UNIVERSITÀ DI PISA

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Internet of Things – University of Pisa

GreenHouse

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ABSTRACT

The objective of this project is to build an IoT telemetry and control system to simulate a smart environment for a greenhouse, using which it is possible to monitor the humidity and temperature of soil and automatically activate or deactivate irrigation or heating protocols as needed.

This application was developed within the context of the course *Internet of Things* at University of Pisa, and as such it was implemented using the tools introduced and covered in the learning material.

This project demonstrates an understanding of the MQTT and CoAP networks, the flow of data between the different devices in the control system, and an unambiguous navigation of the Contiki-NG operating system, including the Cooja tool.

***Keywords**: Internet of Things, Smart Environment, Control System, Contiki-NG, Cooja, MQTT, CoAP.*

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INTRODUCTION

GreenHouse was developed for the purpose of monitoring humidity and temperature in plant soil without the need of human intervention, and its regulation by automatic activation or deactivation of available irrigation and heating protocols. This is achieved by designing a smart system composed of sensors and actuators, as well as software to store and process the collected data.

Functionalities

There are two different networks of IoT devices in the system. First the **MQTT** network, it includes a sensor deployed at the level of the soil, which reports humidity and temperature values periodically to a Java collector through a border router. This collector stores the values into a database then sends the appropriate command to the irrigation or heating actuators.

The actuators are deployed on a **CoAP** network, where a device receives single commands of activation and deactivation. For visual representation, the activation of irrigation turns on a green LED light for irrigation and a red LED light for heating.

If the CoAP resource's response is successful, the Java collector executes simple logic to simulate the regulation of humidity and temperature, and the values are again stored in the database for future uses.

Technologies Used

Contikier: The container on which the IoT application runs on top of the Ubuntu VM.
Cooja: A Contiki-NG tool for running a simulation of the system.
MQTT: used for implementing a Mosquitto broker and Mosquitto humidity/temperature publishers.
CoAP: used for implementing the irrigation/heating actuators.
Java: used for implementing the collector and the logic, runs locally on the Ubuntu VM.
MySQL: the DBMS chosen for this project, runs locally on the Ubuntu VM.

NETWORKS

MQTT

Humidity and temperature values are monitored by the MQTT sensors and sent via a connection established by the MQTT broker, in a publisher/subscriber mechanism. The publisher sends the data periodically on the humidity topic, every 30 seconds, and the Java collector plays the role of the subscriber to retrieve the message. Here is the code snippet responsible for this at the level of the MQTT node.

Since there are two types of observable resources, each of the topics are monitored on different ports, **port:1883** for humidity and **port:1880** for temperature.

The rest of the report will discuss in detail the workings of the Humidity resource monitoring only to avoid repetition. Temperature monitoring is implemented similarly and is executed along the other.

Here is an example of the humidity publishing function.

```
                if(state == STATE_SUBSCRIBED){

                        //publish humidity percentage every 30 seconds
                        etimer_set(&publish_timer, DEFAULT_PUBLISH_INTERVAL);
                        PROCESS_WAIT_EVENT_UNTIL(etimer_expired(&publish_timer));

                        sprintf(pub_topic, "%s", "humidity");

                        //Random humidity values
                        humidity_perc = (rand() % 40);

                        sprintf(app_buffer, "{\"HUM\":%d}",humidity_perc);

                        printf("%s \n",app_buffer);

                        mqtt_publish(&conn, NULL, pub_topic, (uint8_t *)app_buffer,
strlen(app_buffer), MQTT_QOS_LEVEL_0, MQTT_RETAIN_OFF);
```

There are two timers in the code, a periodical timer which is the duration after which the MQTT client connection is checked, and a publishing timer which specifies the frequency of the messages. The humidity publishing timer is reset at the expiration of each 20s period with the use of the *PROCESS_WAIT_EVENT_UNTIL*.

For temperature, the publishing timer is 30s for the sake of differentiation and readability.

