

## Master Thesis Presentation

# Design and Implementation of Wireless Sensor Networks Using LoRaWAN, MQTT and Cloud Computing

*Creating long-range, low-power sensor network for applications in smart cities,  
industrial automation and smart agriculture.*

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6. Discussions

# Introduction

**Motivation:** To create the network layer of an IoT platform **Obodo** for application in smart cities. Small scale Wireless Sensor Networks (WSNs) were created as proof of concept for this IoT Platform.

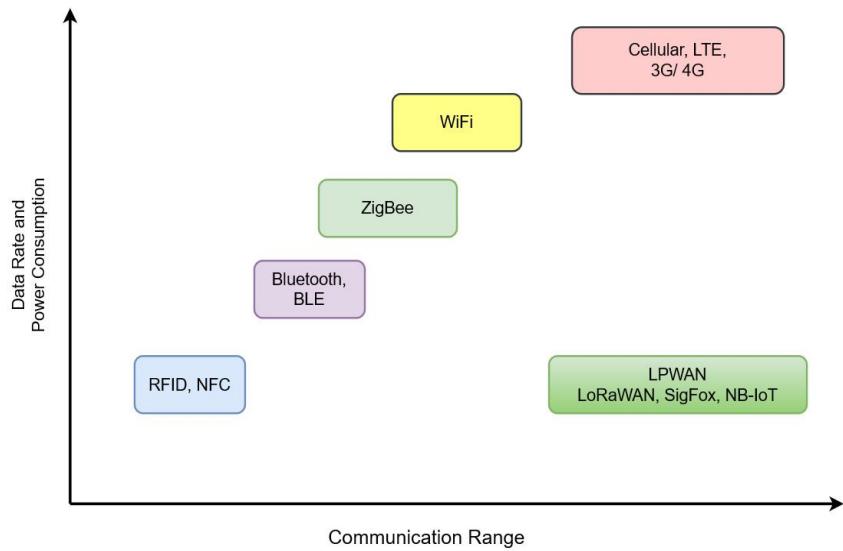
**Key requirements:** Long range, low power, low cost sensor nodes

**Key tasks:** Selection of suitable technology stack - communication protocols, Network hardware, regulatory compliance, system reliability

**Research:** Thesis investigates the optimal system architecture of the WSNs based on LoRaWAN, MQTT and Cloud computing / on-premise servers.

**Funding:** Research was sponsored by **APS Tech Group GmbH** in form of network equipment, computing infrastructure, electronics and other lab resources.

# Selection of technology stack - LoRaWAN



- Technology: Only **LPWAN** meets the requirement of long range and low power and suitable for sensor networks.
- WiFi and bluetooth offers high data transfer rate but at the cost of high power consumption and significantly low range.
- 3 main competing technologies in LPWAN space: **Sigfox, NB-IoT, LoRaWAN**

**LoRaWAN** was selected to be most appropriate communication technology:

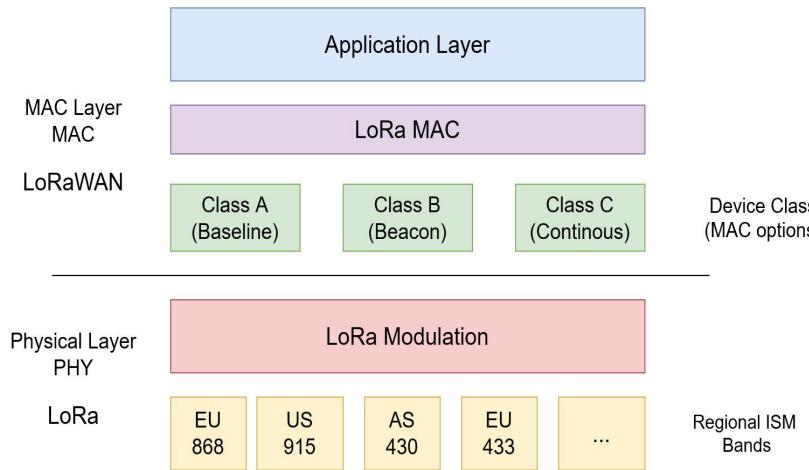
- Range and power consumption,
- Data rate and payload size
- ***Cost and ease of network deployment***

# LoRa and LoRaWAN Overview

LoRa - RF modulation based on Chirp Spread Spectrum

LoRaWAN - Protocol on top of LoRa Physical layer

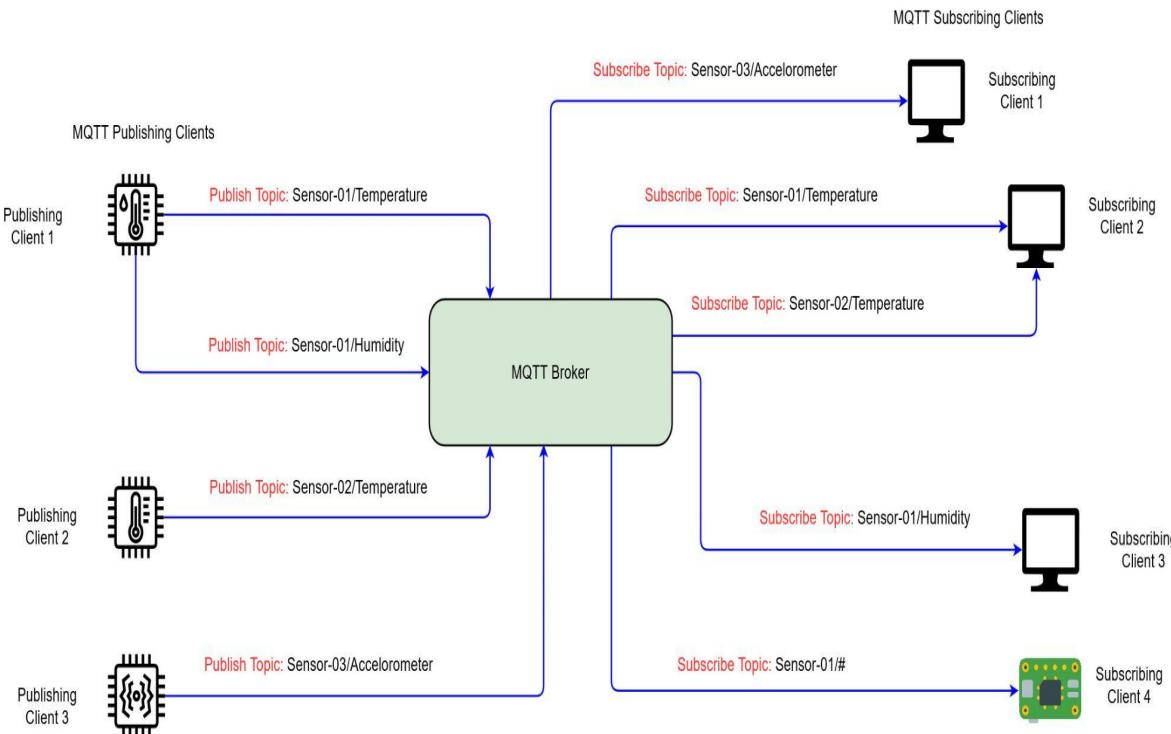
This is not based on TCP/IP stack.



## Key Features

- Long Range wireless communication technology.
- Unlicensed Sub GHz ISM spectrum which varies from region to region.
- End devices run upto 10 years with 2- 10 Km range\*
- Only suitable for sending small data packets (Max 243 bytes), at low bit-rate.
- LoRaWAN is an open standard (ITU-T Y.4480) maintained by LoRa Alliance.
- LoRa modulation is proprietary technology of Semtech Corporation

# Selection of technology stack - MQTT



## Key Features

- Lightweight pub-sub M2M message transport protocol.
- Application layer of TCP IP
- Decoupled relationship between message producers and message consumers
- Clients publish and subscribe to topics via broker.
- Works on range of devices- PCs, servers, SBCs, MCUs
- Various QoS
- Clients are easy to write, broker is difficult to implement.

# Application areas for LPWAN based WSNs

## Industrial automation:

- Temperature and humidity and indoor air quality monitoring in pharmaceutical and food processing industry
- Fluid level monitoring in tanks for industries like chemical, textile and petroleum

## Smart cities:

- Air quality index and particulate matter monitoring
- City waste management and garbage collection
- Parking occupancy by smart parking sensors
- Ambience monitoring in smart buildings

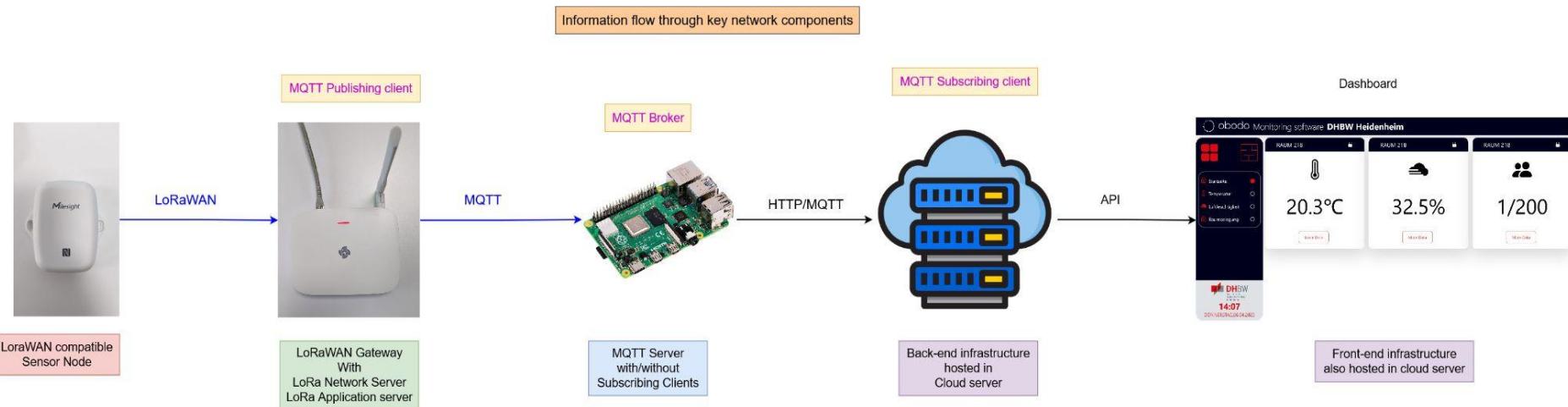
## Smart agriculture:

- Monitoring crop growing conditions like light intensity, soil moisture etc
- Toxic gas level monitoring in compost and livestock enclosures
- Outdoor weather stations, irrigation

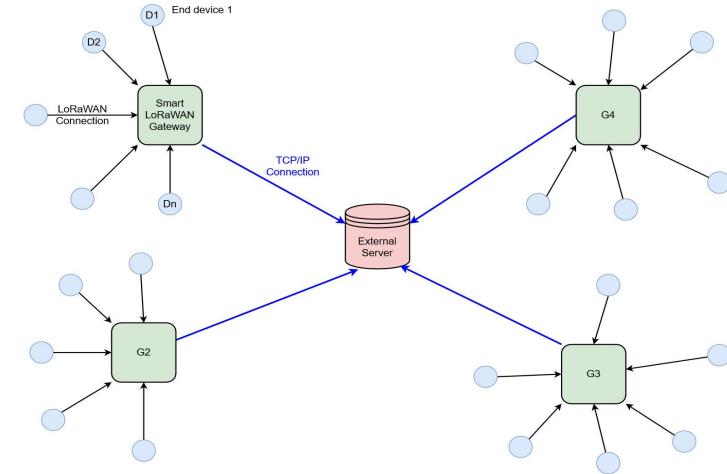
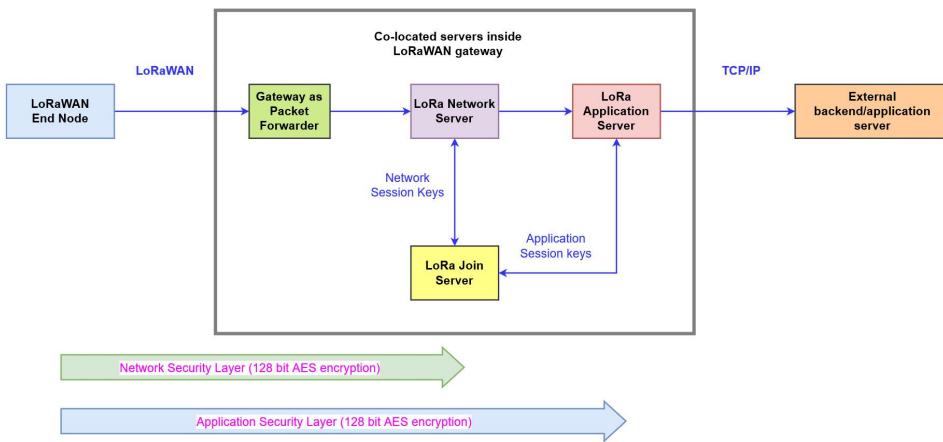
# High level Information flow through Network Devices

Key Network devices - Sensor nodes, Gateways, Servers

Key communication protocols - LoRaWAN, MQTT, HTTP



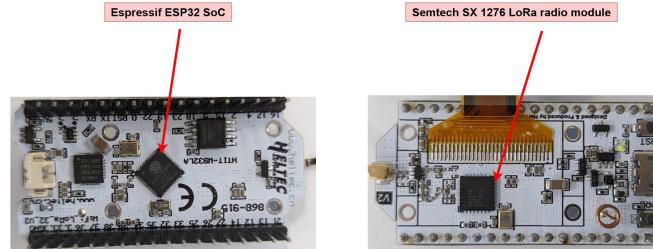
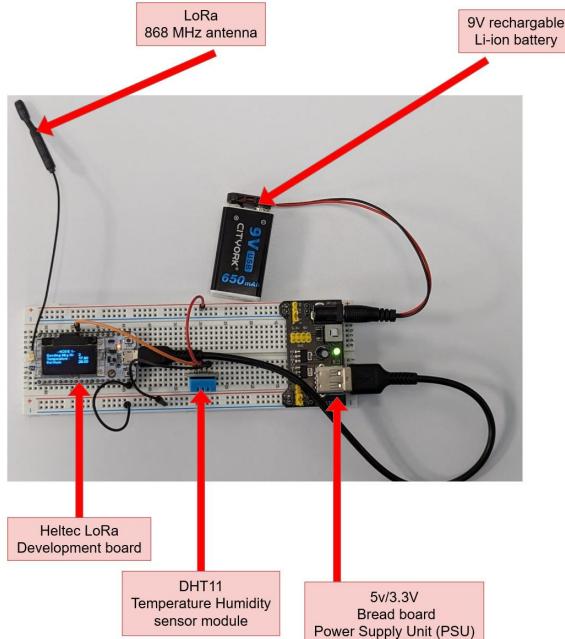
# LoRaWAN Network Topology



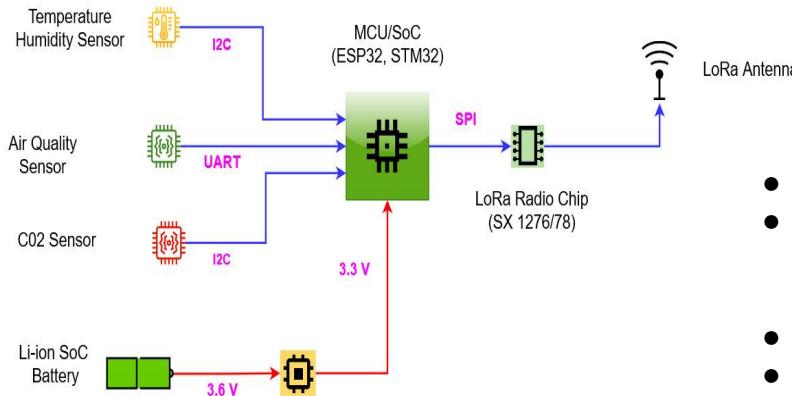
- LoRaWAN follows star of star network topology.
- Gateway acts a bridge between sensors and the internet / external servers.
- Key components in LoRaWAN network- End device, gateway, Join Server, LoRa Network Server, LoRa application server

# Sensor Nodes / End devices

Sensor node created with LoRa development board



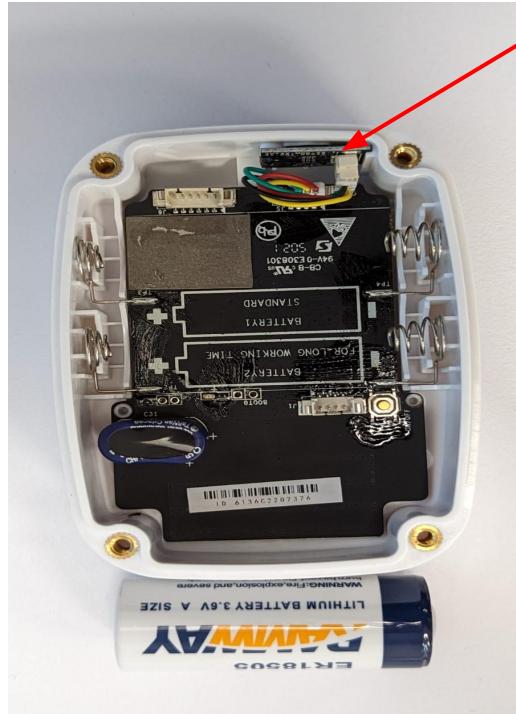
Internal architecture of LoRa sensor Node



