ROBOTS IN ASSISTED
LIVING ENVIRONMENTS

UNOBTRUSIVE, EFFICIENT, RELIABLE AND MODULAR SOLUTIONS FOR INDEPENDENT AGEING

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DELIVERABLE 7.15

Guidelines for RADIO configuration and deployment

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Abstract

This document provides the guidelines for the RADIO configuration and deployment. The configuration and deployment process is divided into the main components of the overall RADIO architecture: Smart home, Wireless sensor networks, robot platform, and localisation module.

History and Contributors

Ver	Date	Description	Contributors
0.1	23/02/2018	Document structure	S&C
0.2	22/03/2018	Input from partners	NCSR-D, TWG, ROBOTNIK
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Abbreviations and Acronyms

AAL	Active Assisted Living
ADL	Activities of Daily Life
BLE	Bluetooth Low Energy
IoT	Internet of Things
MQTT	Message Queuing Telemetry Transport
ROBOTNIK	Robotnik Automation SLL
ROS	Robot Operating System
RUB	Ruhr Universitaet Bochum
S&C	Sensing & Control Systems S.L.
TWG	Technical Educational Institute of Western Greece

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1 INTRODUCTION

1.1 Purpose and Scope

This deliverable provides the guidelines for the deployment and configuration of the RADIO system. These guidelines contain information about those steps which must be carried out in order to have the different software components working properly.

This document provides guidelines that summarise the experience gained during the project so that designers of specific RADIO configurations and deployments can take full advantage of the system's modularity and extendibility. This material will be made available to be used by anybody for preparing educational material or any other commercial or freely available resources.

1.2 Approach

As mentioned, this deliverable has the purpose of creating guidelines to facilitate the deployment and configuration of the different software modules to target audiences. The deliverable is structured in the following way:

Section 2 will provide the guidelines of the smart home solution. This implies the installation of the sensors and the configuration of the installation and sensors related to the installation. Section 3 will describe the steps to configure the robot platform by setting up the network, mapping the home, and definition of points of interest. Section 4 will show the steps to set up the wireless network connection. Finally, section 5 will provide the guidelines of the localisation module for both robot and objects.

1.3 Relation to other Work Packages and Deliverables

This deliverable is prepared within Task 7.5 (Dissemination and communication plan) and clarifies the steps tht have to be carried out in order to deploy and configure the different components developed within RADIO and integrated into the pilot deployment. The D7.15 is linked to deliverables D7.10 (Sustainability, uptake, and market positioning plan and report III), D7.12 (Roadmap to integrating robots in home automation and assistive environments), and D7.14 (Roadmap to expanding alternatives to hospitalization).

2 Smart Home

2.1 Introduction

The present guidance about the smart home solution is based on the commercial product named as enControl. In this section, only those functionalities used in the pilots will be described although some screen shots show all functionalities. The requirements are the same to the ones needed for the complete solution.

2.2 Requirements

The deployment of the smart home solution implies to have a pack of sensors, a gateway already configured and the corresponding wires and batteries. Once the gateway is connected to the broadband internet service, make sure your gateway is connected to your home router. Also, you will need a computer with internet access to go online and register your account. When you sign up with the service, you will receive your login credentials. If you cannot login, one of these errors could have occured:

- Your account has not been activated yet. Contact your service provider and ask them to do so.
- You have forgotten the password. In this case, please click on the **"Forgot your password"** link on the login screen and follow the steps.

There are other general requirements to take into consideration:

- Please note that if internet is down, data will be stored in the gateway's internal memory while it is disconnected. Once the connection is back, all the data collected will be sent over to the cloud so you do not lose any data. Some functionalities require access to the cloud so they will be unavailable until your internet connection is active again.
- If the power goes out, you will be not able to control your devices until the power is restored.
- The maximum distance between the gateway and the sensor depends on the type of your home. Devices maintain connectivy up to 30 metres, straight-line without obstacles.
- The maximum number of devices supported by your gateway is up to 125 Z-Wave devices and 10 IP Cameras.
- There are different types of sensors, some just draw power from mains and some others may need their battery replacement.

2.3 Creating your first installation

When you connect the platform for the very first time, the system automatically detects that you do not have any current installation and start the installation wizard. Please follow next steps to configure your installation for the first time:

- Open your preferred web browser (Internet Explorer, Google Chrome, Mozilla Firefox, etc.)
- In the address line, type:

  http://domainofserviceprovider/Account/Login
- Enter the username and password supplied with the welcome to the service email sent when you activated your account, then click **"LOG IN"**.

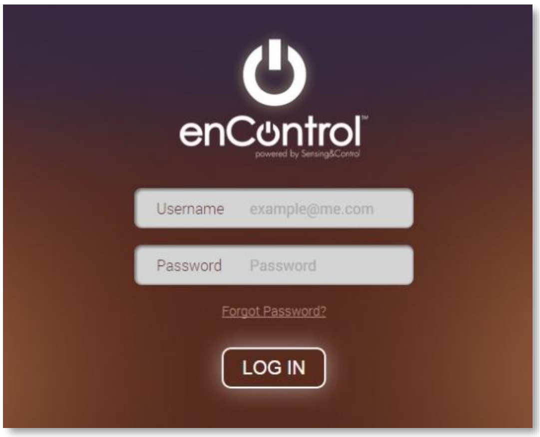

Figure 1. Login screen for the Smart Home application

2.3.1 Name your installation and activate your gateway

The installation wizard starts with the first step, consisting in two easy actions:

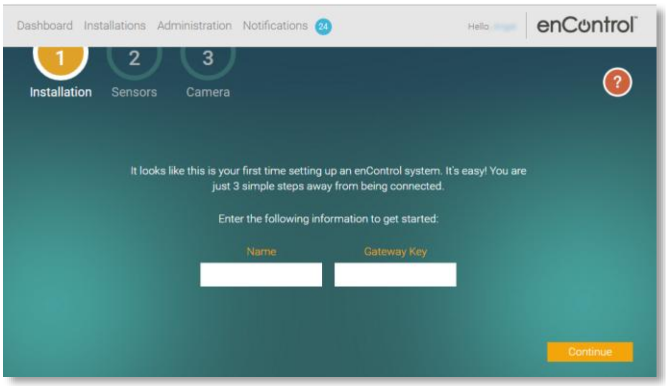

Figure 2. Name the installation

- Put a name to your installation (i.e. "My House")
- Introduce your gateway serial number (this should be provided by your service provider. If you have not received this number, please contact your service support).

