTE	Long Term Evolution
LVTTL	Low Voltage Transistor-Transistor Logic
MCU	Main Core Unit
MQTT	MQ Telemetry Transport
NMEA	National Marine Electronics Association
PCB	Printed Circuit Board
PWM	Pulse Width Modulation
RAM	Random Access Memory
RTOS	Real Time Operating System
SPI	Serial Peripheral Interface

TCP/IP	Transmission Control Protocol / Internet Protocol
UART	Universal Asynchronous Receiver Transmitter
VOC	Volatile Organic Compound
WCDA	Weather and Climate Data API
WMO	World Meteorological Organization
XML	Full extensible markup language

TABLE OF PARTNERS

ACRONYM	PARTNER
Avio Aero	GE AVIO SRL
Atos	BULL SAS
AWI	ALFRED WEGENER INSTITUT HELMHOLTZ ZENTRUM FUR POLAR UND MEERESFORSCHUNG
BLABS	BAYNCORE LABS LIMITED
CEA	COMMISSARIAT A L ENERGIE ATOMIQUE ET AUX ENERGIES ALTERNATIVES
CIMA	CENTRO INTERNAZIONALE IN MONITORAGGIO AMBIENTALE - FONDAZIONE CIMA
CYC	CYCLOPS LABS GMBH
ECMWF	EUROPEAN CENTRE FOR MEDIUM-RANGE WEATHER FORECASTS
EURAXENT	MARC DERQUENNES
GFZ	HELMHOLTZ ZENTRUM POTSDAM DEUTSCHESGEOFORSCHUNGSZENTRUM GFZ
ICHEC	NATIONAL UNIVERSITY OF IRELAND GALWAY / Irish Centre for High-End Computing
IT4I	VYSOKA SKOLA BANSKA - TECHNICKA UNIVERZITA OSTRAVA / IT4Innovations National Supercomputing Centre
ITHACA	ASSOCIAZIONE ITHACA
LINKS	FONDAZIONE LINKS / ISTITUTO SUPERIORE MARIO BOELLA ISMB
LRZ	BAYERISCHE AKADEMIE DER WISSENSCHAFTEN / Leibniz Rechenzentrum der BAdW
NUM	NUMTECH
O24	OUTPOST 24 FRANCE
TESEO	TESEO SPA TECNOLOGIE E SISTEMI ELETTRONICI ED OTTICI

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EXECUTIVE SUMMARY

This report depends primarily upon the workflows defined by the Weather and Climate Large-scale Pilot (WP7) and collects the outcomes of its predecessors, specifically Deliverable D7.3 [1] that has drawn the basics of the design of a weather station relying on an IoT-to-HPC architecture.

This deliverable shows how the design of such equipment was turned into a scalable, engineered, and industrialized unit deployed on the field and ready to be launched on the market, where the prescribed physical quantities are collected by the sensors, pre-processed by gateway, and fed to the HPC.

Position of the deliverable in the whole project context

This document is the final part of Task 7.3 which is the third task in WP7 Weather and Climate Large-scale Pilot. The Smart Gateway, together with sensor nodes, demonstrate the improvement over conventional observation and the enhancement of the predictive capability of HPC executed regional weather models.

In such context, Deliverable D7.7 is the release and deployment of a test-bed performing meteorological observations and feeding the HPC with pre-processed data. Thanks to such features, future uses of the Smart Gateway and its related Weather Sensors Node will be part of the exploitation plan within the Deliverable D9.10 entitled "Impact KPI and metrics achievement report and plan" [2] due in M36. For this reason, the demonstrator and its key-parts have been engineered to be easily adapted to future uses thanks to flexibility and scalability.

Furthermore, to better demonstrate the flexibility and market readiness of the Smart Gateway, actions have been taken in the Open Call framework making it available to those participants needing to feed the HPC with data collected by sensor nodes. In progress actions were taken to harmonize the Smart Gateway design, its form-factor, and the destination of the data flow.

Description of the deliverable

This deliverable first reports how the outcomes of Deliverable D7.3 [1] were translated into an easy manufacturable and deployable unit. For this purpose, the IoT distinctive functional blocks of the Smart Gateway and of the Weather Sensors Node were combined to achieve an efficient layout, allowing rugged construction for a long-lasting operation.

Section 2 also illustrates how the Smart Gateway was engineered for both of the purposes mentioned above: a front-door to the HPC for the meteorological observations on one side, and on the other for the "connected things" eventually involved in the use-cases proposed by the Open Call participants.

The report then enters the details of the electronic design of the Smart Gateway and of the Weather Sensors Node. All electronic cards composing the system are extensively described and motivation for the key engineering and integration choices is given.

The deliverable then focuses on the firmware implementation of the on-board processors: details are given on the operating system, hardware management libraries and main application.

Despite the primary importance of above mentioned topics, the pillar of the Weather Station is in the dataset (as a conjunction point between a data acquisition unit and the HPC infrastructure) and in the communication with the Lexis Platform that is the brand new feature developed since Deliverable D7.3 [1]. Extensive description is given for all sensors and devices, how data is collected, validated, pre-processed, and fed to the Lexis infrastructure.

This report ends with the main validation tests and with the installation of the demonstrators at TESEO and at CIMA premises.

1 INTRODUCTION

The outcomes of Deliverable D7.3 [1] provided the focus on how IoTs have become key assets in several sectors and how the IoT gateways play the role of powerful devices that link the sensors acquiring physical magnitudes to the cloud/HPC infrastructure in a computing continuum.

Despite the engineering effort was mostly dedicated to the gateway, because of the centrality of its role into the IoT ecosystem, it was considered more exhaustive to treat the mechanical layout first.

Section 2 shows how the Gateway+Node IoT architecture was shaped into a weather station, where mechanical layout has been planned and executed, where the functional blocks have been assigned to a given electronic card and where the deployable unit has been finally assembled.

In parallel, Section 2 also reports engineering of the Smart Gateway as a stand-alone unit dedicated to the Open Call participants.

Section 3 goes deep into the description of the electronic design of the cards composing the unit. The selection of the main components and integrated modules is presented and motivated and hints are given on their implementation on each of the electronic boards. Several peripherals, interface utilities and subsystems were implemented to allow flexible and scalable set-ups. For this reason, it is important to focus on some extra features that push the Smart Gateway beyond the IoT context. With this arrangement, not only the Smart Gateway will collect from the nodes and pre-process the data prescribed by a given use case, but also carries on-board a set of its own sensors to contribute to the Data Lake concept. This additional data may be of a minor interest for "that" use case, but once pushed into a structured database, it may contribute to useful information after further and specific processing.

Section 4 provides an overview of the software running on the on-board processors. The section illustrates how the hardware is abstracted through the low level libraries, how tasks are managed thanks to a real-time Free RTOS and how the main application behaves.

Furthermore, Section 5 provides a deep focus on data acquisition and pre-processing, that is the unifying trait between the Smart Gateway and the Cloud infrastructure. Additionally, this section gives details, constraints and working parameters for both on-board sensors and off-board devices that collect the physical magnitudes. Finally, the section retraces the principles of the device monitoring and data validation.

Section 6 illustrates the last step of the data-flow into the IoT ecosystem. Specifically, the section highlights the network communication structure, data formatting and subsequent submission. It is worth to notice that making available the Smart Gateway to the Open Calls participants, made this unit strictly adhere to the IoT definition presented in Deliverable D7.3 [1]. Indeed, instead of being just a Weather Station that generates specialized data for a specific cloud infrastructure, the Smart Gateway's design turned into a device that provides a multitude of unspecialised data to a multi-purpose platform like LEXIS is. The data will be retrieved at the Cloud level and specialized into useful information after being processed by dedicated Analytics.

Section 7 of this deliverable briefly describes the testing that was made on the units before their deployment. A hardware-in the loop test bench was made to validate the acquisition from the wind and rain sensors, while the temperature sensor readings were validated in a climatic chamber together with a reference instrument. The climatic chamber test was also useful to determine the temperature range for the assembled unit to perform correctly. On the dataset side, a web based dashboard was set in place to view the data from the equipment and to monitor the functionality of the devices.

Finally, the last Section 8 describes proof of concept deployment of the first two units: one at TESEO premises in Druento, Italy; the second at CIMA Premises in Savona, Italy.

2 ARCHITECTURE AND GENERAL LAYOUT

This section describes how the IoT concept of Smart Gateway and Weather Sensor Node was shaped into a deployable market ready device.

In order to fulfil the requirements of the WP7 use-case and despite the wide spread of applications the Smart-Gateway was foreseen for, the Weather and Climate demonstrator (hereafter, Weather Station) was engineered in a monolithic assembly consisting of the Gateway and of a single node carrying all the sensors needed to acquire the magnitudes of interest.

This configuration balances the flexibility and scalability of the system at manufacturing level, together with a straightforward installation convenience. Also, when it comes to turn a high-level design into an engineered device, it is of primary importance to keep the unit as simple as required by the use-case in order to grant robustness, to minimize engineering and manufacturing risks and to make the commissioning easy.

Furthermore, the above mentioned simplicity plays a great role in terms of power consumption of the unit. To make real and efficient ultra-low-power devices, it is true that power management within the unit is a key factor; nevertheless, minimizing the components count and sub-systems count still is a winning strategy.

Within the overall project context and following up to the evolution of the dissemination tasks into WP9, the Smart Gateway has been introduced into the Open Call program as the Lexis front-door for deep-edge devices and for third-party sensor nodes. Although this strand of application was not initially foreseen, the Smart-Gateway is perfectly at ease in this context because of its architecture and because of some implementation choices that were made during the work progress and that are detailed further in this report.

2.1 IOT SMART GATEWAY AS A WEATHER STATION

The IoT concept applied to the WP7 use-case has been synthesized in a single-gateway/single-node architecture as depicted in Figure 1.

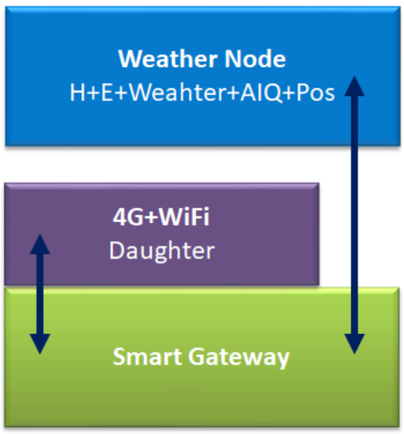

Figure 1 - Weather and Climate demonstrator architecture

The figure shows the gateway and the “weather node” together with a 4G+WiFi daughter board that is part of the gateway, but it was split in order to rationalize the mechanical arrangement because of the onboard antennas. Eventually, the daughterboard can be omitted in case the gateway is ethernet connected.

Within the high-level block diagram of Figure 1, each block is detailed in the following sections:

- Smart Gateway main board - Section 3.1,
- Wireless 4G+Wi-Fi daughter board - Section 3.2,
- Weather Sensor Node - Section 3.3.

Hereafter details are given on the general layout and mechanical arrangement of the weather station integrating the gateway, the wireless board, and the weather node.

Layout planning and preliminary engineering choices

Since the WP7 use case required the equipment to behave as a weather station, the unit was engineered to behave so from the very beginning. The challenge was to become to a rugged outdoor device, easy to install, easy to deploy and easy to service in case of malfunction, keeping in mind that installation may not be carried out by trained personnel.

Additionally, the design needed to be scalable, flexible, opened to further developments and able to fulfil the future exploitation that is part of the plan delivered with the Deliverable D9.10 Impact KPI and metrics achievement report plan - final version M36 [2].

A "sandwich" mechanical arrangement was adopted since it allows to be scaled-up easily. The gateway is always the pillar of such arrangement and it is located on the bottom of the assembly because of the need to access to the wired part of the system (power supply input, RJ45 Ethernet cable, RS485 serial link, etc.).

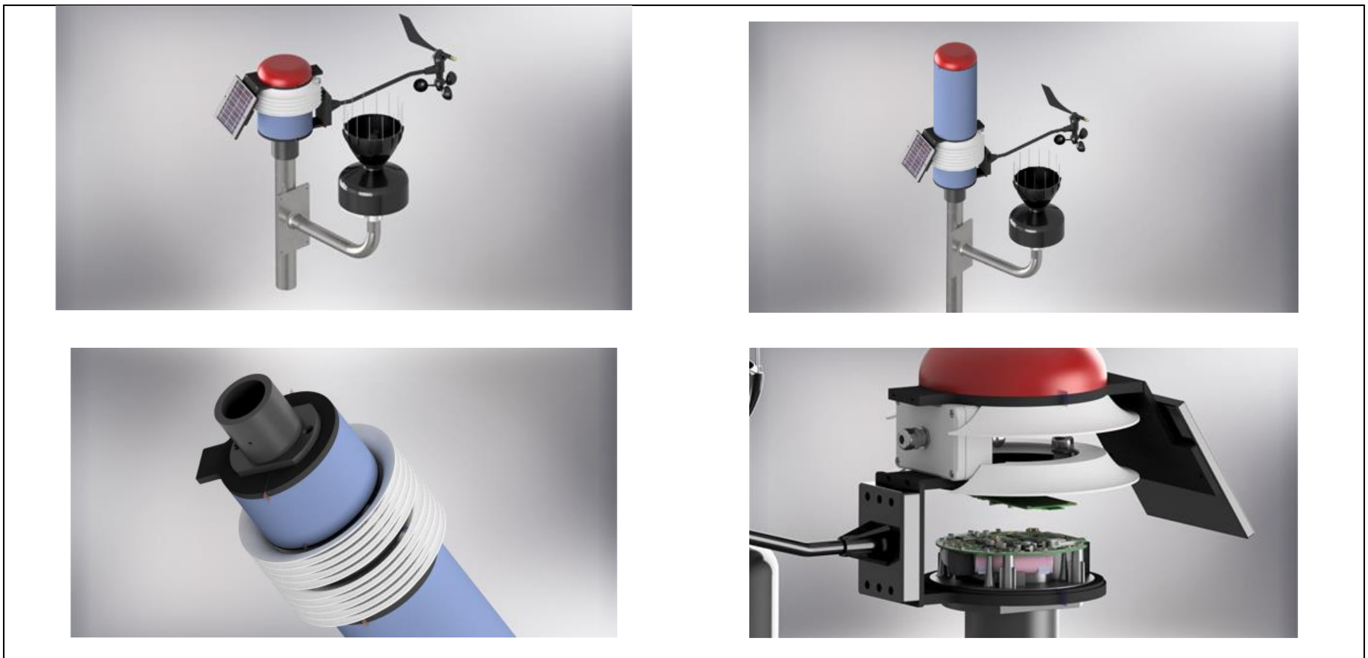

Figure 2 - Preliminary engineering weather station drafts

Such arrangement allows for a pole mount on the bottom to stack-up the sensor node modules, according to the application. Clearly, the weather station will just have the Weather Node on top and all mounts and inputs from the third party wind direction/speed sensor and rain-gauge.

Sensor or nodes that are listed as "nice to have" will be eventually added as additional layers.

Finally, the design is arranged in "dry compartments" for all those parts of the unit that need to be protected from the elements, and in "wet compartments" (see Figure 3). This is the case of temperature, pressure, humidity and in general all sensors that need to be exposed to free air. Conversely, the dry compartments will house like electric and magnetic fields probes and in general all those sensors that do not need to be exposed to free air.

Wet and dry compartments can be superposed and/or alternated according to the requirements of the finished unit.

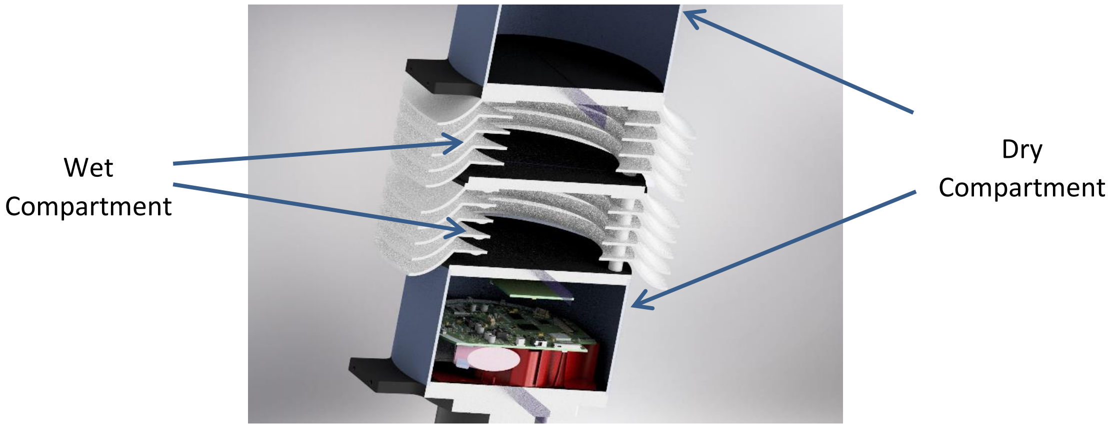

Figure 3 - Wet and dry compartments

It is worth to mention that all design stages were carried out to come to a TRL8/9 fully engineered product ready to be mass manufactured. Specifically, all mechanical parts have been designed to be easily machined and/or injection moulded.

Final layout

Figure 4 shows the exploded view of the final layout. From bottom to top, the part labelled (15) is the mast mount that holds all the rest of the assembly and gives access to the connector hatch on the bottom of the unit.

(3) is the Smart Gateway main board and (5) is the 4G-Wi-Fi card that can eventually be omitted if wireless interfaces are not needed. Both Gateway and 4G-Wi-Fi card belong into a dry compartment. Stepping up, the plate (11) isolates the bottom dry compartment from the upper wet compartment where the environmental sensor is exposed to the air. The discs (6) have been designed with a specific profile that allow the air to freely flow and do not allow the rain to get inside, even in case of strong winds.

The marketplace sealed enclosure on position (17) contains the sensor node card. Because the gateway and the node rest in the same assembly, a wired connection was chosen to allow data sharing between the two MCUs. Additionally, the sensor node gets power directly from the Gateway.