To simulate a humidity resource observation, a random value in the range of 0 to 40 (0 to 20 for temperature) is generated and the message is composed in the following format: “{HUM: 31}”. *mqtt_publish()* is the method responsible for sending it via the topic “humidity”.

```java
public class ClientMqttHumidity implements MqttCallback{

    String subscriber_topic = "humidity";
    String broker = "tcp://127.0.0.1:1883";
    String clientId = "Application";
    int value = 0;
    Interface i = new Interface();

    MqttClient mqttClient;

    public ClientMqttHumidity() throws MqttException{
        try {
        mqttClient = new MqttClient(broker,clientId);
        }catch (Error e) {
            System.out.println(e);
        }
        mqttClient.setCallback(this);
        mqttClient.connect();
        mqttClient.subscribe(subscriber_topic);

        System.out.println("Subscribing to the " +subscriber_topic+ " topic..\n");
```

The message is then received by the Java collector in the *ClientMqttHumidity* class (or *ClientMqttTemperature*), which contains an MQTT client subscribed to the topic “humidity” and the method MessageArrived(); this extracts the payload, parses the JSON content and stores the humidity value in the dedicated database.

```
public void messageArrived(String topic, MqttMessage message) throws Exception {

    String json_message = new String(message.getPayload());

    //parsing
    JSONParser parser = new JSONParser();
    JSONObject jsonObject = null;
    try {
        jsonObject = (JSONObject) parser.parse(json_message);
        //System.out.println(jsonObject);
    } catch (ParseException e) {
        e.printStackTrace();
    }
    if(jsonObject != null) {
        Long v = (Long) jsonObject.get("HUM");
        this.value = v.intValue();
        System.out.println("Humidity observed is: "+ this.value);

        if (this.value < 20) {
            i.irrigationReq = true;
        } else i.irrigationReq = false;

          SimpleDateFormat dateFormat = new SimpleDateFormat("dd-MM-yyyy HH:mm:ss");
          Date d = new Date();
          String[] tokens = dateFormat.format(d).split(" ");
          String date = tokens[0];
          String time = tokens[1];

        i.storeMqttData(time, date, this.value, i.irrigationReq, "mqtt_humidity");
        i.MonitorHumidity();
    }
}
```

After collecting comes processing the data, and that is done using simple logic implemented at the level of the Java application. After the MySQL insertion code, *MonitorHumidity()* is called to check the value of the humidity observed and decide accordingly whether to turn irrigation on or not.

```java
public void MonitorHumidity() {
    int hum = 0;

    try {
        Class.forName("com.mysql.cj.jdbc.Driver");
    } catch (ClassNotFoundException e1) {
        // TODO Auto-generated catch block
        e1.printStackTrace();
    }
      String connectionUrl = "jdbc:mysql://localhost:3306/greenhousesql";
      String query = "SELECT * FROM mqtt ORDER BY time DESC LIMIT 1;";
      try {
          Connection conn = DriverManager.getConnection(connectionUrl,"root","admin");
          Statement st = conn.createStatement();
          ResultSet rs = st.executeQuery(query);

          if (rs.next()) {//get first result
              hum = rs.getInt(3);
            }

          System.out.println(hum);

          if(hum < 20) {
              irrigationReq = true;
              String code = actuatorActivation("irrigation-actuator");
              regulateHumidity(code);
          }
          irrigationReq = false;
          set = false;
          conn.close();
      }catch(SQLException e){
          e.printStackTrace();
      }
```

This first method is used to read the latest stored record in the database. If the humidity is lower than a threshold of 20 (10 for temperature), the irrigation system is activated via the *actuatorActivation()* method.

CoAP

This network is reserved for the actuator part of the architecture. Before using it, it is necessary to register its resources into the CoAP application using the *CoAPResource* class.

```
public static void addResources(String source, String response) {

    String[] resources = response.split(",");

    for(int i = 1; i < resources.length; i++) {
        try{

            String[] parameters = resources[i].split(";");
            String path = parameters[0].split("<")[1].split(">")[0];
            String name = path.split("/")[1];


            Resource newResource = new Resource(name, path, source);

            Interface.registeredResources.put(name,newResource);

            System.out.println("\n" + name + " is registered.");
```