As soon as you are done, click **"Continue".**

Next is to search for your city. This is useful in order to present you external weather conditions based on your location.

1. Type in your city name, then click on **"Search"** button.
2. If more than one coincidence, select the one corresponding to your country.

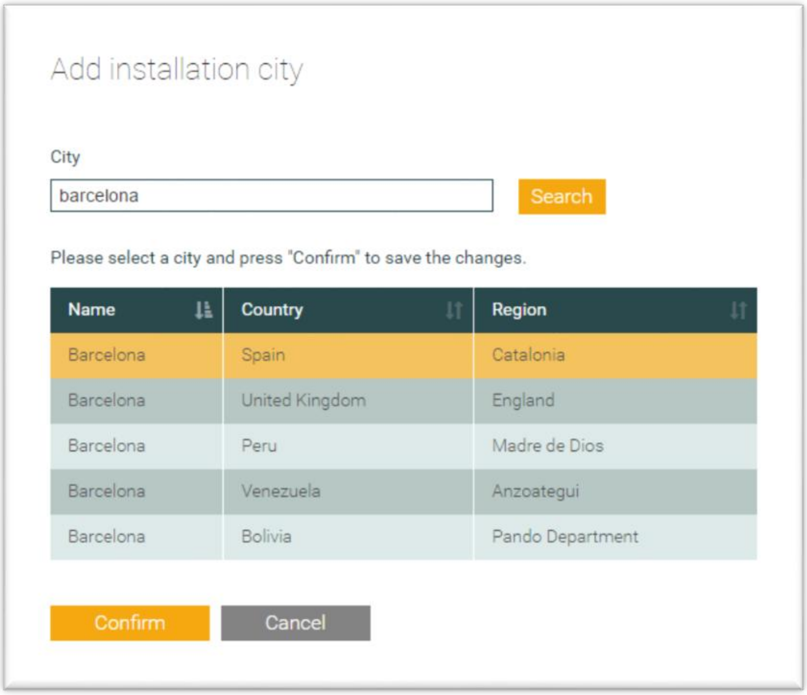

Figure 3. Adding the installation location

Tip: Maybe you live in a small town not appearing in the list. In this case please choose a big city near you. Once you find your city, select it with the mouse and click **"Confirm"** button.

2.3.2 Adding devices

Now you are going to start adding your devices. The system guides you through all the process. Please follow the on-line instructions. First of all you should select the type of device you want to include in your installation. At the moment enControl support sensors from Z-Wave, Wireless M-Bus or WiBeee types.
Click in any icon to start the wizard that will guide to you through the process of adding that type of sensor.

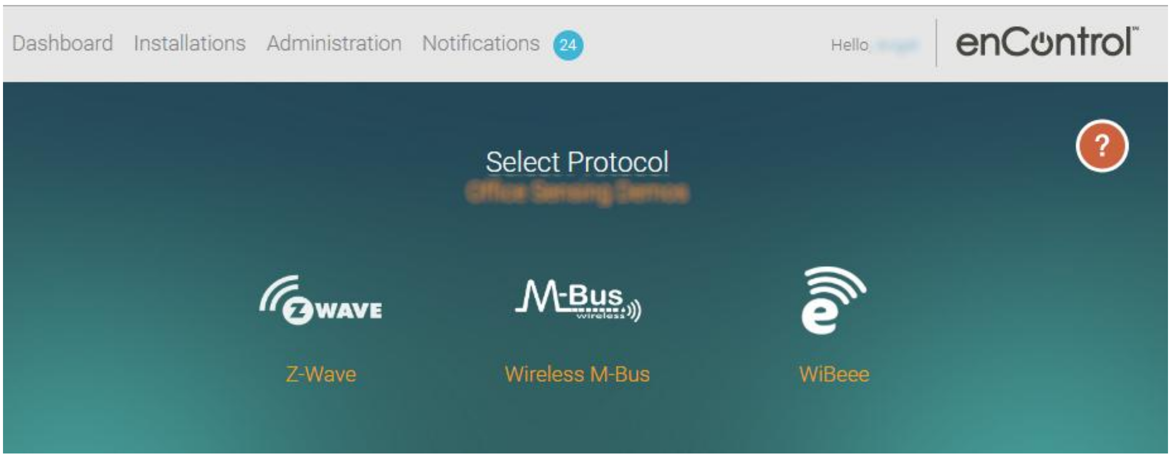

Figure 4. Selection of communication protocol

2.3.2.1 Adding Z-Wave devices

To start adding devices, click **"Link Sensor"** button.

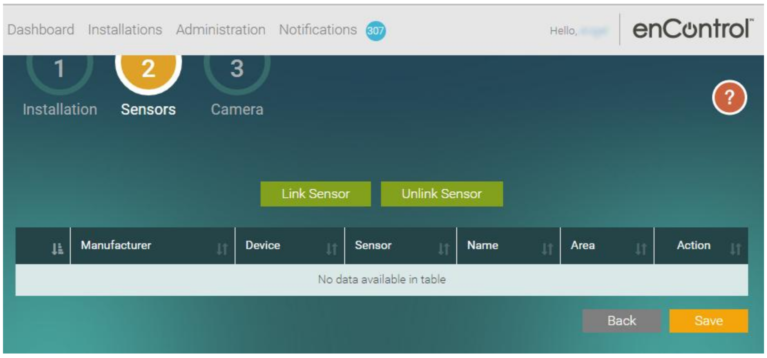

Figure 5. Adding devices screen

The system will wait for you to activate the device you are including.