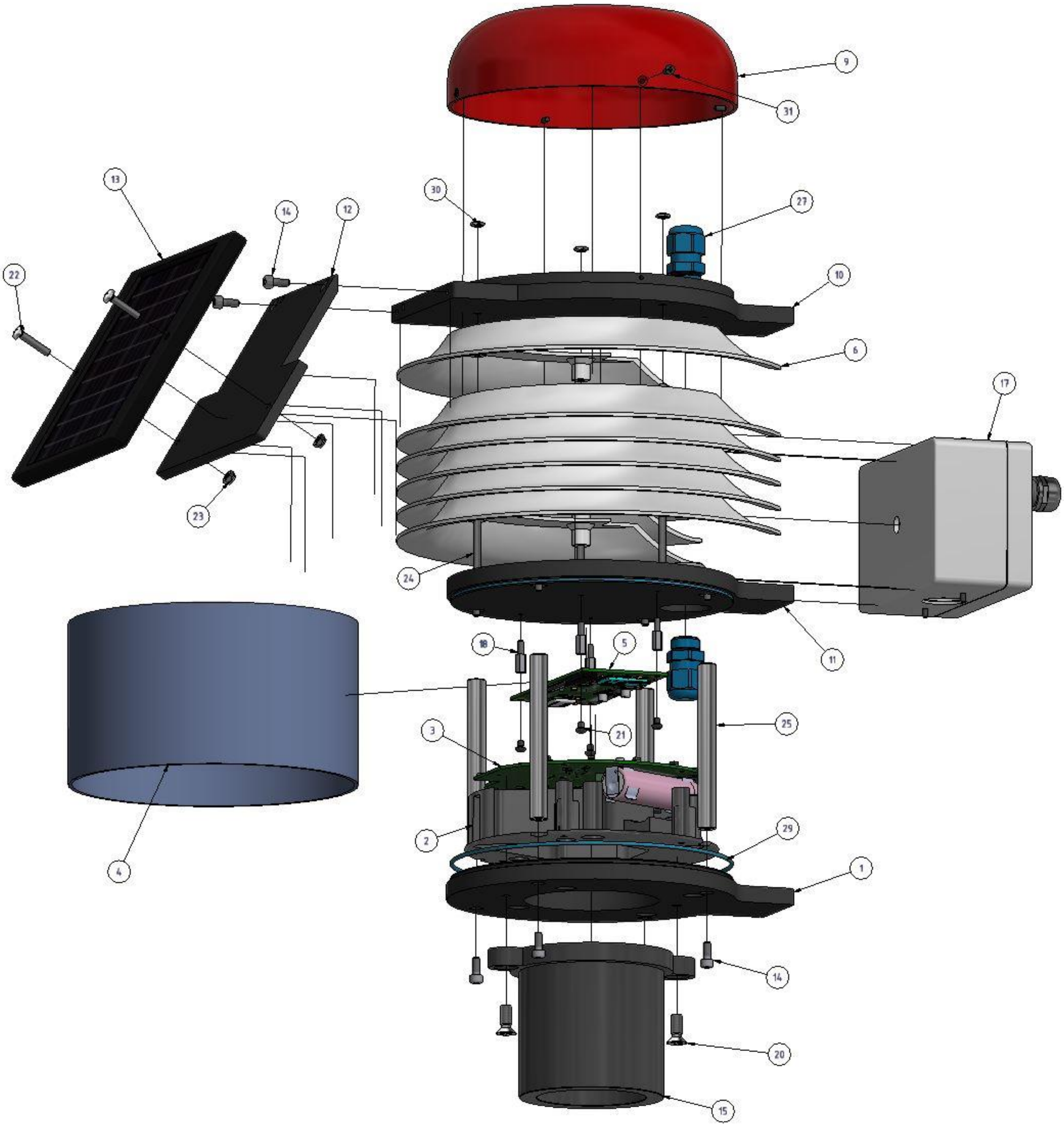

Figure 4 - Weather station exploded view

The plate on position (10) isolates the mid wet compartment from the dry upper compartment that is not used in this particular application. A cap (9) is installed on top of the assembly.

In case a wired low voltage power supply is not available on site, the unit is ready for a solar panel (13) together with its mounting hardware. If any of the above is available, but the mains is, a COTS AC/DC converter can be foreseen as an external module.

Figure 5 - Assembly details

Figure 5 gives a better detail of the mechanical arrangement. Below the cap, in the wet compartment, the sensor node card is highlighted together with the environmental sensor and GPS patch antenna.

On the bottom, in the dry compartment, the Smart Gateway is clearly visible.

The electronic boards were engineered to the above mentioned layout.

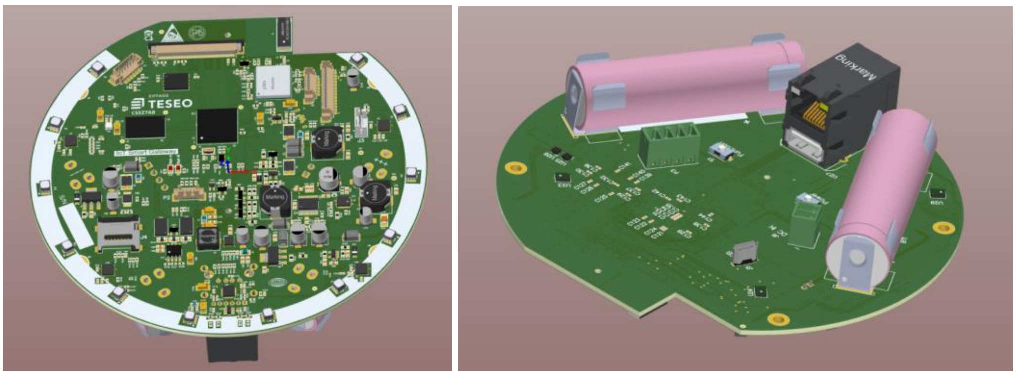

Figure 6 - Smart Gateway top and bottom views

The Smart Gateway main board was designed in a round shape to be accommodated on the bottom of the unit (see Figure 6).

On the top-side of the main board, the power management and battery charger take the most of the available space. Although all details of the circuit design will be given in Section 3.1, it is interesting to notice the STM32 MCU, the DRAM, the LoRa module together with its embedded antenna, and the uSD card. On the bottom side, the two LIon batteries, the Ethernet connector, the power connector, the USB plug and the RS485 header are clearly visible. All connectors are accessible from the hatch on the bottom of the unit.

Figure 7 - 4G/Wi-Fi Daughterboard

It was found to be convenient to implement the wireless features of the Gateway on a separated electronic card (see Figure 7), except for the LoRa. This arrangement was chosen in order to optimize the radiating pattern of Lora, 4G and Wi-Fi antennas such that they do not influence each other. Eventually, because 4G and Wi-Fi are on a separate board, this can be omitted in case the gateway pushes its data through the Ethernet port, saving on both costs and power. Conversely, the LoRa module belongs on the Gateway main board because its purpose is to establish long range, low power communication to other wireless sensor nodes.

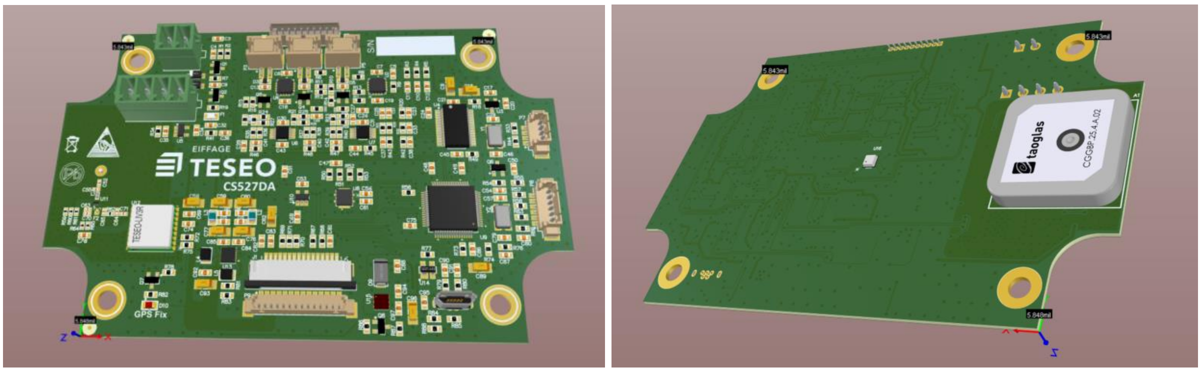

Figure 8 - Weather node card, top and bottom view.

The weather node card (see Figure 8) is designed to be installed in the plastic box shown in Figure 10. Although it is wired to the Gateway, the Weather Node features an independent MCU that manages the local hardware and provides for the very first pre-processing and validation of the data coming from the sensor. The main air sensor is visible in the middle of the board on the bottom side. It is an integrated component from Bosch Sensortech that measures most of the magnitudes of interest (details are given in Sections 5.2-5.5). Always on the bottom side, the GPS patch antenna is found on the right side of the figure. On top-left side of the picture, the headers for the rain gauge and wind sensor are visible.

Because of the many resources available in the weather node MCU, and because of the space on the board, all conditioning electronics and circuits were foreseen to implement the Electric Field meter, that was one of the "nice to have" features listed in Deliverable D7.3 [1]. The debugging and consolidation of the electric field sensor is still a work-in progress. More details will be given further on in this report.

Demonstrator assembly

The assembly of the weather station starts with the installation of the Smart Gateway board on the bottom mounting plate (see Figure 9).

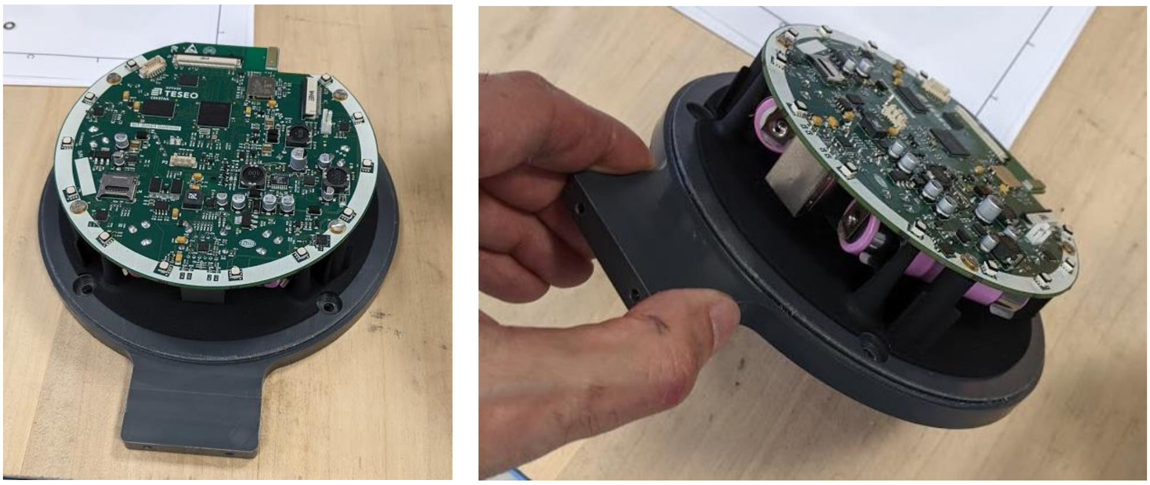

Figure 9 - Installing the Smart Gateway mainboard

The wet section is assembled as shown in Figure 10. The rings are held in place by three threaded pins and the sensor node box is installed in the cutaway. Notice the cone that exposes the sensor to the free airflow.

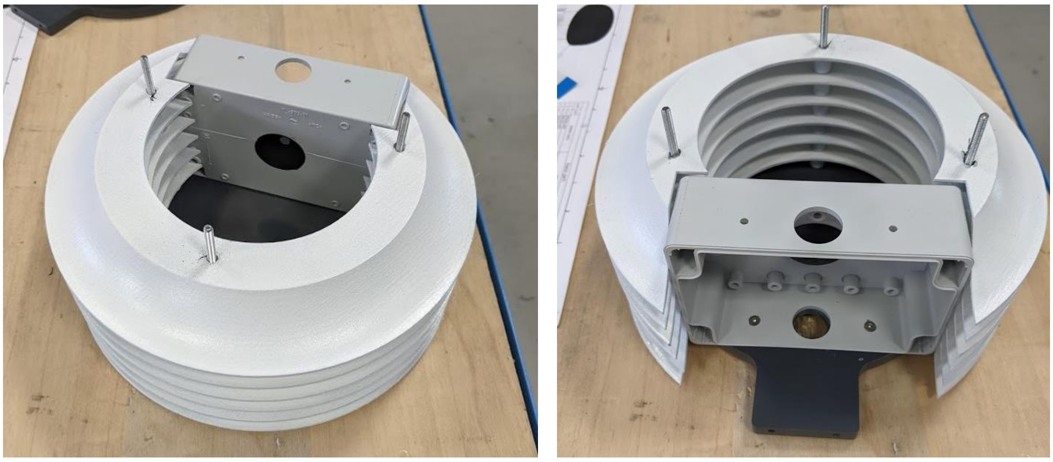

Figure 10 - Mounting the wet section of the unit

The weather node card is installed in its sealed box (see Figure 11) and the wireless card in the dry compartment plate (see Figure 12). Notice the flat-wire pigtails to connect the boards to the Smart Gateway.

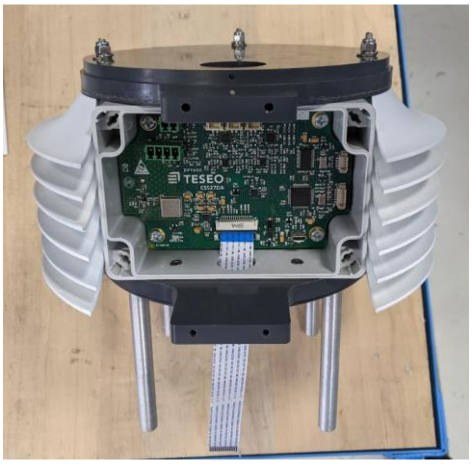

Figure 11 - Installing the weather node card

Figure 12 - Installing the wireless board

The unit is finally assembled (see Figure 13) and completed with the covering cap and mast mount (see Figure 14)

Figure 13 - Final assembly

Figure 14 - The finished unit on its mast

2.2 IOT SMART GATEWAY FOR THE LEXIS OPEN CALL

The Smart Gateway dedicated to the Open Call participants shares the very same main board and wireless card that was used in the weather station, but is housed in a desktop case (see Figure 15 to Figure 18)

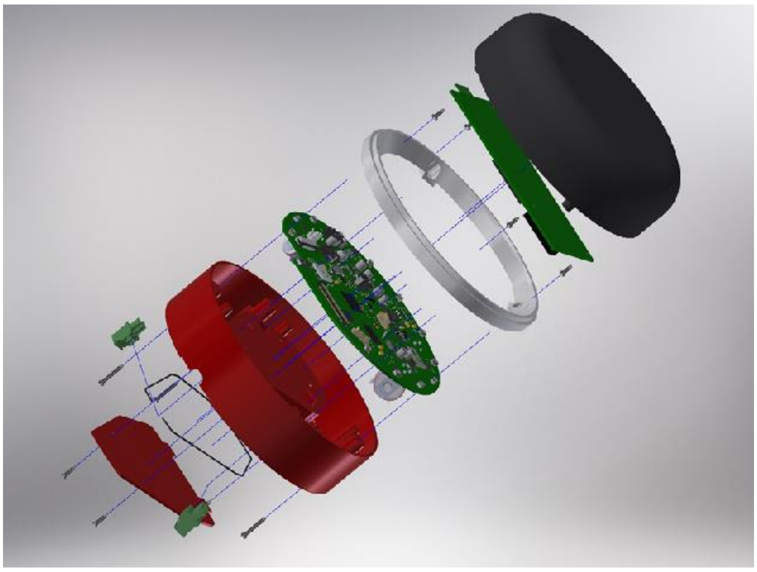

Figure 15 - Open Call desktop smart gateway exploded view

Figure 16 - Desktop assembly of the Smart Gateway

Notice the clear plastic annular ring. Its function is to connect the top-cover and the bottom of the case and to reflect the light from the LEDs that are installed on the perimeter of the board (see Figure 16). The annular ring allows the gateway to give visual information to the user about its status.

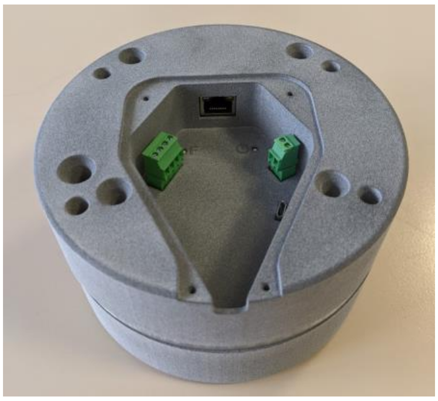

Figure 18 - The Open Call assembled Smart Gateway

Figure 17 - Connectors bottom hatch

3 HARDWARE IMPLEMENTATION

In this section, a detailed description of the Smart Gateway and of the weather node electronic boards are given. The key design choices will be reported, from the selection of the components to the circuit implementation and integration into mass-manufacturable cards.

3.1 SMART GATEWAY MAINBOARD

The block diagram in Figure 19 gives high-level overview for a better understanding of the Smart Gateway architecture.

In the middle of the figure, the STM32 Cortex-M7 MCU is the core of the overall system. The communication ports and facilities, both wired and wireless, are on the right side. From top to bottom: the LoRa long range wireless module, the 4G and Wi-Fi modules on the detached daughterboard, the Ethernet and USB ports and the USB-Device port. An RS485 half duplex balanced serial port with output power has been foreseen. This port may be very useful in all cases where a sensor node needs to push an uninterrupted stream of raw of data to the gateway on a copper link up to 500 meters. Finally, a serial port that is used for firmware and hardware debug purposes.

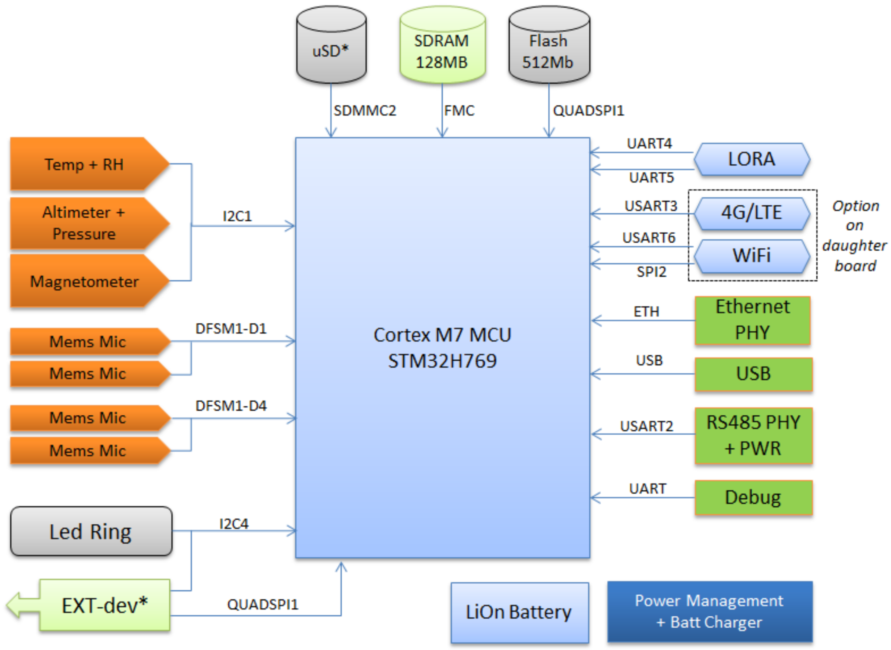

Figure 19 - IoT Smart Gateway Block Diagram

The memories are reported on the top of the Figure 19: 128MB of SDRAM were foreseen to support the computing power of the processor. The 512Mb of non volatile Flash EEPROM was foreseen to store parameters or look-up tables and finally, whenever needed, a microSD card is present as the system mass memory.

