MULTISCALE SENSING FOR DISEASE MONITORING IN VINEYARD PRODUCTION

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EUROPEAN CONSORTIUM

- A system for identification the vine disease is developed in France, Romania and Grece
- INSTITUT NATIONAL DES SCIENCES APPLIQUEES CENTRE VAL DE LOIRE – France
- CONSTANTA MARITIME UNIVERSITY-Romania
- RESEARCH STATION FOR VITICULTURE AND OENOLOGY MURFATLAR-Romania
- UNIVERSITY OF WEST ATTICA-Greece
- INSTITUT FRANCAIS DE LA VIGNE ET DU VIN – France
- ATOS-France

GENERAL OBJECTIVES

- Vine disease is a major risk for viticulture, involving economic loss, yield quality reduction and environmental impact when using chemicals treatments.
- MERIAVINO project advocates a multidisciplinary approach, which is based on several scientific fields to address the problem of disease and yield estimation in vineyard.
- The environment parameters are used for the vines disease identification for prevention and control the plant growth.
- The proposed multi-scale methodology consists of inter-combining and implementing IoT, remote sensing and big data in order to interconnect the vineyard parcels, as well as to develop a non-invasive, eco-friendly and low-cost technology for vine disease detection/warning.

MAIN HYPOTHESIS

- Multiscale sensing approach and heterogeneous data from vineyards in different countries will enable to develop robust decision tools based on AI through:
- H1: Intelligent acquisition methods and processing of Big Data by using dedicated software towards improving production efficiency and operating costs.
- H2: Machine Learning approach for finding data patterns enables earlier detection of the vine diseases, and the estimation of yield quality and quantity.
- H3: Earlier disease detection will help winegrowers to reduce phytosanitary chemicals.

CMU - FINANCIAL INFORMATION

- **Project code: COFUND-ICT-AGRI-FOOD-MERIAVINO-1**
- **Project title:** Multiscale Sensing for Disease Monitoring in Vineyard Production
- **Acronym:** MERIAVINO
- **Funding:** state budget
- **PN III Program name:** European and International Cooperation – Subprogram 3.2 – Horizon 2020
- **Project type:** ERANET
- **Realization period:** 02/12/2020 – 02/12/2023
- **Contract duration:** 36 months
- **Total contract value:** 633.100,00 lei / 130.000,00 Euro

MERIAVINO

SPECIFIC OBJECTIVES

The objective is to supervise daily processes using multi-sensing and Agriculture Internet of Things (AIoT) devices in order to interconnect the vineyard parcels, as well as to develop a non-invasive, eco-friendly and low-cost technology for vineyard monitoring, allowing high precision analysis.

IoT system design and implementation to detect the vine disease

↓

Data storage in FOG and cloud

↓

Big Data analysis to identify and prevent the vine disease

STAGE 1: ORGANIZATION OF PROJECT TASKS AND PREPARATION OF PRACTICAL IMPLEMENTATION

Activity 1.1: Organization of the project
Activity 1.2: Establishment of microbiological protocols
Activity 1.3: Acquisition and deployment of IoT sensors
Activity 1.4: Preliminary acquisition of data and setting the conditions for the security of their transfer
Activity 1.5: Setting requirements for datasets used in training Machine Learning algorithms
Activity 1.6: Correlation of results between partners and the Phase I report dissemination of results

STAGE 2: ACQUISITION AND PROCESSING OF EXPERIMENTAL DATA

- Activity 2.1: Organization of Phase II of the project
- Activity 2.2: Implementing IoT sensor networks and establishing in-situ data communication
- Activity 2.3: Acquisition of data and ensuring the security of their transfer
- Activity2.4: Testing selected machine learning models of data
- Activity 2.5: Evaluation and exploitation of results
- Activity 2.6: Correlation of results between partners and the Step 2 report. Dissemination of results

STAGE 3: IOT PLATFORM INTEGRATION AND TESTING. OPTIMISATION OF ACQUISITION, PROCESSING AND COMMUNICATION OF EXPERIMENTAL DATA

- Activity 3.1: Organization of Phase III of the project
- Activity 3.2: Testing the system in real conditions
- Activity 3.3: Testing selected Machine Learning models of data
- Activity 3.4: Evaluation and exploitation of results
- Activity 3.5: Final Report

SPECIFIC ESTIMATED RESULTS

Monitoring the vines using IoT technology in the field of Research Station for Viticulture and Oenology Murfatlar, Romania

- implementation of IoT sensors in situ;
- building a network of IoT sensors;
- saving data in Cloud / FOG;
- data security testing;
- develop the models for data processing in the cloud;
- process and evaluation of collected data;
- testing the chosen models on the acquired data in situ;

- Correlation of results between partners
- Publishing the results in journals, proceeding conferences and applying for a patent
- Annual reports at the end of the stage.

THE EXPERIMENTAL DESCRIPTION

- The aim is to identify the vine disease and prevent them in three untreated plots of Murfatlar vineyard using intelligent sensors.
- For the assessment of diseases, weekly observations were carried out on the installment of the following diseases:
  - Downy mildew – Plasmopara viticola
  - Powdery mildew – Uncinula necator
  - Gray rot – Botrytis cinerea
- In the first stage of the experimental part we implement a standard sensors kits based on the IoT technology and the results are compared with data acquired with the classical method.
- In order to extend the number of parameters measured and acquired from the vineyard it is developed a second network, consisting of two Nodes sending data to the FOG/cloud.