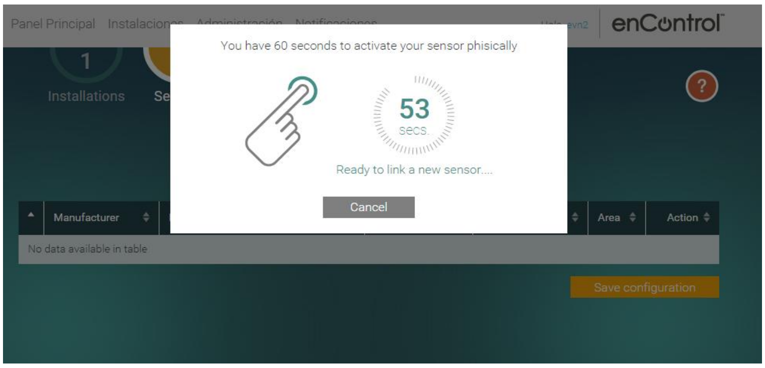

Figure 6. Sensor activation screen

The only thing you should do when unboxing and linking your devices are:

1) Put the batteries in (please mind polarity!) or plug the device into to the power supply.
2) Wait for 3 seconds.
3) Press the Wake-up or Z-Wave button (please keep in mind that every manufacturer has its own method to wake-up the devices sometimes it is 1 click, sometimes 3 clicks please review the included sensor manual in order to learn the required clicks for each device).

Here are a few examples:

Figure 7. Example of battery change and activation button

The system has detected your first device, congratulations!

If you want to add another device just make click again in **"Link Sensors"** and follow the previous steps.

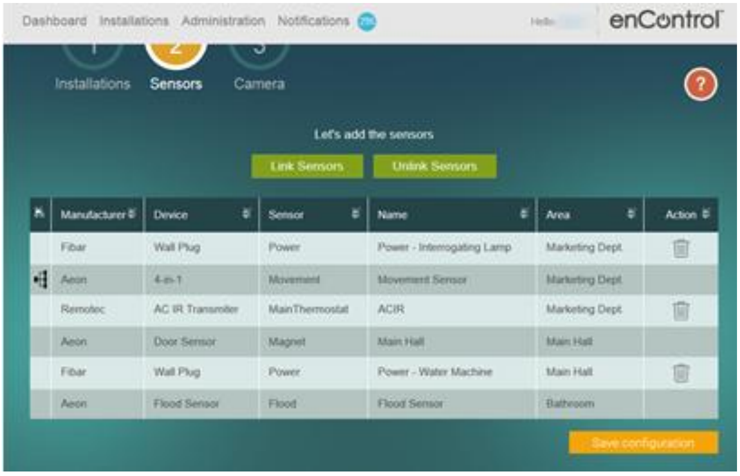

Figure 8. Adding more devices

Please note that some battery-powered devices need an additional click to finish their configuration after the gateway discovered them. You will detect them because they appear with a finger icon in the action area.

In order to fix the device configuration, just click again the Z-Wave or Wake-up button for the device according the manufacturer's instructions.

Once you have added all your Z-Wave devices click on **"Save configuration".**

2.4 Congratulations for setting up your first enControl installation!

Now check the different options. You are presented with the following options:

- ***Configure my Smart Home***: this button leads to the Sensor Configuration area, where you can fine tune how you want the sensors or the system to work for you.
- ***Add another sensor or cameras:*** sends you to the previous menus (cf. Section 2.3.2).
- ***Use enControl:*** allows you to start enjoying your new Smart Home installation!
- Should you have any doubt? Click on **"*Check our FAQ's*"** button

2.5 Configuring your Smart Home

Once you have all your devices in place, you need to configure the system to work the way you like. We will manage this easy process through the **"Sensor Configuration"** screen.

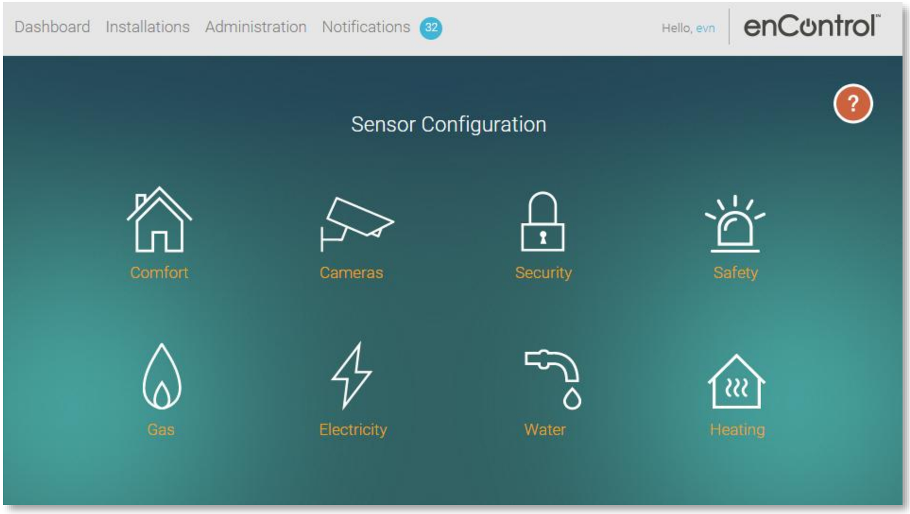

Figure 9. Sensor configuration screen

2.5.1 Comfort sensors

Click the Comfort Icon to access the **"Comfort Sensors"** configuration screen.

Please fill the names for each of your sensor according to the area, the type and location you plan to install them in order to easily identify later. You can also choose the main thermostat and configure it.