The left side of the block diagram shows the MEMS sensors that are fitted on-board the gateway as a standard. As said previously, these may contribute to the Data-Lake concept allowing to push to the cloud a set of heterogeneous data that shall be processed consequentially. The gateway implements temperature, humidity, ambient pressure, and a magnetometer. Additionally, a set of 4 microphones allows to make sound analysis of the environment (es. acoustical pollution). Furthermore, because the microphones are placed at the vertices of a square (i.e. in a known geometrical position), it is possible to perform sound tracking and to detect the direction of a given sound over a spheric cap.

Scrolling down on the left side of the block diagram, the led ring and its controllers is shown, and just below it, the “Ext-DEV” block indicates the connector carrying the facilities to connect additional equipment or integrated sensor nodes. This is the connector where the weather node is plugged to the gateway.

On the bottom of the figure, the power management blocks are shown. These consist of the main power supply, battery charger and housekeeping voltage regulators.

3.1.1 CORE PROCESSOR AND MEMORIES

The Smart Gateway leverages on the STM32H769 MCU [3]. This powerful SOC (System On Chip) consists of a high performance Arm Cortex-M7 32bit, 216Mhz CPU with 1M of Flash memory, DSP, FPU, L1 cache and SDRAM (see Figure 20).

Figure 20 - STM32H769 Cortex M7 MCU Block Diagram

The STM32H769 MCU is part of one of the most recent families of MCUs from ST Microelectronics based on the high performance ARM Cortex-M7 32 bit core operating at 216MHz clock. The Cortex-M7 core features a single floating point unit that supports all ARM single precision data processing instructions and data types. It also implements a full set of DSP instructions and a memory protection unit which enhances the application security. The device incorporates high speed embedded memories with a flash memory of 1 Mbyte, 320 Kbyte of SDRAM, including 64 Kbyte of Data TCM RAM for critical real-time data, 16 Kbyte of instruction TC RAM for critical real time routines, 4 Kbyte of backup SDRAM available in the lowest power mode, and an extensive range of enhanced I/O and peripherals. All of those previously mentioned are interconnected by APB/AHB buses, by a 32 bit multi-AHB bus matrix and by the multilayer AXI supporting internal and external memory access. The device also features three 12 bit analogue to digital converters, a low power real time clock, thirteen general purpose 16 bit timers including two PWM generator and one low power timer available in stop mode, two general purpose 32 bit timers, and finally a true random number generator. The MCU also integrates standard and advanced communication interfaces.

The STM32H769 comes in a compact TGBA216 package (Ball Grid Array, 216 balls, ball pitch 0.8mm).

To support the MCU and enhance the performance of the Smart Gateway, the board features an additional 64 Mbytes high speed CMOS SDRAM. The MT48LC4M32B2B from Micron is internally configured as a quad-bank DRAM with asynchronous interface. Each of four banks is organized in 4,096 rows by 256 columns by 32 bits.

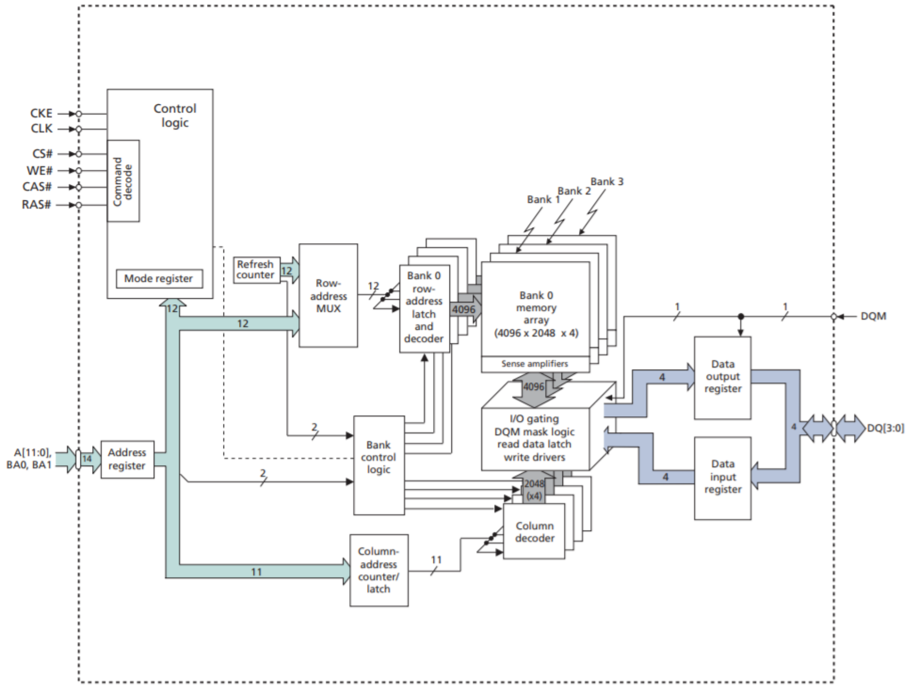

Figure 21 - MT48LC4M32B2B SDRAM Block Diagram

It is worth to notice that this particular component (SDRAM) was chosen because it fits the requirements of the FMC (Flexible Memory Controller) embedded into the STM32 MCU in terms of banks arrangement, row & columns size, interface bus and control signals that are wired to the main processor. The block diagram in Figure 21 shows the architecture of the MT48LC4M32B2B SDRAM.

As depicted on the top of Figure 19, the Smart Gateway carries a non volatile 512Mb Flash memory that is useful to store configuration data and/or system parameters. The component found to be the best choice is the MT25QL512ABB1EW9, again from Micron. This is a high performance multiple input/output serial Flash memory device. It features a high-speed SPI-compatible bus interface, execute-in-place (XIP) functionality, advanced write protection mechanisms and extended address access. Compared to other similar devices, the one that was chosen features an innovative dual and quad input/output command sets that double or quadruple data transfer rate for both read and write operations over the same SPI clock frequency. Figure 22 shows the block diagram of such Flash memory.

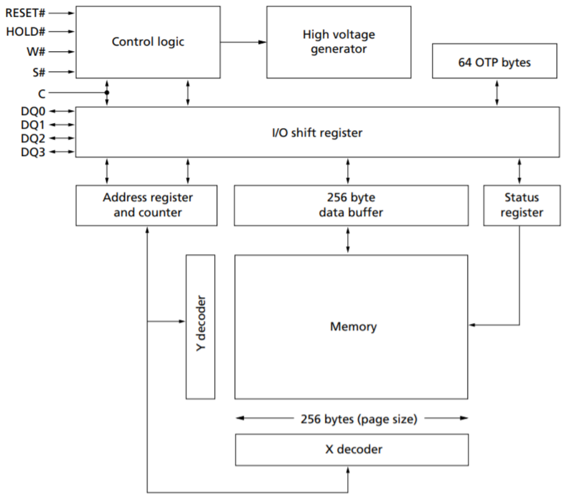

Figure 22 - MT25QL512ABB1EW9 Flash Block Diagram

The microSD card hardware implementation does not need any particular comment since it is just a card holder mounted on the circuit board and directly wired to the MCU in a 4 bits wide bus arrangement and where it is managed by the MCU's internal SD/MMC controller.

Figure 23 shows the portion of the Smart Gateway schematic diagram with the memories that were discussed so far.

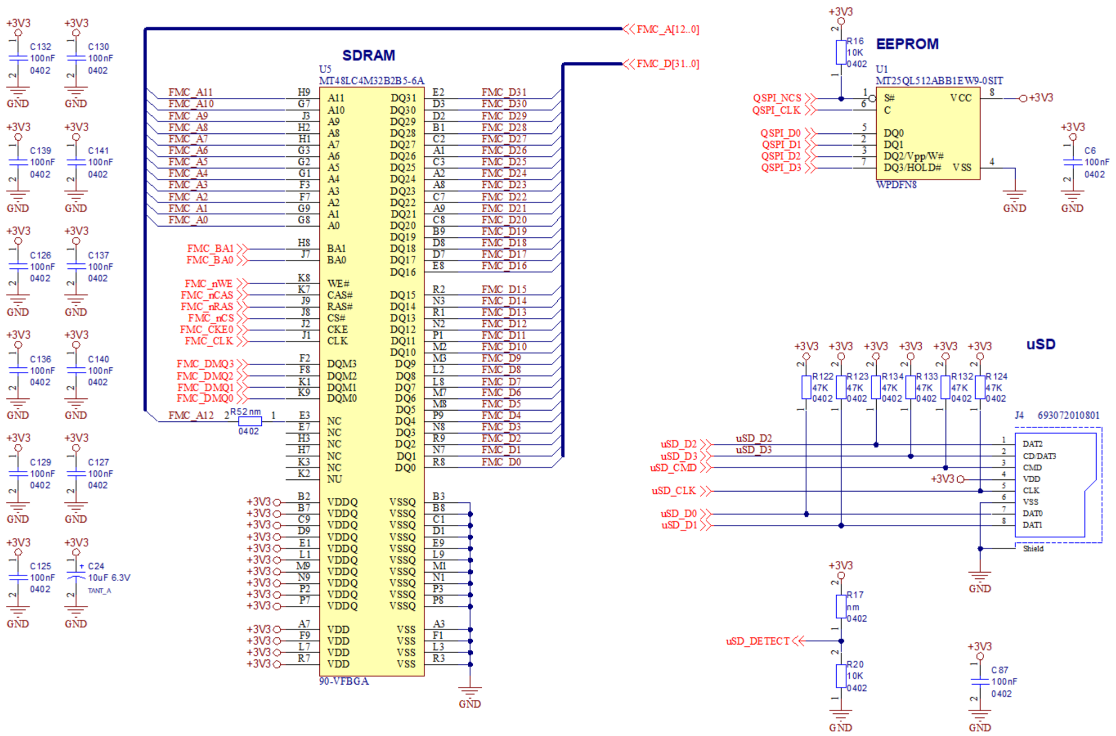

Figure 23 - Schematic portion of the Smart Gateway with SDRAM, Flash and uSD memories

Translating the abstract of a schematic diagram into a real-life circuit board was some kind of a challenge. Because of the multitude of 100 MHz signals between the MCU and the SDRAM, these two components were placed close to each other to minimize the track lengths and to avoid propagation delays or signal reflections. Additionally, because of the ball pitch arrangement of the MCU package, a 6 layer PCB stack-up was adopted: 4 layers were dedicated to signal routing and 2 layers were reserved for ground and power supply planes.

Figure 24 shows the position of the MCU, Flash and SDRAM on the Smart Gateway main board. Figure 25 highlights some of the complexity of the signal traces between the above mentioned components.

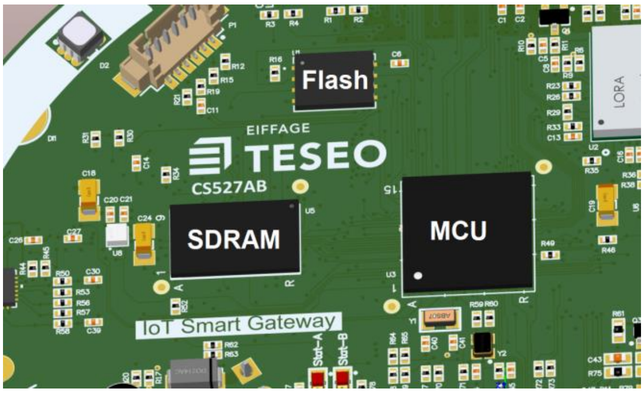

Figure 24 - MCU, Flash and SDRAM component placement

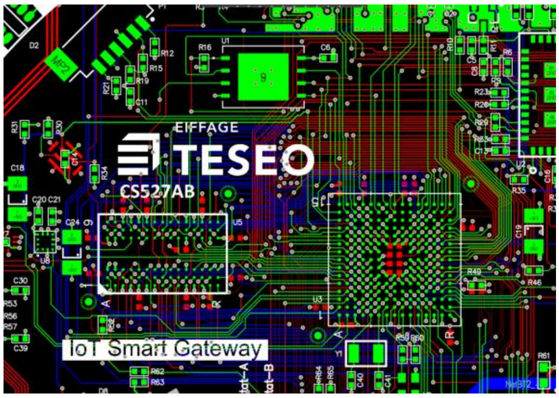

Figure 25 - MCU, Flash and SDRAM component routing

3.1.2 COMMUNICATION INTERFACES

Referring back to the right side of block diagram in Figure 19, because of its primary function as a bridge between the sensor nodes and cloud, the Smart Gateway features extensive communication capabilities in order to maximize its flexibility in any application environment.

Wi-Fi and cellular features are all belonging to the Smart Gateway, but they are implemented on a separated electronic card for the reasons that were previously mentioned. Further details are given in Section 3.2.

Here below, details are given on the communication interfaces that are physically implemented on the Smart Gateway main board.

LoRa Long Range wireless interface

The LoRa interface was chosen because it perfectly fits the communication needs to the sensor nodes in terms of very low power. Its low data rate (from 0.3 Kbits/s to 27 Kbits/s on a sub-GHz carrier spread spectrum modulation) is not a trade-off because in an IoT ecosystem the nodes need to push low quantity of data sporadically.

For the design convenience, an integrated module was selected. Specifically, the Smart Gateway implements the type ABZ LoRa module from Murata (see Figure 26). This device integrates an STM32L Cortex-M0 MCU, the STX1276 LoRa modem from Semtech and all radio frequency matching network and switches allowing a direct connection to the antenna.

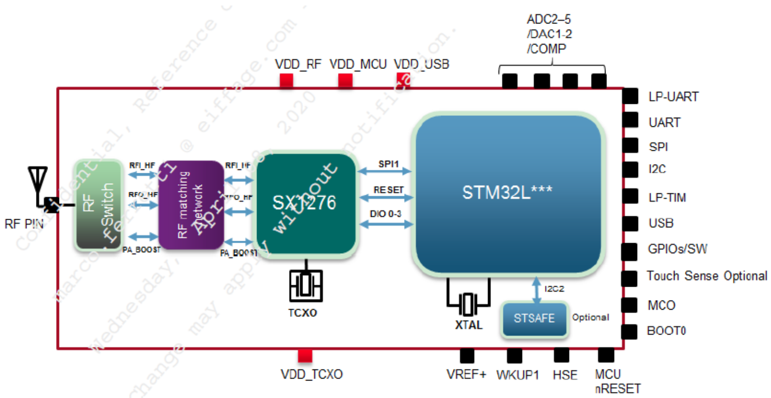

Figure 26 - Murata type ABZ LoRa module block diagram.

It is worth to mention that the Murata type ABZ module comes as a pre-programmed LoraWAN (LoRa Wide Area Network) device that needs to link to a LoRaWAN server. However, the manufacturer gives full access to the on-board Cortex-M0 host processor allowing to implement a proprietary communication stack leveraging on the native LoRa physical layer. For this reason, the implementation into the Smart Gateway (see Figure 27 and Figure 28) foresees a dedicated programming connector to download the proprietary stack into the ABZ LoRa module.

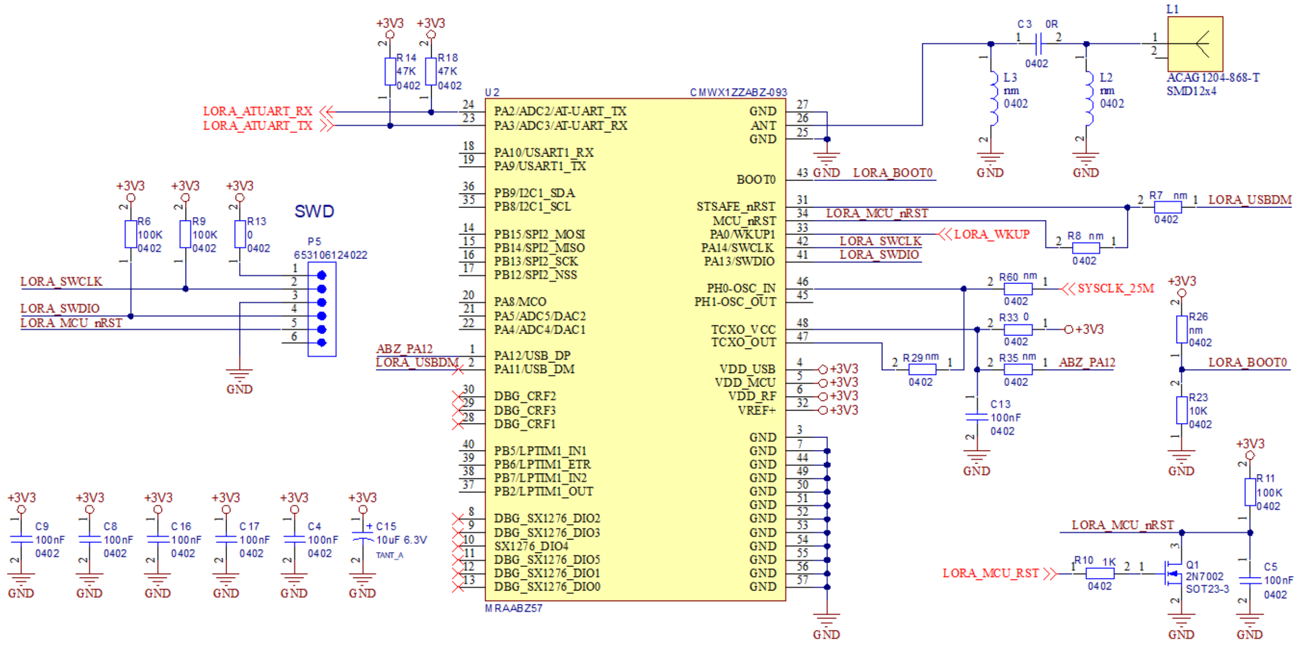

Figure 27 - ABZ LoRa schematic

In order to grant the easiest installation and repetitiveness of the performance, the choice was to integrate the LoRa antenna into the Smart Gateway main board. Figure 28 shows the portion of the board with the LoRa patch antenna. Notice the cutaway in the printed circuit board to grant proper geometry for RF performance.