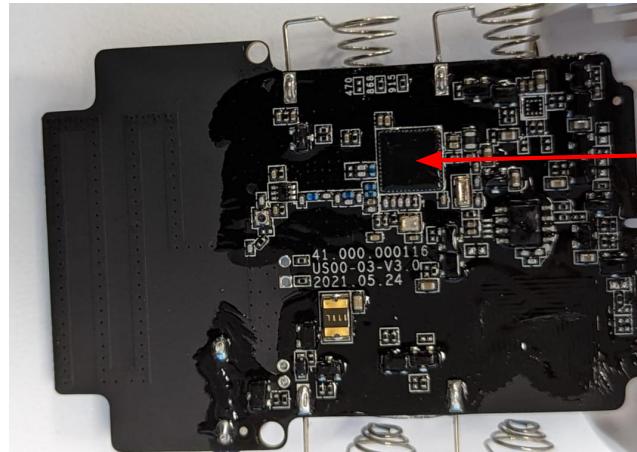
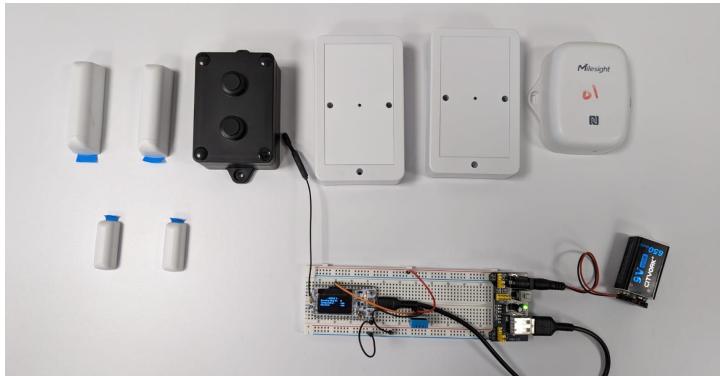
- System on Chip (SoC)
- LoRa Radio module (embedded/ stand alone)
- LoRa antenna
- Sensor Module
- Power supply with Li-ion batteries

# Commercial LoRaWAN compatible sensor nodes

Relative humidity and temperature  
sensor node from milesight



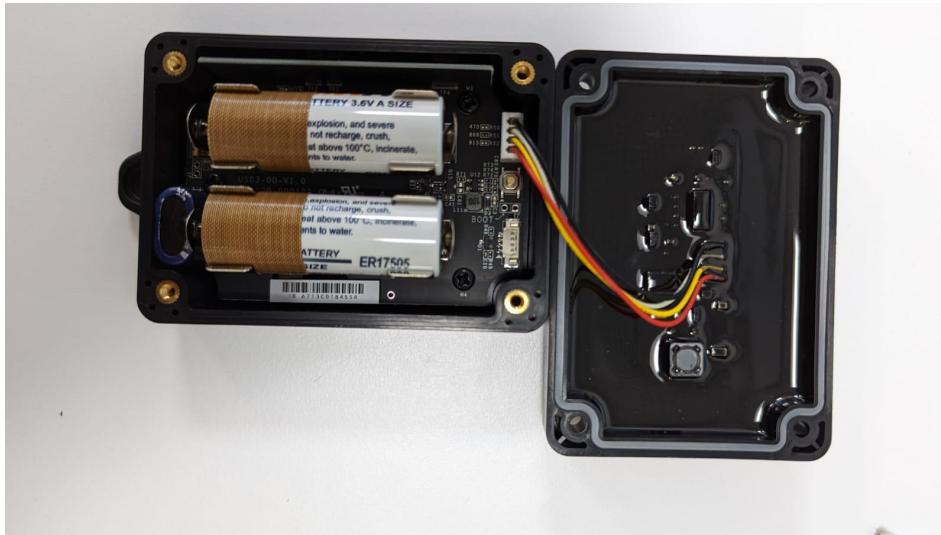
Sensor module  
connected via I2C



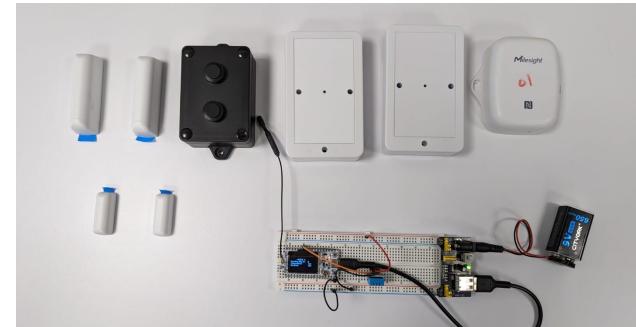
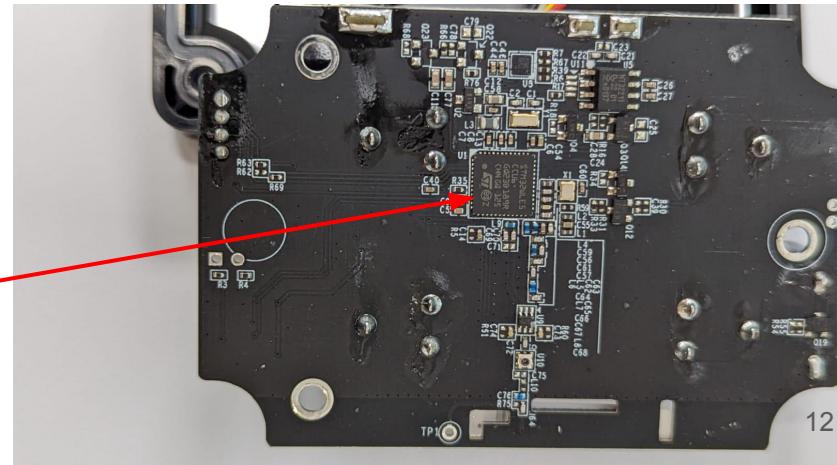
SoC and LoRa radio  
module in one chip

# Commercial LoRaWAN compatible sensor nodes

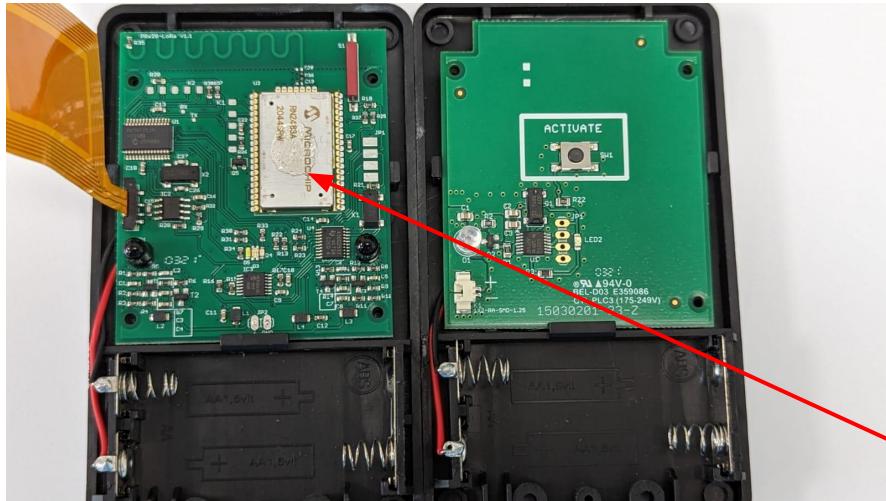
## Ultrasonic Distance Sensor from Milesight



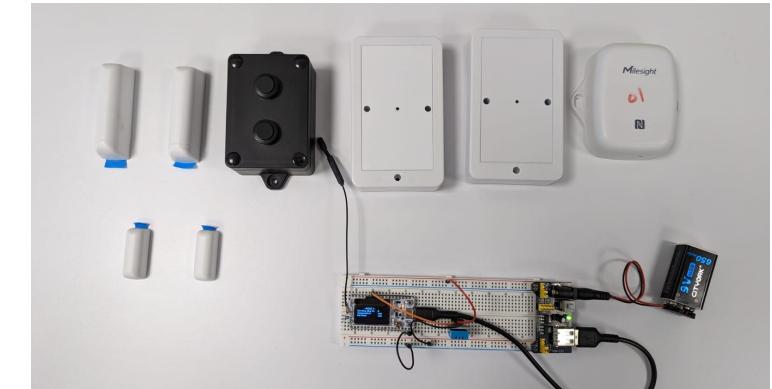
STM32 WLxx series chip



## Commercial LoRaWAN compatible sensor nodes

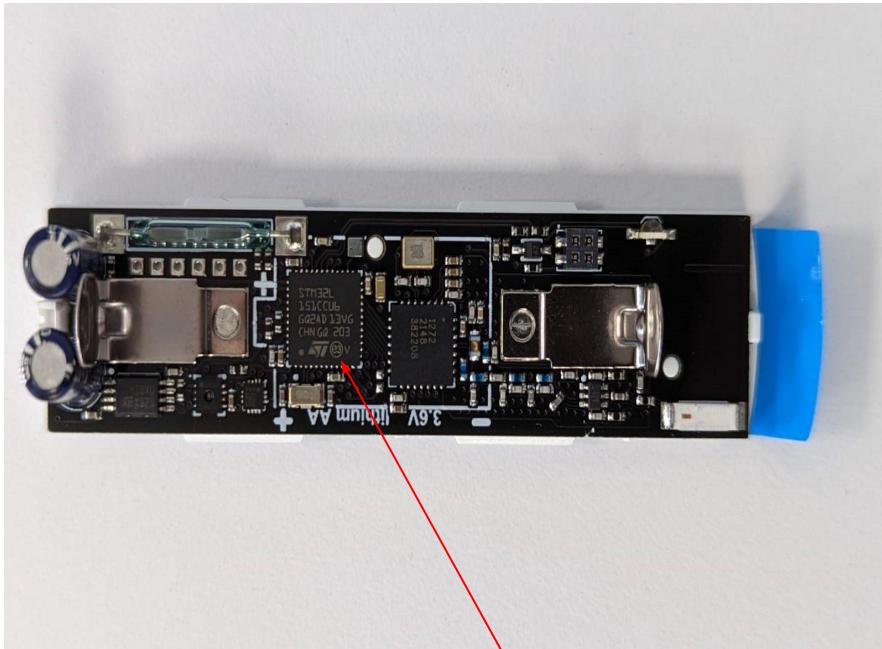


Infrared based  
People Counter Sensor  
from IM Buildings

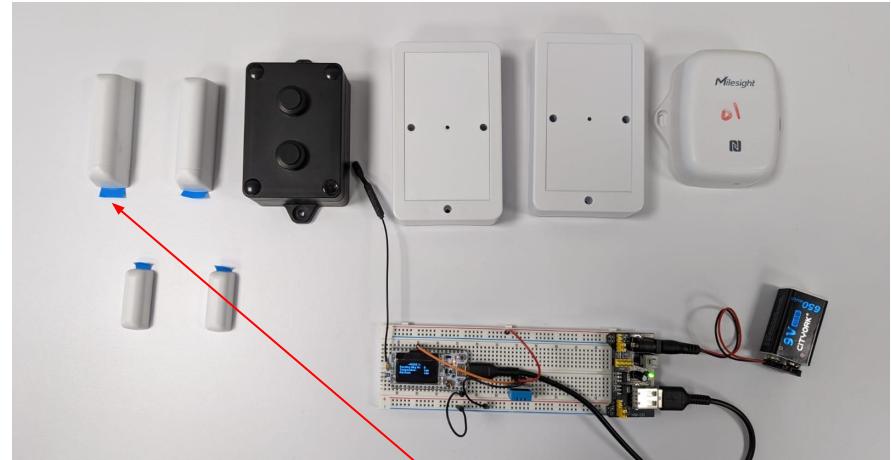


Microchip  
RN2483 LoRa  
stand alone  
radio module

## Commercial LoRaWAN compatible sensor nodes



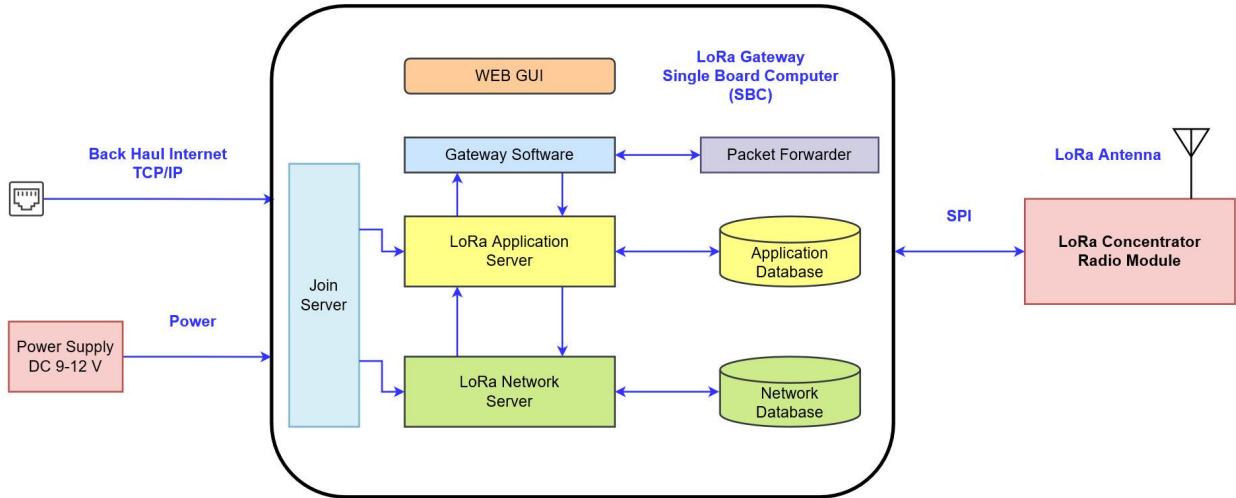
SoC and LoRa radio  
module in one chip



Magnetic contact switch door sensor by ELESYS

## LoRaWAN Gateway internal Architecture

LoRaWAN Gateway  
(RAK wireless indoor 7268C)



- Single Board Computer (Arm based multi-core processors)
- Multi-channel LoRa concentrator radio module/chip like iC880A or SX1302
- Usually 8, 16, 64 channel gateway
- Chips capable of connecting to backhaul internet (WiFi/LTE Sim)
- Power Supply: DC adapter or Power over Ethernet (PoE).
- Separate Antennas for LoRa, WiFi and GPS
- Smart gateways have embedded LoRa Network Server and Application Server

# Web GUI of Gateway - Applications, Devices and LoRaWAN parameters

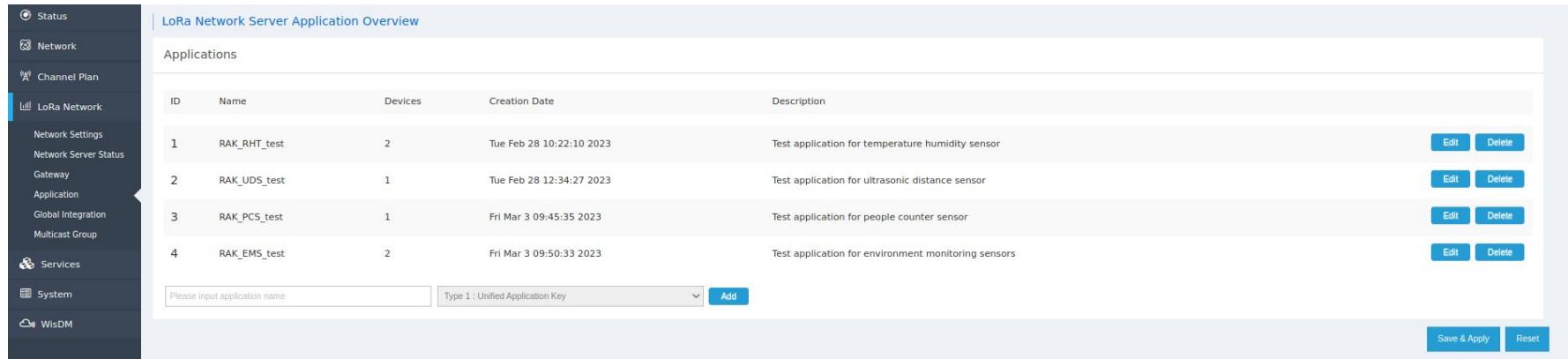
LoRa Network Server Application Overview