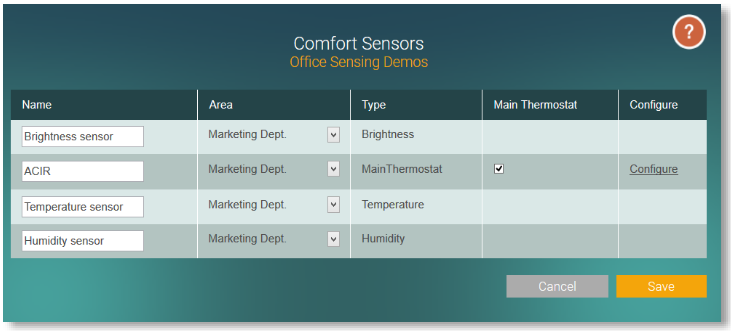

Figure 10. Comfort sensors configuration screen

Select “Area” and then “Add New Area” to create as many areas as you need. In example, you can create “Main room”, “Bedroom”, “Kitchen” and “Bathroom” areas.

You can add as many areas as you need at any time.

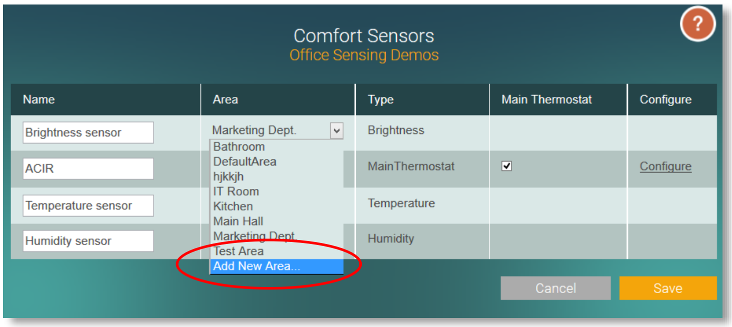

Figure 11. Adding new area

Once you have set a name to each sensor, created and selected an Area for each of them, click **“Save”** button to save the configuration. Then use the “back” button of your web browser to get back to the “Sensor Configuration” main screen.

2.5.2 Sensors’ configuration

2.5.2.1 Safety sensors

Click the Security Icon to access the **“Safety Sensors”** configuration screen.
Please fill the names for each of your sensors according to the area and the type.

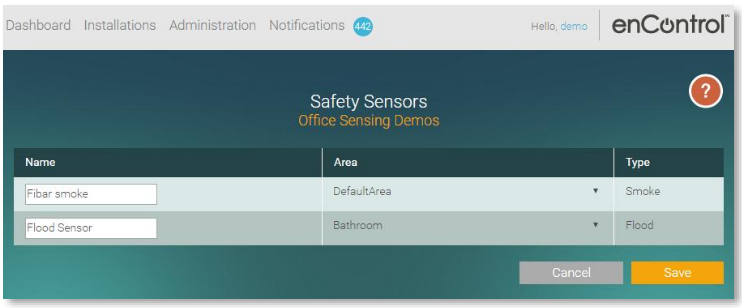

Figure 12. Safety sensors configuration screen

Select "Area" for this sensor or create a new one if needed. Remember that you can add as many areas as you need at any time.

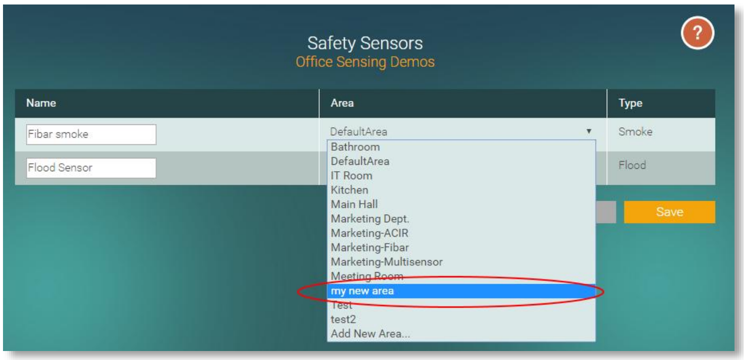

Figure 13. Selecting one area associated to the sensor

Once you have set a name to each sensor, created and selected an Area for each of them, click **"Save"** button to save the configuration. Then use the "back" button of your web browser to get back to the **"Sensor Configuration"** main screen.

2.5.2.2 Electricity sensors

Click the Electricity Icon to access the **"Electricity Sensors"** configuration screen.

Please fill the names and select Area for each of your sensor according to your need. Sensor's type should be automatically recognized and assigned. Select the category Master to tell enControl that is the main Electricity meter you have in your installation. Then select other categories for the rest of your sensors depending on where they are connected to (light, wash machine, Home Cinema, etc).

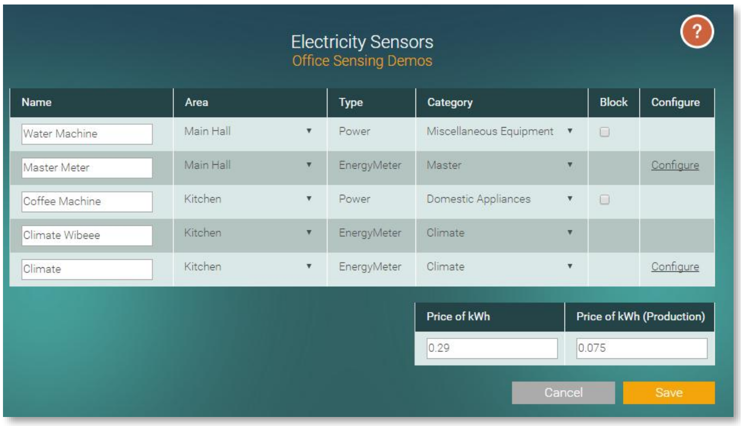

Figure 14. Electricity sensors configuration screen

Fill in the values for kWh price as well as the Price per kWh (Production) if they apply to your case. kWh price should appear in your electricity bill or should be provided by your utility or energy supplier. For Wireless M-Bus sensors, click on **"Configure"** button if you need to change some Sensor Parameter or Scaling Values for the sensor.

Change any of these fields only if you need to change the sensor ID or the Scalling Values.