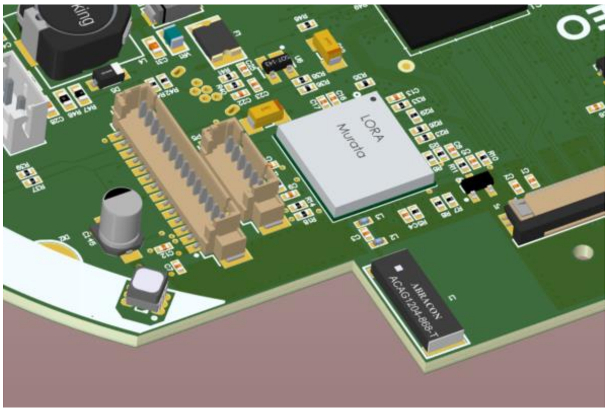

Figure 28 - Murata type ABZ LoRa module and patch antenna

Ethernet

The implementation of the Ethernet port into the Smart Gateway relies on the embedded IEEE-802.3.2002 compliant media access controller (MAC) for LAN communication through the industry standard MII interface (medium independent interface) or its RMII reduced version (see Figure 29). The two differ by the width of the communication bus between the controller inside the STM32 MCU and the PHY (Physical Layer Transceiver).

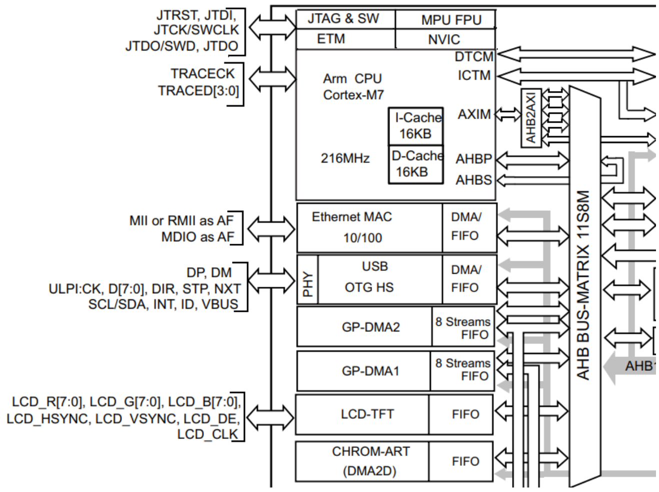

Figure 29 - Portion of the STM32H769 MCU showing the MAC and USB controllers

The physical layer IC found to be a good fit is the LAN7842 from Microchip. This component is a low-power 10BASE-T/100BASE-T full-duplex transceiver compliant to IEEE 802.3 and IEEE 802.3u standards that supports communication with the Ethernet MAC inside the MCU on a RMII interface allowing auto-negotiation to determine the best possible speed of operation. Finally, the LAN7842 contains the power drivers that allow direct connection to the TX/RX isolation transformers. For the Smart Gateway, an RJ45 connector with integrated magnetics and surge protections was chosen. Figure 30 shows the portion of the Smart Gateway schematic referring to the Ethernet PHY. From left to right, the RMII interface to the MCU, the LAN8742 and on the right the RJ45 connector.

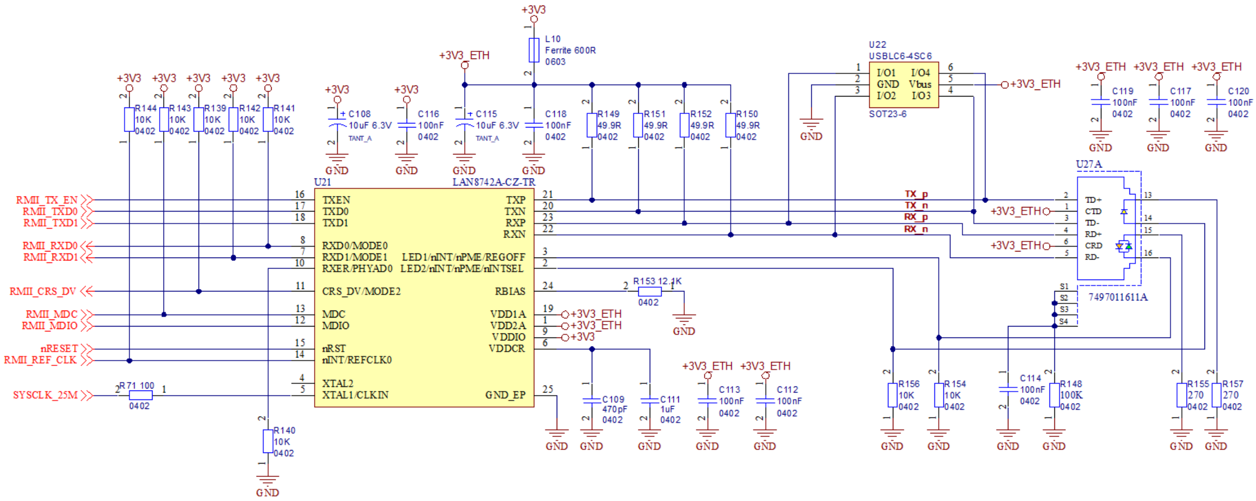

Figure 30 - Ethernet PHY schematic

USB

The Smart Gateway carries a USB port that is useful for debugging purposes to configure the unit. The connector is accessible from the bottom of the board. No particular comments are needed for the USB port since the controller is embedded into the STM32H769 MCU (see Figure 20). The implementation of the USB port is as simple as placing a dedicated connector and filtering the data lines (see Figure 31).

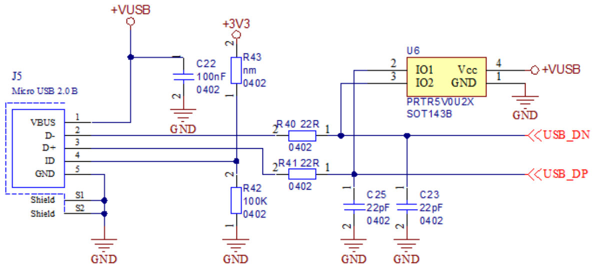

Figure 31 - USB schematic

It is worth to mention that the 5V USB power is routed to the main power supply regulator (refer to Fig. 31). It contributes to power the unit and recharge the onboard batteries.

Serial RS485

The interface capabilities are further enhanced by the half duplex multi-point RS485 serial communication differential bus. The RS485 allows the Smart Gateway to communicate with sensor nodes over a rugged industrial-grade physical layer that allows hundreds of meters of cable.

Again, the serial communication relies over the MCU's integrated Universal Synchronous/Asynchronous Receiver Transmitter (USART) peripherals. The physical layer is entrusted to the SN75HVD08 transceiver from Texas Instruments that is followed by a surge limiter, over-current and short-circuit protections in order to give further ruggedness to this communication bus (see Figure 32).

Additionally, raw power supply is split from the Smart Gateway's internal batteries and fed to a dedicated connector pin through the fully protected TPS1H200A high-side power switch from Texas Instrument. The power switch is commanded by the MCU through a dedicated enable pin. Another pin feeds back the MCU with an eventual fault flag.

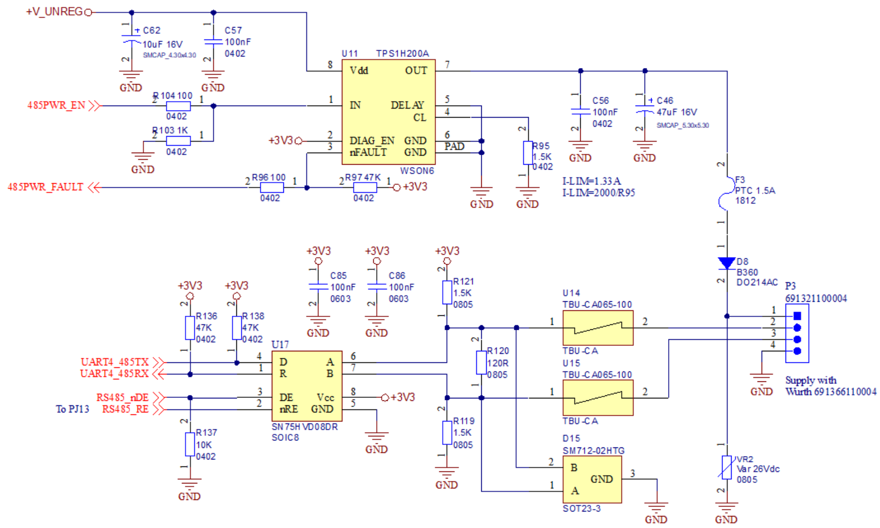

Figure 32 - RS485 and power switch schematic

EXT-DEV Port

The Smart Gateway features and additional connector (see Figure 33) carrying one I2C bus, an SPI bus addressed over two lines, and both regulated 3.3V and unregulated battery voltages. All bus voltages are al LVTTL level. The purpose of this connector is to interface the Smart Gateway to one or more sensor node electronic card within the same mechanical assembly of the device.

This is the case of the weather station, consisting of the Smart Gateway and of the Weather node that is the object of this Deliverable.

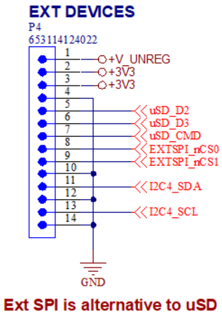

Figure 33 - External devices connector schematic

Because the uSD and the SPI bus on the external devices connector share the same peripheral pins on the main MCU, the trade-off is that these cannot be used simultaneously.

In this D7.7 demonstrator, the Smart Gateway and the Weather node communicate over the I2C bus, thus leaving the SPI pins free to be used to run the uSD card.

3.1.3 ONBOARD SENSORS

The Smart Gateway is able to contribute to the Data Lake concept thanks to a set of MEMS sensors that are located on its main board. These MEMS sensors from ST Microelectronics offer performance, low power and reduced cost (see Figure 34).

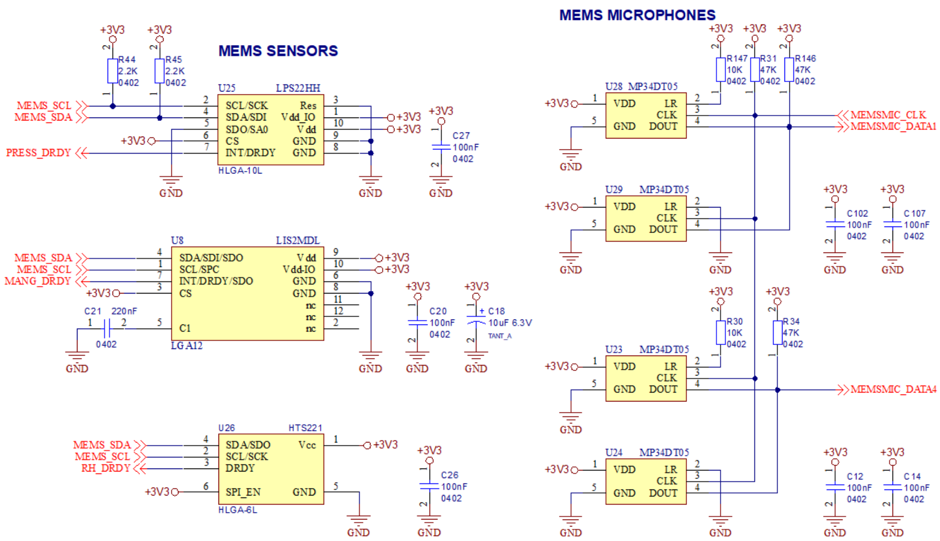

Figure 34 - MEMS sensors schematics

All sensors, except the LIS2MDL magnetometer (see Figure 35) are placed on the bottom of the board so that they can be exposed to the surrounding environment thanks to dedicated openings on the bottom of the case. These openings will allow free air to hit the HTS221 temperature/humidity sensor and the LPS22HH pressure sensor.

The four MP34DT05 microphones are placed at the vertices of a square at a distance of 74mm (see Figure 36). The known distance between the microphones and their synchronization within the MCU's peripheral allows to perform sound recognition and sound tracking.

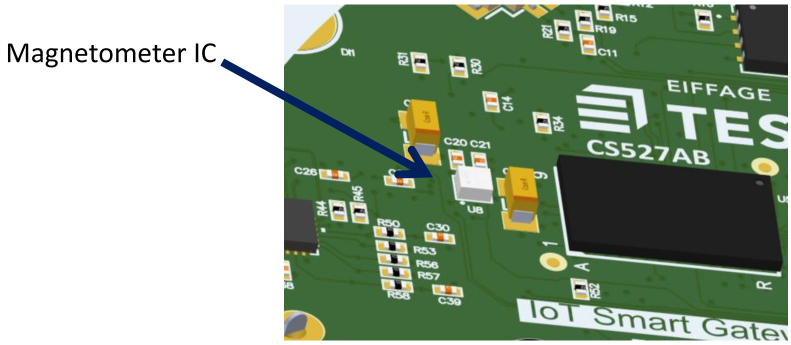

Figure 35 - LIS2MDL magnetometer placement

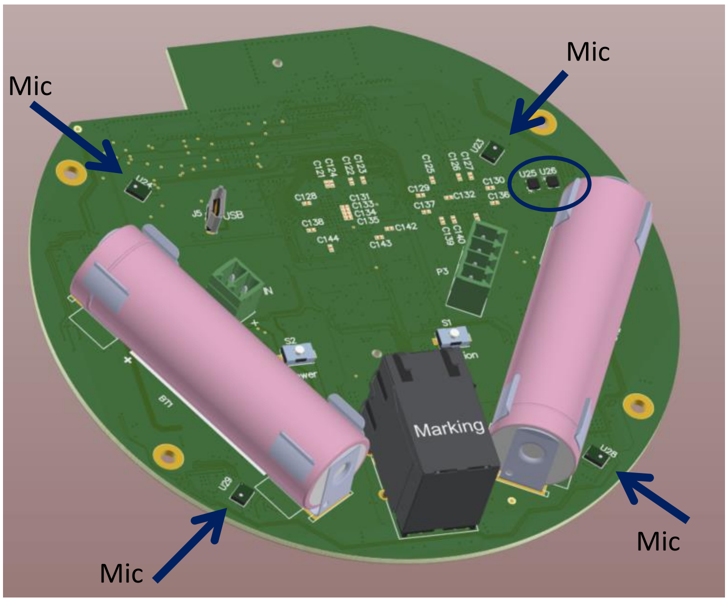

Figure 36 - HTS221 temperature &RH, LPS22HH pressure and MP34DT05 microphones placement

3.1.4 POWER MANAGEMENT

Power management plays a very important role in the context of a flexible equipment that needs to be connected to a variety of not pre-defined power sources. The assumption was that the kind of a power source that is available in the field is unpredictable; so the Smart Gateway shall be able to accept any DC power inputs, from 5V to 24V and shall operate also with high impedance sources such as solar panels. Additionally, in case it is operated with a solar panel, it should have sufficient energy stored to allow overnight operation. Figure 37 illustrates the architecture of the power management section of the Smart Gateway and Figure 38 shows the implementation at electronic circuit level.

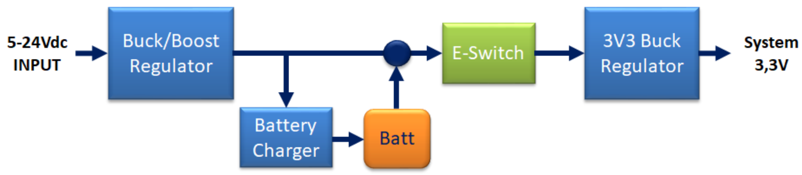

Figure 37 - Power management block diagram

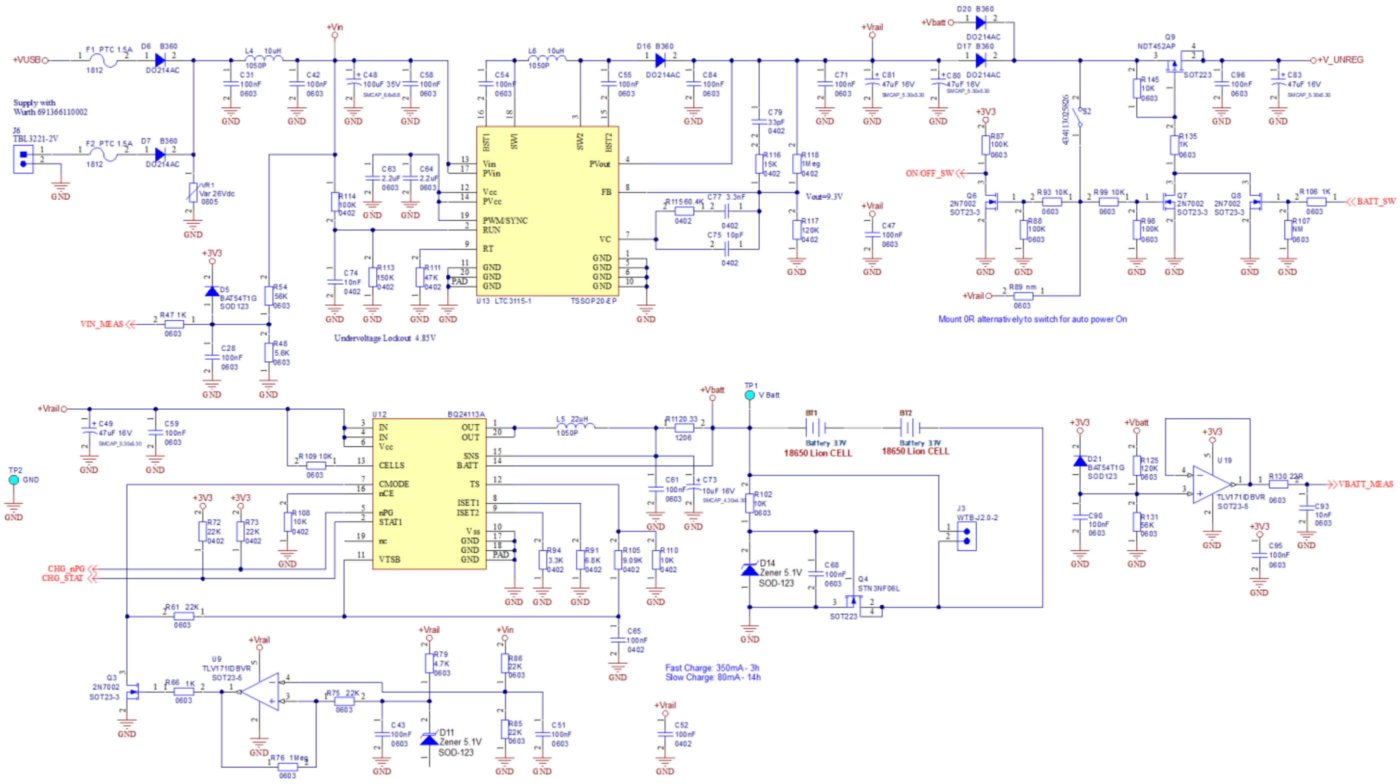

Figure 38 - Power management circuit

The buck/boost regulator fed by the input plug (or USB power) produces a regulated output voltage that was set to 9.5V whatever the input voltage is. This allows the Smart Gateway to operate from 5V to 24Vdc and with solar panel that are known to have an output voltage that is very dependent on light intensity.