The CoAP resource It is responsible for switching on and off the irrigation/heating systems based on a command sent by the Java collector through the *actuatorActivation()* and *actuatorDeactivation()* methods.

```
public void actuatorActivation(String name) {
    /* Resource discovery */

    CoapClient client = new CoapClient(registeredResources.get(name).getCoapURI());

    CoapResponse res = client.post("mode="+ "on", MediaTypeRegistry.TEXT_PLAIN);

    String code = res.getCode().toString();

    registeredResources.get(name).setActuatorState(true);

    if(!code.startsWith("2")) {
        System.err.print("error: " + code);
        throw new Error ("Actuator Not Turned ON!!");
    }

}
```

The first one is called after comparing the value of humidity/temperature to the minimum threshold, it sends a plain text command “on” to the appropriate CoAP device connected on port 5683. Irrigation is considered active by turning on a GREEN_LED, at the level of the CoAP code. Heating is considered active by turning on a RED_LED, at the level of the CoAP code.

```
if((len = coap_get_post_variable(request, "mode", &irrigation_status_x))){

        printf("Getting the mode");

        if(strncmp(irrigation_status_x, "on", len)== 0){
                irrigation_status = true;
                LOG_DBG("Beginning Irrigation...\n");
                leds_on(LEDS_NUM_TO_MASK(LEDS_GREEN));
                irrigation_status = 1;
                success = 1;

        } else if(strncmp(irrigation_status_x, "off", len)== 0){
                irrigation_status = false;
                LOG_DBG("Stopping Irrigation...\n");
                leds_off(LEDS_NUM_TO_MASK(LEDS_GREEN));
                irrigation_status = 0;
                success = 1;
        }

        if(success==1){
                coap_set_status_code(response, CHANGED_2_04);
        } else coap_set_status_code(response, BAD_REQUEST_4_00);
```

If irrigation was indeed required and the irrigation was successfully activated, a simple consistency management portion of code is executed, aiming to assign a new “regulated” humidity value. It is also a random number within the acceptable threshold 20 to 40 (10 to 20 for temperature))and it is again stored into the database.

```
public void regulateTemperature() {

    int min = 10;
    int max = 20;
    int newtemp = (int)Math.floor(Math.random()*(max-min+1)+min);
    temp_set = true;
    heating_status = "ON";

    SimpleDateFormat dateFormat = new SimpleDateFormat("dd-MM-yyyy HH:mm:ss");
    Date d = new Date();
    String[] tokens = dateFormat.format(d).split(" ");
    String date = tokens[0];
    String time = tokens[1];

    System.out.println("Heating actuator: " + heating_status + "\n");

    storeMqttData(time, date, newtemp, heatingReq, "mqtt_temperature");

    try {
        TimeUnit.SECONDS.sleep(5);

        System.out.println("Heating Complete!");
        actuatorDeactivation("heating-actuator");
        heating_status = "OFF";
        System.out.println("Heating actuator: " + heating_status );

    } catch (InterruptedException e) {
        e.printStackTrace();
    }


    System.out.println("Humidity after regulation: " + newtemp + "\n");

}
```

To make the mechanism slightly more realistic, the LED light is turned off 5 seconds after activation, using *actuatorDeactivation()* to show that water has been administered to the plant.

```
public void actuatorDeactivation(String name) {
    /* Resource discovery */

    CoapClient client = new CoapClient(registeredResources.get(name).getCoapURI());

    CoapResponse res = client.post("mode="+ "off", MediaTypeRegistry.TEXT_PLAIN);

    String code = res.getCode().toString();

    registeredResources.get(name).setActuatorState(false);

    if(!code.startsWith("2")) {
        System.err.println("error: " + code);
        throw new Error ("Actuator Not Turned OFF!!");
    }
}
```

SIMULATION

The simulation was done using Cooja, which allows users to create and load nodes with their respective C code to demonstrate the communication between them.

There are 3 nodes in the GreenHouse simulation, the first one deployed is the border router, connected to a Server port at address 600001. The second is the CoAP node, for which the LED panel is open, and the third one is the MQTT node.

The log shows the initialization of the nodes, then the connection of the router is established at the specified port. The MQTT node begins its connection to the broker (which should be started ulteriorly using the appropriate command), and finally the CoAP resource (Irrigation) is registered to finish the setup.