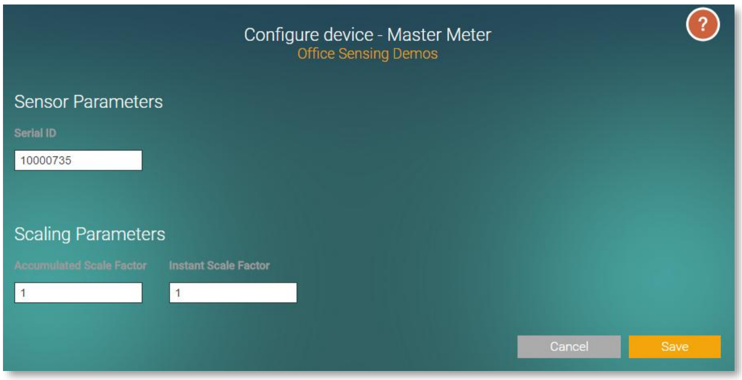

Figure 15. Safety sensor parameters screen

Once you are done with the configuration settings, click **"Save"** button to save the configuration. Then use the "back" button of your web browser to get back to the "Sensor Configuration" main screen.

2.5.3 Actuators

Click the Actuators Icon to access the **"Actuator Sensors"** configuration screen.
Please fill the names and select Area for each of your sensor according to your need. Sensor's type should be automatically recognized and assigned.

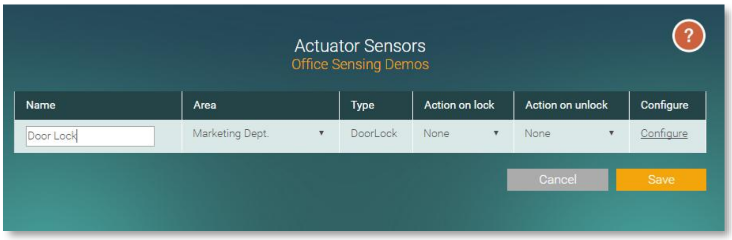

Figure 16. Actuators configuration screen

Depending on the actuator type you will be presented some additional options you should check to adjust in order the actuator work in the way best fits your needs.
Once you are done with the configuration settings, click **"Save"** button to save the configuration. Then use the "back" button of your web browser to get back to the "Sensor Configuration".

2.6 Check sensors

Once you have added the sensors, you can check their status on the Administration panel. Look for the installation you want to check and then Actions menu; several options will display. The ones we are interested in are:

- Sensor status: It shows all the devices configured in the installation, areas, battery levels and its status according to the system.

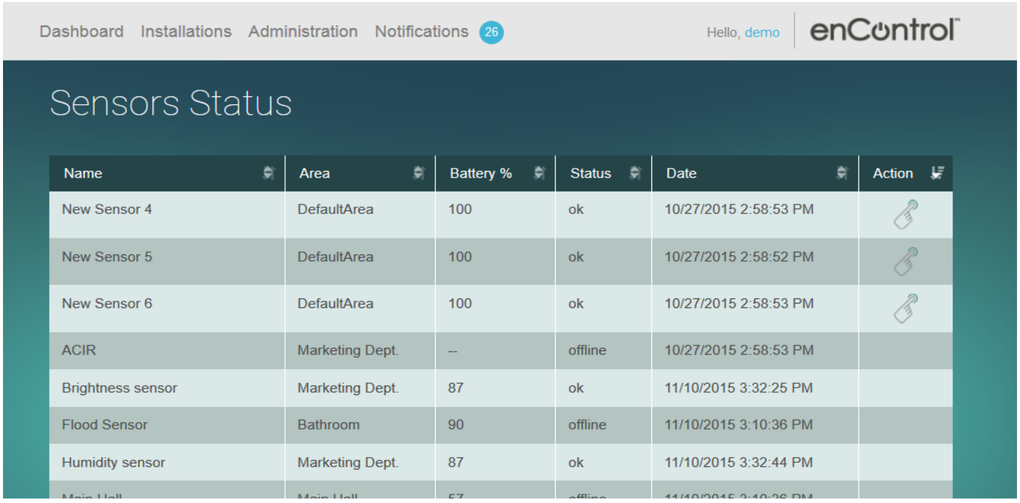

Figure 17. Sensor status screen

- Add sensors: A new window will display. It shows the device, sensor/s that it contains and names given during the installation process. Also an icon will describe its status:

    - **Bin**: *use with caution, do not use it with a working device*. By clicking this icon enControl will remove the device from the system and all the data from the database will be erased, but the network configuration from the sensor and the gateway will remain active.

    - **Hand**: will be displayed if the device is pending to receive the configuration from enControl. Power gear devices will get the configuration in a few seconds, while Battery powered devices may take up to 5 minutes to receive the configuration due to internal states (sleep and wake-up modes).

3 ROBOT PLATFORM

3.1 Requirements

In order to be able to install the robot in a new house, you will need a computer machine with the following two capabilities:

- SSH
- ROS

The instructions in the following sections should work in any machine under any operating system that fulfills the above requirements, but it is recommended to use Ubuntu14.04 and above. Beware; some of the instructions that follow include information only for the recommended operating system.

For more information on SSH, please visit:

Linux/Mac: https://www.ssh.com/ssh/command/
Windows: http://www.putty.org/

For more information on ROS, please visit:

All platforms: http://wiki.ros.org/

All the instructions provided in this document assume that you have set the following environment variables as listed:

ROS_IP=<MACHINE IP>
ROS_MASTER_URI=http://<ROBOT IP>:11311
ROS_HOSTNAME=<MACHINE HOSTNAME>

Under Linux, in order to avoid having to set those environemt variable everytime, in your home .bashrc file, you can add (or replace older values with) the following lines:

export ROS_IP=<MACHINE IP>
export ROS_MASTER_URI=http://<ROBOT IP>:11311
export ROS_HOSTNAME=<MACHINE HOSTNAME>

Regardless of your operating system, in order to find out your hostname, just type in a terminal:

hostname

3.2 Robot TurtleBot2

The robot configuration for a new deployment requires the following steps:

- network configuration,
- mapping of the home and
- definition of the points of interests like docking station or ADLs detection poses.

3.2.1 Network configuration

The robot has to be connected to the home WiFi network in order to interconnect with the main controller and the rest of modules.