To fulfil the task, the LTC3115-1 from Linear Technology was chosen because it is a high-voltage monolithic synchronous buck/boost DC/DC converter. The component features programmable PWM frequency up to 2MHz and allows up to 93% efficiency in buck mode.

The battery charger is implemented with the BQ24113A from Texas Instruments. This IC is part of a family of highly integrated Lithium-Ion and Lithium-Polymer switch-mode charge management devices developed around a synchronous PWM controller with integrated power MOSFET transistors capable of high accuracy current and voltage regulation, charge pre-conditioning and charge termination. The IC manages the charge of the battery autonomously, but some status signals are routed to the MCU in order to monitor its state.

Two 18650 standard size, 3.7V, 2200mA/h, Li-On batteries are installed on the bottom of the Smart Gateway main board as previously seen in Figure 36.

The circuit of the power management unit is arranged so that when the power input is missing or the input voltage is below the under-voltage cut-out threshold, the battery takes over to maintain the main power supply rail.

A discrete power switch allows to shut down the unit without drawing power from the battery, but just a bias current in the order of tens of nano-Amperes.

The electronic switch finally feeds the buck regulator (see Figure 39) that provides 3.3V to the system. The TPS62130 from Texas Instruments was chosen because of its high efficiency, compact size and high switching frequency that allows the use of a small inductor for an enhanced power density and fast transient response required to power digital circuits.

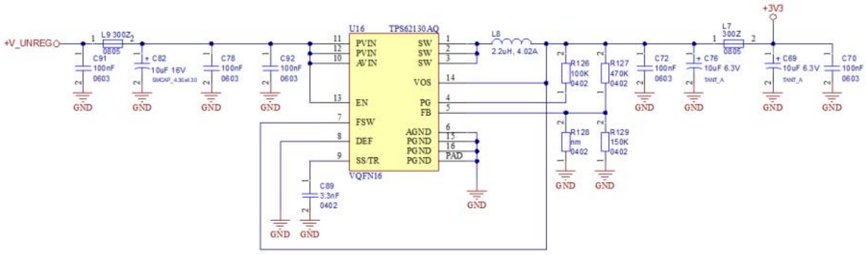

Figure 39 - Main 3.3V step-down buck regulator

Since the power management unit has several cascaded switching regulators, in the circuit in Figure 39, specific EMC filters have been implemented on both input and output of the main 3.3V regulator.

3.2 WI-FI AND 4G WIRELESS BOARD

The Wi-Fi and 4G connectivity are both features belonging to the Smart Gateway, but it was chosen to implement them on a separated card because of the reasons that were previously mentioned.

The wireless daughterboard consists of a GSM integrated module, a Wi-Fi integrated module, and a dedicated buck regulator since the GSM module needs a specific voltage of 3.9V.

The GSM module that was chosen is the BG95 from Quectel. This multi mode LPWA module supports LTE Cat M1, Cat NB2 and EGPRS. It performs a data rate of 588 Kbps downlink and 1119 Kpbs uplink under LTE Cat M1. Notice that the data-rate is in any case dramatically oversized if compared to the amount of data that the Smart Gataway needs to share with the cloud. Its power consumption makes it suitable for an edge device such as the Smart Gatway that, in some condition, is battery operated.

Figure 40 shows its block diagram and its form-factor is visible in Figure 41.

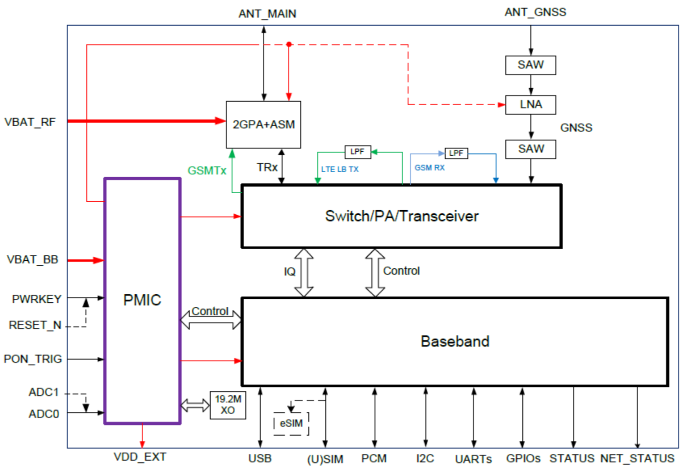

Figure 40 - Quechtel BG95 block diagram

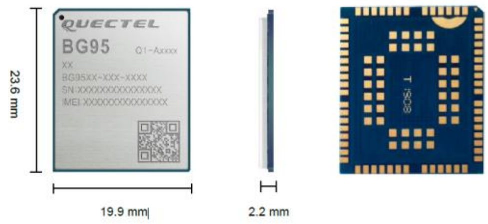

Figure 41 - Quechtel BG95 form factor

In order to grant the easiest installation and repetitiveness of the performance, the choice was to integrate the antenna into the wireless daughterboard card, despite the need for a dedicated matching circuit that was optimized to ensure an effective tuning of the antenna.

Figure 42 shows the portion of the board with the GSM antenna in the corner and the GSM module on the back.

Figure 42 - GSM module and antenna implementation on the Wireless Daughterboard

The choice for the Wi-Fi module was for the ISN43362-M3G from Inventek System. This embedded Serial to Wi-Fi module is 802.11 b/g/n compliant and features a MAC/Baseband/Radio device from Cypress. It contains a full TCP/IP stack that minimizes the load on the main processor into the Smart Gateway thanks to a serial communication over IWIN AT commands. The module features ICMP (Ping), ARP, DHCP, TCP and UDP together with WEP-128, WPA-PSK and WPA2-PSK authentication. Finally, the integration of its functionalities was flawless thanks to extensive libraries available from ST Microelectronics for its STM32 Cortex-M7 processors family.

The hardware integration was flawless as well thanks to the integrated microstrip antenna.

Figure 43 shows the ISM43362-M3G module block diagram and Figure 44 shows the integration on the wireless daughterboard.

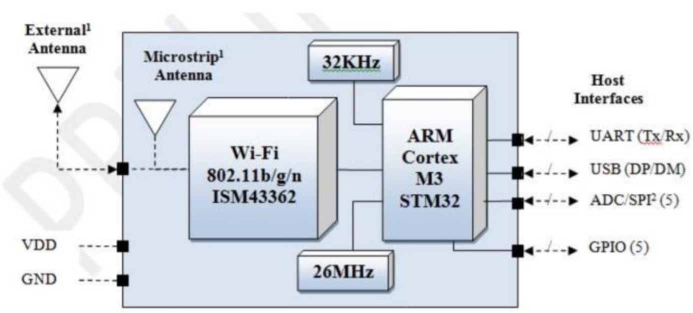

Figure 43 - ISM43362-M3G block diagram

Figure 44 - ISM43362-M3G implementation on the Wireless Daughterboard

The Wireless Daughter board is powered directly from the Smart Gateway though the flat leads connector, except for the local 3.9V buck regulator that powers the GSM module. Needless to comment this part of the circuit since it leverages on the very same TPS62130 used on the Smart Gateway but set for a different output voltage.

3.3 WEATHER NODE BOARD

The weather node board is the part of system that, according to the IoT architecture, operates the collection of the physical magnitudes, validates the data, and delivers it to the Smart Gateway.

The module consists of a dedicated MCU, on-board sensors and all interface and conditioning circuits for off-board sensors that are wired to the board.

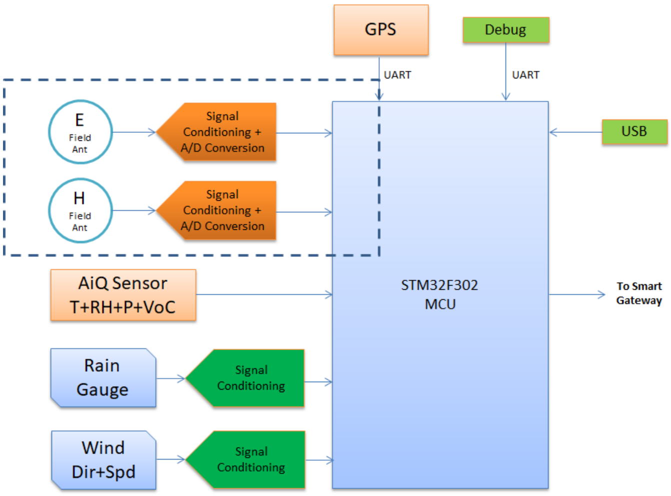

Figure 45 - Weather node block diagram.

As reported in the block diagram in Figure 45, the weather node, other that the core processor, consists of an on-board integrated sensor that measures several physical magnitudes of the environment, interface circuits to the rain gauge and to the wind speed/direction sensor and a GPS receiver with an integrated antenna and RF pre-amplifier and filter section.

Additionally, the module is fitted with a 24bit, 8-channel analogue to digital converter and conditioning circuit for an isotropic electric field sensor in the range 100 KHz - 6 GHz and is ready to also accept a magnetic field sensor (future development). The possibility to measure the environmental pollution from electric and magnetic fields was indicated in Deliverable D7.3 [1] as “nice-to-have”. Still, these sensors need to be consolidated in both hardware and firmware and in the present delivery the results obtained so far will be reported.

To complete the overview of the weather node block-diagram, it is worth to mention that the unit is also provided of a serial and an USB port that are mostly used for off-line debug purposes.

3.3.1 CORE PROCESSOR

The weather node implements an STM32F302 MCU from ST Microelectronics. This Cortex-M4 32 bit processor running at 72 MHz is equipped with a floating point unit, it incorporates high-speed memories (64 Kb RAM and 512 Kb Flash) and an extensive range of enhanced I/Os.

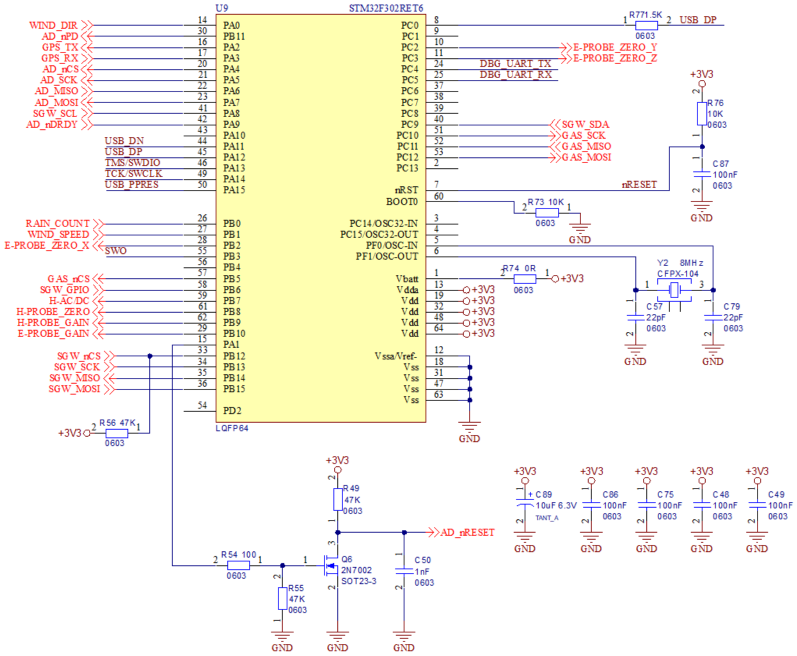

Figure 46 - Core processor schematic diagram

Figure 46 reports the core processor schematic diagram. Because of the highly integration of such MCU, its implementation into the finished module is extremely straightforward, thus contributing to the reliability and ruggedness of the system.

3.3.2 ONBOARD SENSORS

AIR and GAS Sensor

The air and gas sensor selected for the weather module is the BME680 from Bosch Sensortec. This highly integrated component performs the measurement of ambient temperature, relative humidity, barometric pressure, and volatile organic compounds (VOC) that are combined to compute an air quality index.

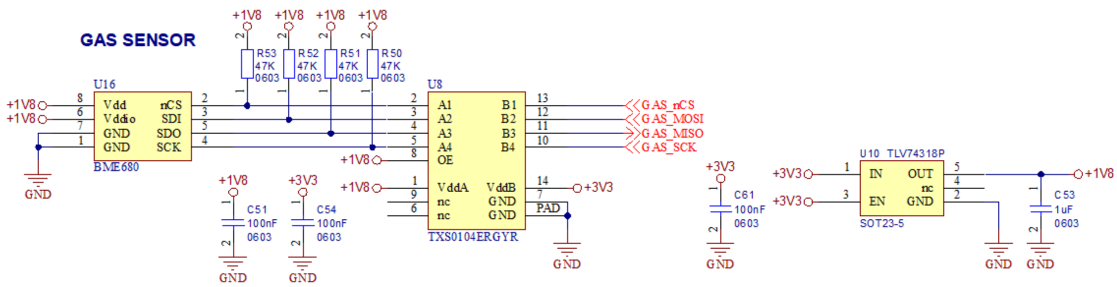

Figure 47 - AIR/GAS sensor circuit diagram

In integrating the BME680 into the application, several constraints were taken into account. Since the sensor is powered at 1.8V and conversely all other parts of the unit are operated at 3.3V, it was necessary to provide for a local step-down regulator and for a level shifter to adapt the bus voltages (see schematic diagram in Figure 47).

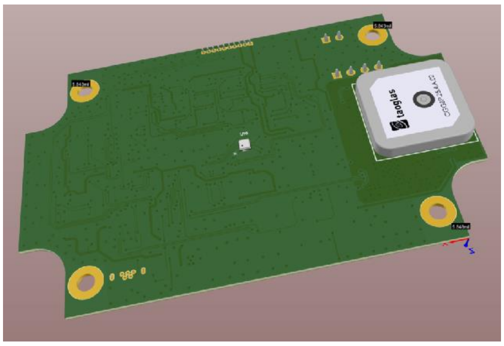

Figure 48 - Bottom board sensors location

The sensor is located on the bottom of the electronic card so that it can be exposed to free-air. Additionally, the sensor should not be disturbed by the temperature of the other electronic components mounted on the board. For this reason, both power and ground planes of the multi-layer printed circuit board were cleared from copper in the area of the BME680 sensor (see Figure 49).

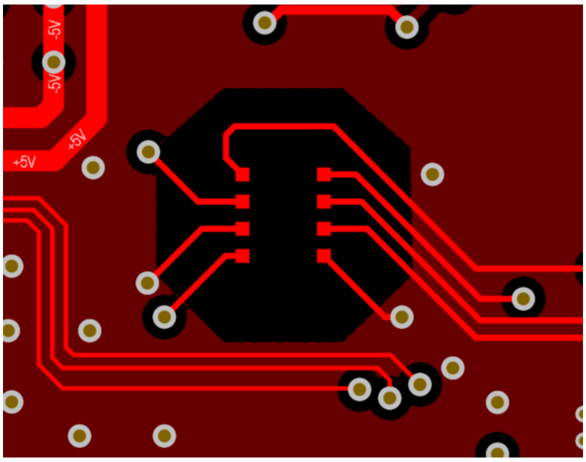

Figure 49 - Power and ground planes clearance in the BME680 area

GPS receiver

The weather station that is detailed in this delivery, was designed as a mass deployable and easy commissionable unit. For this reason, in order to minimize operator data entry, the unit was fitted with a GPS receiver allowing to report its location to the cloud automatically.

The GPS section relies on the LIV3R integrated receiver from ST Microelectronics. This highly integrated module feeds the system processor with standard NMEA strings over a serial link. Such module is usually connected to an external active antenna trough a coaxial cable. Again, in order to minimize any wiring to the system, the design choice was to integrate the antenna and preamplifier circuit into the module itself.

The selected antenna is a patch-type ceramic unit from Taoglass, specifically designed for GPS receiver applications. Because of the available space on the bottom of the board, the largest model of antenna was selected (see Figure 48) for the best sensitivity. The antenna is followed by a BGA725L6 low noise pre-amplifier operating the GNSS frequency range and a bandpass SAW filter (see schematic diagram on Figure 50).

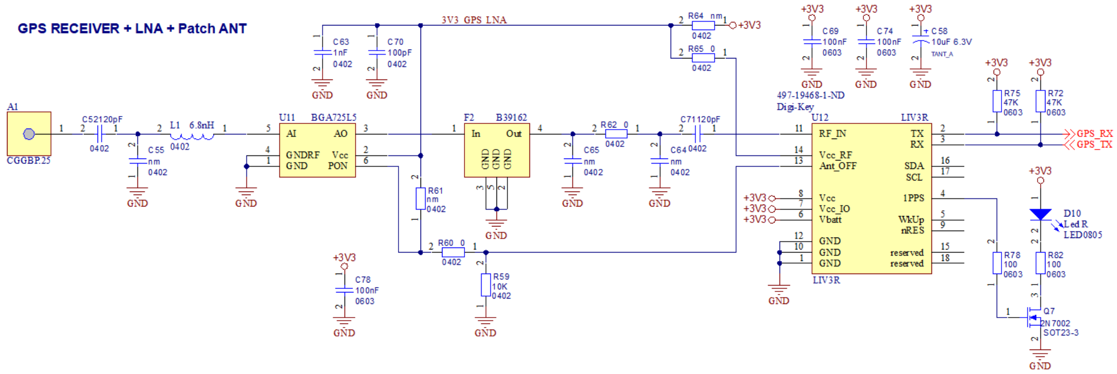

Figure 50 - GPS receiver, antenna and preamplifier circuit

3.3.3 OFFBOARD SENSORS CONDITIONING AND INTERFACEMENT

The other magnitudes required by-design for this delivery are wind speed, wind direction and rainfall. These measurements are performed by the Davis 7911 anemometer & wind direction detector and by the Davis 6465 rain gauge.

Conversely, the measurement of the Electric and Magnetic field was indicated as “nice-to-have”, so the weather node does already implement the necessary conditioning and acquisition circuitry.

Here below, a description will be given for the interface and conditioning circuitry for the above-mentioned sensor heads that are wired to the weather node.

Wind speed

The wind speed sensor into the Davis 7911 provides a 5 ms pulse train. The timing distance between the pulses is proportional to the wind speed and is ruled by the equation *V=P*(2.25/T)* where V is the wind speed in miles per hour, P is number of pulses that are counted over the *T* sampling time window.