IMPLEMENTATION

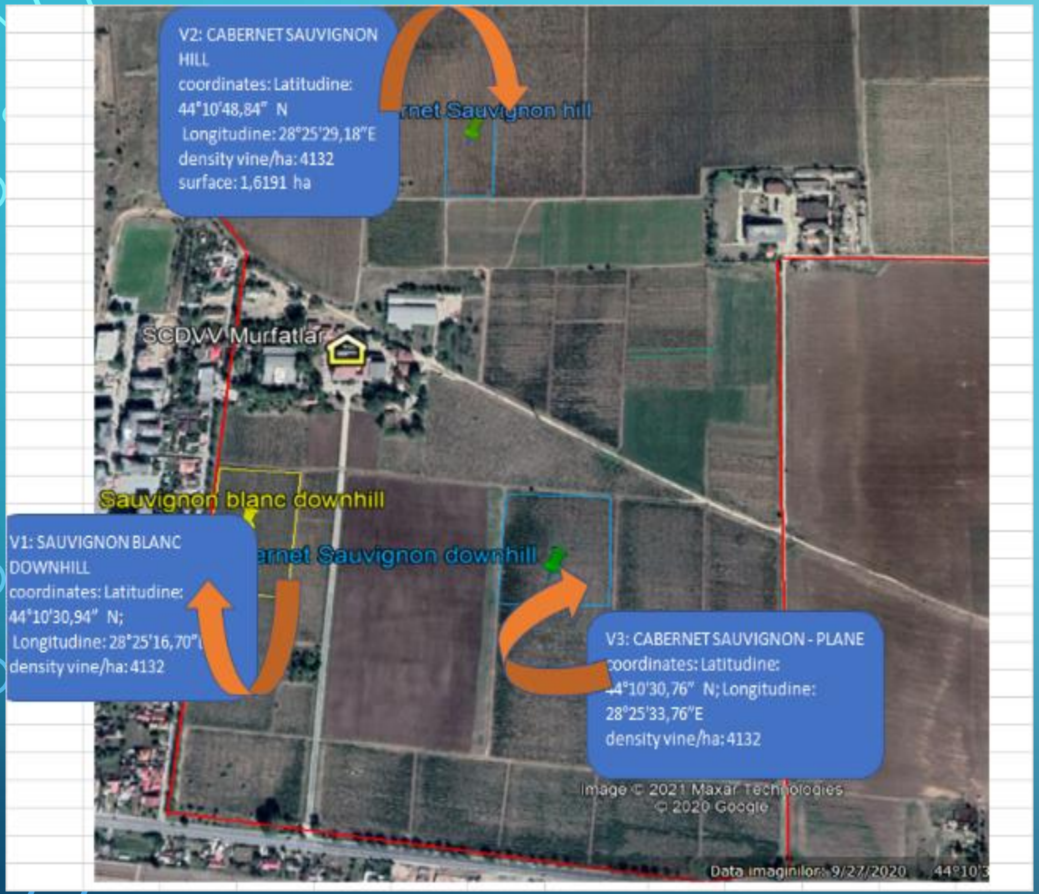


Fig.1.Three Murfatlar plots with Cabernet Sauvignon and Sauvignon Blanc

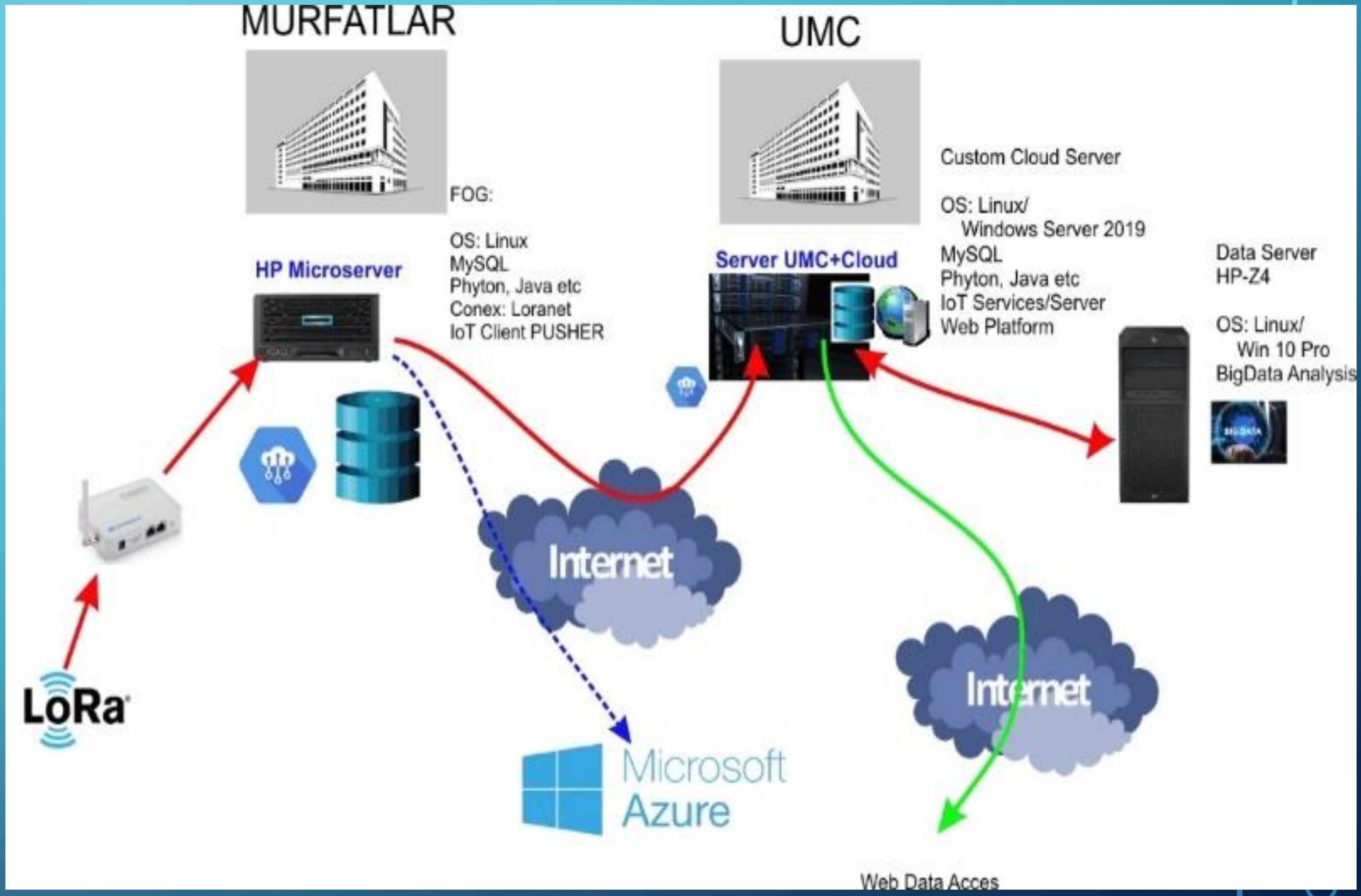
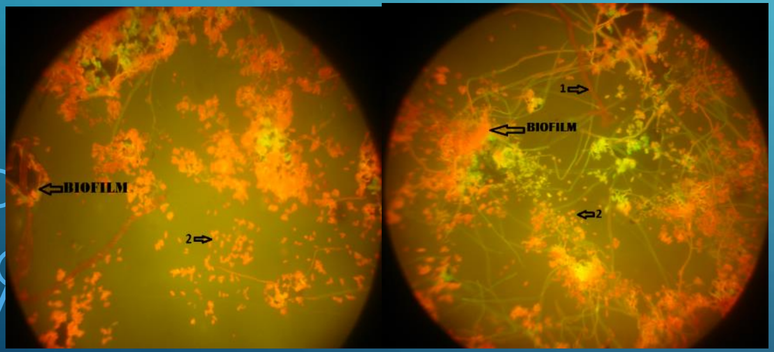


Fig. 2. Data communication

CLASSICAL METHODS
SVM MURFATLAR

- An agronomic protocol is elaborated by SVM Murfatlar in order to gather information on the health of the grapevine, which included disease monitoring and plant physiology determinations, namely stomatal conductance and leaf relative chlorophyll content.
- A Steady state porometer is used to determine the stomatal conductance and a SPAD 502 Plus chlorophyll meter is used to perform the chlorophyll measurements.
- The measurements are achived on 10 leaves are analyzed, measuring values on 10 distinct points for each of them.
- The data collected with classical methods are compared with sensors data.

- Images will be taken with a digital camera (Sony DSC-P200, 7.2 megapixels);
- automatic image analysis using the CellC cell counting software and the Image J software for cell



Biofilms formed on vine leaves

EXPERIMENTAL PLOT 1					
leaf at the base of the stem					
		Untreated		Treat	
		abaxial	adaxial	abaxial	adaxial
square 1	No. Cells/cm^2				
	Bacterial cells				
	Fungal structures				
square 2	No. Cells/cm^2				
	Bacterial cells				
	Fungal structures				
square 3	No. Cells/cm^2				
	Bacterial cells				
	Fungal structures				
the leaf in the middle of the stem					
		Untreated		Treat	
		abaxial	adaxial	abaxial	adaxial
square 1	No. Cells/cm^2				
	Bacterial cells				
	Fungal structures				
square 2	No. Cells/cm^2				
	Bacterial cells				
	Fungal structures				
square3	No. Cells/cm^2				
	Bacterial cells				
	Fungal structures				
the leaf at the top of the stem					
		Untreated		Treat	
		abaxial	adaxial	abaxial	adaxial
square 1	No. Cells/cm^2				
	Bacterial cells				
	Fungal structures				
square 2	No. Cells/cm^2				
	Bacterial cells				
	Fungal structures				
square3	No. Cells/cm^2				
	Bacterial cells				
	Fungal structures				
EXPERIMENTAL PLOT 2					
…					
EXPERIMENTAL PLOT 3					
…					

STANDARD IOT SYSTEM
SYSTEM DESCRIPTION

- The first IoT systems are implemented to Murfatlar vineyard in April 2021
  - The kit IoT (by ICT International +cloud AZURE)
    - The standard kit contains the following sensors: air temperature and humidity sensor; solar radiation sensor; leaf humidity sensor; sap flow meter; soil temperature and humidity sensor; soil oxygen sensor.