The robot PC has to be connected to the home network through the internal wifi router included in the robot.

Connect a laptop to the router via an Ethernet cable.

The router can be configured as repeater, enabling the robot to connect to an external WiFi network and extending the range of it.

1. Acces to the router panel via a network browser (*router.asus.com* or the current ip address)
2. Reset the configuration to factory values or go to the Setup Wizard.
3. Check connection:
    1. Select Manual Setting

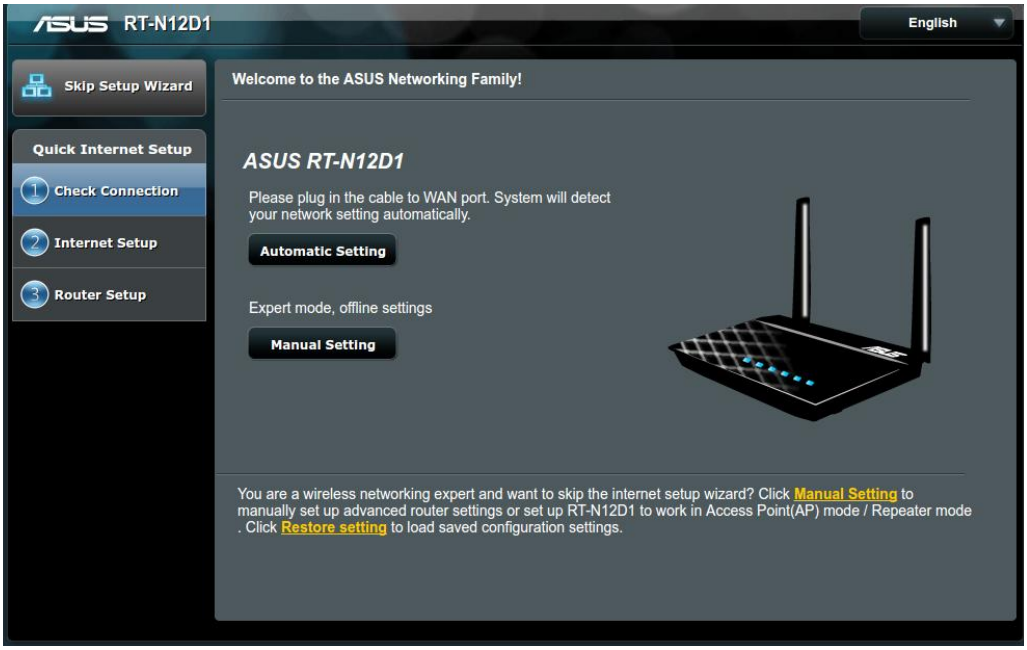

Figure 18. Check connection screen

4. Login information setup
5. Internet Setup:
    1. Select "Repeater Mode"

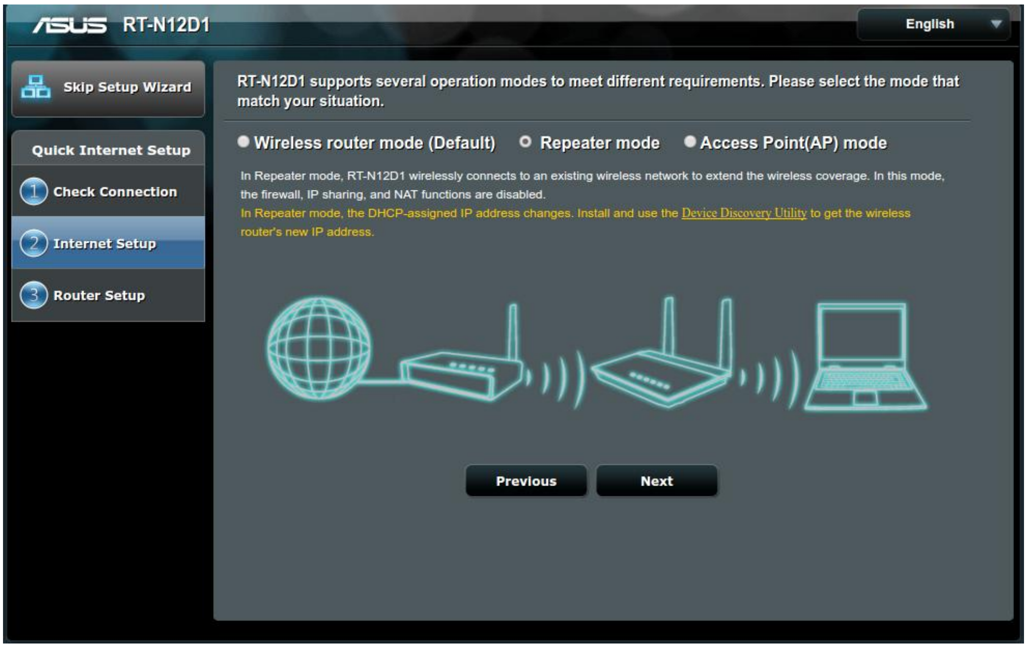

Figure 19. Internet setup screen

6. Select the network you want to connect.

7. Wireless settings.
    1. Use the default settings
8. LAN IP Settings
    1. Set ‘Yes’ to get the LAN IP automatically.