## Applications

| ID | Name         | Devices | Creation Date            | Description   | Edit                 | Delete                 |
|----|--------------|---------|--------------------------|---|----------------------|------------------------|
| 1  | RAK_RHT_test | 2       | Tue Feb 28 10:22:10 2023 | Test application for temperature humidity sensor    | <a href="#">Edit</a> | <a href="#">Delete</a> |
| 2  | RAK_UDS_test | 1       | Tue Feb 28 12:34:27 2023 | Test application for ultrasonic distance sensor     | <a href="#">Edit</a> | <a href="#">Delete</a> |
| 3  | RAK_PCS_test | 1       | Fri Mar 3 09:45:35 2023  | Test application for people counter sensor          | <a href="#">Edit</a> | <a href="#">Delete</a> |
| 4  | RAK_EMS_test | 2       | Fri Mar 3 09:50:33 2023  | Test application for environment monitoring sensors | <a href="#">Edit</a> | <a href="#">Delete</a> |

Please input application name:  Type 1 : Unified Application Key:  [Add](#)

[Save & Apply](#) [Reset](#)



## Device Management

Application Edit - app\_4

### Application RAK\_EMS\_test

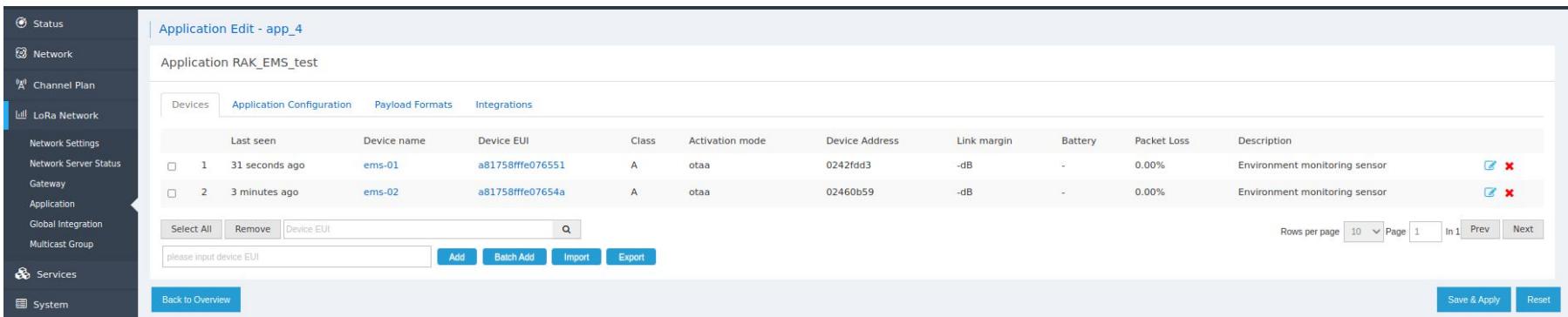
| Devices                  |                  |             |                 |       |                 |                |             |         |             | Application Configuration     |                                     | Payload Formats |  | Integrations |  |
|--------------------------|------------------|-------------|-----------------|-------|-----------------|----------------|-------------|---------|-------------|-------------------------------|-------------------------------------|-----------------|--|--------------|--|
|                          | Last seen        | Device name | Device EUI      | Class | Activation mode | Device Address | Link margin | Battery | Packet Loss | Description                   |                                     |                 |  |              |  |
| <input type="checkbox"/> | 1 31 seconds ago | ems-01      | a81758ffe076551 | A     | otaa            | 0242fd3        | -dB         | -       | 0.00%       | Environment monitoring sensor | <input checked="" type="checkbox"/> |                 |  |              |  |
| <input type="checkbox"/> | 2 3 minutes ago  | ems-02      | a81758ffe07654a | A     | otaa            | 02460b59       | -dB         | -       | 0.00%       | Environment monitoring sensor | <input checked="" type="checkbox"/> |                 |  |              |  |

Select All [Remove](#) Device EUI:  [Q](#)

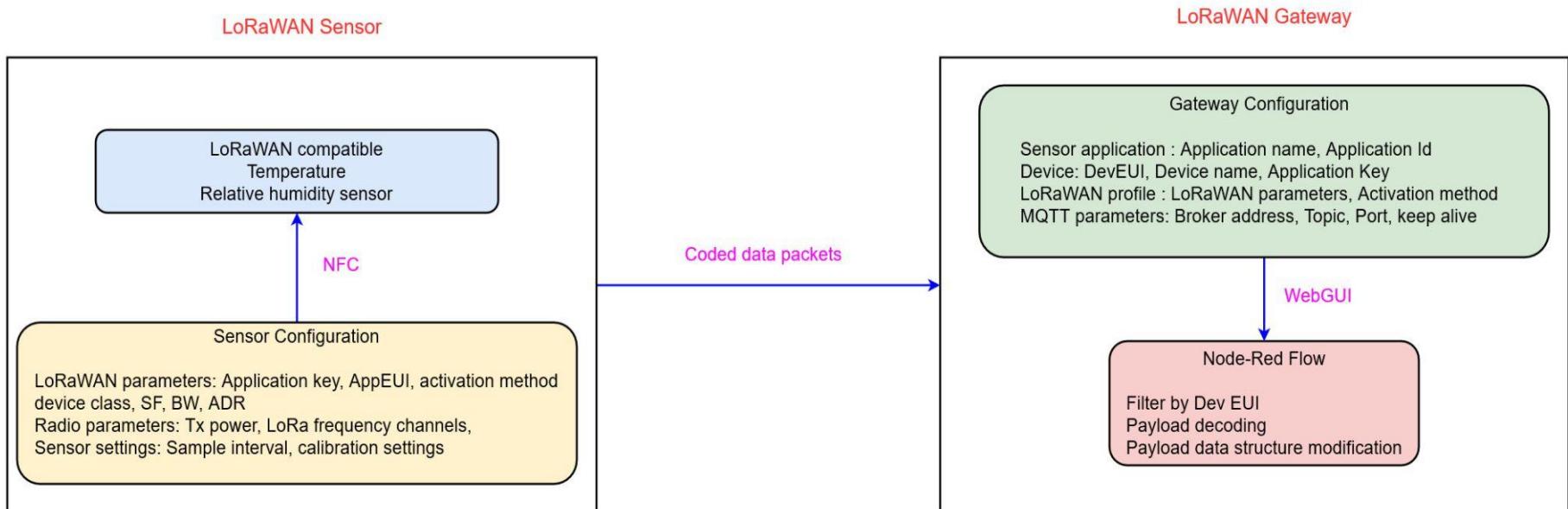
Rows per page:  10 [Page](#)  1 [In 1](#) [Prev](#) [Next](#)

please input device EUI:  [Add](#) [Batch Add](#) [Import](#) [Export](#)

[Back to Overview](#) [Save & Apply](#) [Reset](#)



# Configuring Commercial LoRaWAN Network devices.



# Web GUI of Gateway : Device configuration, security

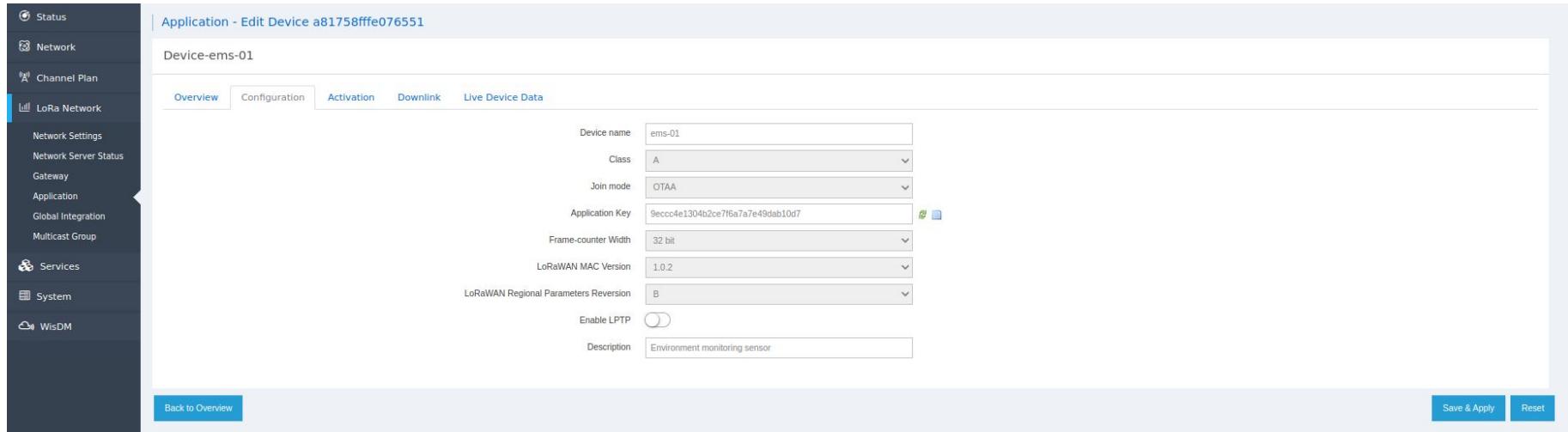
Application - Edit Device a81758ffe076551

Device-ems-01

Overview Configuration Activation Downlink Live Device Data

Device name: ems-01  
Class: A  
Join mode: OTAA  
Application Key: 9ecc04e1304b2ce7f6a7a7e49dab10d7  
Frame-counter Width: 32 bit  
LoRaWAN MAC Version: 1.0.2  
LoRaWAN Regional Parameters Reversion: B  
Enable LPPT:   
Description: Environment monitoring sensor

Back to Overview Save & Apply Reset



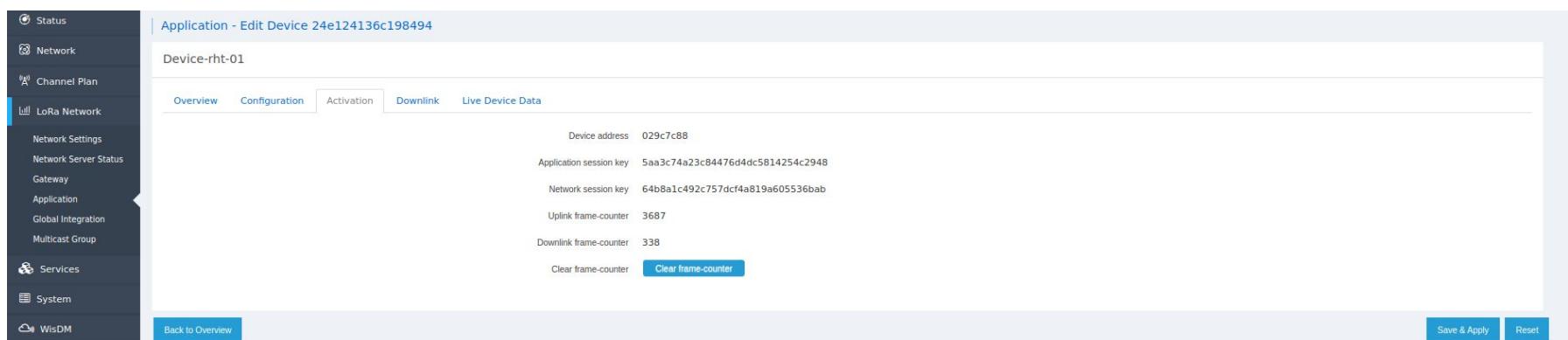
Application - Edit Device 24e124136c198494

Device-rht-01

Overview Configuration Activation Downlink Live Device Data

Device address: 029c7c88  
Application session key: 5aa3c74a23c84476d4dc5814254c2948  
Network session key: 64b8a1c492c757dcf4a819a605536bab  
Uplink frame-counter: 3687  
Downlink frame-counter: 338  
Clear frame-counter:

Back to Overview Save & Apply Reset



# Sensor configuration application : Device configuration, security

**ToolBox**

Status    Setting **Setting**    Maintenance

Device Address

LoRaWAN Version  
V1.0.3

Work Mode  
Class A

RX2 Data Rate  
DR0 (SF12, 125 kHz)

RX2 Frequency  
869525000

\* Support Frequency  
EU868

868.1

**Write**

**Device**    **Template**

**Sensor settings**

**AppKey**  
32 hex digits (16 bytes)

**LoRaWan configuration**

**OTAA**  
 Enabled

Over the air activation

**Confirmed message**  
 Off

Request acknowledgement from server every message (use with care)

**Frequency plan**  
EU868

LoRaWAN frequency plan

**Sub-band**  
Band0 Ch:0-7

Only in combination with hybrid mode

**Settings link**

**WRITE**

**Sensor settings**

XXXXXXXXXXXXXXXXXXXX 2.X.X

**Sensor**  
EMS Door

**Timebase**  
600   
Main timebase for the sensor in seconds

**Sample times**

**Sensor keys**

**AppEui**  
16 hex digits (8 bytes)

**AppKey**  
32 hex digits (16 bytes)

**LoRaWan configuration**

**OTAA** **WRITE**  
 Enabled

# Integration of Gateway with MQTT Server

The screenshot shows the 'Application Server Integration' configuration page. On the left, a sidebar lists various network management options: Status, Network, Channel Plan, LoRa Network (selected), Network Settings, Network Server Status, Gateway, Application, Global Integration, Multicast Group, Services, System, and WisDM. The main area is titled 'Application Server Integration' and contains the following fields:

- Integration Mode: Generic MQTT
- MQTT Broker Address: 192.168.178.xxx
- MQTT Broker Port: 1883
- MQTT Protocol Version: V3.1
- Client ID: (empty input field)
- Clean Session: Enabled (blue toggle switch)
- Will Retain: Enabled (blue toggle switch)
- QoS: 1 - At least once
- keepalive: 60
- Enable User Authentication: Enabled (blue toggle switch)
- Username: (empty input field)
- Password: (empty input field)
- SSL/TLS Mode: Disable
- Join Topic: application/{{application\_ID}}/device/{{device\_EUI}}/join  
Event published when a device joins the network.
- Uplink Topic: application/{{application\_ID}}/device/{{device\_EUI}}/rx  
Contains the data and meta-data for an uplink application payload.
- Downlink Topic: application/{{application\_ID}}/device/{{device\_EUI}}/tx  
Scheduling downlink data by application server
- Ack Topic: application/{{application\_ID}}/device/{{device\_EUI}}/ack  
Event published on downlink frame acknowledgements.
- Status Topic: application/{{application\_ID}}/device/{{device\_EUI}}/status  
Event for battery and margin status received from devices.
- Multicast Downlink Topic: mcast\_group/{{mcast\_ID}}/tx  
Scheduling multicast downlink data by application server

Key Parameters:

Broker address  
MQTT port  
MQTT version  
MQTT Topic

---

Security:

Username  
Password  
TLS certificate

---

Client Id  
QoS  
Acknowledgement  
Keep Alive

## MQTT Server and Clients

MQTT Client Devices used in this project ranged from PCs SBCs like RPi (RP3 and RP400) and a windows network server.

Mosquitto MQTT broker was configured on windows server and Raspberry Pi using CLI.

Gateway acted as a publishing client

PCs and another raspberry Pi was used as subscribing client to log the data.

Node-Red flows and Python scripts were used subscribing clients and data logging.