STANDARD IOT SYSTEM

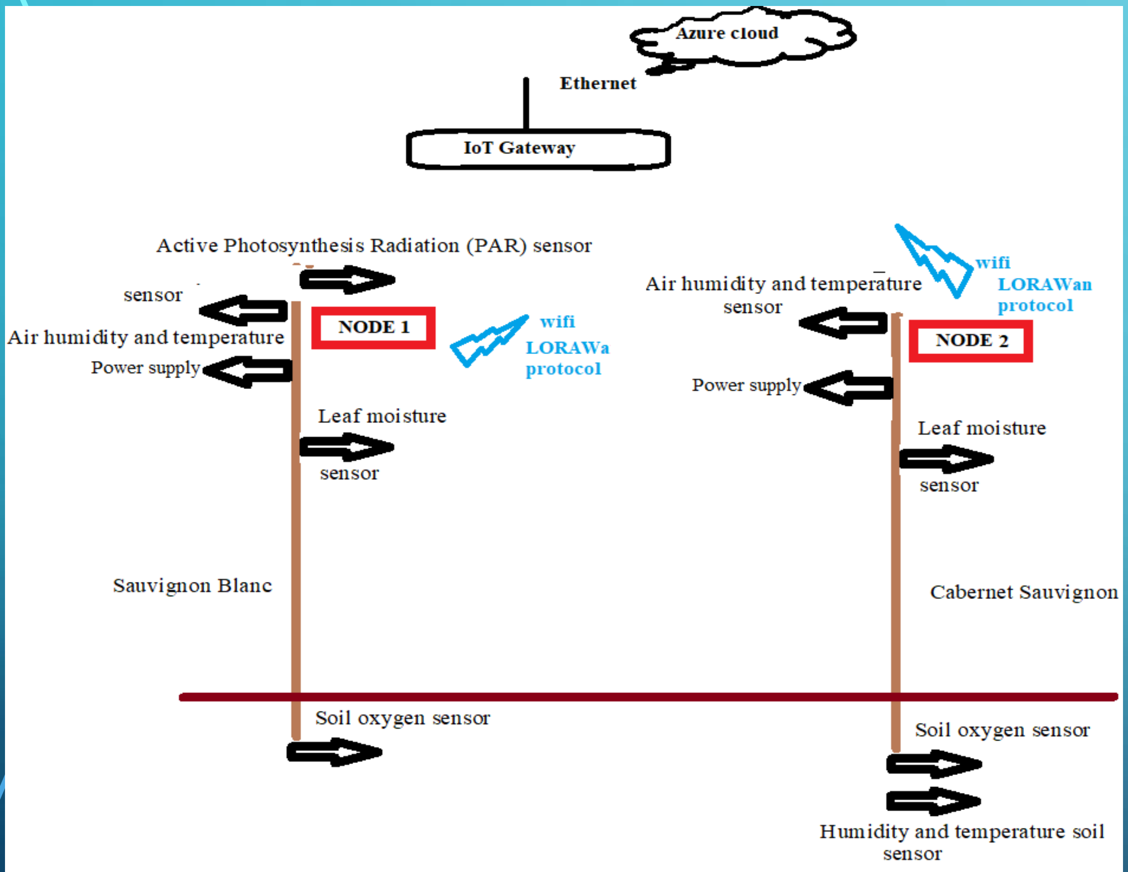


Fig. 3. Data Sensors transmission

Fig. 4. IoT sensors kit

SYSTEM DESCRIPTION-CLOUD AZURE

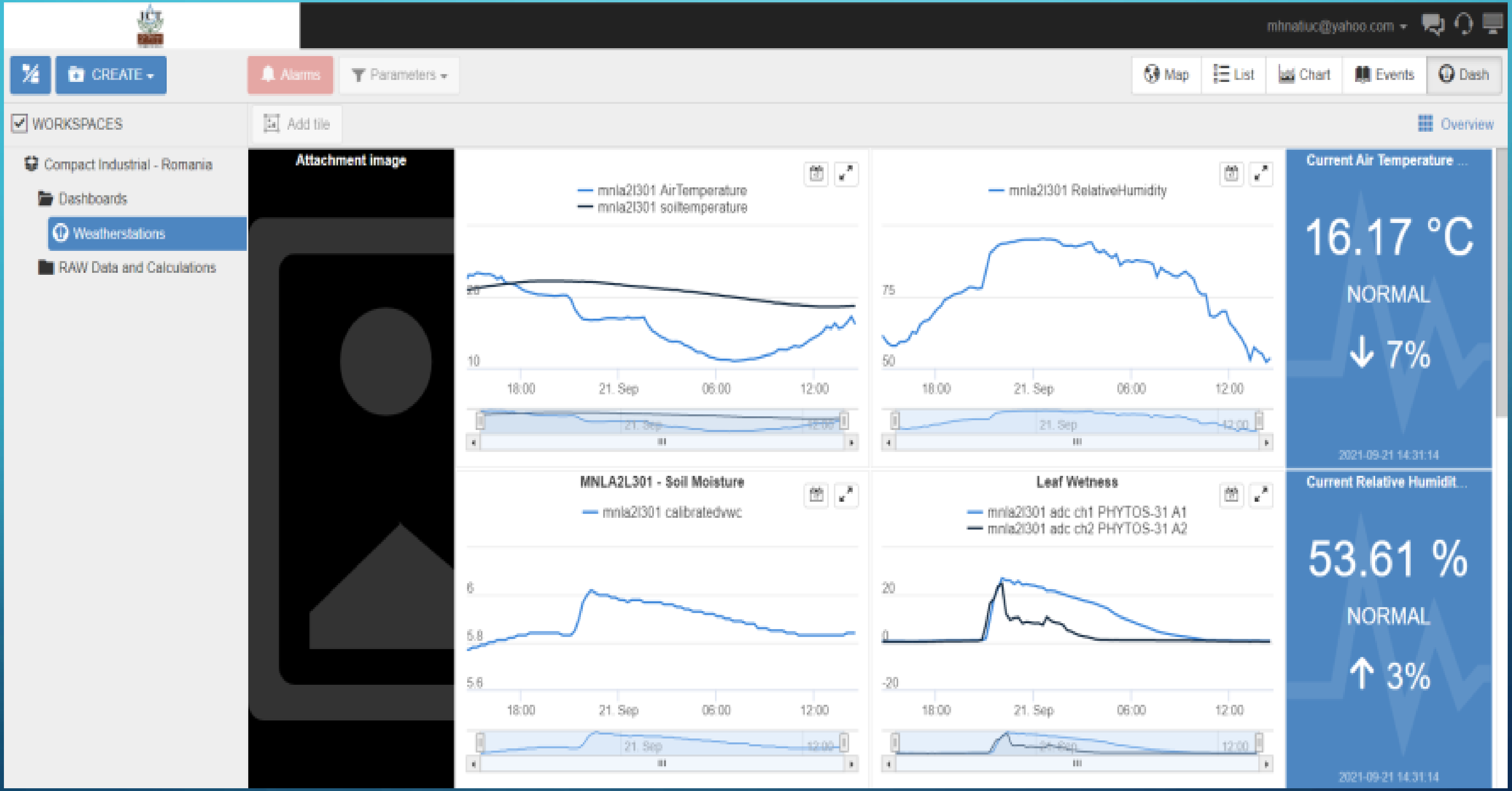


Fig.5. Data representation on the cloud AZURE

IOT SYSTEM DEVELOPED IN CMU LABORATORY

Node	Sensor	Measured parameter	Con-nec-tivity	Units	Accuracy
1	TEROS-12	soil moisture, temperature and electrical conductivity	SDI-12	m^3/m^3, °C, mS/cm	3 %
1	SQ-521	photosynthetically active radiation	SDI-12	μmol m^{-2} s^{-1}	5 %
1	SO-411	soil oxygen	SDI-12	%	3 %
1	SP-421	solar irradiance	SDI-12	W/m^2	3 %
1	ATMOS-41	solar irradiance, precipitation, lightning strike, wind speed, gust and direction, barometric pressure, vapor pressure, relative humidity, air temperature	SDI-12	W/m^2, mm, strikes, m/s, m/s, degrees, kPa, kPa, %, °C	5 %
1	NPK	soil pH, soil temperature, soil humidity, soil nitrogen, phosphorus, and potassium content	CAN Bus	pH, °C, %, mg/Kg	2 %
1	PHYTOS-31	leaf humidity	analog voltage	%	unstated
2	MLX 90614	infrared temperature	I2C	°C	0.5 °C
2	BME 680	volatile organic compounds (VOC), relative humidity, air temperature, barometric pressure	I2C/SPI	ppm, %, °C, kPa	15 %
2	DS18B20	soil temperature at 5 different depths	1-Wire	°C	0.5 %
2	SCD30	carbon dioxide (CO_2)	I2C	ppm	3 %
2	Rain drops grid	rain drops	analog voltage	%	unstated
2	Capaci-tive soil moisture sensor	soil moisture	analog voltage	%	unstated
2	AS7265x	leaf color (spectroscopy)	I2C		12 %