9. Apply the changes and wait until the router applies the modifications.

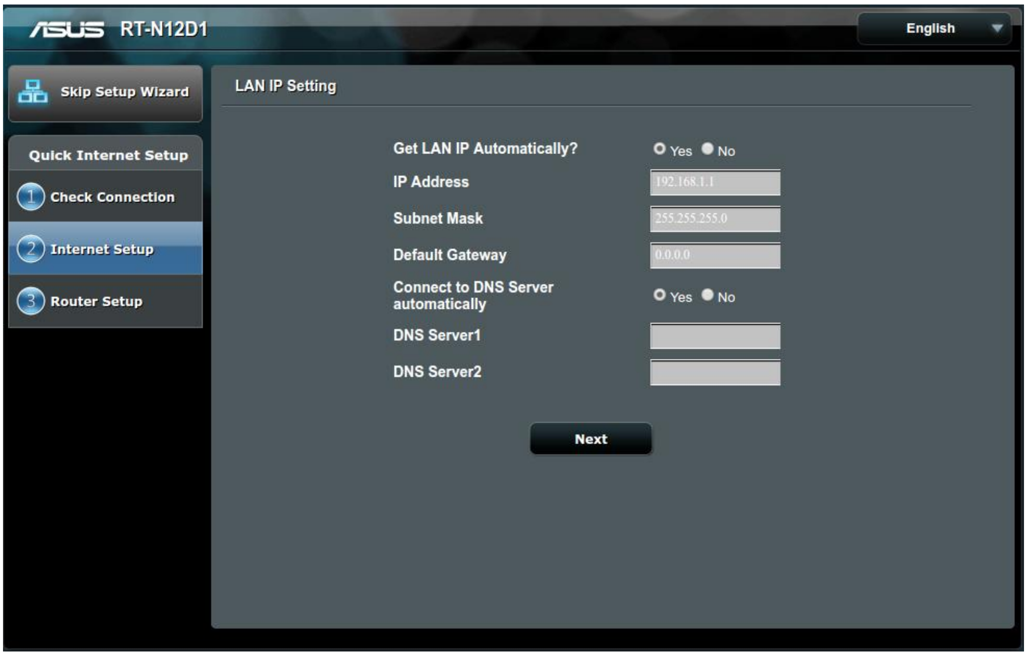

Figure 20. Applying changes to the router parameters

NOTE: do not forget to update the network configuration in the PC controller in order to work with the new IP.

3.2.2 Robot teleoperation control

The robot can be teleoperated through a wireless gamepad.

Figure 21. Top gamepad view

Figure 22. Side gamepad view

Table 1. Actions associated to the buttons

Button	**Action**
D-pad Up	Initialize Robot Position (in front of the AR Marker)
D-pad Down	Clear Obstacles on Robot's Map
LB	Stop Robot's Movement (for as long as it's pressed)
LB+LeftStick	Control Robot's Linear Velocity
LB+RightStick	Control Robot's Angular Velocity
RT+RightStick[Pressed]	Enable Auto-Docking (charging)
Start	Send report for the latest participant
Back	Cancel Navigation Goal
X	Start 4 meter walking ADL
RT+X	Stop 4 meter walking ADL
A	Start Chair Transfer ADL
RT+A	Stop Chair Transfer ADL
B	Start Bed Transfer ADL
RT+B	Stop Bed Transfer ADL
Y	Start Pill Intake ADL
RT+Y	Stop Pill Intake ADL
RT+RB	Bed transfer position
RT+D-pad	Right Chair transfer position
RT+D-pad	Left 4 meters walk position
RT+LeftStick[Pressed]	Pill intake position

3.2.3 Map creation

A new map needs to be created to localize and navigate in the new home.

To create a new map we need a laptop with Ubuntu 14 and ROS Indigo installed. This laptop has to be connected to the same network with the robot.
Log into the robot via ssh:

ssh turtlebot@robot-ip (default password is 'ros')

First, we will see the commands that have to be executed in order to start the mapping procedure, and then we will have an explanation for each one of them.

```
rosnode kill /amcl
rosnode kill /move_base
rosnode kill /map_server
roslaunch turtlebot_navigation gmapping_radio_demo.launch
```

Explanation of commands:

• The localization procedure runs on boot, so we will have to kill it first.

• Move base runs on boot, so we will have to kill it because we will run it again in a following command.

• Map server runs on boot, but since we need to create a new map, we will have to kill it.

• Run the mapping procedure (that also starts a new move base process).

In order to create an effective map for the house, it is required to:

• Move slowly.

• Rotate the robot slightly in place, just to cover hard to see corners.

• Try not to pass from the same place twice.

After the robot has been teleoperated through the whole house (or the part of the house that is going to be used by RADIO) it is time to save the map by running the following commands on the robot (in a separate terminal):

```
roscd turtlebot_navigation/maps
rosrun map_server map_saver -f house
```

The map has now been created. We can close all the running processes, and reboot the on-board PC.

3.3 Definition ADL positions

After the maps creation it is necessary to define all the positions inside the house that the robot needs for performing the ADL detection algorithms as well as the battery docking station.
Make sure that the robot is localized before proceeding. With the robot correctly localized we can teleoperate it to the desired locations to check if they are suitable. Warning: Never place the robot in a desired location by lifting it off the ground. If you have to, make sure to localize it again.

3.3.1 Selecting the positions

The robot positions that have to be set along with their specifications, are the following:

- 4-meter walking ADL: This ADL requires a corridor or open space, where at least four meters are visible by the robot’s laser scanner (180 ◦ FOV)
- Bed Transfer ADL: Ensure that the person of interest, when stood up, fits the camera’s frame with at least 20cm gap between the top of their head and the top of the frame.
- Pill Intake ADL: Ensure that there is direct contact with the pill’s position from the camera.
- Sit to Stand ADL: Ensure that the person of interest, when stood up, fits the camera’s frame with at least 20cm gap between the top of their head and the top of the frame.