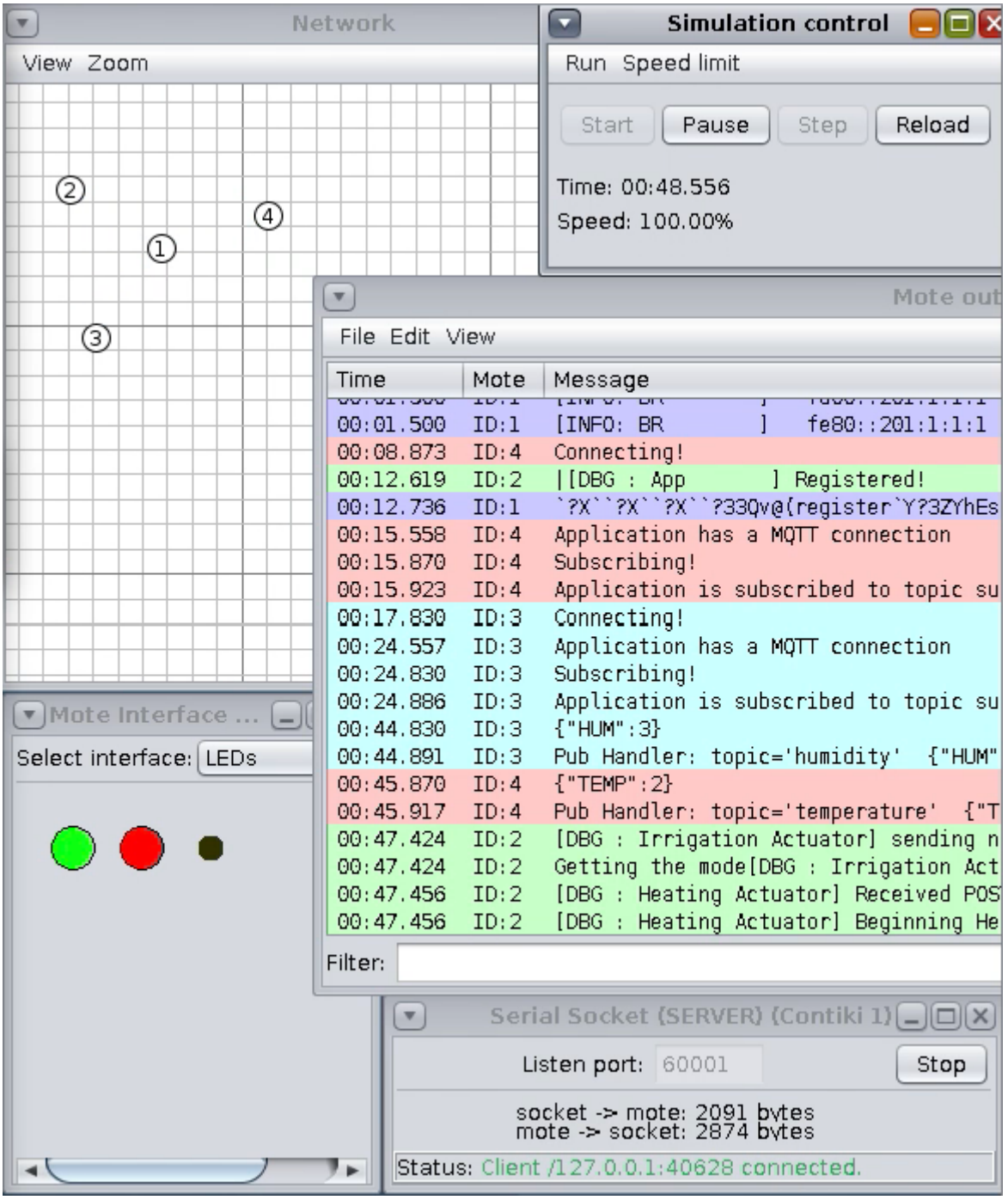
```
00:00.330  ID:3   [INFO: Main      ] Starting Contiki-NG-release/v4.7-467-ga13574
00:00.330  ID:3   [INFO: Main      ] - Routing: RPL Lite
00:00.330  ID:3   [INFO: Main      ] - Net: sicslowpan
00:00.330  ID:3   [INFO: Main      ] - MAC: CSMA
00:00.330  ID:3   [INFO: Main      ] - 802.15.4 PANID: 0xabcd
00:00.330  ID:3   [INFO: Main      ] - 802.15.4 Default channel: 26
00:00.330  ID:3   [INFO: Main      ] Node ID: 3
00:00.330  ID:3   [INFO: Main      ] Link-layer address: 0003.0003.0003.0003
00:00.330  ID:3   [INFO: Main      ] Tentative link-local IPv6 address: fe80::203
00:00.330  ID:3   MQTT Client Process
00:00.370  ID:4   [INFO: Main      ] Starting Contiki-NG-release/v4.7-467-ga13574
00:00.370  ID:4   [INFO: Main      ] - Routing: RPL Lite
00:00.370  ID:4   [INFO: Main      ] - Net: sicslowpan
00:00.370  ID:4   [INFO: Main      ] - MAC: CSMA
00:00.370  ID:4   [INFO: Main      ] - 802.15.4 PANID: 0xabcd
00:00.370  ID:4   [INFO: Main      ] - 802.15.4 Default channel: 26
00:00.370  ID:4   [INFO: Main      ] Node ID: 4
00:00.370  ID:4   [INFO: Main      ] Link-layer address: 0004.0004.0004.0004
00:00.370  ID:4   [INFO: Main      ] Tentative link-local IPv6 address: fe80::204
00:00.370  ID:4   MQTT Client Process