### MQTT Sample Client Script

```
import paho.mqtt.client as paho
import time
import datetime

def Message_handler(client, userdata, msg):
    topic = msg.topic
    msg_decoded = msg.payload.decode("utf-8", "ignore")
    msg_JSON = topic + ":" + msg_decoded
    print(msg_decoded)

    #----Logging messages -------

    #----- Text File -------

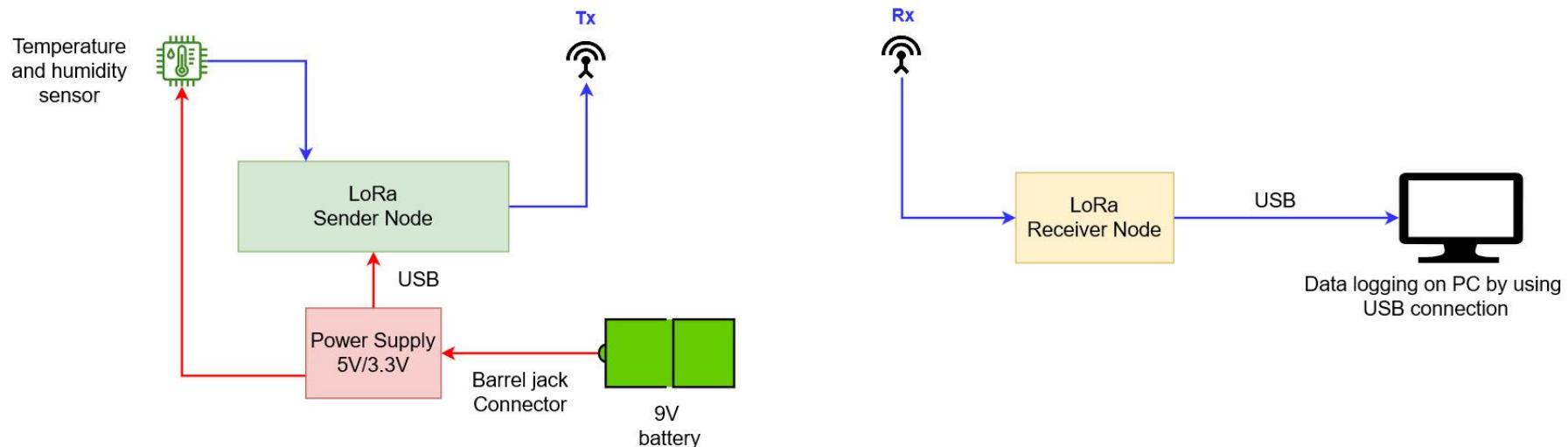
    with open('Filename_dd.mm.yyyy.txt', 'a', encoding = 'utf-8') as f:
        f.write(msg_decoded)
        f.write(",")
        f.write('\n')

    # ----- MQTT Connection handling -------

    MQTT_broker = "192.xx.xx.xx"      # Enter the IP of your broker
    MQTT_port = 1883
    keep_alive = 60
    MQTT_topic = "#"                  # Enter the topics you want to subscribe
```

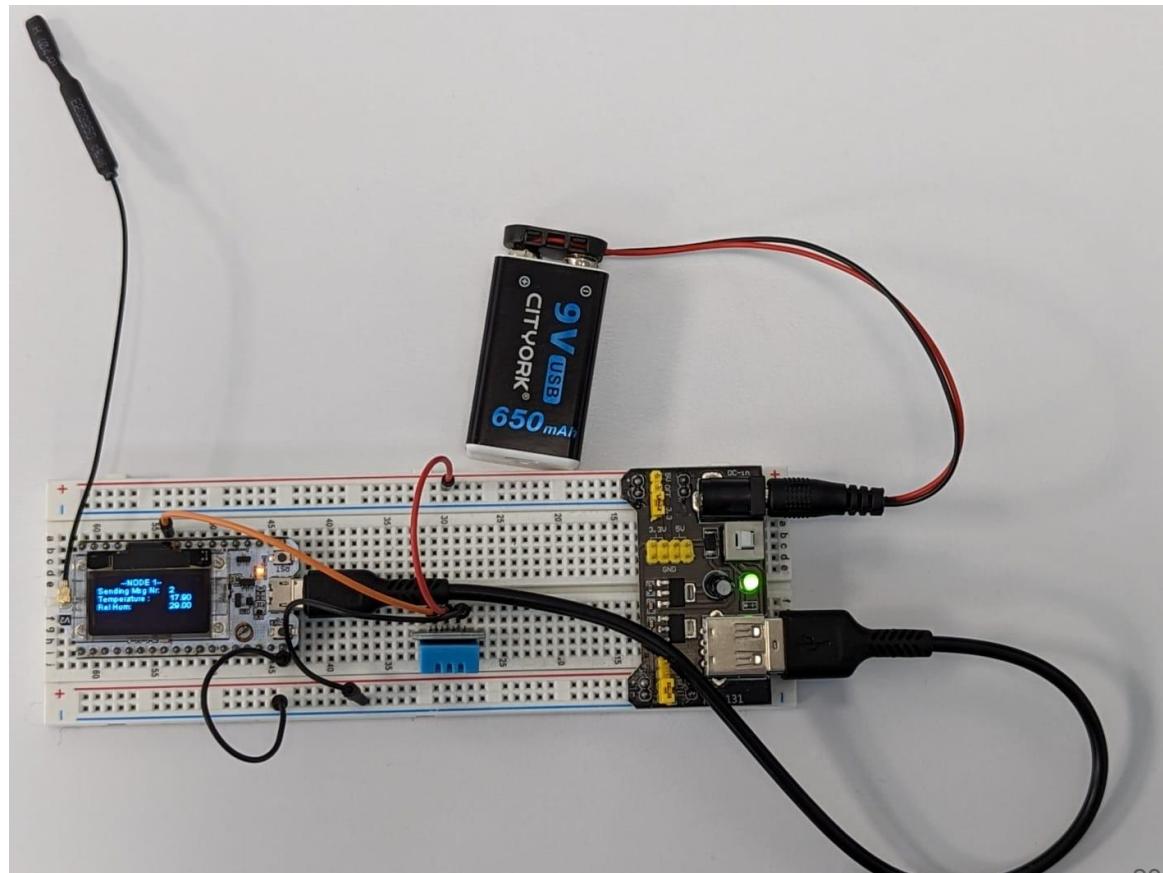
## Initial experiments with LoRa PHY Layer

Schematic of System Setup for Node to Node LoRa Communication



## Initial experiments with LoRa PHY Layer using development boards

| Message_Number | Temp_Celsius | RH_Percent |
|----------------|--------------|------------|
| 1              | 27.3         | 45         |
| 2              | 27.3         | 46         |
| 3              | 27.3         | 46         |
| 4              | 27.3         | 45         |
| 5              | 27.2         | 45         |
| 6              | 27.2         | 45         |
| 7              | 27.2         | 45         |
| 8              | 27.2         | 45         |
| 9              | 27.1         | 45         |
| 10             | 27.1         | 45         |



RSSI\_dBm: -75

Psize\_byte: 48

Node -1- Msg Nr: 1

Temp\_C: 23.60

RH\_%: 52.00

RSSI\_dBm: -73

Psize\_byte: 48

Node -1- Msg Nr: 2

Temp\_C: 23.70

RH\_%: 52.00

RSSI\_dBm: -67

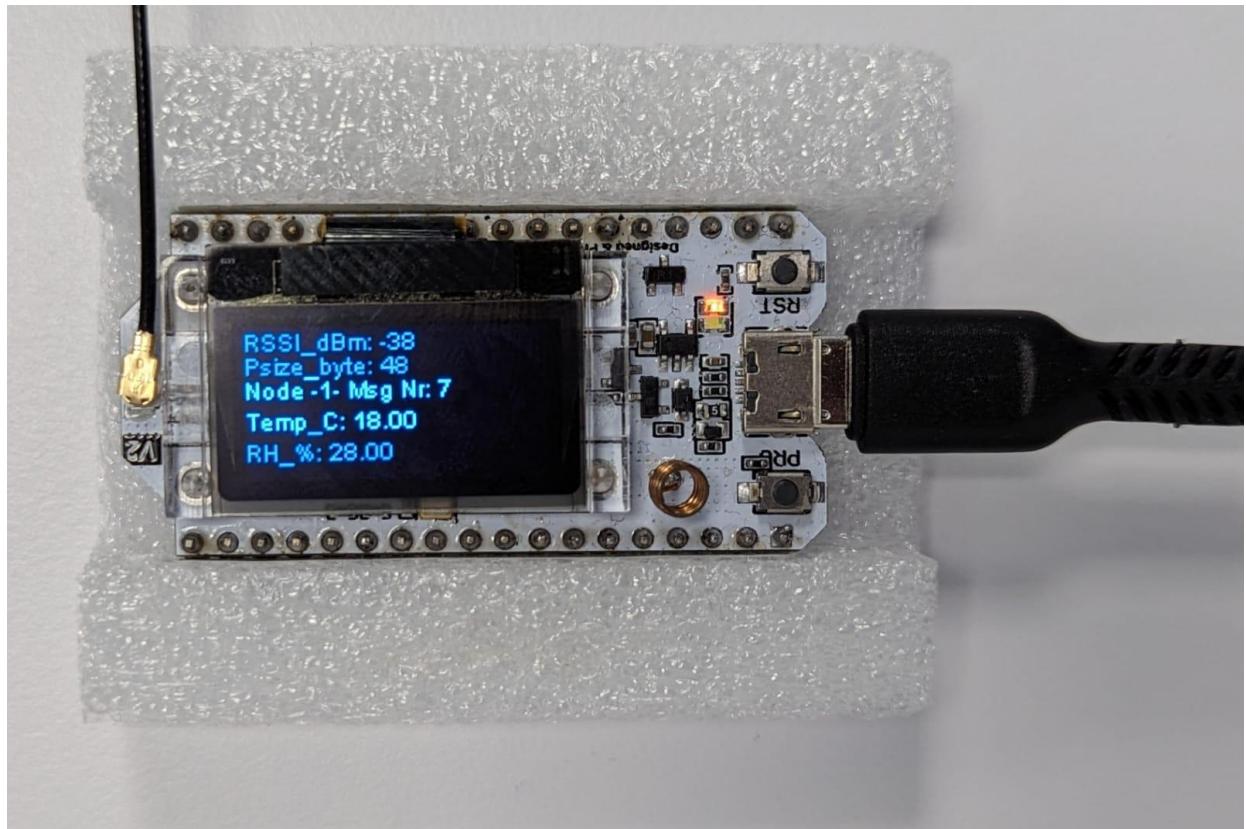
Psize\_byte: 48

Node -1- Msg Nr: 3

Temp\_C: 23.50

RH\_%: 52.00

## Initial experiments with LoRa PHY Layer



# Software written for development boards

```
#include "heltec.h"          // from board manufacturers for LoRa, OLED, ESP32
#include <DHT.h>             // From sensor manufacturer

#define Type DHT11           // Sensor type
#define BAND 868E6            // ISM band in EU is 868MHz for LoRa

// Pin assignment

int Pin_DHT11 = 23;         // Signal pin for DHT object attached to MCU

// variable assignment

unsigned int counter = 0;    // For message Number
String rssi = "RSSI --";    // Received signal strength
String packSize = "--";    // Data packet size
String packet;              // Data packet

int Node_num = 001;          // Sensor Node number
int baudrate = 115200;       // serial communication rate
float NI_Temp = 23;          // Temperature in Celsius
float NI_RH = 55;            // Relative Humidity in percent
int Time_pol = 29000;        // Sample Time for polling the sensor
bool label = true;           // For labeling in serial communication

DHT DHT_Node_1(Pin_DHT11, DHT11); // DHT object attached to Node_1

void setup()
{
    // OLED display initialization (Check Heltec documentation for more info)

    Heltec.begin(true /*DisplayEnable Enable*/, true /*Heltec.Heltec.Lora Disable*/, true /*Serial Enable*/, true /*PABoost Enable*/, BAND /long BAND*/);

    Heltec.display->init();
    Heltec.display->flipScreenVertically();
    Heltec.display->setFont(ArialMT_Plain_10);

    delay(2000);
    Heltec.display->clear();

    Heltec.display->drawString(0, 0, "Starting Node Nr: ");
    Heltec.display->drawString(90, 0, String(Node_num));
    Heltec.display->display();
    delay(3000);

    // Starting communication with sensor DHT11 on Node_1

    DHT_Node_1.begin();
    //Serial.begin(baudrate); Do not use this statement!!!
}

void loop()
{
    // Reading Sensors:
    NI_Temp = DHT_Node_1.readTemperature();
    NI_RH = DHT_Node_1.readHumidity();
```

```
void loop()
{
    // Reading Sensors:
    NI_Temp = DHT_Node_1.readTemperature();
    NI_RH = DHT_Node_1.readHumidity();

    // Display info at sensor Node OLED display:

    Heltec.display->clear();
    Heltec.display->setTextAlignment(TEXT_ALIGN_LEFT);
    Heltec.display->setFont(ArialMT_Plain_10);

    Heltec.display->drawString(30,0, "--NODE 1-- ");
    Heltec.display->drawString(0, 10, "Sending Msg Nr: ");
    Heltec.display->drawString(90, 10, String(counter));
    Heltec.display->drawString(0, 20, "Temperature : ");
    Heltec.display->drawString(90, 20, String(NI_Temp));
    Heltec.display->drawString(0, 30, "Rel Hum: ");
    Heltec.display->drawString(90, 30, String(NI_RH));
    Heltec.display->display();

    // Sending data packet via LoRa modulated radio:

    /* Info from manufacturer of board:

    * LoRa.setTxPower(txPower,RFOUT_pin);
    * txPower -- 0 ~ 20 // 14 dBm is power efficient
    * RFOUT_pin could be RF_PACONFIG_PASELECT_PA BOOST or RF_PACONFIG_PASELECT_RFO
    * - RF_PACONFIG_PASELECT_PA BOOST -- LoRa single output via PA BOOST, maximum output 20dBm
    * - RF_PACONFIG_PASELECT_RFO -- LoRa single output via RFO_HF / RFO_LF, maximum output 14dBm
    */

    LoRa.beginPacket();

    LoRa.setTxPower(14,RF_PACONFIG_PASELECT_PA BOOST); // Transmitting at 14dBm
    // This data packet will be displayed on the LoRa receiver

    LoRa.print("Node -1- Msg Nr: ");
    LoRa.println(counter);
    LoRa.print("Temp_C: ");
    LoRa.println(NI_Temp);
    LoRa.print("RH_S: ");
    LoRa.println(NI_RH);

    LoRa.endPacket();

    // Polling every 30 seconds

    digitalWrite(LED, HIGH);           // turn the LED on (HIGH is the voltage level)
    delay(500);                      // wait for 2 second
    digitalWrite(LED, LOW);           // turn the LED off by making the voltage LOW
    delay(Time_pol);

    counter++;

    // Printing and Data logging via serial communication:
```

```

#include "heltec.h"

#define BAND 868E6 //ISM band in EU is 868MHz for LoRa
String rssi = "RSSI --"; // signal strength for receiver
String packSize = "--"; // Data size of packet in bytes
String packet; // Actual LoRa packet

// For Display on OLED screen on board

void LoRa_OLED(){
    Heltec.display->clear();

    Heltec.display->setTextAlignment(TEXT_ALIGN_LEFT);
    Heltec.display->setFont(ArialMT_Plain_10);
    Heltec.display->drawString(0, 0, rssi);
    Heltec.display->drawString(0, 10, "Packet size " + packSize + " bytes");
    Heltec.display->drawString(0, 20, packet);

    Heltec.display->display();
}

// For reading and calculating packet size

void Packet_reading(int packetSize) {
    packet = "";
    packSize = String(packetSize,DEC); // Packet size in decimal

    for (int i = 0; i < packetSize; i++) {
        packet += (char) LoRa.read();
    }

    rssi = "RSSI--" + String(LoRa.packetRssi(), DEC); // Gives the packet size
    Serial.println(packet);
    LoRa_OLED();
}

// Initial setup

void setup() {

    Heltec.begin(true /*DisplayEnable Enable*/, true /*Heltec.Heltec.LoRa Disable*/, true /*Serial Enable*/, true /*PA BOOST Enable*/, BAND /*long BAND*/);

    Heltec.display->init();
    Heltec.display->flipScreenVertically();
    Heltec.display->setFont(ArialMT_Plain_10);

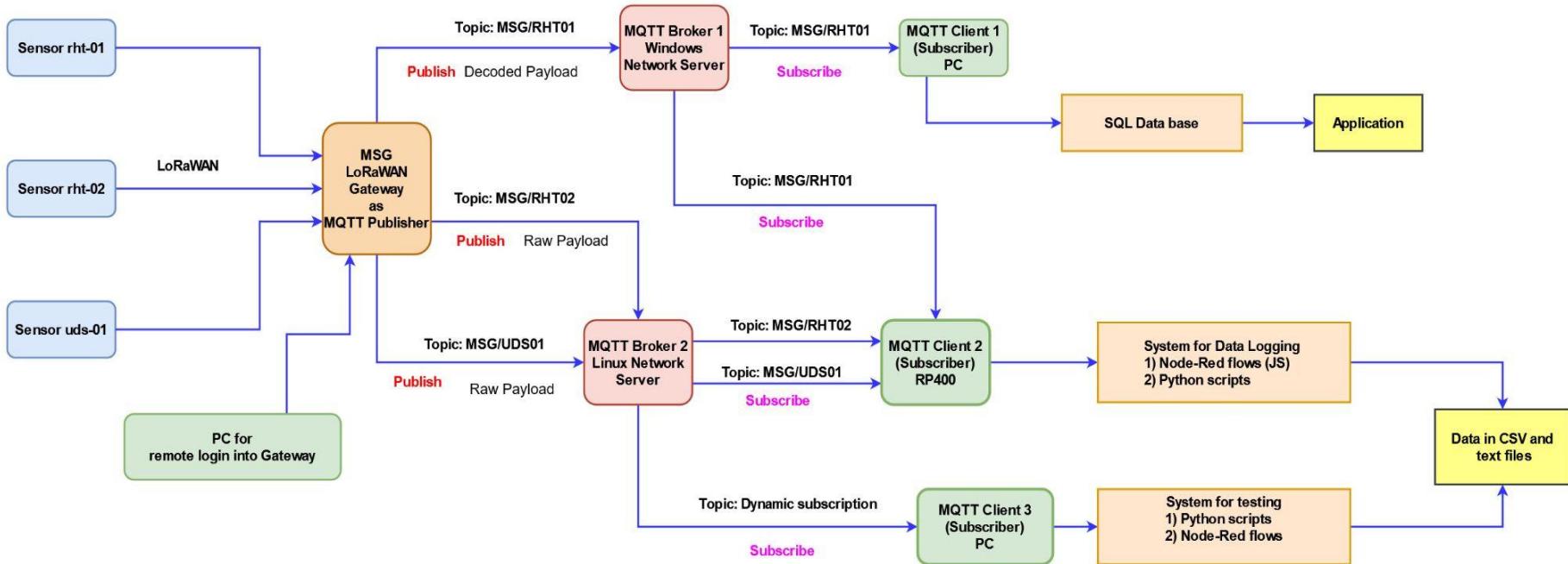
    delay(2000);
    Heltec.display->clear();
    Heltec.display->drawString(0, 0, "Wait for incoming data...");
    Heltec.display->display();
    delay(2000);
    //LoRa.onReceive(cbk);
    LoRa.receive();
}

```

## Limitations of initial tests with development boards

- Not suitable for commercial applications - IP67 enclosure, CE certification, long development time.
- Security: No encryption was implemented in the nodes.
- Not possible to create network topology without LoRaWAN protocol.
- High power consumption - 650 mAh battery lasted about only a day
- Low reliability - Packet drop rate is high at distances around 1 Km.
- Only suitable for lab tests, sensor integration and developing new sensor nodes.