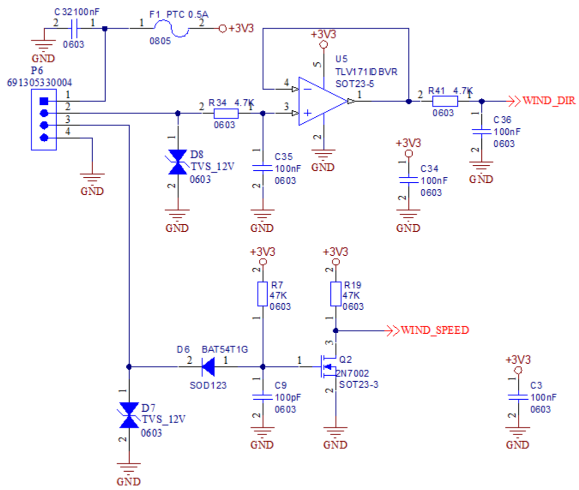

Figure 51 - Wind speed and direction interface circuit

The conditioning circuit (bottom of Figure 51) is simple as an open/close switch detector that feeds the MCU with a logic-level signal.

Wind direction

The wind direction sensor inside the Davis 7911 is a variable resistor that provides a voltage proportional to position of the wind vane. The direction in *degrees* is provided in the relation *deg=Vout*(360/Vcc)* where *Vcc* is the supply voltage, and *Vout* is the output voltage.

Because the same 3.3V voltages powers the Davis 7911 and provides the reference to the MCU's internal 12bit A/D converter, the interface circuit consists of a unity gain buffer (top of Figure 51) and of a basic low-pass filter to reduce incoming noise. As said, the output of the buffer feeds directly the A/D converter embedded in the MCU.

Finally, it is worth to mention that the inputs are protected against surge and ESD (electrostatic discharge).

Rain Gauge

The Davis 6465 rain collector consist of a calibrated swinging spoon that flips by the weight of the water collected by the funnel thus providing an electric pulse. The pulse count is proportional to the rainfall in the magnitude of 0.2 mm of rain per pulse.

The interface circuit is the very same that previously described for the wind speed sensor. Needless to report the electric diagram.

4 FIRMWARE IMPLEMENTATION

4.1 GENERAL OVERVIEW

The system software is developed in the ANSI C language in a firmware oriented technique to maximize power and performance efficiency. Even if the hardware is able to support a complete operating system like Linux embedded, a wired approach was adopted to maximize power efficiency and to simplify the interaction of the dedicated hardware. Such technique is the most suitable to develop the specific hardware drivers required by the use-case application.

However, it is necessary to leverage on software modules for basic functions handling and standard communication buses. For all process handling the use of a minimal and lightweight operating system FreeRTOS was chosen since it offers a complete functions support on a very efficient code.

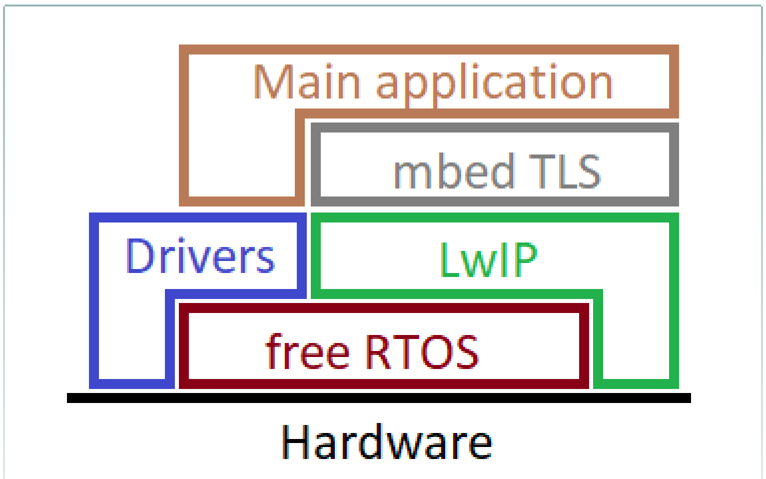

Figure 52 - Software structure

The full stack TPC/IP relies on the LwIP library that is largely used on embedded systems. The support of encryption and security communication is ensured by the mbed TLS library that perfectly integrates with LwIP giving all the basic functions for communicating with remote infrastructures in a secure way. Another advantage of ANSI C and the selected libraries is the possibility to port the code on different architectures having a reduced set of features (CPU performance, RAM, Flash) with a benefit in power consumption and hardware costs. Software is designed in layers where main application is on the top level while low level layers provide for the hardware abstraction and communication functionalities.

4.2 LOW LEVEL LIBRARIES

Low level libraries perform hardware abstraction through a standard set of API that allow eventual code portability between different platforms without the need of further specialization. Furthermore, communication over standard protocols like TPC/IP is granted by standard APIs leveraging on tested and optimized open source code. The benefit in using such libraries in embedded systems, is the possibility to focus on application development without the need to directly manage the hardware for each given function. This report will not be burdened by a detailed description of all low-level libraries provided for the MCU since these are deeply documented by the ST Microelectronics[1]. The vendor also provides a set of tools for its MCUs: compiler, developing environment, debug tools, and HAL libraries supplied in open source free usage (eg. CMSIS Cortex Microcontroller Software Interface Standard). Furthermore, to keep this document light and focused on the demonstrator, no deep description will be given for minor communication libraries such as MQTT and JSON.

[1] ST Microelectronics documentation: www.st.com

4.3 OPERATING SYSTEM - FREERTOS

FreeRTOS [4] (see Figure 53) is a market-leading real-time operating system (RTOS) designed to be small enough to run on a microcontroller. Distributed freely under the MIT open source license, FreeRTOS includes a kernel and a set of libraries suitable for all uses. A microcontroller or a microprocessor is typically a resource constrained real-time system-on-chip that incorporates, the processor itself, read only memory (Flash) to hold the program to be executed, the random access memory (RAM) needed for the code to run, and a set of peripherals for hardware interaction. The program is stored and executed directly from internal read only memory. Microcontrollers are used in deeply embedded applications targeted for a very specific task and with strict power and cost constraints. FreeRTOS provides the core for real-time scheduling functionality, inter-task communication, timing, and synchronization primitives only. For these reasons, it can be considered as a real-time kernel.

Figure 53 - Free RTOS logo

The main features include:

- Portable code structure written in C,
- Supports both tasks and co-routines,
- Queues, binary semaphores, counting semaphores, recursive semaphores and muxes,
- Muxes with priority inheritance,
- Supports efficient software timers,
- Stack overflows detection options,
- Free embedded software source code,
- Royalty free.

4.4 TCP-IP HANDLER - LWIP

LwIP [5] (see Figure 54) is a compact TCP/IP protocol stack library. The focus of the LwIP TCP/IP implementation is to reduce memory usage while still having a full scale TCP suite. This makes LwIP suitable for use in embedded systems with a reduced amount of RAM and ROM. The RAM usage is on the order of tens of kilobytes and the library relies on just 40 kilobytes of code.

Figure 54 - lwIP logo

Main features include:

- Protocols: IP, IPv6, ICMP, ND, MLD, UDP, TCP, IGMP, ARP,
- DHCP client, DNS client, SNMP agent,
- APIs: specialized APIs for enhanced performance, optional Berkeley-alike socket API,
- Extended features: IP forwarding over multiple network interfaces, TCP congestion control, RTT estimation and fast recovery/fast retransmit.

lwIP is licensed under a BSD-style license[2].

4.5 DATA ENCRYPTION - EMBEDTLS

mbed TLS [6] (formally known as PolarSSL) is a cryptographic SSL library accessible through a set of APIs developed in the portable “ansi C” language. It allows to nest SSL/TLS capabilities with a minimal coding footprint. The minimum complete TLS stack requires less than 60KB of program space and less than 64 KB of RAM, making “mbed TLS” suitable for embedded systems.

[2] BSD license: http://lwip.wikia.com/wiki/License

Main features include:

- TCP/IP communication functions: listen, connect, accept, read/write,
- SSL/TLS communication functions: initialize, handshake, read/write,
- X.509 functions: CRT, CRL and key handling,
- Random number generation,
- Hashing,
- Encryption/decryption.

"mbed TLS" is available as open source under the Apache 2.0 license or the GPL 2.0 license.

4.6 MAIN APPLICATION

The main application defines the device behaviour and lies on top of the software stack where it leverages upon the libraries and facilities to handle the hardware (see Figure 55). The focus is to collect environmental values, make data validation, compute metrics, format data and transmit to the LEXIS infrastructure using the MQTT protocol.

Figure 55 - Main application data flow

Data flow crosses vertically all communication modules down to hardware management. Leveraging a time-based policy, it collects values from the sensors installed on the specific environmental acquisition board, pre-processes data and associates it with a known time reference provided by the integrated GPS module. Contextually, individual sensors are monitored and their status is reported in the status mask associated with data bucket to be transmitted to the cloud. Data is then formatted in JSON and sent to the LEXIS infrastructure through the server connection interface. Great importance is given to monitoring the data connection and recovery policies in case of failure. The intervention acts at several levels depending on the failure that is detected, down to the complete reset of the device. The operating parameters of the main board are also shown, such as the power supply and battery voltage, as well as the internal operating temperature.

5 DATASET

5.1 PRE-PROCESSING GENERAL OVERVIEW

The weather node board integrates the air sensor, interfaces for wind speed/direction and rainfall and carries the electronics for electromagnetic field measurement and a GPS for positioning and time reference. For each sensor, data is red from the specific device and transferred to the microprocessor using specific communication methodology, for example the BOSCH BME680 air sensor, communicates via I2C data bus, the GPS uses a common serial port (UART). When data is available in the microprocessor it is first validated before being transmitted to the LEXIS server. Other information, such as derivative, instance averages, minimum and maximum values in a time slot are also retrieved. An important aspect is to monitor the correct workflow of the sensors, monitoring data values and update time. The status of the entire sensor set is printed in the status mask, where each bit act as a flag indicating if that condition is true or false. The status mask is sent to the LEXIS server as a companion dataset allowing remote diagnosis.

5.2 AIR TEMPERATURE

The BME680 from Bosch Sensortech has been chosen because of its performance-to-cost ratio. The BME680 is a digital 4 in 1 sensor with gas, humidity, pressure, and temperature measurements. The sensor is housed in an extremely compact metal-lid LGA package with a footprint of only 3.0 x 3.0 x 1.0 mm. This sensor is furthermore characterized by a low power consumption, which makes it perfectly suitable for this application. The resolution of the temperature measurements is set at 16 bit ADC output and is performed by a silicon diode.

Main characteristics are shown in Table 1:

PARAMETER	CONDITION	MIN	TYP	MAX	UNIT
Operating range	Operational	-40	25	85	°C
Absolute accuracy	25°C		±0.5		°C
	0-65°C		±1		°C
Output resolution			0.01		°C
RMS noise	Lowest oversampling		0.005		°C

Table 1 - BME680 Temperature main characteristic

Air temperature is triggered once per second and buffered to be pre-processed as average, minimum and maximum. When an environmental data set is triggered, external air temperature is transferred as a set of 4 data:

`"tempNow"`: Temperature snapshot expressed in Celsius degree.
`"tempHigh"`: Temperature maximum over the acquisition time window and expressed in Celsius degree.
`"tempLow"`: Temperature minimum over the acquisition time window and expressed in Celsius degree.
`"tempAvg"`: Temperature average over the acquisition time window and expressed in Celsius degree.

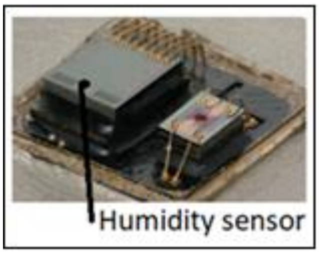

Figure 56 - BME680 internal humidity sensor

5.3 AIR HUMIDITY

The BME680 sensor is able to measure humidity as well as temperature, air quality and pressure. There are no reasons not to take advantage of these features. The air humidity is measured by the relative permittivity change of the integrated polymer-based capacitor. The resolution of the humidity measurements is defined is 16 bits.

Main characteristics are shown in Table 2:

PARAMETER	CONDITION	MIN	TYP	MAX	UNIT
Operating range		-40	25	85	°C
		0		100	% r.H.
Accuracy range		0		65	°C
		10		90	% r.H.
Absolute accuracy	20-80 % r.H. 25°C		±3		% r.H.
Hysteresis	10→90→10 % r.H. 25°C		±1.5		% r.H.
Non-linearity	10→90 % r.H. 25°C		1.7		% r.H.
Response time	0→90 % r.H. 25°C		8		sec
Resolution			0.008		% r.H.
RMS noise			0.001		% r.H.

Table 2 - BME680 Humidity main characteristic

Air humidity is triggered once per second and buffered for average, minimum and maximum computing. When an environmental data set is triggered, external air humidity is transferred as a set of 4 data:

`"humNow"`: Humidity snapshot expressed in percentage.
`"humHigh"`: Humidity maximum over the acquisition time window and expressed in percentage.
`"humLow"`: Humidity minimum over the acquisition time window and expressed in percentage.
`"humAvg"`: Humidity average over the acquisition time window and expressed in percentage.

5.4 PRESSURE

The internal pressure sensor is a piezo-resistive MEMS silicon membrane integrated in the BME680. Atmospheric pressure is measured by the resistance change due to the elongation of the thin membrane. The resolution of the pressure measurements is set in 16 bits at the ADC output.

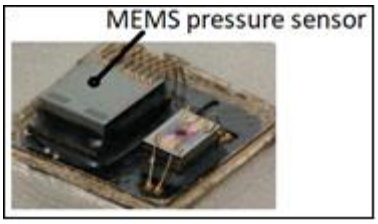

Figure 57 - BME680 internal pressure sensor

Main characteristics is shown in Table 3:

PARAMETER	CONDITION	MIN	TYP	MAX	UNIT
Operating range	Operational	-40	25	85	°C
	Full accuracy	0		65	hPA
Accuracy range		300		1,100	hPa
Absolute accuracy	300-1,100 hPa, 0-65°C		±0.6		hPa
Resolution			0.18		hPa
RMS noise			0.4		hPa

Table 3 - BME680 Pressure main characteristic

Air pressure is triggered once per second and buffered for average, minimum and maximum computing. When an environmental data set is triggered, external air humidity is transferred to LEXIS servers as a set of 4 data:

`"pressNow"`: Air pressure snapshot expressed in ettopascal / millibar.
`"pressHigh"`: Air pressure maximum over the acquisition time window and expressed in hPa / millibar.
`"pressLow"`: Air pressure minimum over the acquisition time window and expressed in hPa / millibar.
`"pressAvg"`: Air pressure average over the acquisition time window and expressed in hPa / millibar.

5.5 AIR QUALITY

The same BME680 has the capability to estimate the air quality (see Figure 58). The conductivity change on an oxide-based sensor by the absorption and subsequent oxidation/reduction on its sensitive layer makes the sensor able to measure the concentration of VOCs (Volatile Organic Componds) and this estimate an air quality index.

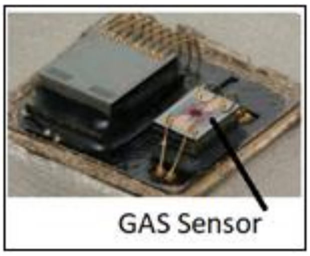

Figure 58 - BME680 internal IAQ sensor

As a raw signal, the BME680 measures a resistance value that changes upon gas concentrations. The higher the concentration of reducing VCOs, the lower the resistance and vice-versa. Since this raw signal is influenced as well by parameters other than VCOs concentration (e.g. humidity level), the raw values are transformed to an index for air quality (IAQ) by algorithms inside the BSEC library provided by BOSH.

IAQ Index	Air Quality	Impact (long-term exposure)	Suggested action
0 – 50	Excellent	Pure air; best for well-being	No measures needed
51 – 100	Good	No irritation or impact on well-being	No measures needed
101 – 150	Lightly polluted	Reduction of well-being possible	Ventilation suggested
151 – 200	Moderately polluted	More significant irritation possible	Increase ventilation with clean air
201 – 250[9]	Heavily polluted	Exposition might lead to effects like headache depending on type of VOCs	optimize ventilation
251 – 350	Severely polluted	More severe health issue possible if harmful VOC present	Contamination should be identified if level is reached even w/o presence of people; maximize ventilation & reduce attendance
> 351	Extremely polluted	Headaches, additional neurotoxic effects possible	Contamination needs to be identified; avoid presence in room and maximize ventilation

Table 4 - IAQ values

The IAQ scale ranges from 0 (clean air) to 500 (heavily polluted air). During operation, the algorithms automatically calibrate and adapt themselves to the environment where the sensor is operated. This automatic background calibration ensures IAQ performance. The calibration process considers the recent measuring history, typically up to four days, to ensure that IAQ ~25 corresponds to good air and IAQ ~250 indicates polluted air.

Main characteristics are shown in Table 5:

PARAMETER	CONDITION	MIN	TYP	MAX	UNIT
Operating range		-40		85	°C
		10		95	rHa
Accuracy range		0		500	IAQ
Resolution			1		IAQ
Sensor-to-sensor deviation			±15%		IAQ

Table 5 - BME680 Air quality main characteristic

Air quality is triggered once per second and buffered for average, minimum and maximum computing. When an environmental data set is triggered, external air quality is transferred to LEXIS servers as a set of 4 data:

`"airQltyNow"`: Air quality snapshot expressed in IAQ.
`"airQltyHigh"`: Air quality maximum over the acquisition time window and expressed as IAQ index.
`"airQltyLow"`: Air quality minimum over the acquisition time window and expressed as IAQ index.
`"airQltyAvg"`: Air quality average over the acquisition time window and expressed as IAQ index.

5.6 RAINFALL INTENSITY

Figure 59 - DAVIS rainfall sensor

Precipitation intensity is defined as the amount of liquid fallen on the ground and it is measured as mm/h, it has been chosen to adopt a tipping bucket rain gauge sensor, which is a particular sensor that collects the water up to a certain amount and then sends an electrical input to a processing unit. This process is repeated over the time. Counting the number of pulses over an hour and knowing the amount of water per pulse gives the amount off fallen rain.

The chosen sensor is the DAVIS AeroCone Rain Collector, which is characterized by a tipping bucket structure that is calibrated to obtain a resolution of 0.2 mm/h (one pulse). The sensor is equipped with bird spikes, that keep wild animals far from the rain collector cone keeping the instrument clean.

Main characteristics are shown in Table 6:

PARAMETER	CONDITION	MIN	TYP	MAX	UNIT
Accuracy	One tip (0.2mm)		±0.01		mm

Table 6 - DAVIS rainfall sensor main characteristics

Rainfall is triggered once per 20 seconds and buffered for average, minimum and maximum computing. When an environmental data set is triggered, rainfall is transferred to LEXIS servers as a set of 4 data:

`"rainfallNow"`: Rainfall snapshot expressed in millimetre/minute (measured in 20 second).
`"rainfallHigh"`: Rainfall maximum in 60 minutes acquisition window expressed in millimetre/minute.
`"rainfallLow"`: Rainfall minimum in 60 minutes acquisition window expressed in millimetre/minute.
`"rainfallAvg"`: Rainfall average in 60 minutes acquisition window expressed in millimetre/hour.