IOT SYSTEM DEVELOPED IN CMU LABORATORY

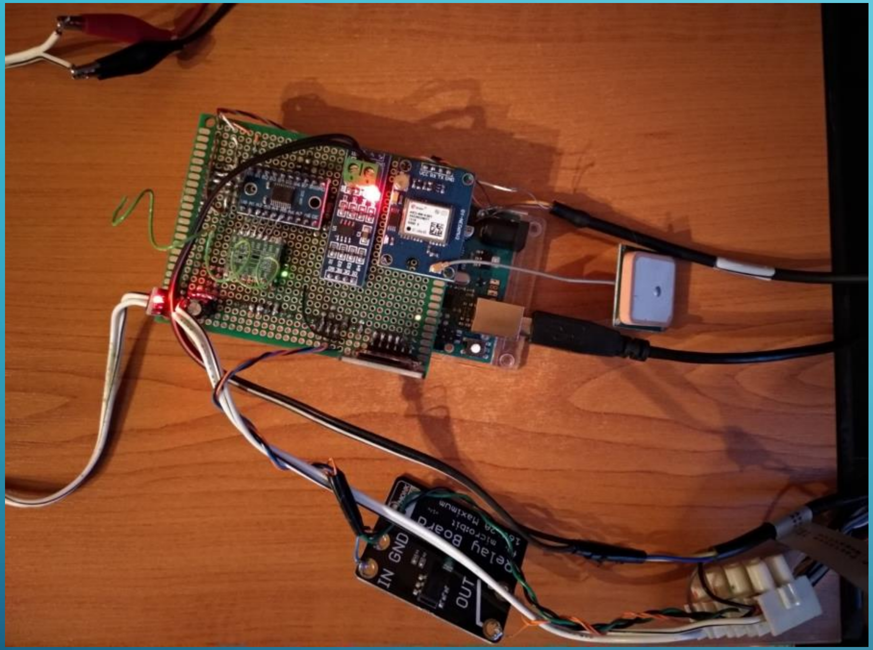


Fig.6. Gatway implemented in laboratory

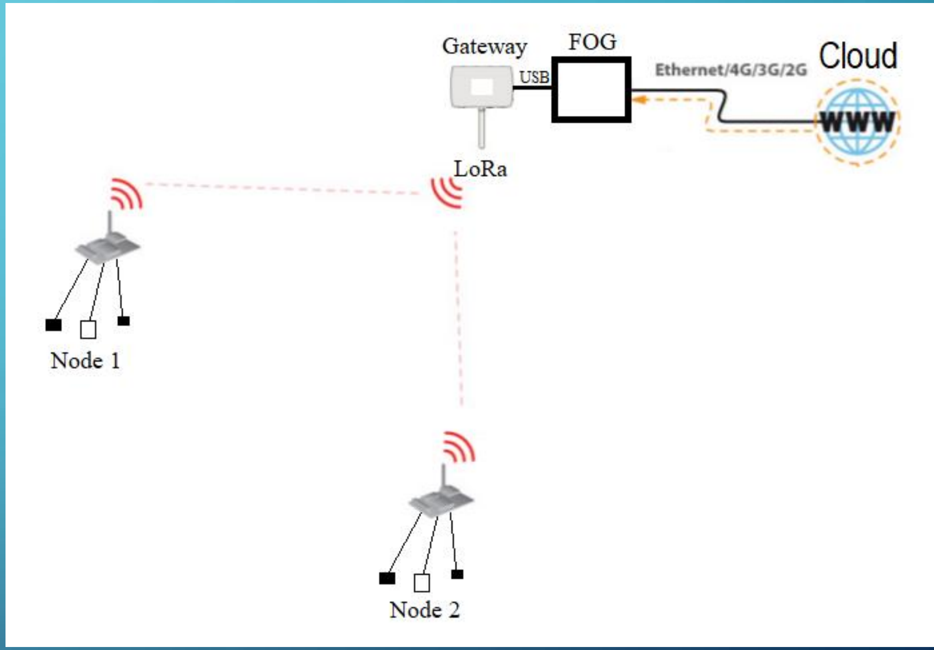


Fig.7. The IoT system block diagram implemented in laboratory

MERIAVINO

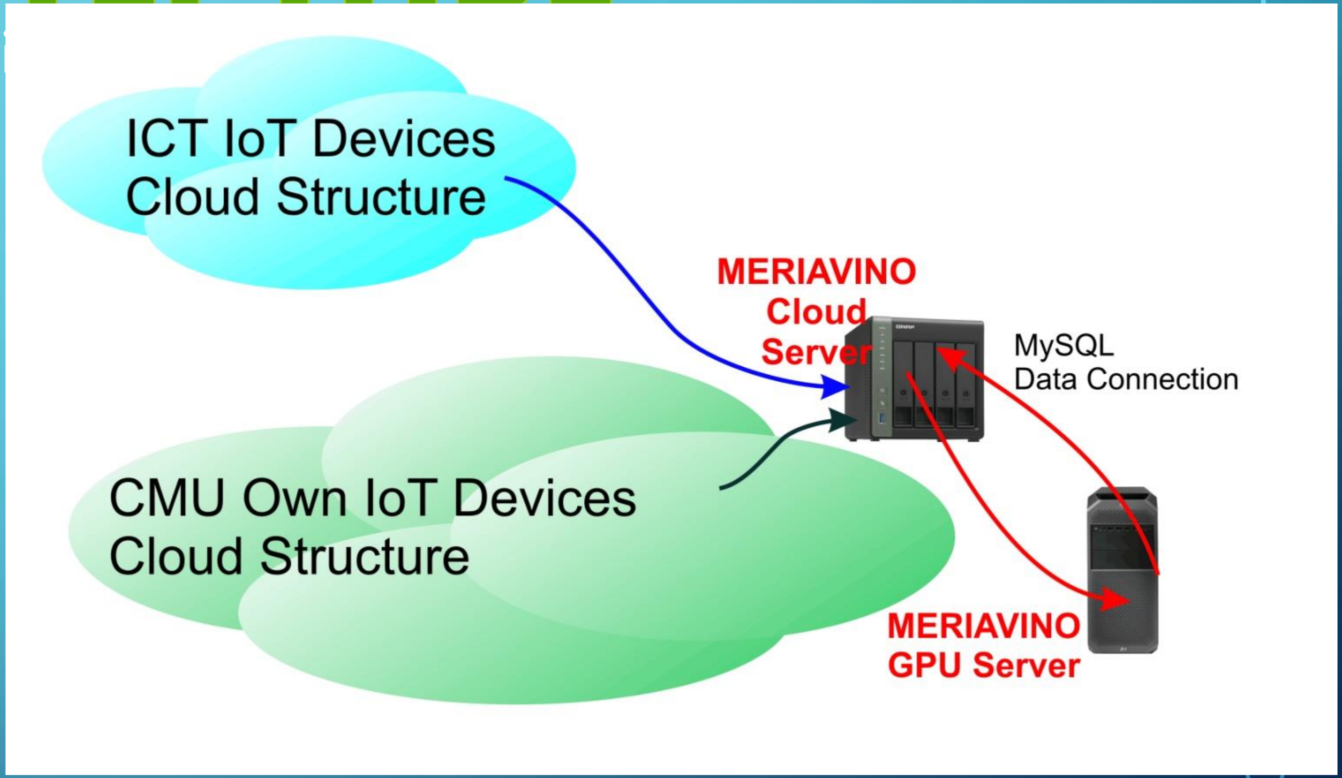
IOT SYSTEM IMPLEMENTENTED ON THE MURFATLAR VINEYARD 03.08.2022

MERIAVINO SYSTEM ARCHITECTURE

We have implemented two integrated linked IoT cloud systems:

- IoT cloud data network based on ICT devi

-CMU cloud data network based on our developed and produced devices



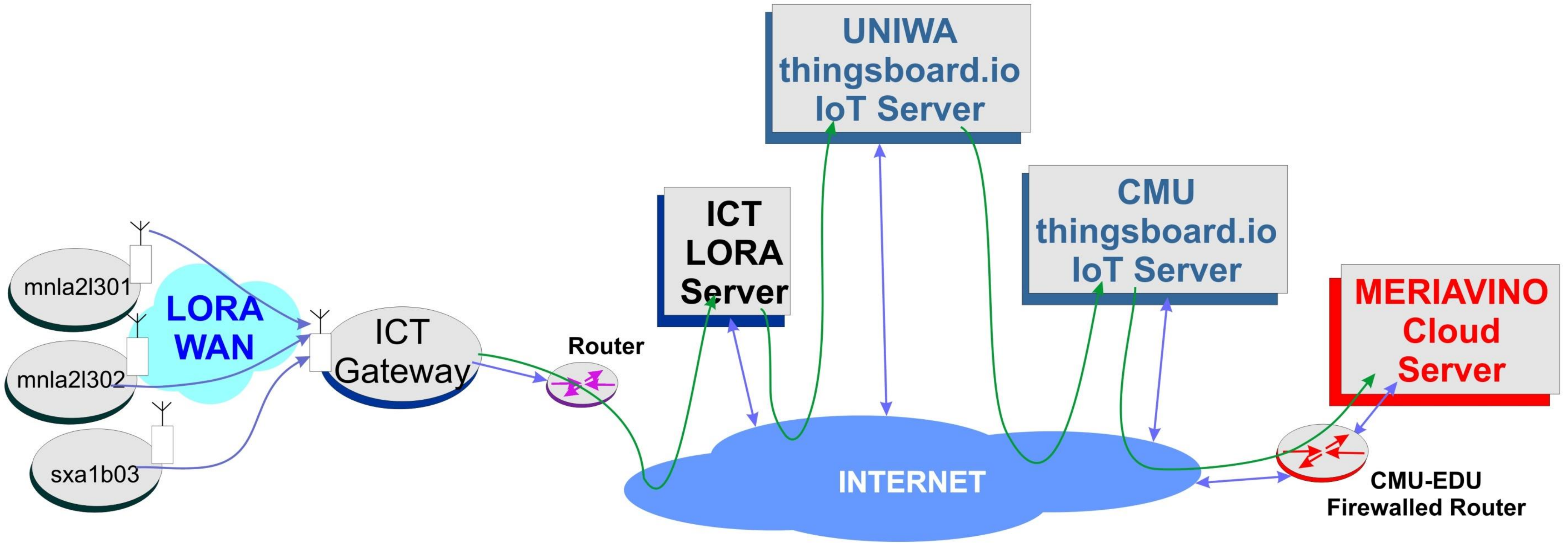
The both networks has similar structure. The difference between them is consists of equipment and some implementation techniques.

Finally, data acquired from the both networks are concentrated on one server, where they are analyzed and compared.

MERIAVINO ICT ARCHITECTURE

- Data acquisition
  - ICT IoT NODES
- Data transfer
  - ICT Gateway
  - ICT Lora Server
  - UNIWA thingsboard.io Server
- Centralized Cloud Server
  - CMU thingsboard.io Server
  - Meriavino CLOUD Server

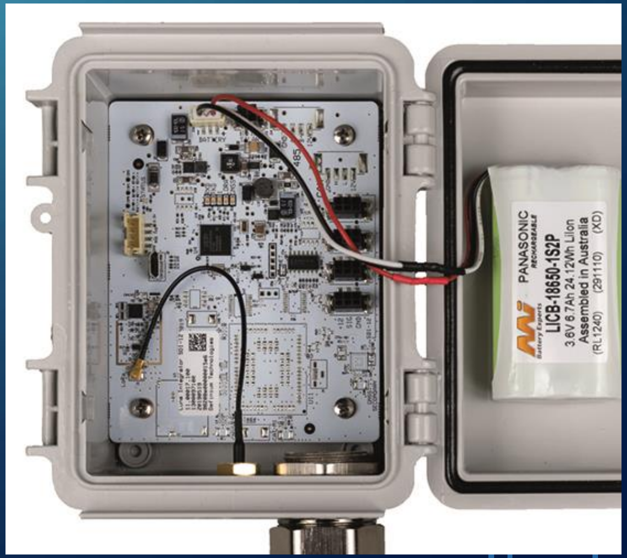
ICT ARCHITECTURE on MERIAVINO Project



ICT NODEs

- Node
  - We configure 3 Lora IoT nodes
  - Two (2) nodes are ICT node general nodes and one is SAP Node
  - They are powered from solar panel with backup battery
  - The nodes are connected with a ICT gateway over LORA WAN Network

  - Nodes send data to Gateway in JSON data format over encrypted communciation protocol
  - Each node have a unique ID
  - Data are sent at regular time intervals (15 minutes)
  - Each acquired sensor has a name in communication data frame



ICT GATEWAY

- Gateway
  - The ICT System uses one ICT Gateway
  - The Gateway connects LORA Network Nodes with ICT LORA over Internet Communication Protocol
  - The Gateway is installed locally on SCDA Murfatlar
  - It is powered locally

  - It operates like a [FIFO] pipe for data received from LORA NET and it delivered over Internet Protocol to ICT LORA Server

ICT LORA Server

- LORA Server
  - The system uses ICT Lora Server
  - It is installed and configured by ICT
  - Transport of data is based on MQTT protocol and data packets are based on JSON data format

- Initially it received data from LORA nodes and send them IoT Azure Cloud

- Actually the **data received from LORA nodes are send the data to UNIWA thingsboard.io IoT server**

UNIWA thingsboard.io Server

- UNIWA thingsboard.io
  - This platform is installed and configured by our Greece colleagues from West Attika University (UNIWA)
  - The server gets data from ICT LORA Server and push them to CMU thingsboard.io Server. This task is implemented using a servlet installed on UNIWA thingsboard.io server. Servlet is developed, created, installed and configured by our Greece colleagues from UNIWA.