# Network Architecture with Local servers



## Applications created for the sensor nodes in LoRaWAN Gateway

| Sensor Name | Description   | Payload Information  | Application Information   |
|-------------|---|--|---|
| rht-01      | Temperature and relative humidity sensor<br>Manufacturer: Milesight | LoRaWAN data packet decoded in the gateway<br>then transmitted to MQTT server as a JSON<br>message | Demo Application 01<br>Topic: MSG/RHT01<br>MQTT Server: MQTT Server 1 (Windows) |
| rht-02      | Temperature and relative humidity sensor<br>Manufacturer: Milesight | Raw data packets transmitted to the MQTT server<br>without doing any modification in gateway       | Test Application 02<br>Topic: MSG/RHT02<br>MQTT Server: MQTT Server 2 (Linux)   |
| uds-01      | Ultrasonic distance sensor<br>Manufacturer: Milesight               | Raw data packets transmitted to the MQTT server<br>without doing any modification in gateway       | Test Application 03<br>Topic: MSG/UDS01<br>MQTT Server: MQTT Server 2 (Linux)   |

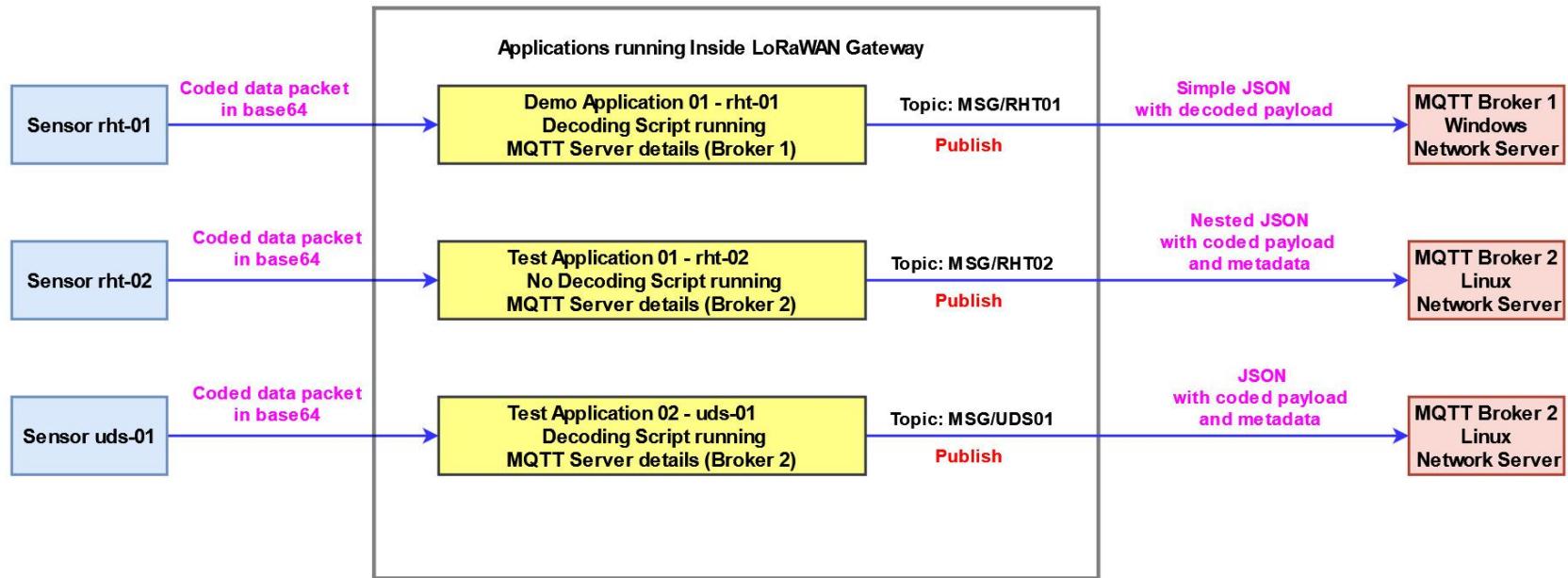


Temperature Humidity Sensor



Ultrasonic Distance Sensor

## Applications in Gateway



## Sample JSON message from Gateway to MQTT Server

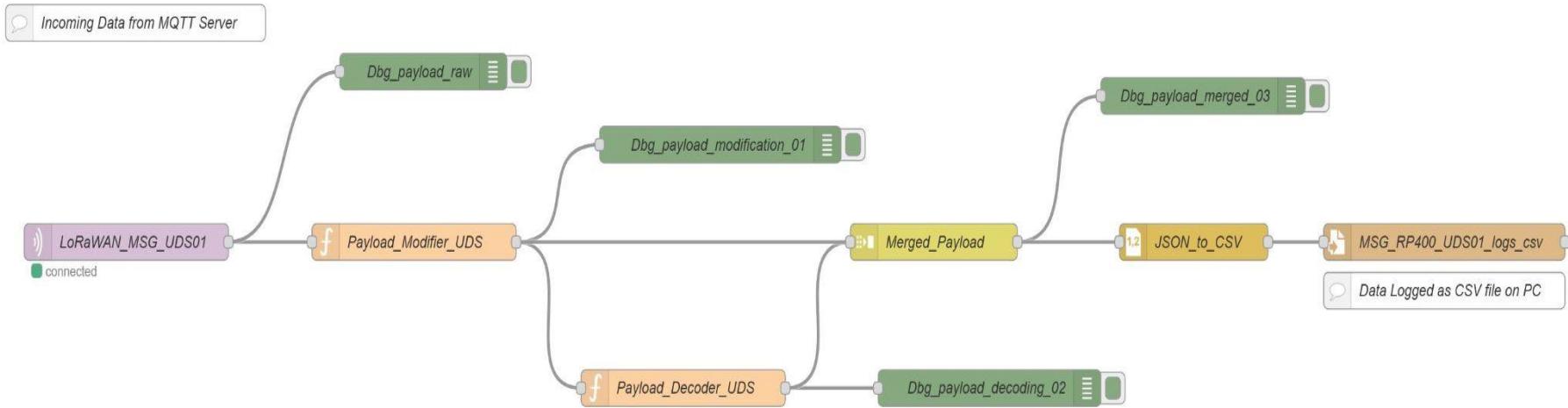
```
1 {  
2     "topic": "MSG/UDS01",  
3     "payload": {  
4         "applicationID": "16",  
5         "applicationName": "Raspberry_Pi_400_UDS",  
6         "data": "AXVjA4J+CgQAAA==",  
7         "devEUI": "24e124713c018455",  
8         "deviceName": "uds-01",  
9         "fCnt": 2007,  
10        "fPort": 85,  
11        "rxInfo": [  
12            {  
13                "altitude": 0,  
14                "latitude": 0,  
15                "loRaSNR": 13.5,  
16                "longitude": 0,  
17                "mac": "24e124ffffef57bd0",  
18                "name": "Local Gateway",  
19                "rssi": -55,  
20                "time": "2023-02-06T12:56:18.062038Z"  
21            }  
22        ],  
23        "time": "2023-02-06T12:56:18.062038Z",  
24        "txInfo": {  
25            "adr": true,  
26            "codeRate": "4/5",  
27            "dataRate": {  
28                "bandwidth": 125,  
29                "modulation": "LORA",  
30                "spreadFactor": 7  
31            },  
32            "frequency": 868300000  
33        },  
34        "qos": 0,  
35        "retain": false,  
36        "_msgid": "a64d9e13d55be44a"  
37    }  
38}
```

Raw Sensor payload and metadata  
from gateway to MQTT Server

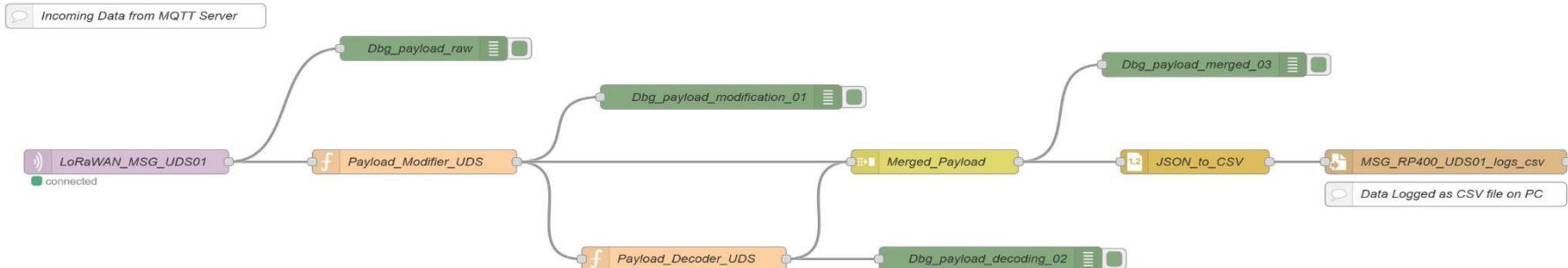
```
1 {"applicationID": "16", "applicationName": "Raspberry_Pi_400_UDS", "data": "AXVjA4KNAQ0AAA==", "devEUI": "24e124713c018455", "deviceName": "uds-01", "fCnt": 3, "fPort": 85, "rxInfo": [{"altitude": 0, "latitude": 0, "longitude": 0}], "time": "2023-02-06T12:56:18.062038Z"},  
2 {"applicationID": "16", "applicationName": "Raspberry_Pi_400_UDS", "data": "AXVjA4Kb8gQAAA==", "devEUI": "24e124713c018455", "deviceName": "uds-01", "fCnt": 4, "fPort": 85, "rxInfo": [{"altitude": 0, "latitude": 0, "longitude": 0}], "time": "2023-02-06T12:56:18.062038Z"},  
3 {"applicationID": "16", "applicationName": "Raspberry_Pi_400_UDS", "data": "AXVjA4KjBgQAAA==", "devEUI": "24e124713c018455", "deviceName": "uds-01", "fCnt": 5, "fPort": 85, "rxInfo": [{"altitude": 0, "latitude": 0, "longitude": 0}], "time": "2023-02-06T12:56:18.062038Z"},  
4 {"applicationID": "16", "applicationName": "Raspberry_Pi_400_UDS", "data": "AXVjA4KfbgQAAA==", "devEUI": "24e124713c018455", "deviceName": "uds-01", "fCnt": 6, "fPort": 85, "rxInfo": [{"altitude": 0, "latitude": 0, "longitude": 0}], "time": "2023-02-06T12:56:18.062038Z"},  
5 {"applicationID": "16", "applicationName": "Raspberry_Pi_400_UDS", "data": "AXVjA4J1CgQAAA==", "devEUI": "24e124713c018455", "deviceName": "uds-01", "fCnt": 7, "fPort": 85, "rxInfo": [{"altitude": 0, "latitude": 0, "longitude": 0}], "time": "2023-02-06T12:56:18.062038Z"},  
6 {"applicationID": "16", "applicationName": "Raspberry_Pi_400_UDS", "data": "AXVjA4J2CgQAAA==", "devEUI": "24e124713c018455", "deviceName": "uds-01", "fCnt": 8, "fPort": 85, "rxInfo": [{"altitude": 0, "latitude": 0, "longitude": 0}], "time": "2023-02-06T12:56:18.062038Z"},  
7 {"applicationID": "16", "applicationName": "Raspberry_Pi_400_UDS", "data": "AXVjA4J3CgQAAA==", "devEUI": "24e124713c018455", "deviceName": "uds-01", "fCnt": 9, "fPort": 85, "rxInfo": [{"altitude": 0, "latitude": 0, "longitude": 0}], "time": "2023-02-06T12:56:18.062038Z"},  
8 {"applicationID": "16", "applicationName": "Raspberry_Pi_400_UDS", "data": "AXVjA4J3CgQAAA==", "devEUI": "24e124713c018455", "deviceName": "uds-01", "fCnt": 10, "fPort": 85, "rxInfo": [{"altitude": 0, "latitude": 0, "longitude": 0}], "time": "2023-02-06T12:56:18.062038Z"}  
9
```

Sensor payload stored as  
text files using Python  
Scripts on MQTT Client

## Node-Red Flow for data logging and decoding running in subscribing client

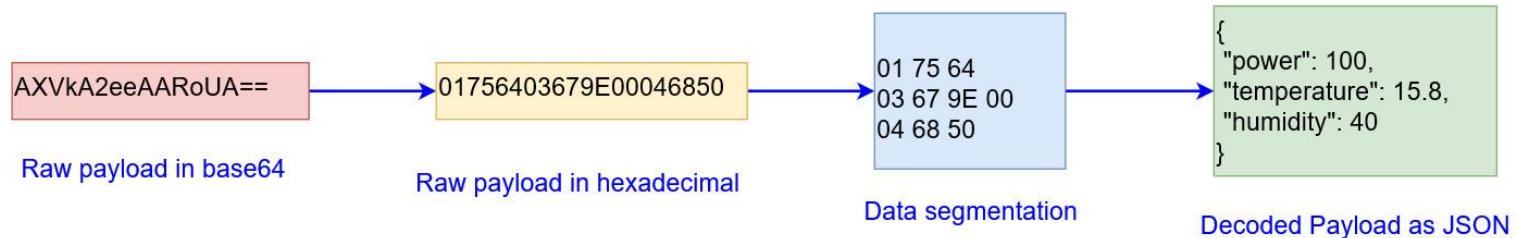


## Node-Red Flow for data logging and decoding running in subscribing client



| 1  | Topic     | timestamp                   | devEUI           | deviceName | Data_raw         | battery | distance | position | gatewayEUI        | rssi | IoRaSNR | frequency |
|----|-----------|-----------------------------|------------------|------------|------------------|---------|----------|----------|-------------------|------|---------|-----------|
| 2  | MSG/UDS01 | 2023-02-06T08:50:18.111428Z | 24e124713c018455 | uds-01     | AXVjA4JeBwQAAA== | 99      | 1886     | normal   | 24e124ffffef57bd0 | -56  | 10      | 868500000 |
| 3  | MSG/UDS01 | 2023-02-06T08:52:18.109342Z | 24e124713c018455 | uds-01     | AXVjA4JeBwQAAA== | 99      | 1886     | normal   | 24e124ffffef57bd0 | -58  | 13.5    | 868100000 |
| 4  | MSG/UDS01 | 2023-02-06T08:52:18.109342Z | 24e124713c018455 | uds-01     | AXVjA4JeBwQAAA== | 99      | 1886     | normal   | 24e124ffffef57bd0 | -58  | 13.5    | 868100000 |
| 5  | MSG/UDS01 | 2023-02-06T08:54:18.116412Z | 24e124713c018455 | uds-01     | AXVjA4LABgQAAA== | 99      | 1886     | normal   | 24e124ffffef57bd0 | -59  | 13.5    | 868100000 |
| 6  | MSG/UDS01 | 2023-02-06T08:54:18.116412Z | 24e124713c018455 | uds-01     | AXVjA4LABgQAAA== | 99      | 1728     | normal   | 24e124ffffef57bd0 | -59  | 13.5    | 868100000 |
| 7  | MSG/UDS01 | 2023-02-06T08:56:18.11149Z  | 24e124713c018455 | uds-01     | AXVjA4LCBgQAAA== | 99      | 1728     | normal   | 24e124ffffef57bd0 | -59  | 12      | 868500000 |
| 8  | MSG/UDS01 | 2023-02-06T08:56:18.11149Z  | 24e124713c018455 | uds-01     | AXVjA4LCBgQAAA== | 99      | 1730     | normal   | 24e124ffffef57bd0 | -59  | 12      | 868500000 |
| 9  | MSG/UDS01 | 2023-02-06T08:58:18.115359Z | 24e124713c018455 | uds-01     | AXVjA4LCBgQAAA== | 99      | 1730     | normal   | 24e124ffffef57bd0 | -62  | 14      | 868100000 |
| 10 | MSG/UDS01 | 2023-02-06T08:58:18.115359Z | 24e124713c018455 | uds-01     | AXVjA4LCBgQAAA== | 99      | 1730     | normal   | 24e124ffffef57bd0 | -62  | 14      | 868100000 |