5.7 WIND DIRECTION

The wind blowing direction is the quantity used to analyse the wind in environmental observations coupled with speed. Being a horizontal direction, it is measured in degrees (°) clockwise referred to the North.

To measure the wind direction and speed, the Davis 7911 was selected.

Figure 60 - DAVIS wind sensor

Main characteristics are shown in Table 7:

PARAMETER	CONDITION	MIN	TYP	MAX	UNIT
Range		0		360	°
Accuracy			±7		°
Resolution			1		°

Table 7 - DAVIS wind direction sensor main characteristics

Wind direction is triggered once per second and buffered for average, minimum and maximum computing. When an environmental data set is triggered, wind direction is transferred to LEXIS servers as a set of 4 data:

`"windDirNow"`: Wind direction snapshot expressed degree (0:360).
`"windDirHigh"`: Wind direction maximum over the acquisition time window and expressed in degrees.
`"windDirLow"`: Wind direction minimum over the acquisition time window and expressed in degrees.
`"windDirAvg"`: Wind direction average over the acquisition time window and expressed in degrees.

5.8 WIND SPEED

The same Davis 7911 is used to measure the wind speed. It is a professional anemometer that uses wind cups to detect the wind speed thanks to a magnetic sensor that provides a pulse for each rotation, ensuring a resolution of 0.1 m/s and an uncertainty of 1 m/s.

Main characteristics are shown in Table 8:

PARAMETER	CONDITION	MIN	TYP	MAX	UNIT
Range		0		89	m/s
Accuracy			±1		m/s
Resolution			0.1		m/s

Table 8 - DAVIS wind speed sensor main characteristics

Wind speed is triggered once per second and buffered for average, minimum and maximum computing. When an environmental data set is triggered, wind speed is transferred to LEXIS servers as a set of 4 data:

`"windSpdNow"`: Wind speed snapshot expressed meter/second.
`"windSpdHigh"`: Wind speed maximum over the acquisition time window and expressed in meters/second.
`"windSpdLow"`: Wind speed minimum over the acquisition time window and expressed in meters/second.
`"windSpdAvg"`: Wind speed average over the acquisition time window and expressed in meters/second.

5.9 GPS POSITION

The Teseo-LIV3R module is a powerful Global Navigation Satellite System (GNSS) stand-alone module, embedding Teseo III single die stand-alone positioning receiver IC working simultaneously on multiple constellations (GPS/Glonass/BeiDou/QZSS). The Teseo-LIV3R modules brings the proven accuracy and robustness of Teseo chips produced by ST Microelectronics. The module has an optimized RF sub-circuitry, and the compactness and cost-effectiveness of this solution makes it ideal for this application. Within its 9.7x10.1 mm tiny size, Teseo-LIV3R offers a good accuracy thanks to the on board 26 MHz Temperature Compensated Crystal Oscillator and a reduced Time To First FIX.

Figure 61 - LIV3R GPS module

Main characteristics are shown in Table 9:

PARAMETER	CONDITION	MIN	TYP	MAX	UNIT
Working range		-40		85	°C
Time to FIX		0		36	S
Horizontal position accuracy			<1.5		m

Accuracy of time			99%RMS		

Table 9 - TESEO-LIV3R GPS module main characteristics

GPS data is a snapshot when an environmental data set is triggered, is transferred to LEXIS servers as a set of 4 data and flags in status mask:

`"gpsTime"`: Acquisition time is a snapshot of GPS module time and date: YYYY-MM-DD hh:mm:ss
`"gpsLat"`: Acquisition position latitude is a snapshot of GPS module latitude expressed in degrees.
`"gpsLon"`: Acquisition position longitude is a snapshot of GPS module latitude expressed in degrees.
`"gpsSat"`: Acquisition position GPS satellite in view number.

- GPS position orientation flags:
    - GPS LATITUDE DIRECTION: Indicates latitude degree value referred to North or South: (0=N/1=S)
    - GPS LONGIUDE DIRECTION: Indicates longitude degree value referred to Est or West: (0=E/1=W)

5.10 E.M. FIELD

Because the electromagnetic field measurement was indicated as a “nice-to-have” on Deliverable D7.3 [1] and because this part of the system is still under consolidation, just a quick hint of the current work-in progress status is given herein. Further details and performance acknowledgements will be given in future reports by the end of the project.

As said previously, the weather station was conceived as a modular unit. Figure 62 was taken during testing and characterization session in the anechoic chamber. Notice the “naked” unit where the electric field probe is added in the upper dry compartment.

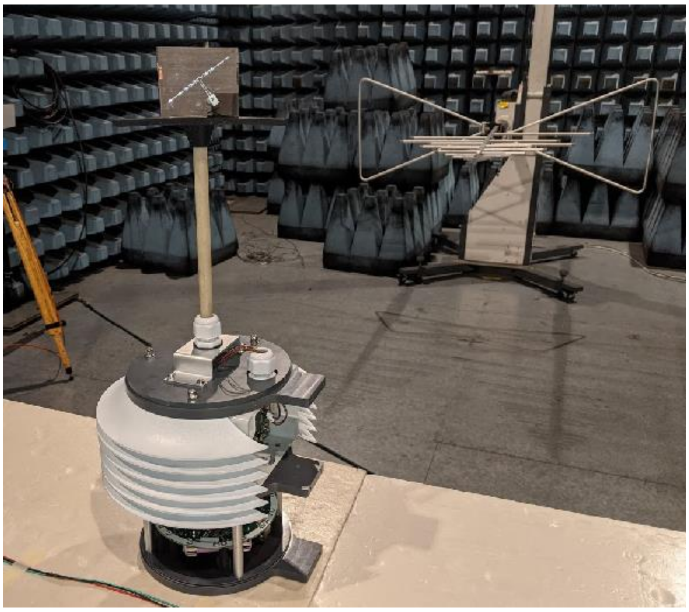

Figure 62 - Characterization in the anechoic chamber of the weather station with E-Field sensor

The isotropic magnitude of electromagnetic field intensity is turned by the probe into a 3-axis analogue signal (see Figure 62) that the microprocessor reads using an amplification/filtering circuitry and an external 24 bit ADC converter. The digital value is used to fill the internal averaging and compute the strength of the field.

The sensor-head is designed to operate broadband, from 100 KHz to 6 GHz and it is sized to electric field magnitudes up to 200V/m. Conversely, the expected sensitivity is 0.2V/m.

5.11 DIAGNOSTIC DATA

Sensor data validity is monitored through a set of flags; each flag is a one bit value in the status mask transmitted to the LEXIS servers as an hexadecimal 32bit value:

`"stnStat"`:The meaning is listed here below:

- GPS Module: The GPS module status is monitored through tree status flags:
  - GPS MODULE PRESENT: Indicates that an ongoing communication between the microprocessor and the GPS. Flag value (0=NOT PRESENT/1=PRESENT)
  - GPS MODULE ERROR: Indicates that the communication between the microcontroller and the GPS module is not respecting the correct format of the NMEA protocol and/or the final CRC check does not match. Flag value (0=OK/1=ERROR)
  - GPS FIX STATUS: Indicates if the GPS module is in satellite view condition with a valid position and time dataset – FIX. Flag value (0=NO FIX/1=FIX)
- Internal temperature sensor status indicates if the communication between the microprocessor and the BME680 MEMS sensor is up an going, data integrity is monitored by CRC. If an error occurs and no valid data is received by microcontroller, this flag becomes true and indicates a fault in the measure. Flag value: (0=DATA VALID/1=ERROR).
- External air temperature is measured by the all-in-one BME680 sensor that communicates with the microcontroller through a I2C data bus, data flow consistency is monitored by a CRC. Raw data is then computed by BSEC library. The consistency of the external temperature value in synthesized in a single flag according to BSEC library data valid indication. Flag value: (0=DATA VALID/1=ERROR).
- Air pressure is measured by the BME680 sensor that communicates with the microcontroller through a I2C data bus, data flow consistency is monitored by CRC. Raw data is then computed by BSEC library. The consistency of the air pressure value in synthesized in a single flag according to BSEC library data valid indication. Flag value: (0=DATA VALID/1=ERROR).
- Air humidity is measured by the BME680 sensor that communicates with the microcontroller through a I2C data bus, data flow consistency is monitored by CRC. Raw data is then computed by BSEC library. The consistency of the air humidity value in synthesized in a single flag according to BSEC library data valid indication. Flag value: (0=DATA VALID/1=ERROR).
- Air quality is measured by the BME680 sensor that communicates with the microcontroller through a I2C data bus, data flow consistency is monitored by CRC. Raw data is then computed by BSEC library. The consistency of the air quality value in synthesized in a single flag according to BSEC library data valid indication. Flag value: (0=DATA VALID/1=ERROR).
- Wind speed sensor presence is a flag indicating that activity has been detected on the specific input, the sensor has been plugged and activated. Flag value: (0=NOT PRESENT/1=PRESENT)
- Wind speed sensor no activity indicates that activity has not been detected for long time: 1 hour. It can indicate that the sensor is idle or broken. Flag value: (0=ACTIVITY/1=NO ACTIVITY)
- Wind direction sensor presence is a flag indicating that activity has been detected on the specific input, the sensor has been plugged and activated. Flag value: (0=NOT PRESENT/1=PRESENT)
- Wind direction sensor no activity indicates that activity has not been detected for long time: 1 hour. It can indicate that the sensor is idle or broken. Flag value: (0=ACTIVITY/1=NO ACTIVITY)
- Rainfall sensor presence is a flag indicating that activity has been detected on the specific input, the sensor has been plugged and activated. Flag value: (0=NOT PRESENT/1=PRESENT)
- Rainfall sensor no activity indicates that activity has not been detected for long time: 1 hour. It can indicate that the sensor is idle or broken. Flag value: (0=ACTIVITY/1=NO ACTIVITY)
- Electric field sensor present, not implemented yet. Flag value: (0=NOT PRESENT/1=PRESENT)
- Electric field sensor error, not implemented yet. Flag value: (0=DATA VALID/1=ERROR)

6 COMMUNICATION WITH LEXIS PLATFORM

6.1 GENERAL OVERVIEW AND REVISION IN PROGRESS DETAILING

The dataflow foreseen in Deliverable D7.3 [1] initially described that the data collected and pre-processed by the weather station should have been submitted to the CIMA infrastructure where they would have been elaborated, then to ECMWF for a proper formatting, and finally to the LEXIS WCDA. Such data flow is schematized in Figure 63. In this scenario the weather station is a specialized data generator focused on feeding CIMA database with environmental observations.

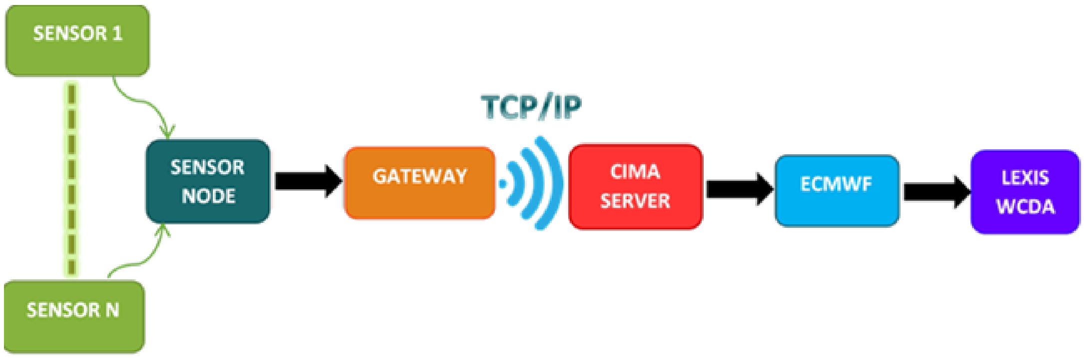

Figure 63 - D7.3 data flow

During the overall project work progress, the weather station has been developed as an application of generic IoT platform consisting of Smart Gateway and of a weather sensor node, as we have so far seen in this report. The Smart Gateway is designed to be as generic as possible and use-case independent. The data is specialized by the "kind" of sensor node connected to it. This is the case of the weather station described herein. Conversely, the Smart Gateway is able to manage, as an example, nodes acquiring mechanical magnitudes, electrical magnitudes, etc. And even all of them together!

This has led to the need to change the dataflow in order to grant the up-said use-case independence. It was so agreed the Smart Gateway to push the data directly into the LEXIS infrastructure; the unified receiver where data will be sorted and specialized on the given use case.

The reviewed data flow (see Figure 64) has allowed to standardize the gateway as an opened and flexible data injection device.

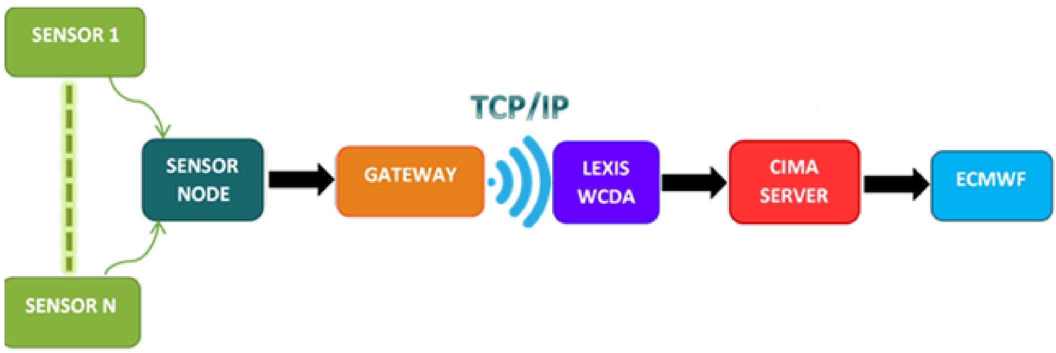

Figure 64 - Reviewed „true" IoT data flow

6.2 NETWORK COMMUNICATION STRUCTURE

Once the physical magnitudes have been collected and pre-processed by the weather station, data will be sent to the LEXIS servers through MQTT protocol. The Message Queuing Telemetry Transport (MQTT) is a lightweight publish/subscribe network protocol that targets data to cloud server. The listening server software is called BROKER, data is addressed to a specific TOPIC supported by the broker, this process is called message publishing. The data type published is plain text in JSON format. Java Script Object Notation (JSON) is a language independent data format, very easy to be formatted and parsed by any programming language. To establish a connection with the broker an authentication with username and password is required, this way the server is able to authorize and identify the sender.

The usage of MQTT protocol with JSON data format is a recognized standard for IoT devices to communicate with big cloud infrastructures through Internet public network. The security is guaranteed by the encryption TLS layer that leverages on a private and public key to ensure the message is validated and read only by the owner of the private key.

For the data exchange with LEXIS by IoT devices, a broker has been deployed, a set of devices has been created and a specific topic was opened for the weather stations. The uploaded data, in JSON format, is then loaded in a time-series database ready for further analysis and manipulation.

6.3 DATA FORMATTING

Data is formatted as a simple JSON text. JSON has become a standard in IoT communication for its simplicity since it is easier to be both generated and processed if compared to other data-formats, such as XML.

Hereafter, a transmission example is reported. The back-bone of is structure is clearly visible. Further on, each of its fields will be commented.


```
{
        "observation": {
                "stnID":"LEXIS_METEO_003",
                "stnStat":"0306A028",
                "intTemp":25.8,
                "gpsTime":"2021-05-25 08:57:40",
                "gpsLat":44.299099,
                "gpsLon":8.450000,
                "gpsSat":12,
                "battVlt":  8.5,
                "supplyVlt":  11.9,
                "environmental": {
                        "tempNow":23.1,
                        "tempHigh":23.1,
                        "tempLow":22.9,
                        "tempAvg":23.0,
                        "pressNow":1016,
                        "pressHigh":1016,
                        "pressLow":1016,
                        "pressAvg":1016,
                        "humNow":49,
                        "humHigh":49,
                        "humLow":49,
                        "humAvg":49,
                        "windSpdNow":0.6,
                        "windSpdHigh":3.5,
                        "windSpdLow":0.0,
```

```
                "windSpdAvg":0.6,
                "windDirNow":43,
                "windDirHigh":161,
                "windDirLow":26,
                "windDirAvg":119,
                "precipNow":0.0,
                "precipHigh":0.0,
                "precipLow":0.0,
                "precipAvg":0.0,
                "airQltyNow":62,
                "airQltyHigh":66,
                "airQltyLow":61,
                "airQltyAvg":63
            }
        }
}
```


Fields´ descriptions:

- "**stnID**": "LEXIS_METEO_003",

  Description: Device name.
  Data type: String
  Data length: 0 to 16 char

- "**stnStat**": "00000000",

  Description: Status mask as hexadecimal value where each bit/flag has a specific meaning.
  Data type: Hex String (0:9/A:F)
  Data length: 8 char

BIT	VALUE	DESCRIPTION
0	x	Not used
1	0	GPS position, latitude degree value referred to: NORTH
	1	GPS position, latitude degree value referred to: SOUTH
2	0	GPS position, longitude degree value referred to: EST
	1	GPS position, longitude degree value referred to: WEST
3	0	GPS module: NOT PRESENT
	1	GPS module: PRESENT
4	0	GPS module status: FUNCTIONAL
	1	GPS module status: ERROR
5	0	GPS position status: NO FIX (GPS position data not valid)
	1	GPS position status: FIX (GPS position data valid)
6	x	Not used
7	x	Not used
8	0	Internal temperature sensor status: DATA VALID

	1	Internal temperature sensor status: ERROR
9	0	External temperature sensor status: DATA VALID
	1	External temperature sensor status: ERROR
10	0	Pressure sensor status: DATA VALID
	1	Pressure sensor status: ERROR
11	0	Humidity sensor status: DATA VALID
	1	Humidity sensor status: ERROR
12	0	Air quality sensor status: DATA VALID
	1	Air quality sensor status: ERROR
13	0	Wind speed sensor status: NOT PRESENT
	1	Wind speed sensor status: PRESENT
14	0	Wind speed sensor activity: ACTIVITY
	1	Wind speed sensor activity: NO ACTIVITY
15	0	Wind direction sensor status: NOT PRESENT
	1	Wind direction sensor status: PRESENT
16	0	Wind direction sensor activity: ACTIVITY
	1	Wind direction sensor activity: NO ACTIVITY
17	0	Rainfall sensor status: NOT PRESENT
	1	Rainfall sensor status: PRESENT
18	0	Rainfall sensor activity: ACTIVITY
	1	Rainfall sensor activity: NO ACTIVITY
19	0	Electric field sensor status: NOT PRESENT
	1	Electric field sensor status: PRESENT
20	0	Electric field sensor: DATA VALID
	1	Electric field sensor: ERROR
21	x	Not used
22	x	Not used
23	x	Not used
24	0	Ethernet link up/down status: DOWN
	1	Ethernet link up/down status: UP
25	0	Ethernet DHCP address: NOT BOUND
	1	Ethernet DHCP address: BOUND