00:00.500  ID:1   [INFO: Main      ] Starting Contiki-NG-release/v4.7-467-ga13574
00:00.500  ID:1   [INFO: Main      ] - Routing: RPL Lite
00:00.500  ID:1   [INFO: Main      ] - Net: sicslowpan
00:00.500  ID:1   [INFO: Main      ] - MAC: CSMA
00:00.500  ID:1   [INFO: Main      ] - 802.15.4 PANID: 0xabcd
00:00.500  ID:1   [INFO: Main      ] - 802.15.4 Default channel: 26
00:00.500  ID:1   [INFO: Main      ] Node ID: 1
00:00.500  ID:1   [INFO: Main      ] Link-layer address: 0001.0001.0001.0001
00:00.500  ID:1   [INFO: Main      ] Tentative link-local IPv6 address: fe80::201
00:00.500  ID:1   [INFO: RPL BR    ] Contiki-NG Border Router started
00:00.500  ID:1   [INFO: BR        ] RPL-Border router started
00:00.608  ID:2   [INFO: Main      ] Starting Contiki-NG-release/v4.7-467-ga13574
00:00.608  ID:2   [INFO: Main      ] - Routing: RPL Lite
00:00.608  ID:2   [INFO: Main      ] - Net: sicslowpan
00:00.608  ID:2   [INFO: Main      ] - MAC: CSMA
00:00.608  ID:2   [INFO: Main      ] - 802.15.4 PANID: 0xabcd
00:00.608  ID:2   [INFO: Main      ] - 802.15.4 Default channel: 26
00:00.608  ID:2   [INFO: Main      ] Node ID: 2
00:00.608  ID:2   [INFO: Main      ] Link-layer address: 0002.0002.0002.0002
00:00.608  ID:2   [INFO: Main      ] Tentative link-local IPv6 address: fe80::202
```