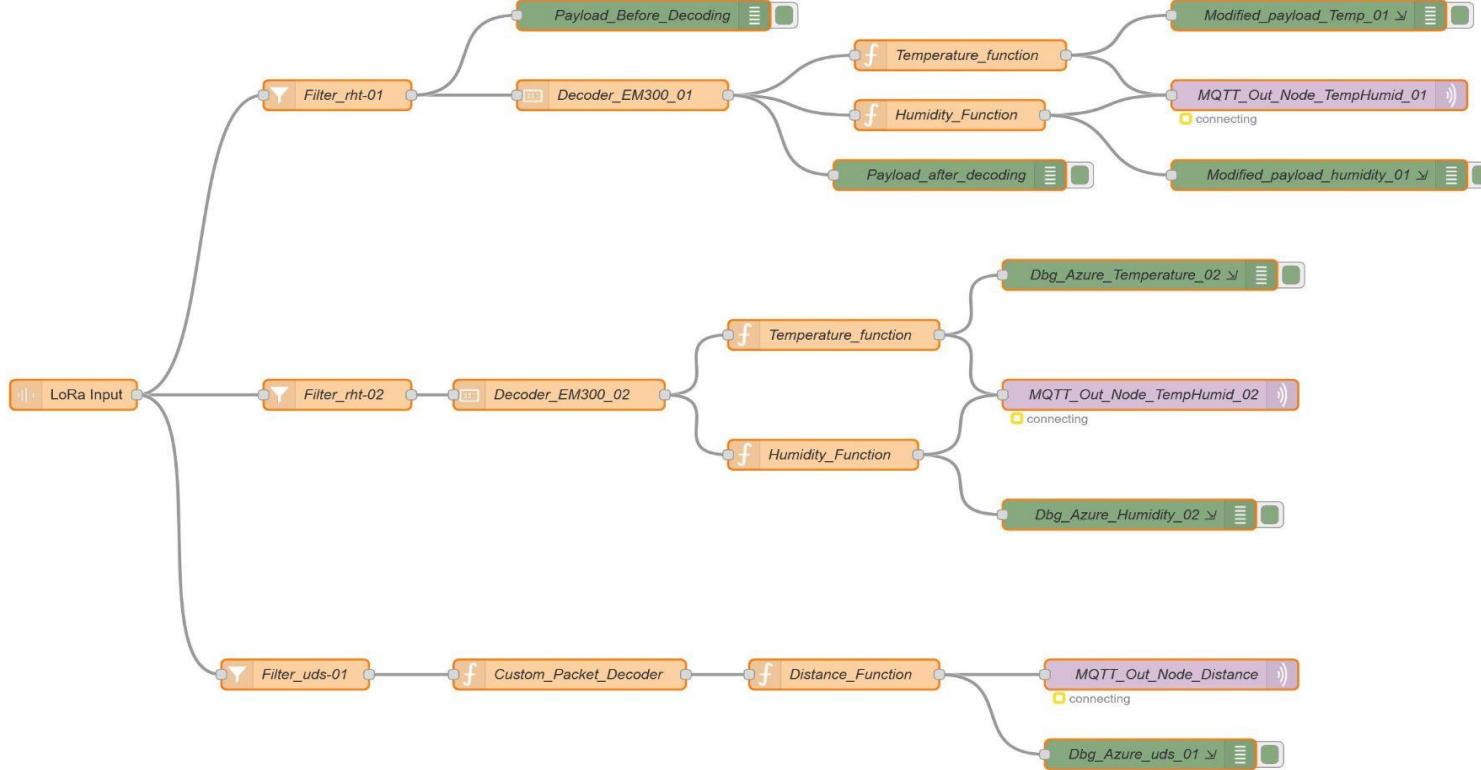
## Sensor Payload decoding logic (With an example of Relative Humidity-Temperature sensor )



### Payload decoding logic for Milesight's EM310 Temperature humidity sensor

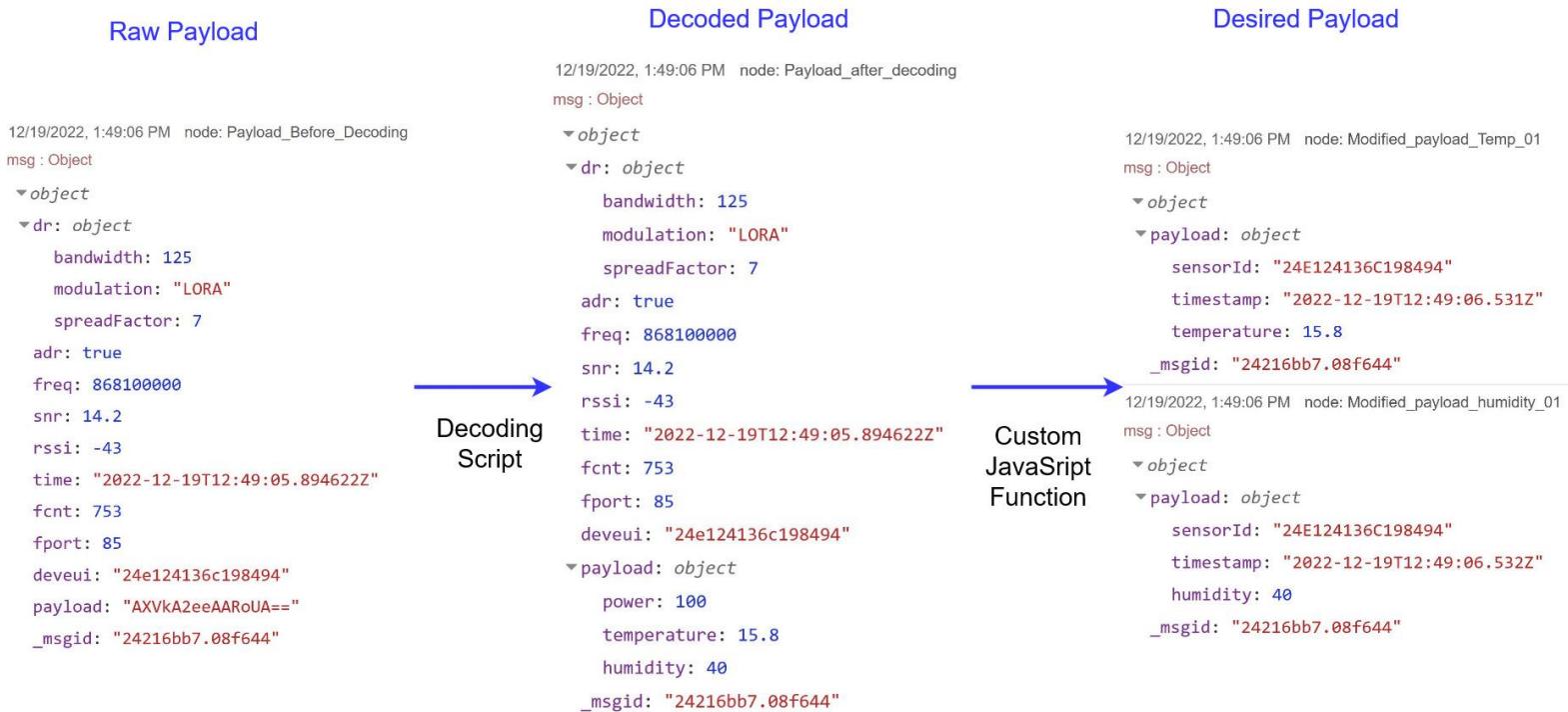
| Channel Id | Channel type | Channel value | Value | Description       | Unit |
|------------|--------------|---------------|-------|-------------------|------|
| 01         | 75           | 64            | 100   | Battery level     | %    |
| 03         | 67           | 9E 00         | 15.8  | Temperature       | °C   |
| 04         | 68           | 50            | 40    | Relative Humidity | %    |

## Node-Red Flow for data logging and decoding running in publishing client (Mile Sight UG65 indoor gateway)

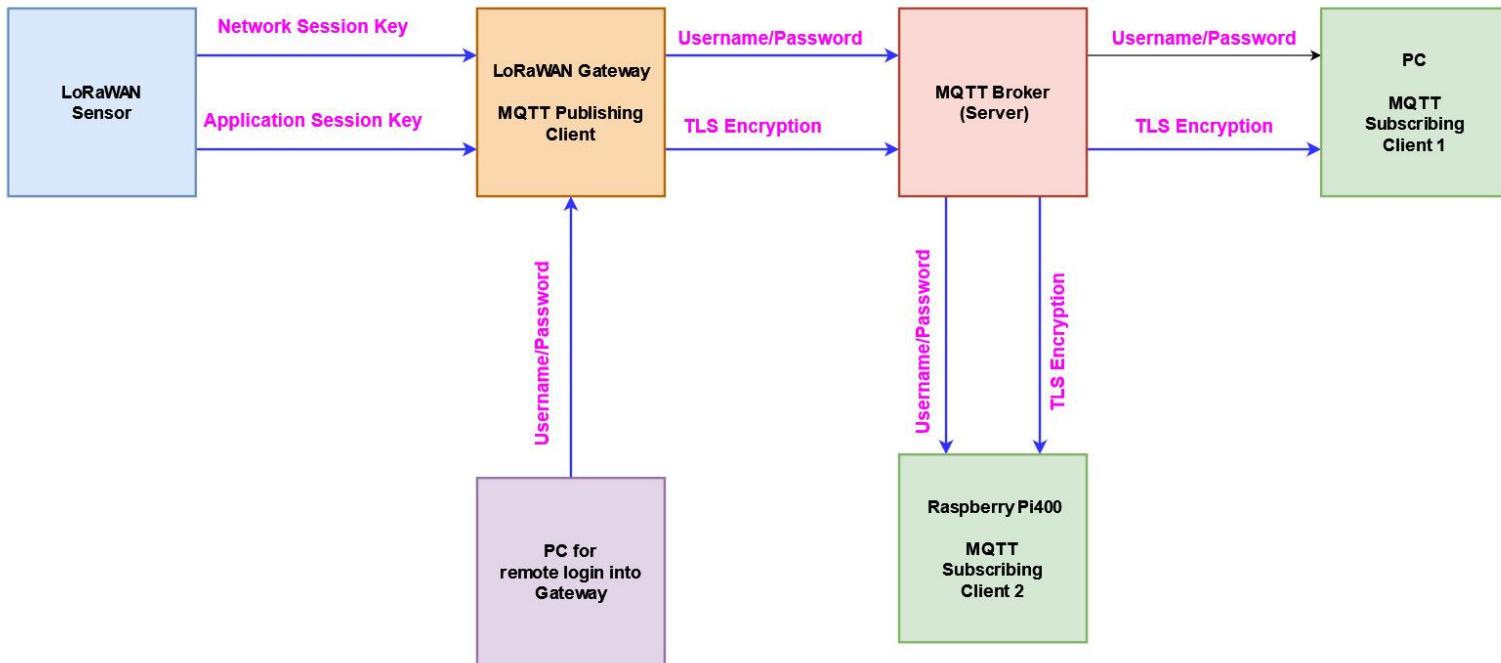


# Sensor payload decoding and data structure modification

## Message Payload modification in Gateway using Node-RED

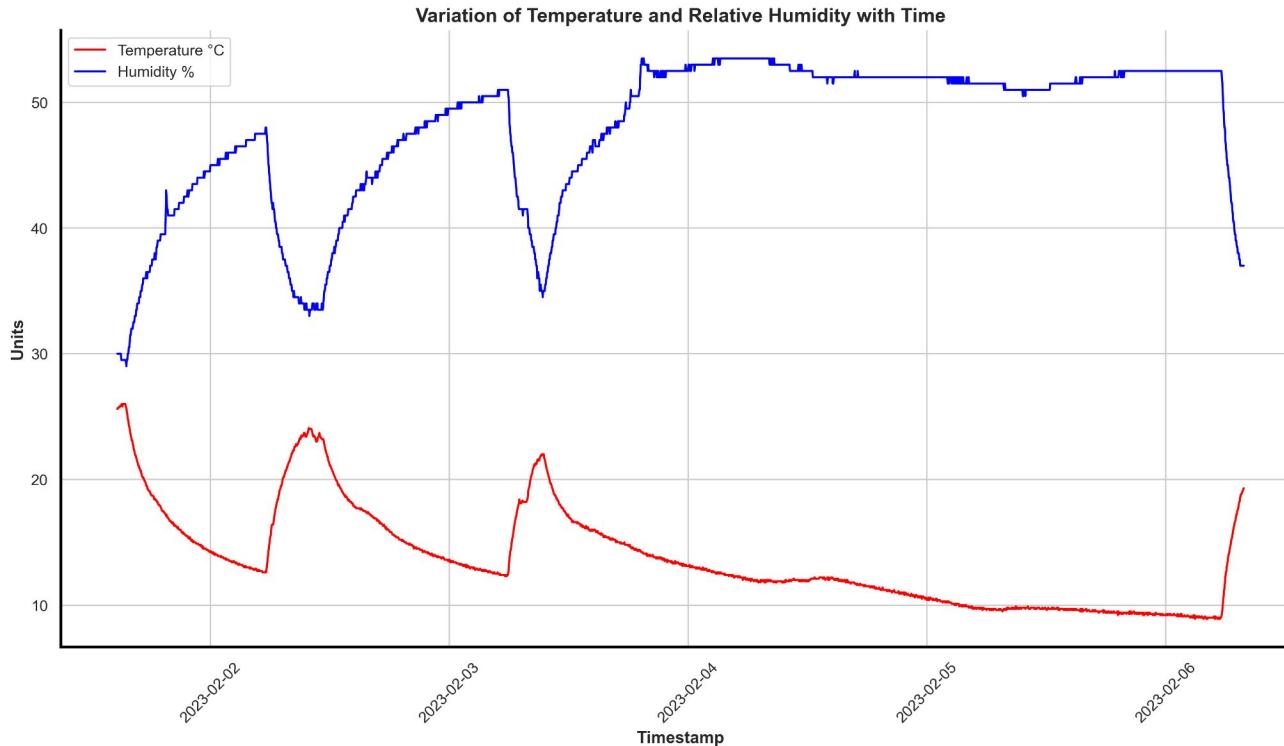


# Network Security Implementation



# Results and Analytics from collected sensor data

Temperature humidity data collected from RHT sensors (rht -01)



Key parameters:

Test duration: 01- 06 Feb 2023

Recorded variables: Temp, RH, timestamp

Polling: 3 minutes

Data samples: 2264

Timestamp: ISO 8601 format

LoRa Frequency : 868 MHz band

# Results and Analytics from collected sensor data

## Temperature humidity data collected from RHT sensor (rht -02)

| 1  | Topic     | timestamp                   | Data         | devEUI           | deviceName | gatewayEUI        | rssi | IoRaSNR | frequency |
|----|-----------|-----------------------------|--------------|------------------|------------|-------------------|------|---------|-----------|
| 2  | MSG/RHT02 | 2023-01-31T15:27:47.584032Z | A2fEAARoVg== | 24e124136c220737 | rht-02     | 24e124ffffef57bd0 | -52  | 13.2    | 868300000 |
| 3  | MSG/RHT02 | 2023-01-31T15:29:47.586139Z | A2fEAARoVg== | 24e124136c220737 | rht-02     | 24e124ffffef57bd0 | -53  | 14      | 868100000 |
| 4  | MSG/RHT02 | 2023-01-31T15:31:47.586622Z | A2fEAARoVQ== | 24e124136c220737 | rht-02     | 24e124ffffef57bd0 | -49  | 11.5    | 868500000 |
| 5  | MSG/RHT02 | 2023-01-31T15:33:47.593672Z | A2fEAARoVQ== | 24e124136c220737 | rht-02     | 24e124ffffef57bd0 | -52  | 13.8    | 868300000 |
| 6  | MSG/RHT02 | 2023-01-31T15:35:47.582386Z | A2fEAARoVQ== | 24e124136c220737 | rht-02     | 24e124ffffef57bd0 | -46  | 13.5    | 868300000 |
| 7  | MSG/RHT02 | 2023-01-31T15:37:47.587635Z | A2fEAARoVA== | 24e124136c220737 | rht-02     | 24e124ffffef57bd0 | -45  | 10.2    | 868500000 |
| 8  | MSG/RHT02 | 2023-01-31T15:39:47.578586Z | A2fEAARoVA== | 24e124136c220737 | rht-02     | 24e124ffffef57bd0 | -47  | 10.2    | 868500000 |
| 9  | MSG/RHT02 | 2023-01-31T15:41:47.582952Z | A2fEAARoVA== | 24e124136c220737 | rht-02     | 24e124ffffef57bd0 | -56  | 13      | 868100000 |
| 10 | MSG/RHT02 | 2023-01-31T15:43:47.586641Z | A2fEAARoVQ== | 24e124136c220737 | rht-02     | 24e124ffffef57bd0 | -50  | 13.5    | 868300000 |
| 11 | MSG/RHT02 | 2023-01-31T15:45:47.580111Z | A2fEAARoVA== | 24e124136c220737 | rht-02     | 24e124ffffef57bd0 | -50  | 9       | 868500000 |
| 12 | MSG/RHT02 | 2023-01-31T15:47:47.584421Z | A2fEAARoVA== | 24e124136c220737 | rht-02     | 24e124ffffef57bd0 | -47  | 13.8    | 868100000 |
| 13 | MSG/RHT02 | 2023-01-31T15:49:47.583109Z | A2fGAARoVA== | 24e124136c220737 | rht-02     | 24e124ffffef57bd0 | -46  | 13.5    | 868300000 |
| 14 | MSG/RHT02 | 2023-01-31T15:51:47.580035Z | A2fEAARoVQ== | 24e124136c220737 | rht-02     | 24e124ffffef57bd0 | -50  | 13.5    | 868300000 |
| 15 | MSG/RHT02 | 2023-01-31T15:53:47.575046Z | A2fEAARoVA== | 24e124136c220737 | rht-02     | 24e124ffffef57bd0 | -48  | 13      | 868100000 |