26	0	System power-down: IDLE
	1	System power-down: POWER DOWN
27	x	Not used
28	0	Sensor board communication status: OK
	1	Sensor board communication status: ERROR
29	0	Server communication status: OK
	1	Server communication status: ERROR
30	x	Not used
31	x	Not used

Table 10 - System status mask flags values

- "**intTemp**": 30.5,

  Description: Device internal temperature measured on the main board circuit
  Data type: Decimal number
  Data unit: Celsius degree

- "**gpsTime**": " 2021-05-05 12:49:59",

  Description: Acquisition data and time coming from GPS module.
  Data type: String
  Data format: YYYY-MM-DD hh-mm-ss
  YYYY → Year value (2021:9999)
  MM → Month value (01:12)
  DD → Day of month value (00:31)
  hh → Hour value (00:24)
  mm → Minute value (00:59)
  ss → Second value (00:59)

- "**gpsLat**": 45.132072,

  Description: Device position latitude coming from GPS module.
  Data type: Decimal number
  Data unit: Angular measure expressed in degrees.
  Data values: 0.0 up to ±90.0

- "**gpsLon**": 7.586638,

  Description: Device position longitude coming from GPS module.
  Data type: Decimal number
  Data unit: Angular measure expressed in degrees.
  Data values: 0.0 up to ±180.0

- "**gpsSat**": 12,

  Description: Number of satellites in view from GPS module / antenna.
  Data type: Integer number
  Data values: 0 up to 99

- "**battVlt**": 8.2,

  Description: Internal battery voltage
  Data type: Decimal number
  Data unit: Volts
  Data values: 0 up to 99.9

- "**supplyVlt**": 14.4,

  Description: Environmental power supply voltage
  Data type: Decimal number
  Data unit: Volts
  Data values: 0 up to 99.9

- "**tempNow**": 28.2,

  Description: Environmental temperature snapshot at acquisition time.
  Data type: Decimal number
  Data unit: Celsius degree
  Data values: -99.9 up to 99.9

- "**tempHigh**": 28.2,

  Description: External temperature highest value between two acquisitions.
  Data type: Decimal number
  Data unit: Celsius degree
  Data values: -99.9 up to 99.9

- "**tempLow**": 28.2,

  Description: Environmental temperature lowest value between two acquisitions.
  Data type: Decimal number
  Data unit: Celsius degree
  Data values: -99.9 up to 99.9

- "**tempAvg**": 28.2,

  Description: Environmental temperature average value between two acquisitions.
  Data type: Decimal number
  Data unit: Celsius degree
  Data values: -99.9 up to 99.9

- "**pressNow**": 983,

  Description: Environmental absolute pressure snapshot value at acquisition time.
  Data type: Integer number
  Data unit: Pressure value in Pascal
  Data values: 0 up to 9999

- "**pressHigh**": 983,

  Description: Environmental absolute pressure highest value between two acquisitions.
  Data type: Integer number
  Data unit: Pressure value in Pascal
  Data values: 0 up to 9999

- "**pressLow**": 983,

  Description: Environmental absolute pressure lowest value between two acquisitions.
  Data type: Integer number
  Data unit: Pressure value in Pascal
  Data values: 0 up to 9999

- "**pressAvg**": 983,

  Description: Environmental absolute pressure average value between two acquisitions.
  Data type: Integer number
  Data unit: Pressure value in Pascal
  Data values: 0 up to 9999

- "**humNow**": 18,

  Description: Environmental relative humidity snapshot value at acquisition time.
  Data type: Integer number

Data unit: Humidity expressed in percentage.
Data values: 0 up to 100

- "**humHigh**": 20,

  Description: Environmental relative humidity highest value between two acquisitions.
  Data type: Integer number
  Data unit: Humidity expressed in percentage.
  Data values: 0 up to 100

- "**humLow**": 16,

  Description: Environmental relative humidity lowest value between two acquisitions.
  Data type: Integer number
  Data unit: Humidity expressed in percentage.
  Data values: 0 up to 100

- "**humAvg**": 18,

  Description: Environmental relative humidity average value between two acquisitions.
  Data type: Integer number
  Data unit: Humidity expressed in percentage.
  Data values: 0 up to 100

- "**windSpdNow**": 1.2,

  Description: Wind speed snapshot value at acquisition time.
  Data type: Decimal number
  Data unit: meter/second
  Data values: 0.0 up to 99.9

- "**windSpdHigh**": 1.6,

  Description: Wind speed highest value between two acquisitions.
  Data type: Decimal number
  Data unit: meter/second
  Data values: 0.0 up to 99.9

- "**windSpdLow**": 0.8,

  Description: Wind speed lowest value between two acquisitions.
  Data type: Decimal number
  Data unit: meter/second
  Data values: 0.0 up to 99.9

- "**windSpdAvg**": 1.1,

  Description: Wind speed average value between two acquisitions.
  Data type: Decimal number
  Data unit: meter/second
  Data values: 0.0 up to 99.9

- "**windDirNow**": 266,

  Description: Wind direction snapshot value at acquisition time.
  Data type: Decimal number
  Data unit: Angular measure expressed in degrees referred to North.
  Data values: 0 up to 359

- "**windDirHigh**": 296,

  Description: Wind direction highest value between two acquisitions.
  Data type: Decimal number
  Data unit: Angular measure expressed in degrees referred to North.
  Data values: 0 up to 359

- "**windDirLow**": 266,

  Description: Wind direction lowest value between two acquisitions.
  Data type: Decimal number
  Data unit: Angular measure expressed in degrees referred to North.
  Data values: 0 up to 359

- "**windDirAvg**": 266,

  Description: Wind direction average value between two acquisitions.
  Data type: Decimal number
  Data unit: Angular measure expressed in degrees referred to North.
  Data values: 0 up to 359

- "**precipNow**": 0,

  Description: Rainfall measurement snapshot value at acquisition time.
  Data type: Decimal number
  Data unit: millimetre/minute
  Resolution: 0.2 millimetre

- "**precipHigh**": 0,

  Description: Rainfall measurement highest value between two acquisitions.
  Data type: Decimal number
  Data unit: millimetre/minute
  Resolution: 0.2 millimetre

- "**precipLow**": 0,

  Description: Rainfall measurement lowest value between two acquisitions.
  Data type: Decimal number
  Data unit: millimetre/minute
  Resolution: 0.2 millimetre

- "**precipAvg**": 0,

  Description: Rainfall measurement average value between two acquisitions.
  Data type: Decimal number
  Data unit: millimetre/hour
  Resolution: 0.2 millimetre

- "**airQltyNow**": 125,

  Description: Environmental air quality snapshot at acquisition time.
  Data type: Decimal number
  Data unit: IAQ
  Data values: Integer number
  Data values: 0 up to 999

- "**airQltyHigh**": 125,

  Description: Environmental air quality highest value between two acquisitions.
  Data type: Decimal number
  Data unit: IAQ
  Data values: Integer number
  Data values: 0 up to 999

- "**airQltyLow**": 119,

  Description: Environmental air quality lowest value between two acquisitions.
  Data type: Decimal number
  Data unit: IAQ
  Data values: Integer number
  Data values: 0 up to 999

- "**airQltyAvg**": 122,

Description:	Environmental air quality average value between two acquisitions.
Data type:	Decimal number
Data unit:	IAQ
Data values:	Integer number
Data values:	0 up to 999

6.4 "PUT" ON THE LEXIS DDI

It was seen so far that the weather station collects environmental magnitudes, performs data validation, computes the metrics, formats data, and transmits to the LEXIS servers in MQTT protocol. In order to accomplish the latter task, the weather station is fitted with a TCP/IP module to provide connection to the Internet. Data is pushed on LEXIS server leveraging a dedicated broker.

A typical transfer rate could be approximatively in one data packet every 5 minutes, but it is possible to increment the transfer rate so as to have the possibility to monitor critical natural events like thunderstorms, hurricanes, floods and so on.

In general, to provide an estimation of the amount of data produced, it is necessary to take into account four key aspects:

- The number of deployed gateways,
- The number of physical magnitudes (i.e. different sensors) acquired by the sensor node,
- The transfer rate at which each gateway will put the data on the server (after the validation and formatting phases),
- The size of a single packet.

Considering those four parameters, Table 11 and Table 12 estimate the amount of data produced according to the several gateways & transfer rates combinations.

10, 20 and 50 were considered as possible number of gateways to be initially deployed. 1, 2.5 and 5 minutes were taken into account as possible transfer rates. The number of physical magnitudes for each unit has been set to a 5, while it has been considered a size of 1.5kB for each packet produced by each of them. Table 11 "Amount of data per hour" estimates the amount of data (expressed in kB) produced by the system in one hour while Table 12 "Amount of data per day" shows the amount of data (expressed in MB) produced per day.

DATA PER HOUR (KB)			
	TRANSMISSION RATE (MIN)		
NUM. OF WEATHER STATIONS	1	2.5	5
1	450	180	90
10	4,500	1,800	900
20	9,000	3,600	1,800
50	22,500	9,000	4,500

Table 11 - Amount of Data Produced per Hour

DATA PER DAY (MB)			
	TRANSMISSION RATE (MIN)		
NUM OF WEATHER STATIONS	1	2.5	5
1	10.55	4.22	2.11
10	105.47	42.19	21.09
20	210.94	84.38	42.19
50	527.34	210.94	105.47

Table 12 - Amount of Data Produced per Day

The tables above refer to the acquisition of meteorological magnitudes only. Considering also the possibility to extend the dataset to other measurements, the size of a single packet might increase the amount of data previously reported.

The weather stations that were deployed were configured for a stress-test data rate that was set as low as 20 seconds.

7 TESTING AND VALIDATION

7.1 HARDWARE IN THE LOOP

In order to test and consolidate both the hardware and firmware metering of wind speed, wind direction and rainfall, the necessity for a hardware simulator arose. The need was to test the system for the correctness of its operation all over the measurement range.

For this reason, a Multifunction DAQ from National Instruments (see Figure 65, bottom left) was used to provide the output signals to simulate the weather instruments and a Labview application (see Figure 66) was designed to implement their behaviour as previously described in Sections 3.3.3, 5.6 and 5.7, through a set of parametrizable counters.

Figure 65 - The weather station and the USB-6366 Multifunction DAQ

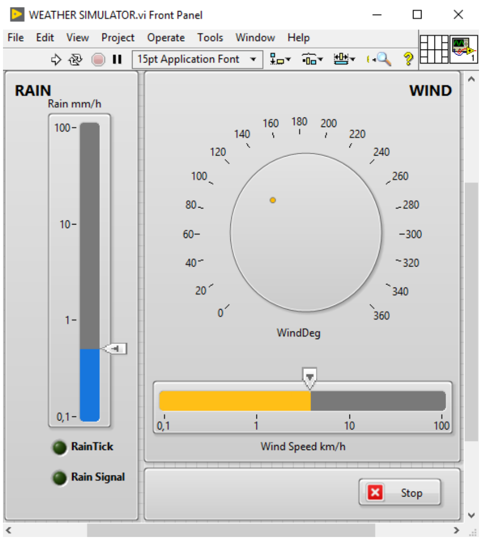

Figure 66 - Labview weather simulator control panel

7.2 TEMPERATURE OFFSET CALIBRATION

Despite the BME680 air sensor that was used in the weather station comes as factory calibrated component, it was worth to verify its acquisition accuracy and evaluate the presence of eventual offsets to be corrected by comparing its readings with whose of a traced-calibration reference laboratory thermometer. Contextually, the climatic chamber session was useful to test the unit to perform correctly under extreme hot and cold temperatures.

Figure 67 - The weather station into the climatic chamber at TESEO premises

The tests proved that the unit operates correctly in a range from -35°C to +85°C.

The comparison of the temperature readings between the weather station showed that in a range from -30°C to 60°C there, was an offset that ranged from +1.80°C to +2.25°C. Consequently, the firmware was set to correct for an offset of -2.0°C allowing an absolute error of +/- 0.4°C over the unsaid measurement range.

7.3 INFLUXDB DEBUG DASHBOARD

InfluxDB is an open source web-based data and metrics visualization software. It allows to explore, query, and visualize data and metrics. It provides tools to turn a time-series database data into graphs and visualizations.

A dedicated test dashboard was set in place for the weather stations. Main information is displayed in an intuitive and attractive appearance. This tool was precious for debug purposes, however at this stage, the access to the InfluxDB interface is reserved and available only via LEXIS developer VPN.

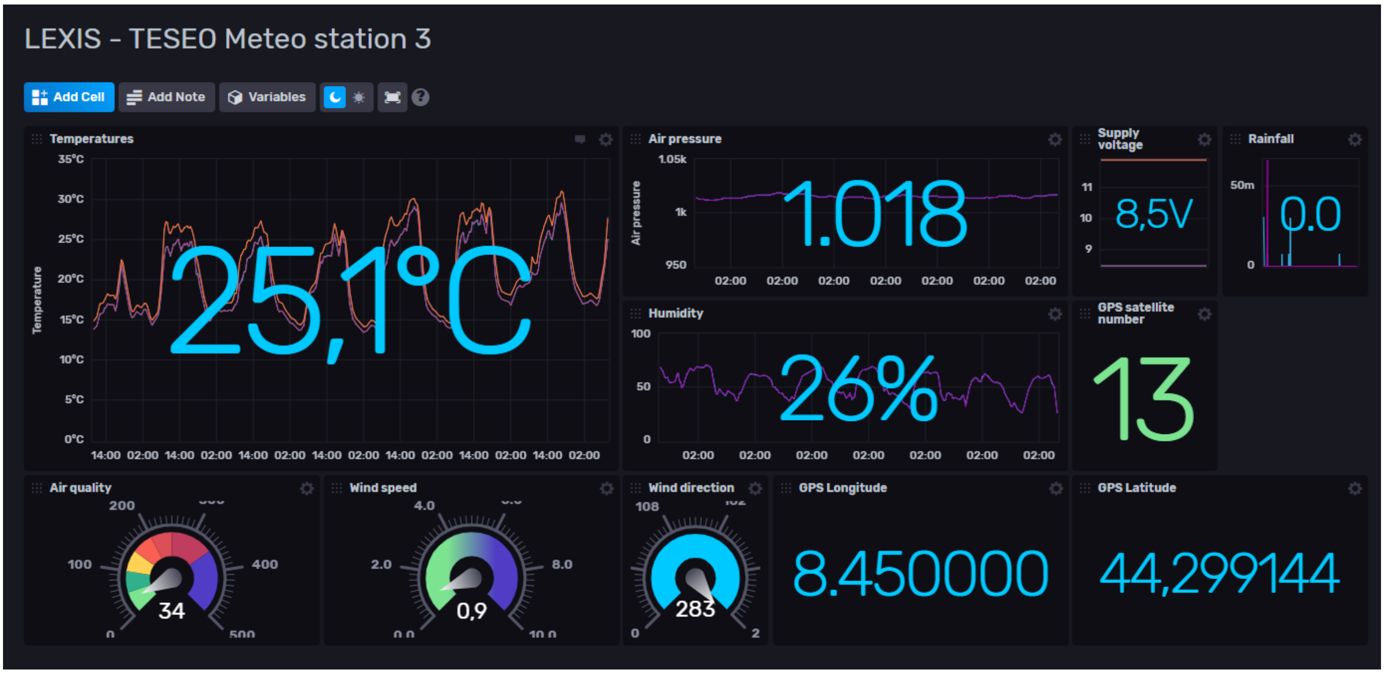

Figure 68 - InfluxDB Meteo Station 3 view

The main data visualised are external and internal air temperature, atmospheric pressure, and humidity.

The interface also displays wind magnitudes such as speed and direction; it reports rainfall intensity, air quality index, geo-localization of the unit, number of satellites in view and power status of the unit. The entire data bucket can be displayed in raw format.

“Meteo Station 3” shown in Figure 69 is operating in Savona (IT) on the rooftop of CIMA Foundation building. The snapshot that was taken on 30/05/2021 at 9:40 shows 7 day data readings.

8 ON FIELD INSTALLATION

8.1 INSTALLATION AT TESEO PREMISES

A specimen of the weather station was installed at the TESEO premises in Druento, Italy, on March the 2nd 2021. The mast was secured to the fire escape stairway.

Because the facility makes available both electric power and internet connection, the unit was powered with an AC/DC power supply and connected to the Cloud through its RJ45 ethernet port.

Figure 69 - Weather station installed at TESEO premises

Because the unit is placed between adjacent buildings, it was not possible to get an accurate measurement of both wind speed and direction.

For this reason, the wind sensor was detached from the unit and installed on top of the stair leading to the roof where it is clear from obstacles in all directions.

The unit installed at the TESEO premises is labelled as “Meteo Station 5” on the INFLUXDB.

Figure 70 - Wind sensor installation

The rain gauge installation is less critical. The gauge was placed on fire escape floor.

Figure 71 - Rain gauge installation

The function of the weather station was monitored within 30 days from the installation. The firmware was consolidated with minor adjustments and bug-fixing before releasing a second specimen to be installed at the CIMA premises.

8.2 INSTALLATION AT CIMA PREMISES

The installation at the CIMA premises in Savona, Italy, was performed on May the 20th 2021.

The unit was placed on building roof where other weather stations and related equipment are placed.

Figure 72 - Installation at the CIMA premises

Since the roof is cleared from obstacles all around the weather station was installed with the wind sensor on the main body and rain gauge was installed on the same mast.

Because the facility makes available both electric power and internet connection, the unit was powered with an AC/DC power supply and connected to the Cloud through its RJ45 ethernet port.

The unit installed at the CIMA Foundation premises is labelled as “Meteo Station 3” on the INFLUXDB.

9 CONCLUSIONS

The weather station that was presented in this deliverable as an engineered and ready for manufacturing unit, has demonstrated how an IoT based design can be the bridge between a very specific instrument and a multi-purpose HPC/Cloud infrastructure.

In fact, the magnitudes are acquired, validated, and pre-processed on board the unit and sent to the HPC/Cloud as trusted data through a MQTT protocol over a TCP/IT wireless or even wired link. This deliverable has also demonstrated the flexibility of such technological arrangement and its ability to be scalable and easy to upgrade (i.e. adding additional sensors for additional physical magnitudes).

When taking into account the specificities of the WP7 "Weather and Climate Large-scale Pilot" into the overall LEXIS Project, the ease of installation and commissioning, data capture and submission allows the deployment of a multitude of units for the highest acquisition density. On the other hand, the HPC/Cloud infrastructure allows the submission and management of such a great amount of data.

REFERENCES

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