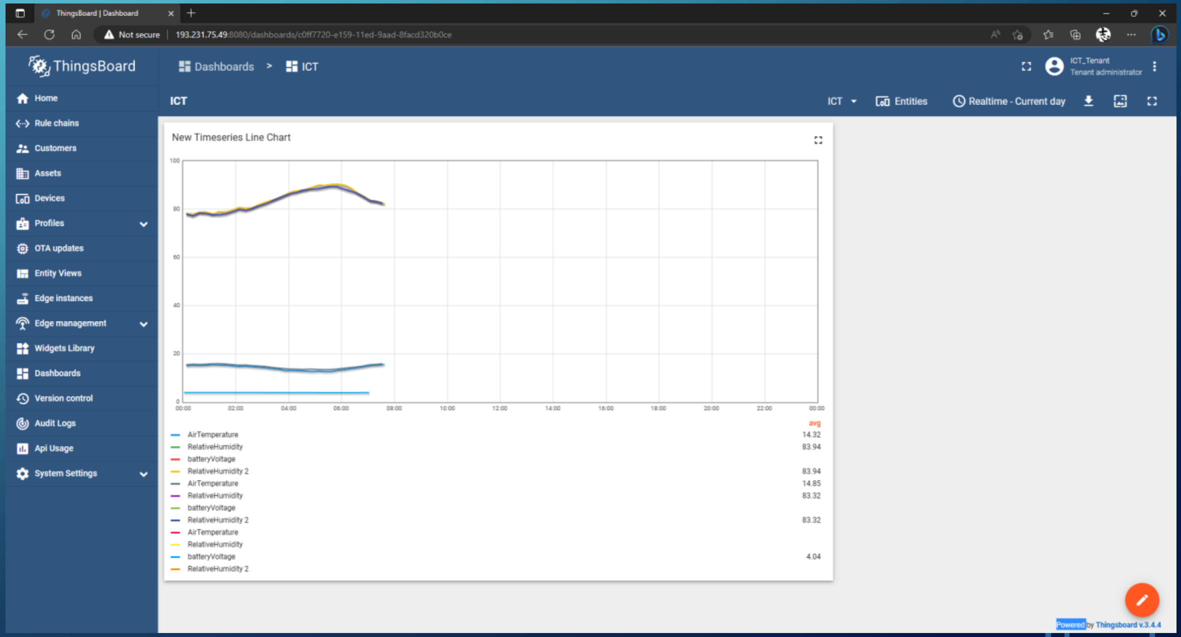
ThingsBoard

Azure Stack

CMU thingsboard.io

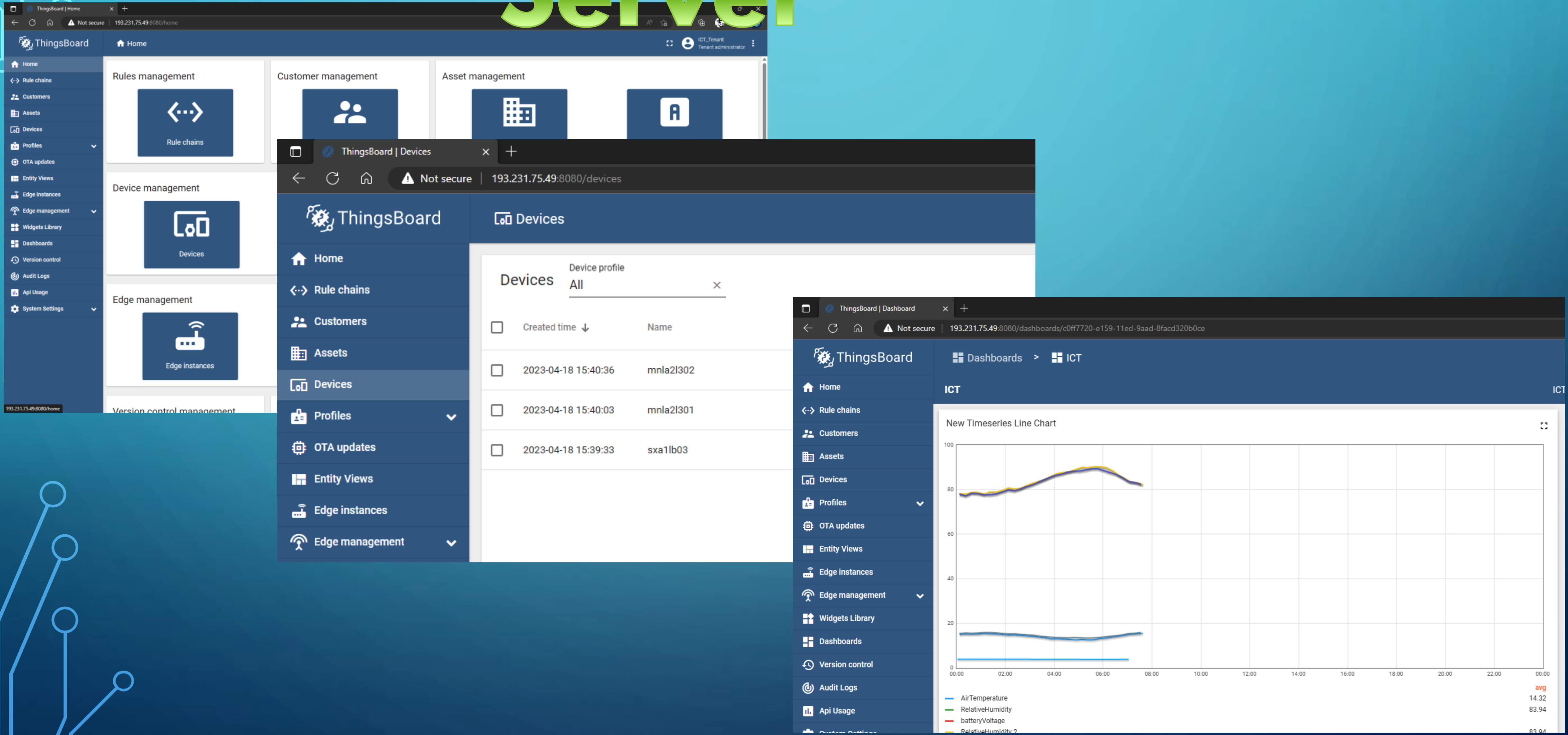
ThingsBoard

- CMU thingsboard.io **Server**
  - This platform is installed and configured by our CMU colleagues from Constanta Maritime University (CMU)
  - The server is installed on Linux Ubuntu 20.04 LTS operating system in a virtual machine located in CMU Azure Stack Server.
  - The server received data from UNIWA thingsboard.io Server and store them locally to be analyzed and presented.