The CoAP node begins registering its resources, and the MQTT sensors make their connection through the started MQTT broker.

```
00:08.873  ID:4   Connecting!
00:12.619  ID:2   |[DBG : App       ] Registered!
00:12.736  ID:1   `?X``?X``?X``?33Qv@(register`Y?3ZYhEsBgum5(
00:15.558  ID:4   Application has a MQTT connection
00:15.870  ID:4   Subscribing!
00:15.923  ID:4   Application is subscribed to topic successfully
00:17.830  ID:3   Connecting!
00:24.557  ID:3   Application has a MQTT connection
00:24.830  ID:3   Subscribing!
00:24.886  ID:3   Application is subscribed to topic successfully
```

After running the executable Java executable file of the Application, the automatic humidity/temperature monitoring system begins receiving messages from the MQTT nodes, and subsequently running the necessary methods.

```
xxxxxxxxxxxxxxxxxxx GREEN HOUSE AUTO SYSTEM xxxxxxxxxxxxxxxxxxx

This application serves to monitor the humidity and temperature
of soil in a greenhouse and regulate those values accordingly.

xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx

irrigation-actuator is registered.

heating-actuator is registered.

Humidity observed is: 3
Temperature observed is: 2

Irrigation is required.

Heating is required.

Irrigation actuator: ON

Heating actuator: ON

Irrigation Complete!
Irrigation actuator: OFF
Humidity after regulation: 29

Heating Complete!
Heating actuator: OFF
Humidity after regulation: 15
```



MySQL

For the database part of the application, two tables are used to store all the information, consisting of four columns for both:

Time: the time of observation.
Date: the date of observation.
Humidity/Temperature: the value observed.

Irrigation/Heating: includes 3 possible values:

- Non-Required: The humidity/temperature value is above the threshold.
- Required: The humidity/temperature value is below the threshold.
- Regulated: This should always appear in the record after “Required” as it shows that the irrigation/heating has been activated and a new humidity/temperature value was assigned.

```
mysql> SELECT * from mqtt_humidity;
+----------+------------+----------+--------------+
| time     | date       | humidity | irrigation   |
+----------+------------+----------+--------------+
| 12:42:39 | 07-09-2022 |        3 | Required     |
| 12:42:41 | 07-09-2022 |       29 | Regulated    |
| 12:42:59 | 07-09-2022 |       39 | Non-Required |
| 12:43:19 | 07-09-2022 |        1 | Required     |
| 12:43:19 | 07-09-2022 |       24 | Regulated    |
| 12:43:39 | 07-09-2022 |       12 | Required     |
| 12:43:39 | 07-09-2022 |       30 | Regulated    |
| 12:43:59 | 07-09-2022 |       22 | Non-Required |
| 12:44:19 | 07-09-2022 |       33 | Non-Required |
| 12:44:39 | 07-09-2022 |       27 | Non-Required |
+----------+------------+----------+--------------+
```

```
mysql> SELECT * from mqtt_temperature;
+----------+------------+-------------+-----------+
| time     | date       | temperature | heating   |
+----------+------------+-------------+-----------+
| 12:42:40 | 07-09-2022 |           2 | Required  |
| 12:42:41 | 07-09-2022 |          15 | Regulated |
| 12:43:10 | 07-09-2022 |           8 | Required  |
| 12:43:10 | 07-09-2022 |          11 | Regulated |
| 12:43:40 | 07-09-2022 |           3 | Required  |
| 12:43:40 | 07-09-2022 |          17 | Regulated |
| 12:44:10 | 07-09-2022 |           6 | Required  |
| 12:44:10 | 07-09-2022 |          13 | Regulated |
| 12:44:40 | 07-09-2022 |           4 | Required  |
| 12:44:40 | 07-09-2022 |          14 | Regulated |
+----------+------------+-------------+-----------+
```

DATA ENCODING

For the MQTT publisher, a **JSON** format was chosen because of its many qualities with respect to memory, time and efficiency. It is less wordy and more compact than XML, therefore it takes less space and consequently less time to be processed and transmitted. It is readable as it is allowed to put a label on the value observed, this can be particularly useful when data collected from multiple sensors is hubbed in a transit node, as done in a

hierarchical architecture for example. The data will be properly labeled and no chance for confusion will occur.

From the Java application to the CoAP application, a **Plain Text** format is used as the commands are simple“on/off”. The message is never processed or used elsewhere than by the node itself, it is concise and self explanatory, so it doesn’t need more structure or space than that.

CONCLUSION

Developing **GreenHouse** was a good way to get used to the IoT technologies, it takes the learning material beyond theory and sheds light on the different practical aspects and implementation issues one may run into. This project is also a good basis for a grander application, gardening and agriculture are without a doubt domains of precision and diligence, and process automation is not only prefered but needed. GreenHouse can surely be scaled into a fully fledged smart system.

References

Project implementation https://github.com/aidahimm/GreenHouse