Key parameters:

Test duration:  
31.01.2023 - 01.02.2023

Recorded variables:  
Raw payload, timestamp, RSSI,  
SNR, LoRa frequency

Polling: 2 minutes

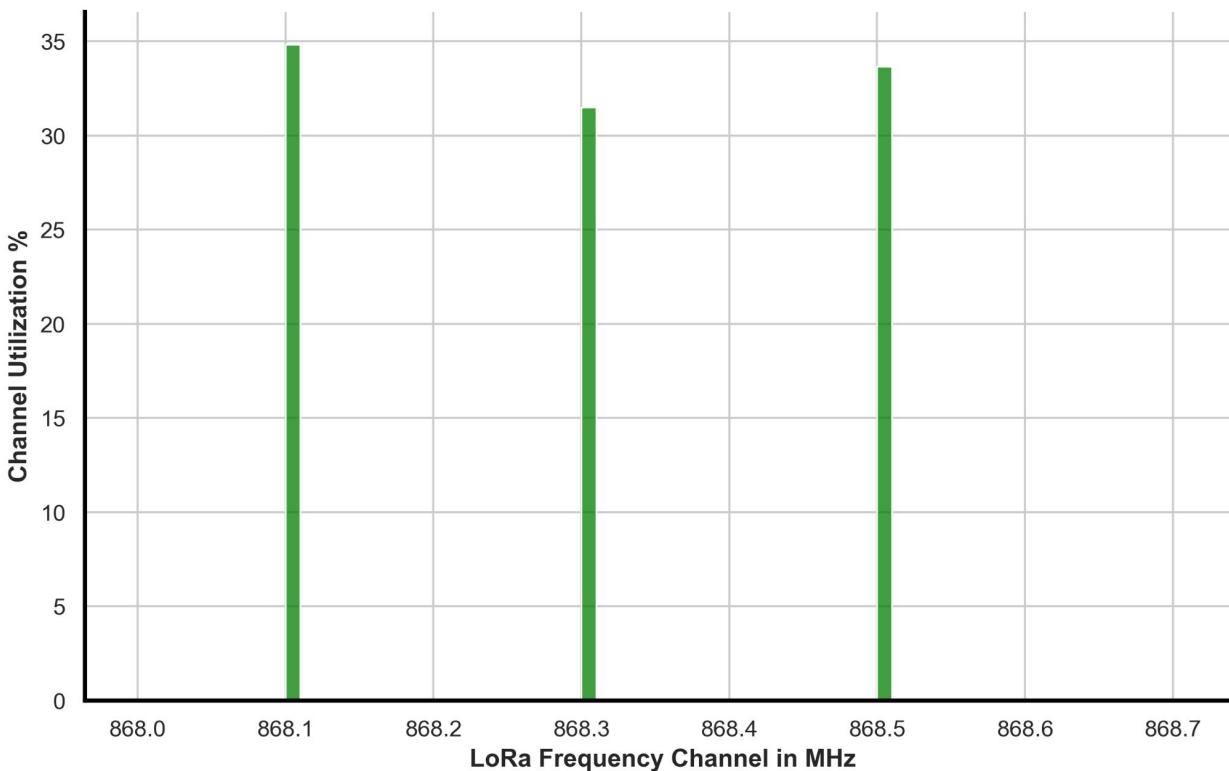
Data samples: 689

Timestamp: ISO 8601 format

LoRa Frequency : 868 MHz band

# Results and Analytics from collected sensor data

## LoRa Frequency channel usage (rht -02)



Key parameters:

Test duration:  
31.01.2023 - 01.02.2023

Recorded variables: Raw payload, timestamp, RSSI, SNR, LoRa frequency

Polling: 2 minutes

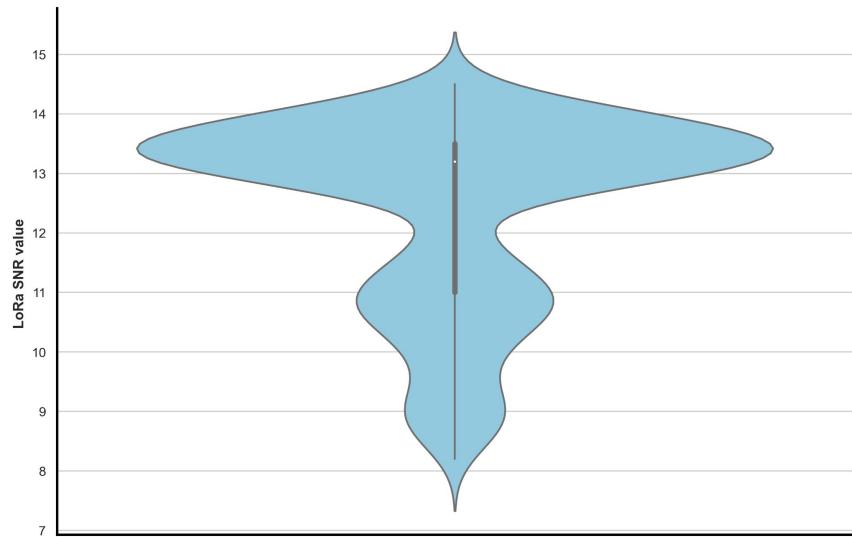
Data samples: 689

Timestamp: ISO 8601 format

LoRa Frequency : 868 MHz band

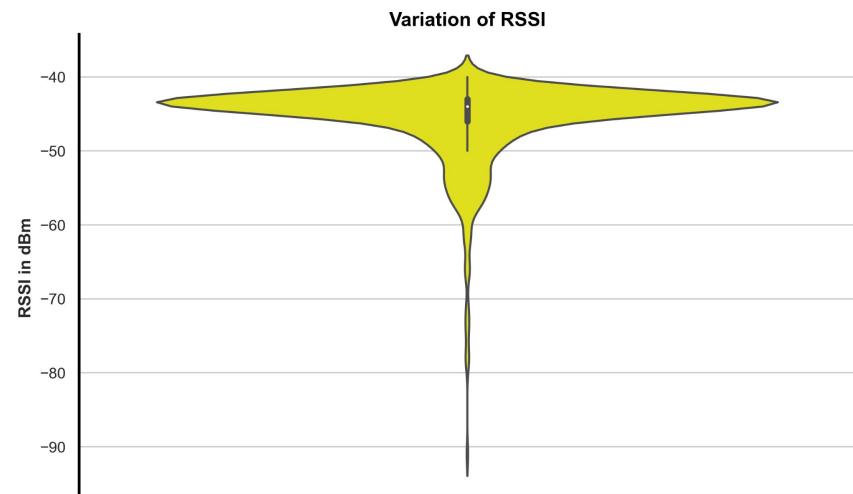
## RSSI and LoRa SNR variation from RHT sensor (rht -02)

LoRa SNR Variation



SNR varied from 8.2 to 14.5, Median SNR = 13.2

LoRa RSSI Variation



RSSI varied from -91 dBm to -40 dBm , Median RSSI = -44 dBm

# Results and Analytics from collected sensor data

## Data collected from Ultrasonic distance sensors (uds -01)

| 1  | Topic     | timestamp                   | devEUI           | deviceName | Data_raw         | battery | distance | position | gatewayEUI        | rssi | IoRaSNR | frequency |
|----|-----------|-----------------------------|------------------|------------|------------------|---------|----------|----------|-------------------|------|---------|-----------|
| 2  | MSG/UDS01 | 2023-02-06T08:50:18.111428Z | 24e124713c018455 | uds-01     | AXVjA4JeBwQAAA== | 99      | 1886     | normal   | 24e124ffffef57bd0 | -56  | 10      | 868500000 |
| 3  | MSG/UDS01 | 2023-02-06T08:52:18.109342Z | 24e124713c018455 | uds-01     | AXVjA4JeBwQAAA== | 99      | 1886     | normal   | 24e124ffffef57bd0 | -58  | 13.5    | 868100000 |
| 4  | MSG/UDS01 | 2023-02-06T08:52:18.109342Z | 24e124713c018455 | uds-01     | AXVjA4JeBwQAAA== | 99      | 1886     | normal   | 24e124ffffef57bd0 | -58  | 13.5    | 868100000 |
| 5  | MSG/UDS01 | 2023-02-06T08:54:18.116412Z | 24e124713c018455 | uds-01     | AXVjA4LABgQAAA== | 99      | 1886     | normal   | 24e124ffffef57bd0 | -59  | 13.5    | 868100000 |
| 6  | MSG/UDS01 | 2023-02-06T08:54:18.116412Z | 24e124713c018455 | uds-01     | AXVjA4LABgQAAA== | 99      | 1728     | normal   | 24e124ffffef57bd0 | -59  | 13.5    | 868100000 |
| 7  | MSG/UDS01 | 2023-02-06T08:56:18.11149Z  | 24e124713c018455 | uds-01     | AXVjA4LCBgQAAA== | 99      | 1728     | normal   | 24e124ffffef57bd0 | -59  | 12      | 868500000 |
| 8  | MSG/UDS01 | 2023-02-06T08:56:18.11149Z  | 24e124713c018455 | uds-01     | AXVjA4LCBgQAAA== | 99      | 1730     | normal   | 24e124ffffef57bd0 | -59  | 12      | 868500000 |
| 9  | MSG/UDS01 | 2023-02-06T08:58:18.115359Z | 24e124713c018455 | uds-01     | AXVjA4LCBgQAAA== | 99      | 1730     | normal   | 24e124ffffef57bd0 | -62  | 14      | 868100000 |
| 10 | MSG/UDS01 | 2023-02-06T08:58:18.115359Z | 24e124713c018455 | uds-01     | AXVjA4LCBgQAAA== | 99      | 1730     | normal   | 24e124ffffef57bd0 | -62  | 14      | 868100000 |
| 11 | MSG/UDS01 | 2023-02-06T09:00:18.107491Z | 24e124713c018455 | uds-01     | AXVjA4LABgQAAA== | 99      | 1730     | normal   | 24e124ffffef57bd0 | -62  | 8.2     | 868500000 |
| 12 | MSG/UDS01 | 2023-02-06T09:00:18.107491Z | 24e124713c018455 | uds-01     | AXVjA4LABgQAAA== | 99      | 1728     | normal   | 24e124ffffef57bd0 | -62  | 8.2     | 868500000 |
| 13 | MSG/UDS01 | 2023-02-06T09:02:18.106684Z | 24e124713c018455 | uds-01     | AXVjA4LDBgQAAA== | 99      | 1728     | normal   | 24e124ffffef57bd0 | -64  | 13.5    | 868300000 |
| 14 | MSG/UDS01 | 2023-02-06T09:02:18.106684Z | 24e124713c018455 | uds-01     | AXVjA4LDBgQAAA== | 99      | 1731     | normal   | 24e124ffffef57bd0 | -64  | 13.5    | 868300000 |

Key parameters:

Test duration: 06 Feb 2023

Recorded variables:

Distance, position, LoRa parameters

Polling: 2 minutes

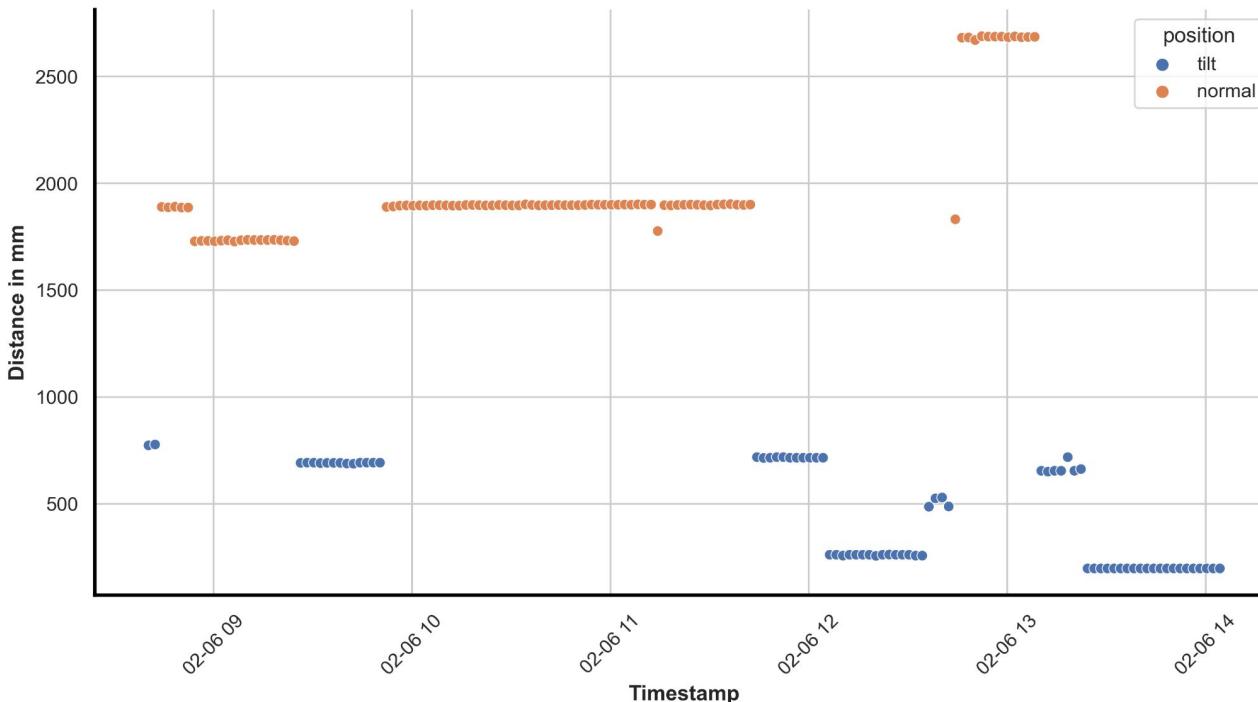
Data samples: 163

Timestamp: ISO 8601 format

LoRa Frequency : 868 MHz band

# Results and Analytics from collected sensor data

Data collected from Ultrasonic distance sensors (uds -01)



Key parameters:

Test duration: 06 Feb 2023

Recorded variables:  
Distance, position, LoRa  
parameters

Polling: 2 minutes

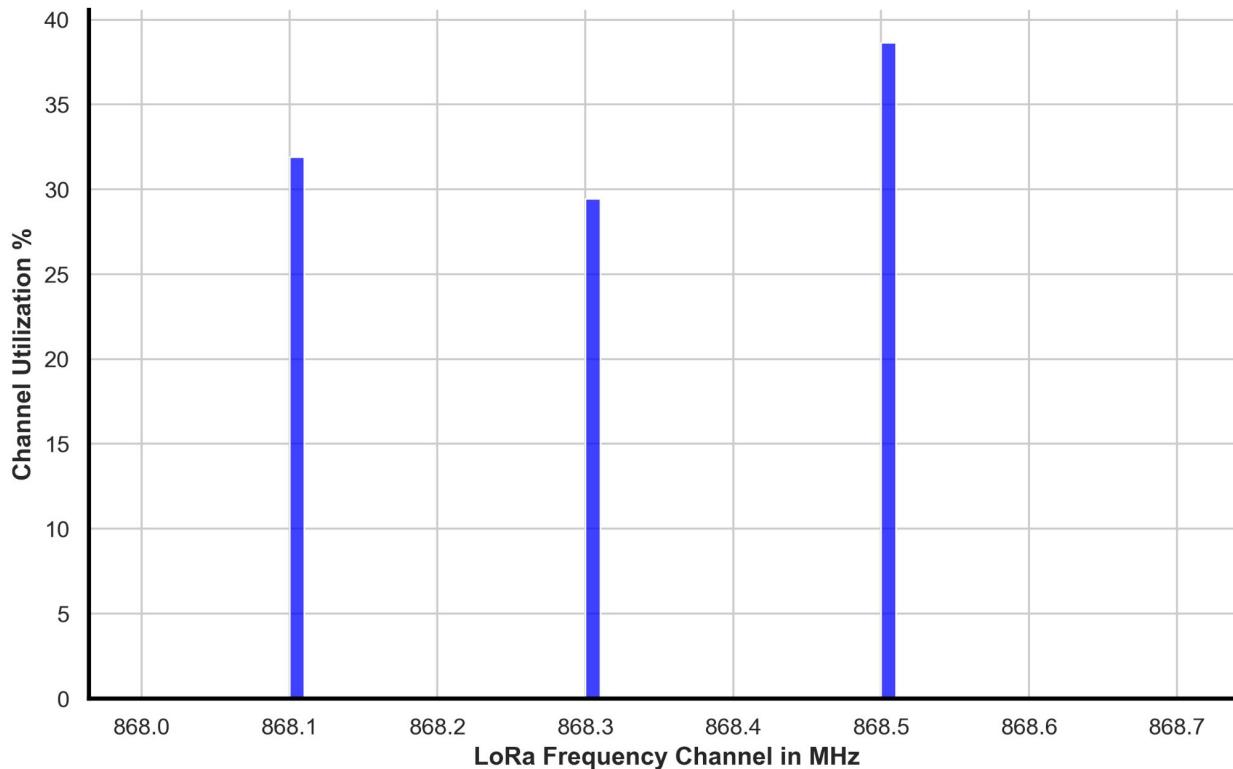
Data samples: 163

Timestamp: ISO 8601 format

LoRa Frequency : 868 MHz band

# Results and Analytics from collected sensor data

## LoRa Frequency channel usage (uds -01)



Key parameters:

Test duration: 06 Feb 2023

Recorded variables:  
Distance, position, LoRa  
parameters

Polling: 2 minutes

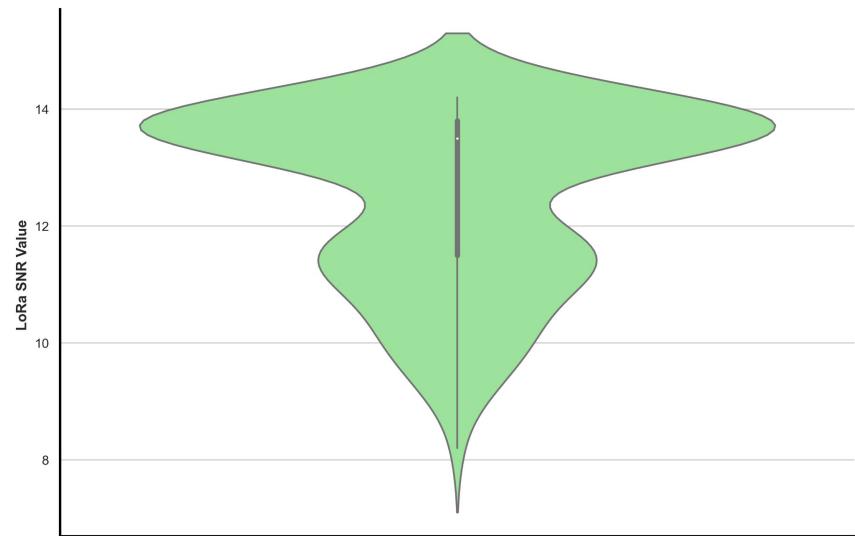
Data samples: 163

Timestamp: ISO 8601 format

LoRa Frequency : 868 MHz band

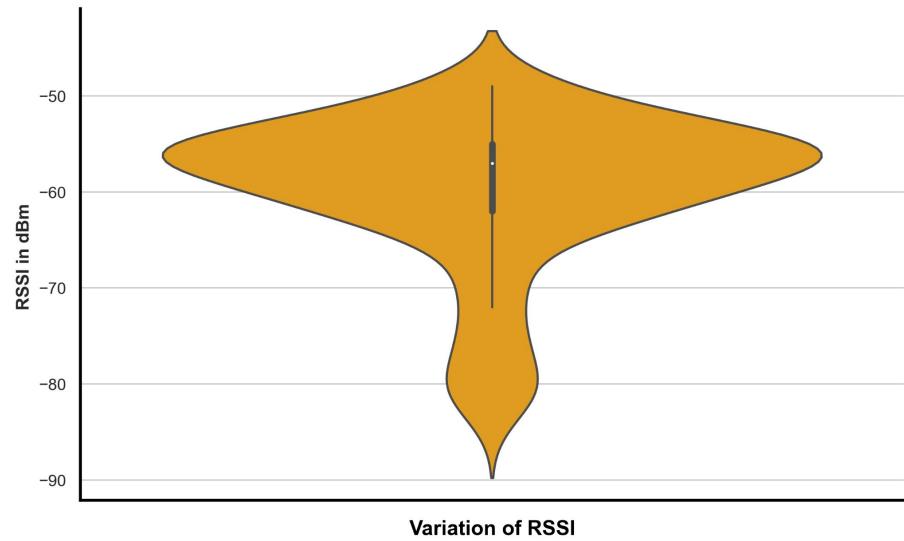
## RSSI and LoRa SNR variation from UDS sensor (uds-01)

LoRa SNR Variation



SNR varied from 8.2 to 14.2, Median SNR = 13.5

LoRa RSSI Variation

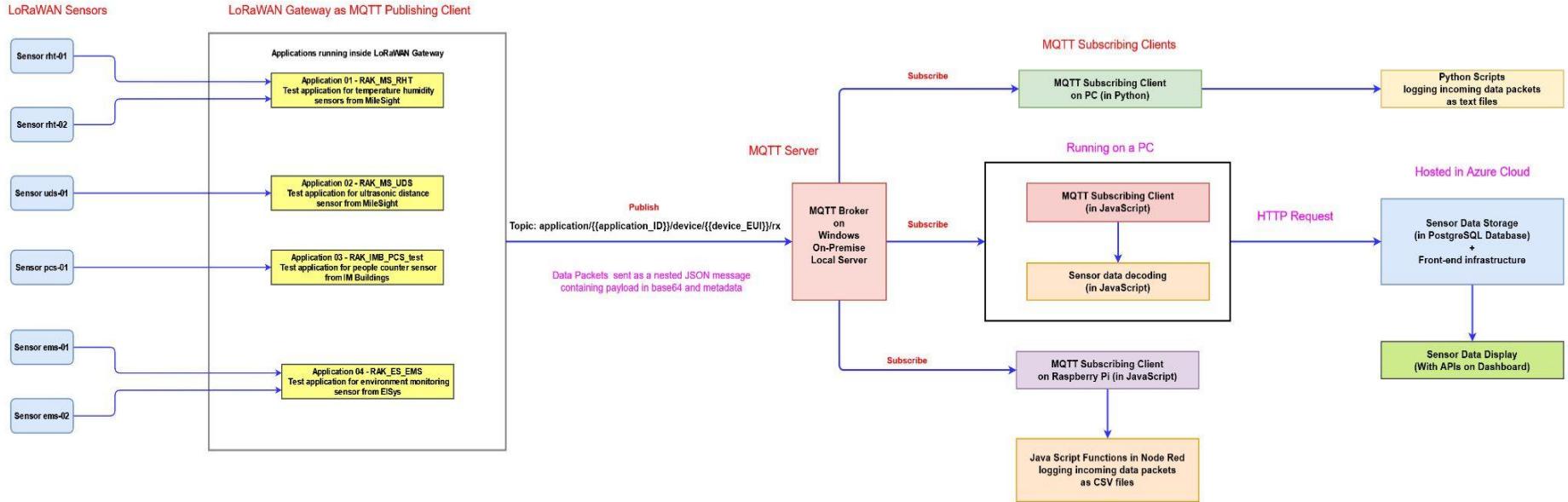


RSSI varied from -84 dBm to -49 dBm , Median RSSI = -57.6 dBm

## Analysis on system architecture and test results

- It is possible to do the computational tasks of sensor payload decoding and data structure modification on either the publisher and the subscriber.
- Both methods works reliably. However not all gateways have the ability to run the decoding script. In this case only subscribing client can be used for these essential tasks.
- What happens when gateways from different manufacturers are used?
- What happens when there are a large number of gateways in the network?
- Gateway is already owned essential infrastructure, cloud / on-premise server requires additional costs and expertise. Example Azure IoT hub.
- Need of improvement in gateway software.

# Network I - Test network in Campus



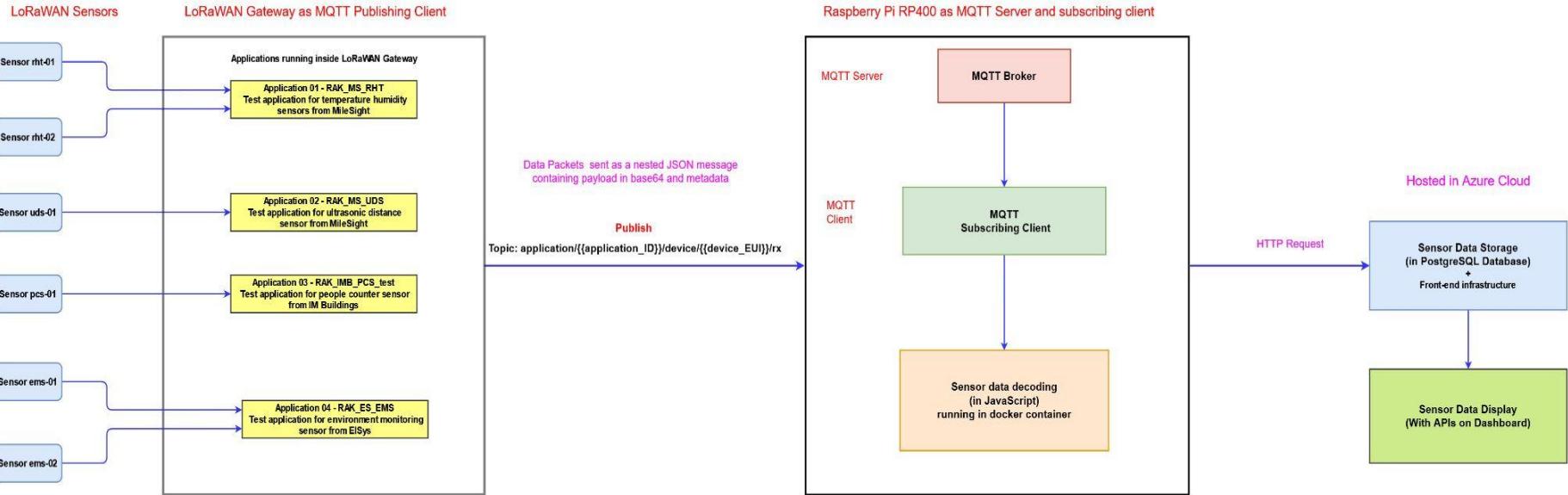
## Key Features:

- Single point of integration for LoRaWAN gateway and MQTT Server.
- Improved application structure and no payload decoding in gateway.
- Simplified topic structure by application ID and Device EUI.
- Decoding scripts and MQTT subscribing clients were written mostly in JavaScript Mostly.

# Network I - Collected Data

| 1  | Topic                                    | Time_stamp | Application_Name | Application_ID | Gateway_EUI     | Device_EUI       | Device_Name | Data                             | RSSI | LoRa_SNR | LoRa_Frequency | Data_Rate |
|----|--|------------|------------------|----------------|-----------------|------------------|-------------|----------------------------------|------|----------|----------------|-----------|
| 2  | application/4/device/a81758ffe07654a/rx  | 1678783701 | RAK_ES_EMS       | 4              | ac1f09ffe070717 | a81758ffe07654a  | ems-02      | AQDSAiYDAQBAbw4vCwAAAA4NAQ8AEgA= | -22  | 13.8     | 867300000      | 5         |
| 3  | application/1/device/24e124136c198494/rx | 1678783805 | RAK_MS_RHT       | 1              | ac1f09ffe070717 | 24e124136c198494 | rht-01      | A2fIAARoWQ==                     | -342 | 0        | 868800000      | 7         |
| 4  | application/2/device/24e124713c018455/rx | 1678783880 | RAK_MS_UDS       | 2              | ac1f09ffe070717 | 24e124713c018455 | uds-01      | AXVjA4JNBwQAAA==                 | -342 | 0        | 868800000      | 7         |
| 5  | application/4/device/a81758ffe076551/rx  | 1678783887 | RAK_ES_EMS       | 4              | ac1f09ffe070717 | a81758ffe076551  | ems-01      | AQDTAiYDAAA9Bw4lCwAAACcNAQ8AEgA= | -26  | 13.8     | 868300000      | 5         |
| 6  | application/4/device/a81758ffe07654a/rx  | 1678784001 | RAK_ES_EMS       | 4              | ac1f09ffe070717 | a81758ffe07654a  | ems-02      | AQDSAiYDAAxABw4vCwAAAA4NAQ8AEgA= | -22  | 13.3     | 868300000      | 5         |
| 7  | application/3/device/0004a30b00f7eac6/rx | 1678784004 | RAK_IMB_PCS      | 3              | ac1f09ffe070717 | 0004a30b00f7eac6 | pcs-01      | AgYABKMLAPfqxgABJgAAAACAAAsACKQ= | -40  | 10.3     | 867100000      | 0         |
| 8  | application/1/device/24e124136c198494/rx | 1678784105 | RAK_MS_RHT       | 1              | ac1f09ffe070717 | 24e124136c198494 | rht-01      | A2fIAARoWA==                     | -342 | 0        | 868800000      | 7         |
| 9  | application/2/device/24e124713c018455/rx | 1678784180 | RAK_MS_UDS       | 2              | ac1f09ffe070717 | 24e124713c018455 | uds-01      | AXVjA4JZBwQAAA==                 | -342 | 0        | 868800000      | 7         |
| 10 | application/4/device/a81758ffe076551/rx  | 1678784187 | RAK_ES_EMS       | 4              | ac1f09ffe070717 | a81758ffe076551  | ems-01      | AQDSAiUDAP9Bw4lCwAAACcNAQ8AEgA=  | -28  | 10       | 868500000      | 5         |
| 11 | application/4/device/a81758ffe07654a/rx  | 1678784301 | RAK_ES_EMS       | 4              | ac1f09ffe070717 | a81758ffe07654a  | ems-02      | AQDRAiYDAAxABw4vCwAAAA4NAQ8CEgA= | -23  | 10       | 868500000      | 5         |
| 12 | application/1/device/24e124136c198494/rx | 1678784405 | RAK_MS_RHT       | 1              | ac1f09ffe070717 | 24e124136c198494 | rht-01      | A2fIAARoWA==                     | -342 | 0        | 868800000      | 7         |
| 13 | application/2/device/24e124713c018455/rx | 1678784480 | RAK_MS_UDS       | 2              | ac1f09ffe070717 | 24e124713c018455 | uds-01      | AXVjA4JaBwQAAA==                 | -342 | 0        | 868800000      | 7         |
| 14 | application/4/device/a81758ffe076551/rx  | 1678784487 | RAK_ES_EMS       | 4              | ac1f09ffe070717 | a81758ffe076551  | ems-01      | AQDSAiYDAAA+Bw4lCwAAACcNAQ8CEgA= | -27  | 14       | 867700000      | 5         |
| 15 | application/4/device/a81758ffe07654a/rx  | 1678784601 | RAK_ES_EMS       | 4              | ac1f09ffe070717 | a81758ffe07654a  | ems-02      | AQDQAiYDAP9Bw4vCwAAAA4NAQ8AEgA=  | -22  | 13.8     | 867900000      | 5         |
| 16 | application/1/device/24e124136c198494/rx | 1678784705 | RAK_MS_RHT       | 1              | ac1f09ffe070717 | 24e124136c198494 | rht-01      | A2fIAARoWA==                     | -342 | 0        | 868800000      | 7         |
| 17 | application/2/device/24e124713c018455/rx | 1678784780 | RAK_MS_UDS       | 2              | ac1f09ffe070717 | 24e124713c018455 | uds-01      | AXVjA4JfBwQAAA==                 | -342 | 0        | 868800000      | 7         |
| 18 | application/4/device/a81758ffe076551/rx  | 1678784787 | RAK_ES_EMS       | 4              | ac1f09ffe070717 | a81758ffe076551  | ems-01      | AQDRAiYDAP8+Bw4lCwAAACcNAQ8AEgA= | -30  | 13.5     | 868100000      | 5         |
| 19 | application/4/device/a81758ffe07654a/rx  | 1678784901 | RAK_ES_EMS       | 4              | ac1f09ffe070717 | a81758ffe07654a  | ems-02      | AQDQAiYDABw4vCwAAAA4NAQ8AEgA=    | -23  | 13.3     | 867900000      | 5         |
| 20 | application/3/device/0004a30b00f7eac6/rx | 1678784904 | RAK_IMB_PCS      | 3              | ac1f09ffe070717 | 0004a30b00f7eac6 | pcs-01      | AgYABKMLAPfqxgABJgAAAACAAAsACKU= | -41  | 9.8      | 868300000      | 0         |

# Network II - Network deployed for real world application



# Dashboard designed for visualization of sensor data

obodo Monitoring software-**DHBW Heidenheim**

RAUM 218

RAUM 218

RAUM 218

Startseite

Temperatur

Luftfeuchtigkeit

Raumbelegung

20.3°C

32.5%

1/200

More Data

More Data

More Data

DHBW  
Dualen Hochschule  
Bielefeld-Nürnberg  
Heidenheim

14:07

DONNERSTAG, 06.04.2023

## Challenges and scope for future work

### Challenges with LoRaWAN gateway:

- Output JSON not standardized- Effects database design
- MQTT integration with external server - (control level, application wise and global integration)
- MQTT client information control level varies from manufacturer to manufacturer
- Remote access to gateway - Difficult to access gateway from outside the network

### Challenges with LoRaWAN sensor nodes:

- Sensor node configuration tools - Difficult to use, varying level of control for user
- Sensor payload decoding scripts - Only in JavaScript, No standardisation of logic
- Use of non standardized form factor in batteries - Vendor lock in

### Challenges with MQTT and cloud integration

MQTT connection with cloud servers has problems due to:

Security - TLS Certificate, MQTT protocol version, No connection on port 1883