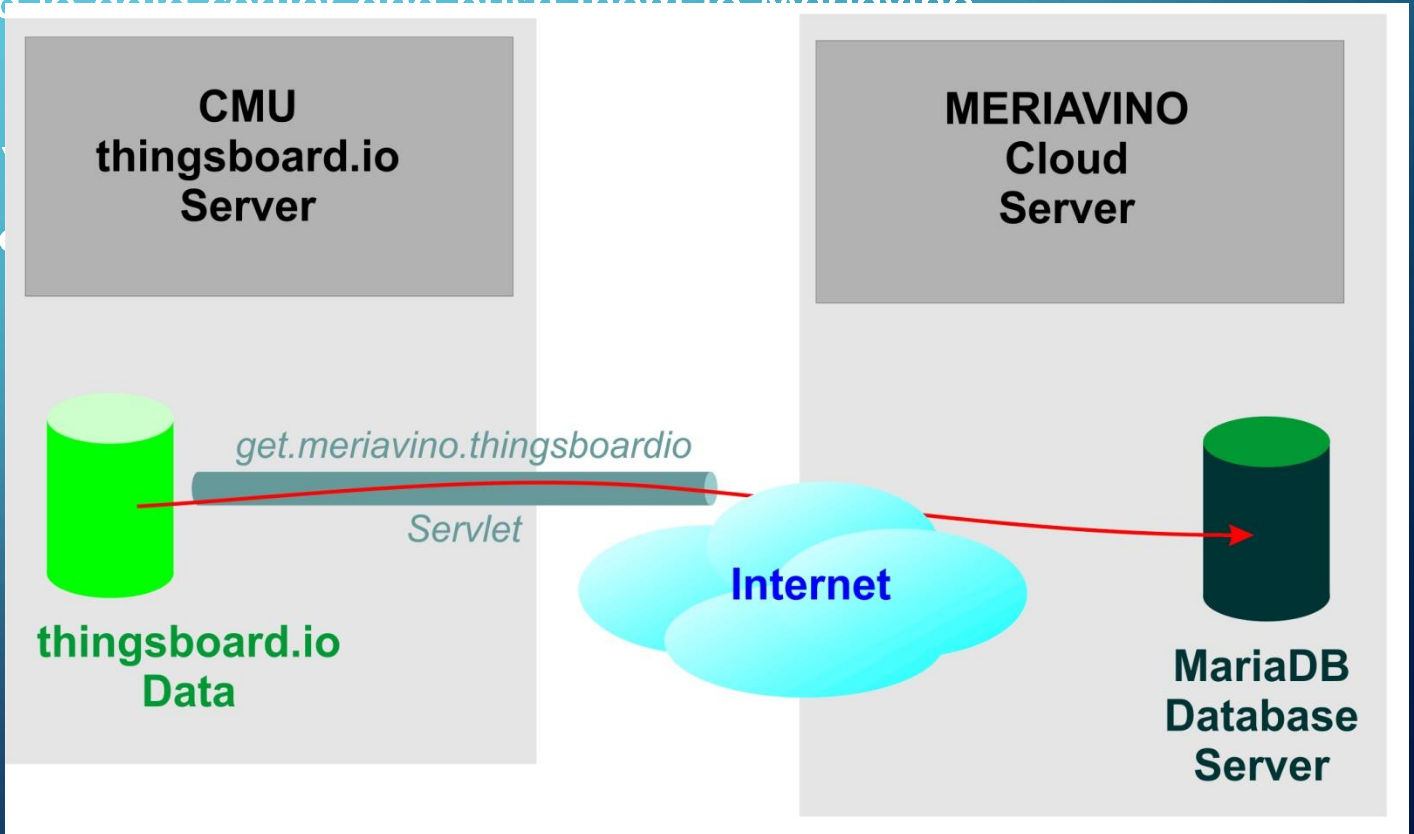
CMU thingsboard.io

- CMU thingsboard.io Server



CMU thingsboard.io Server

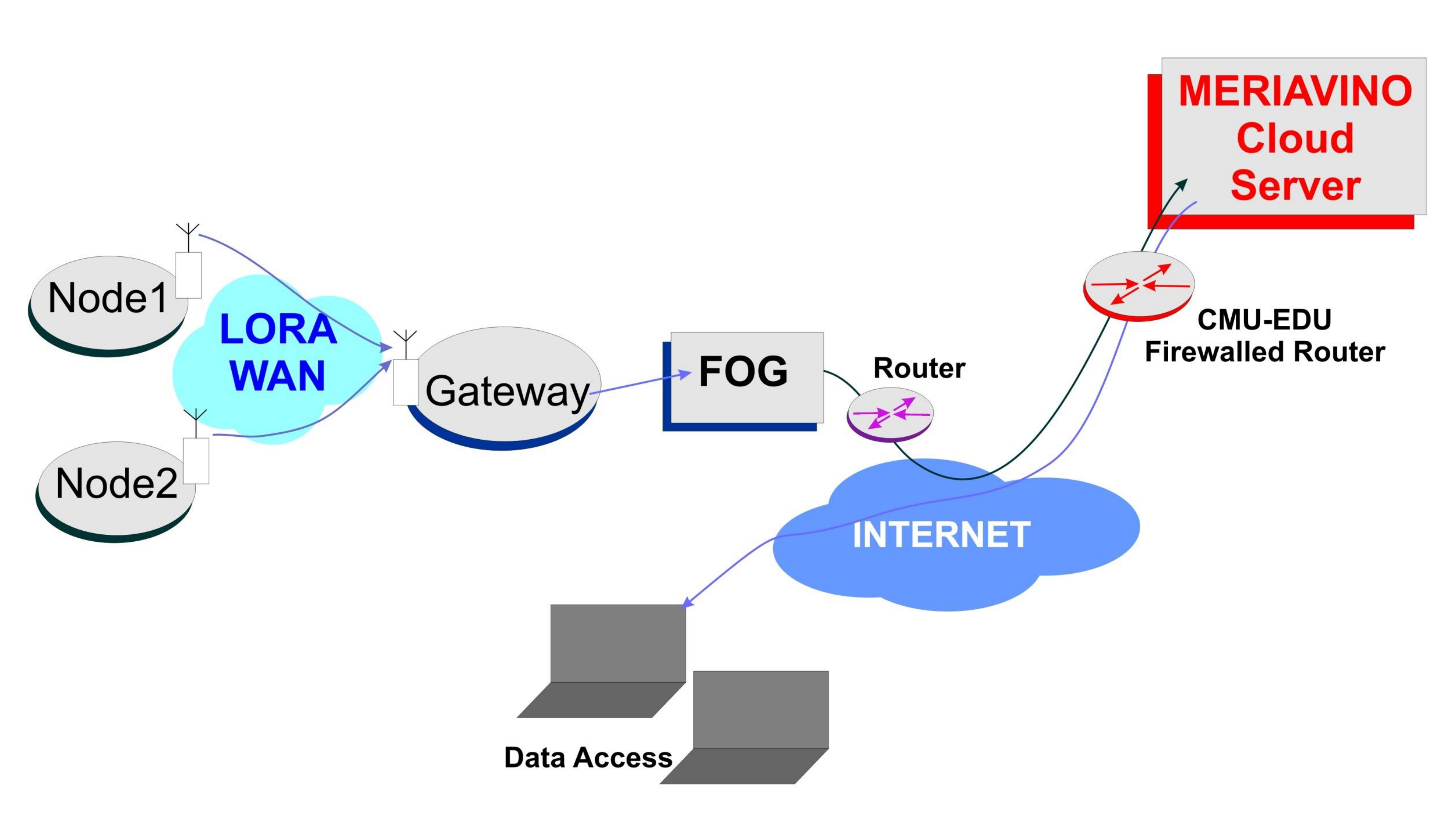
- CMU thingsboard.io
  - On this server we implemented a servlet that push data to Meriavino Cloud Server.
    - This servlet is activated hourly
    - It get data from locally thingsboard.io data center and push them to Meriavino Cloud Server
    - The pushed data are transferred o
    Internet using MariDB SQL Connecti



ERIAVINO CMU ARCHITECTURE

- Data acquisition
  - NODES
- Data transfer
  - Gateway
  - Meriavino FOG
- Centralized Cloud Server
  - Meriavino CLOUD Server

MERIAVINO ARCHITECTURE



MERIAVINO NODE

- Node
  - We implemented 2 nodes
  - Each node is based on 32 bits controller's architecture
  - It is powered from solar panel with backup battery
  - The nodes are connected with a gateway over LORA WAN Network

  - Nodes send data to Gateway In binary mode
  - Each node have a unique ID
  - Each data frame have a fixed length
  - Data are sent at regular time intervals
  - Each acquired sensor has a fixed index in communication data frame

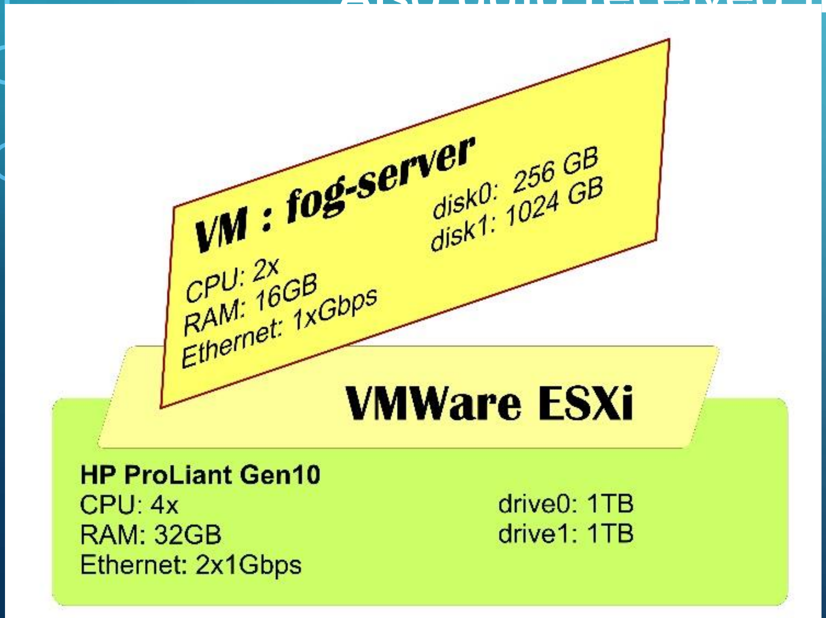
MERIAVINO GATEWAY

- Gateway
  - We implemented 1 Gateway
  - It bases on a 32 bits microcontroller architecture
  - The Gateway connects LORA Network Nodes with FOG Server
  - Connection with FOG is made using virtual serial protocol over USB bus
  - It is powered from USB bus

  - It operates like a [FIFO] pipe for data received from LORA NET and it deliver data over serial communication channel

MERIAVINO FOG

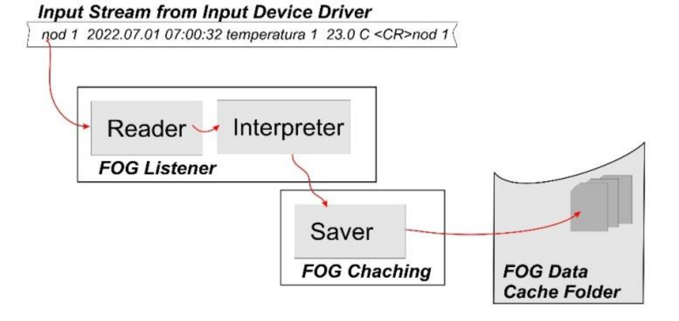
- FOG
  - We implemented 1 FOG
  - It bases on HP Proliant Microserver Gen 10
  - The FOG is implemented into a Linux Ubuntu v22 on a virtualized machine
  - The FOG receive data from LORA nodes and send them to the MERIAVINO Cloud Server
  - Also data received from LORA nodes is stored localy (on a local database)
  - Internet connection is made over Ethernet port



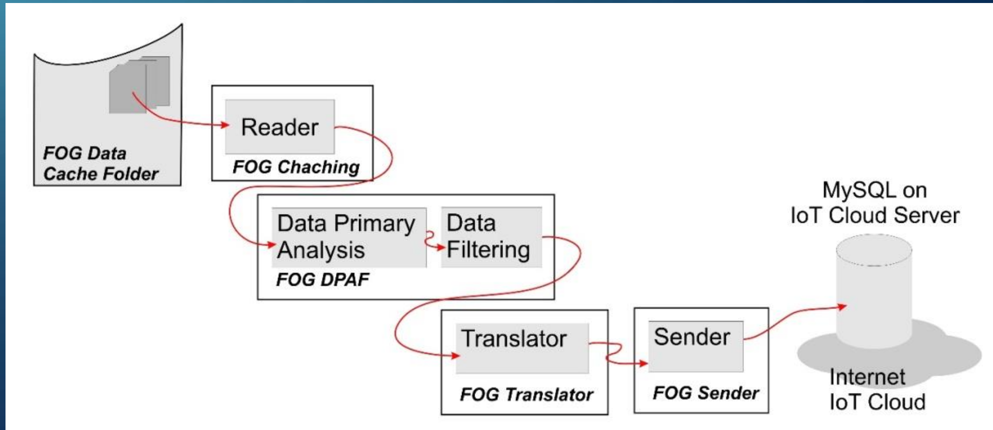
MERIAVINO FOG

- FOG
  - Data received is stored locally into a cache memory
  - Data is pushed to Meriavino server at regular time intervals

  - To implement these operations we have two base software modules
    - fog-receiver



    - fog-provisioner

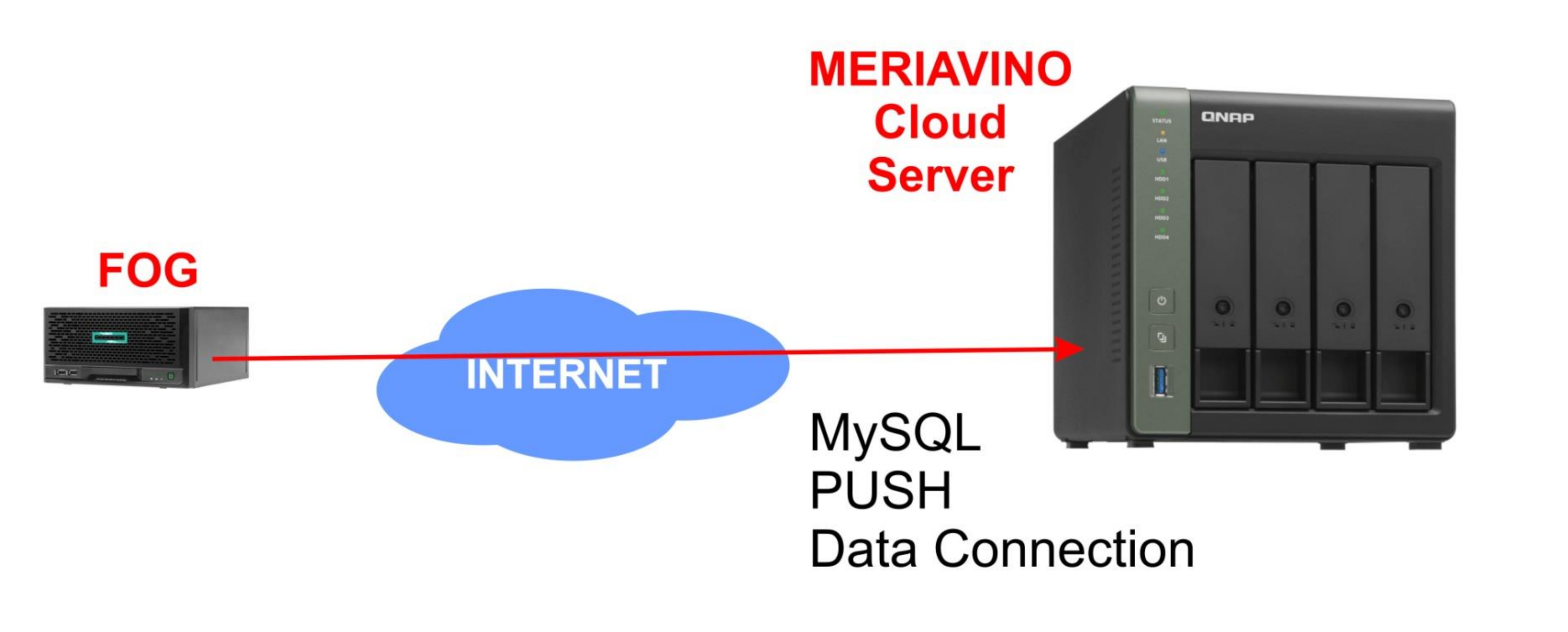


MERIAVINO SERVER

- SERVER
  - We implemented 1 Cloud Server
  - It bases on QNAP Platform with Quad Logical CPU, 4GB RAM, 32TB HDD (RAID5 configured)
  - On server is installed Web Server, MariaDB (SQL) server, WebDAV access, FTP access
  - On server is installed Ubuntu 22.04 Linux Station
  - Internet connection is made over Ethernet port
  - Protection of server is ensured with CMU advanced Firewalled Router (this router is part of CMU Networking)

MERIAVINO SERVER

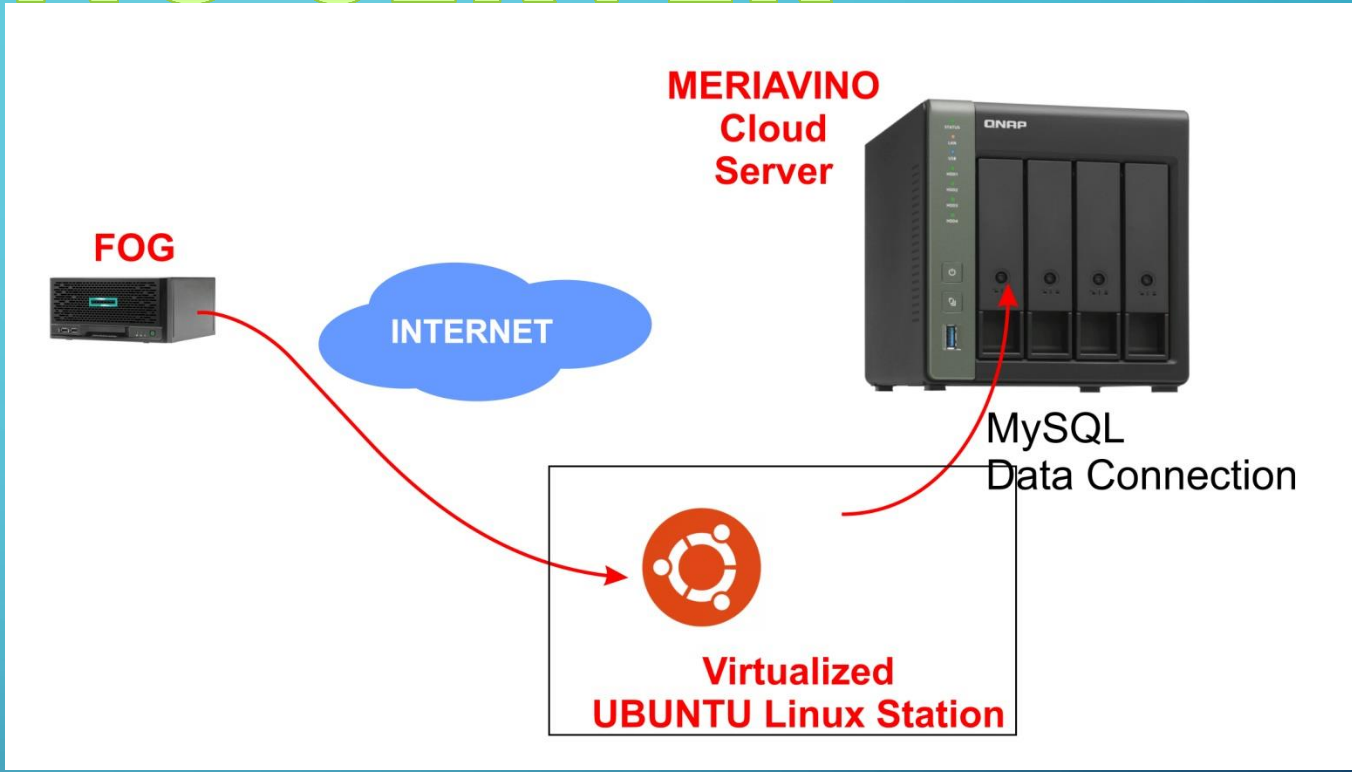
- SERVER



- FOG transfer data to MariaDB database using MySQL pushing data technology
- MySQL Authentication is based on user name/password
- Data Encryption is based on MySQL data connector
- Data transfer is initiated by FOG server

MERIAVINO SERVER

- SERVER

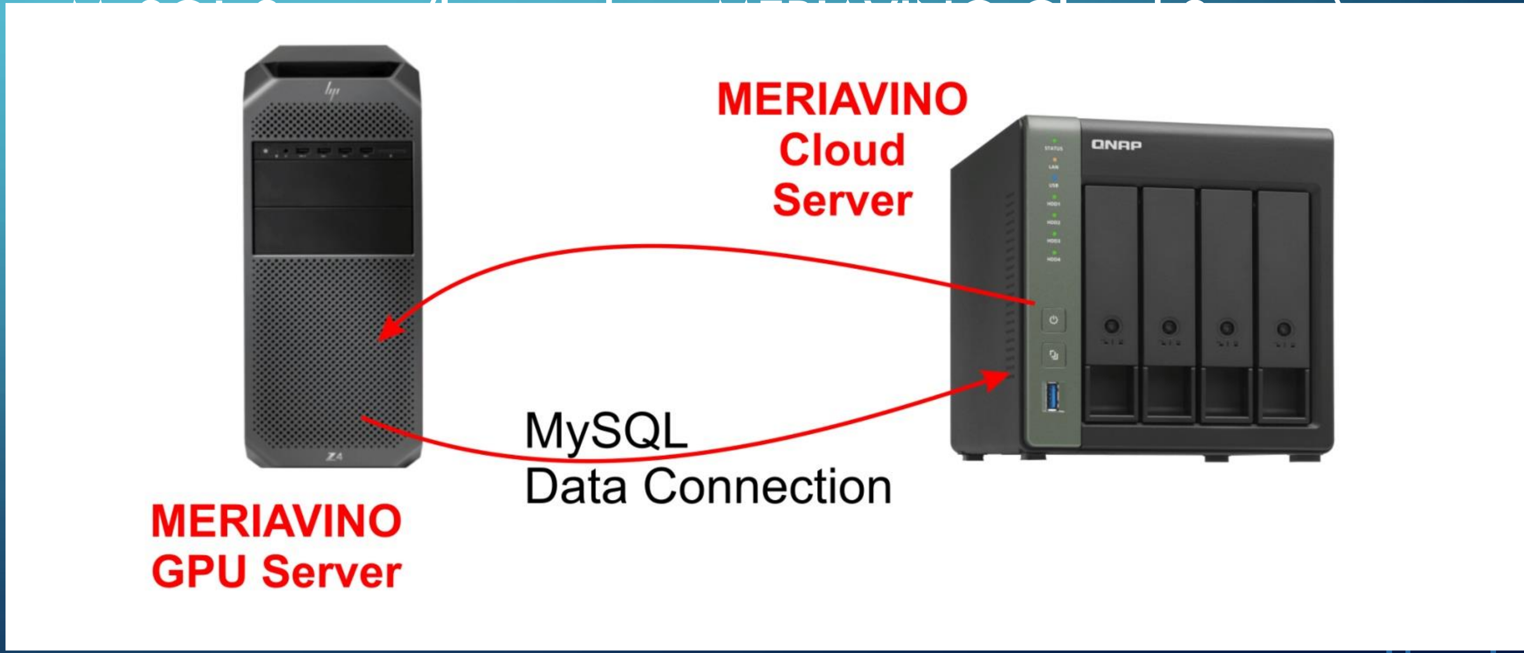


- In case of FOG transfer data to IoT Cloud Server using specific data connection
- On Virtualized UBUNTU Linux Station can be implemented data connector for data pushing into MySQL server
- Data Connector decrypt communication and translate data into MySQL commands
- Data transfer is initiated by FOG server, the connector is translate and push data to MySQL Server

MERIAVINO SERVER

- GPU SERVER
  - AI algorithms are implemented on MERIAVINO GPU Server
  - Is located in the same network area with Cloud Server (behind CMU Firewalled Router)
  - It is based on Core i9 CPU with a multicore GPU card installed in computer
  - On this computer running Python implemented algorithms
  - Input data are retrieved fro
  - Data results are stored on

MySQL data server



DATA ANALYSIS

- The data storage from the sensors are analyzed for features extraction and prediction algorithms
- The data are processed in Python programming language, using open source PyCharm development environment
- TensorFlow software is used to analyses data for predictions.

DATA INGESTION

- Established connection to the MySQL database using the engine from the sqlalchemy library.
- Fetched data using the read_sql_query function from pandas, which executes a SQL query using the engine.
- Stored the data in a DataFrame format.

DATA PREPROCESSING

- The date and time columns are merged and converted to the datetime format and only the unique values from this new date column are kept.
- The column names are automatically created using the parameter names and units of measurement.
- We resample to hourly frequency using mean.
- Filling missing data: - for at most 3 consecutive 'NAN' cells, we use the average of the first non-NAN cells above and below the missing values;

  - for at most 2 days of missing values, we use linear interpolation;

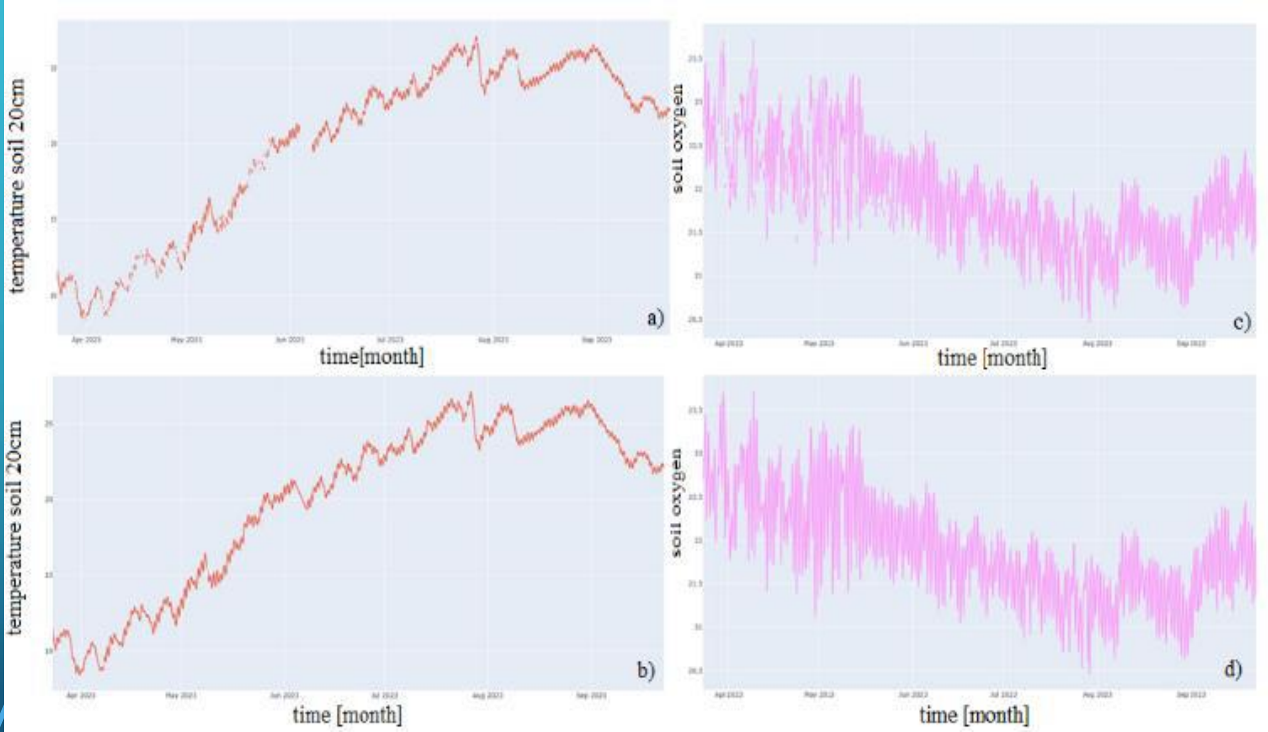
  - for longer periods of missing data we use MSTL decomposition, as it better captures the wave form.
- After that, we save the data in a .csv file and we plot it using plotly online.

AUTOMATING DATA INGESTION & PREPROCESSING

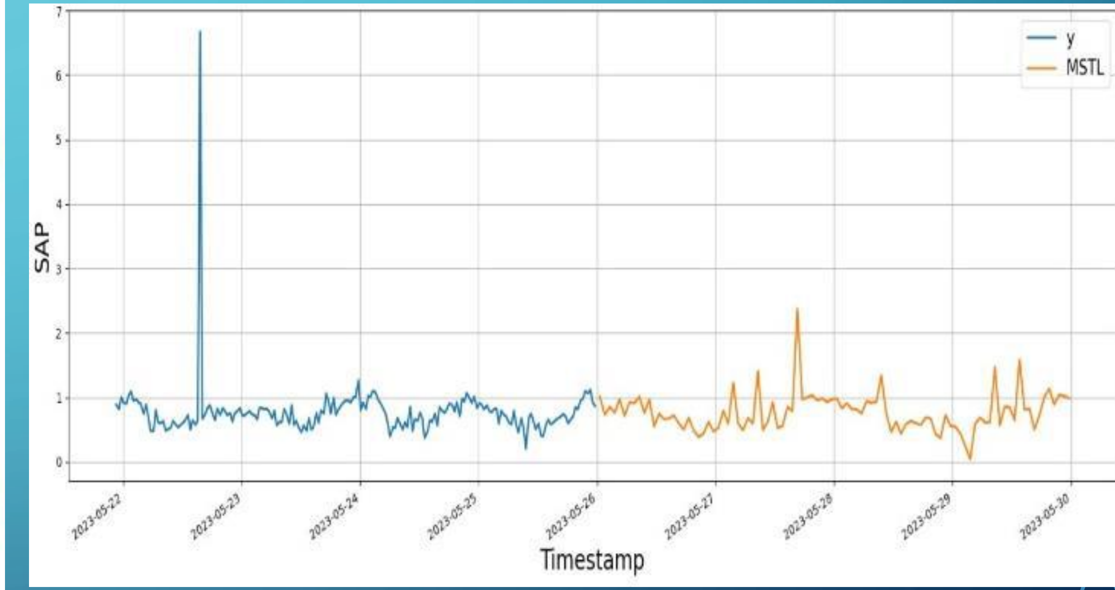
- The data acquisition batch file runs in the background, every hour, using the BackgroundScheduler from apscheduler.schedulers.background. The main thread is kept running using an infinite loop.
- Logging is performed using the logging library.
- To check if the scheduler is still running we use the psutil library.

MERIAVINO

AUTOMATING DATA INGESTION & PREPROCESSING



The data representation for soil temperature raw data a) soil temperature clean data b) soil oxygen raw data c) soil oxygen clean data d)



The data prediction in the preprocessingstage. The blue signal represents the real data and the yellow signal is the predicted values using MSTL

DATA ANALYSIS

K-Means clustering

- K-Means clustering was applied on air temperature and humidity data obtained during the vegetation period. We obtained two clusters and some scattering was noticeable, mainly at the edges of the clusters.

Inertia	834,418.46
Silhouette Score	0.63
Calinski–Harabasz Index	27,863.24
Davies–Bouldin Index	0.491

Binary Classification

- We added the target column, which contains the state of the plant: diseased or healthy. We compared the results of K-fold cross-validation (3 folds) obtained with the Random Forest and Decision trees algorithms and observed comparable results.

	Accuracy - Subset 1	Accuracy - Subset 2	Accuracy - Subset 3
Decision Tree	0.974	0.974	0.978
Random Forest	0.980	0.981	0.983

Binary vs. Multiclass Classification

- For the multiclass classification we used a target column containing three classes: Plasmopara viticola, Botritis Cinera and healthy. We also added new predictors: soil and air temperature and humidity, soil oxygen and PAR from the 2022 vegetation period.

		Precision	Recall	F1 score	Accuracy
Decision Tree Classifier (two classes)	Healthy	1	1	1	0.99
	Diseased	0.96	0.97	0.96	
Random Forest Classifier (two classes)	Healthy	1	1	1	1
	Diseased	0.99	0.96	0.97	
Random Forest Classifier (three classes)	Healthy	1	1	1	1
	Plasmopara viticola	1	1	1	
	Botrytis cinerea	1	1	1	
Decision Tree Classifier (three classes)	Healthy	1	0.92	0.96	0.97
	Plasmopara viticola	1	1	1	
	Botrytis cinerea	0.91	1	0.95	

Conclusions

- The goal of the research is to reduce economic loss of quantity and the environmental impact using various sensors
- The testing activities carried out allowed the optimization of the solution. Currently, the system is still in the monitoring phase, to obtain more data and allow their analysis.
- Artificial intelligence (AI) with machine learning (ML) methods will be combined along with the development of sensors for effective vineyard monitoring.
- The first tests of data collected of the standard IoT system are developed
- The IoT kit system is a reference for the new IoT developed in the laboratory
- The new IoT system collects more data parameters from the environment at a small cost
- It is develop the new algorithms for disease identification and data partner

PUBLICATIONS

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General information

- **Cod project:** COFUND-ICT-AGRI-FOOD-MERIAVINO-1
- **Title project** Multiscale Sensing for Disease Monitoring in Vineyard Production
- **Acronym:** MERIAVINO
- **Financing:** state budget
- **Name of the Program PN III:** European and International Cooperation – Subprogram 3.2 – Horizont 2020
- **Proiect type:** ERANET
- **Period of development:** 02/12/2020 – 02/12/2023
- **Duration of contract:** 36 months
- **PROJECT BUDGET:** 340.900,00 lei represented 70.000,00 euro

Financing sources:

- **Source 1** – state budget: 171.234,07 lei represented 35.161,00 euro
- **Source 2** – other sources (own financial contribution): 0,00 lei represented 0,00 euro
- **Source 3** – European Commision: 169.665,93 lei represented 34.839,00 euro
- **Contracting Authority:** Unitatea Executivă pentru Finanțarea Învățământului

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