Figure 23. Robot position for bed transfer

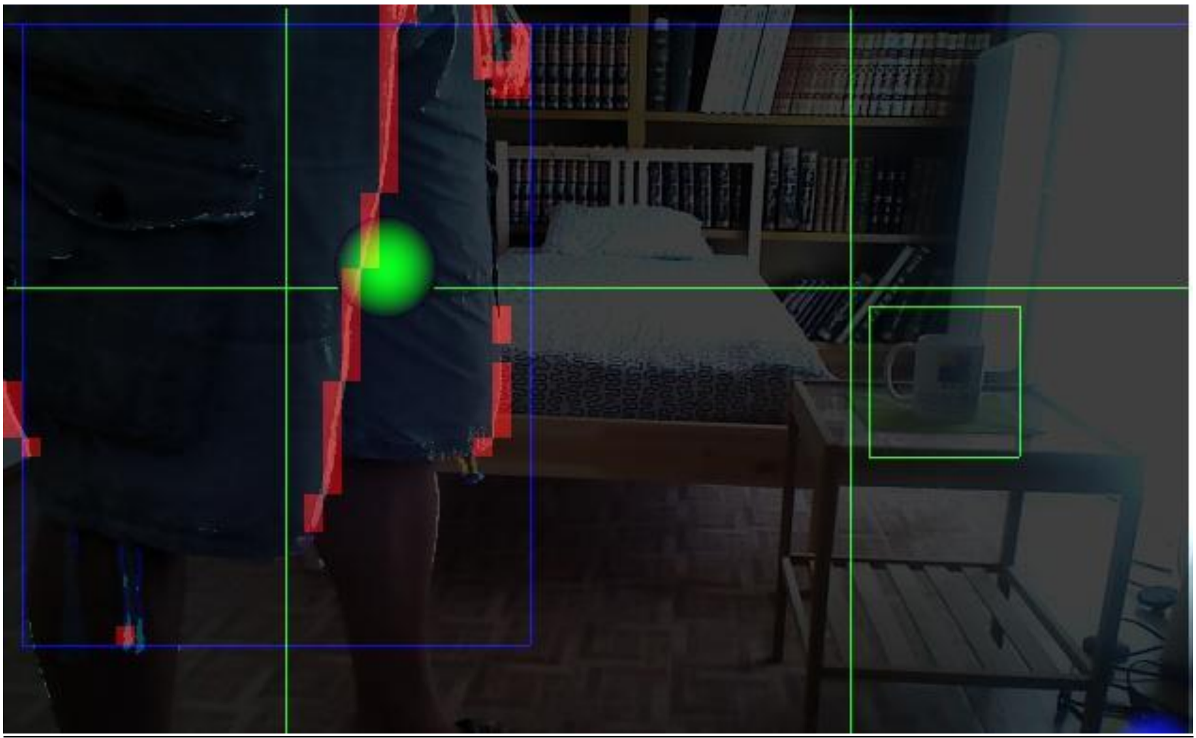

Figure 24. Pill intake and sit to stand

Bed transfer

The robot is too close to the bed, so the camera's pole has been shifted up, in order to fit the person in the frame when stood up. Generally, the robot should be further away from the bed if possible.
Ideally, the setup should be done in such that the 3d camera view compared to the real view would be as shown in Figure 23.

Pill intake and Sit to Stand

This position of the robot is an efficient choice because it can be used for two ADLs: Pill Intake and Sit to Stand.
The Pill Intake's position is marked with a red rectangle. Sit to Stand should be recorded from the sofa on the right of the small table. Ideally the object should be locked in to the green rectangular as depicted in Figure 24.

Pill Intake and 4-meter walking

This is another good position choice, because it combines the Pill Intake and the 4-meter Walking ADLs. The pill should be placed inside the marked rectangle, and the 4-meters walking can be recorded in the corridor on the right of the small table.

Figure 25. Pill intake and 4-meter walking

3.3.2 Checking the positions

Now that we know the requirements for the position of each ADL, let's see how we can check each selected position.

• **4-meters walking:** This ADL does not require a machine to check, since the only thing that has to be done in order to ensure the effectiveness of the recording, is to make sure that there is a a straight line (or even a curve) that is always visible by the robot's laser scanner and is at least four meters long.

• **Pill Intake:** See the robot's camera by running in a terminal on your machine:
rqt_image_view /radio_cam/rgb/image_raw/compressed
Adjust the selected position accordingly.

• **Bed Transfer:** See the robot's camera by running in a terminal on your machine:
rqt_image_view /radio_cam/rgb/image_raw/compressed
Adjust the selected position accordingly.

• **Sit to Stand:** See the robot's camera by running in a terminal on your machine:
rqt_image_view /radio_cam/rgb/image_raw/compressed
Adjust the selected position accordingly.

3.3.3 Saving the positions

When you are happy with the selected ADL position, you can save it by following the steps below:

1. See the robot coordinates by running in a terminal on your machine:
   rostopic echo /amcl_pose
2. Take a note of the position.x, position.y, orientation.
3. In a terminal on the main controller run:
   roscd radio_node_manager_main_cotroller/config/
4. In the same terminal edit the *parameters.yaml* file and add the coordinates to the equivalent variables.

3.3.4 Configuration of ADLs

Upon selecting the positions, some ADL methods require further configuration. The ADL methods that need additional actions are listed below:

• **Pill Intake:** You need to move and resize the detection rectangle so that it covers the position of the pill inside the camera frame. You can also adjust the CUPTHRESHOLD and CUPTHRSCOUNT to make the method more or less sensitive.
• **Bed Transfer:** You need to set the left and right limits of the bed, so that there is enough room for a person to be stood up next to the bed, and still be inside inside the limits. It is recommended to use at least 1 meters from each side of the bed. You also need to adjust the upper limit, so the head of the person in interest when stood up is over it. You can also adjust the SENSITIVITY to make the method more or less sensitive.

In order to configure all the above, you need to run the following commands on the robot (each command in a separate terminal):
roslaunch motion_analysis new_configuration.launch
rosservice call /motion_analysis/node_state "command: 11"

Also, run the following command on your machine:

rqt_image_view /motion_analysis/motion_analysis_viz/compressed

In the terminal that you ran the first command on the robot you can now adjust the limits by following the onscreen instructions. If you save your current configuration but need to come back later to it, instead of the first command on the robot run:

roslaunch motion_analysis edit_current_configuration.launch

and run the rest of the commands as described earlier.
In either case, when done, close all running processes and reboot the robot.

3.4 Definition of the docking station position

The docking station used for charging the robot needs to be installed together with an AR (Augmented Reality) code. This code is stuck on the wall above the docking station. Once it is ready its position needs to be saved and registered with the map of the home. This code will be used to initialize the robot pose as well as to locate the docking station at home.

Figure 26. AR code installed above the docking station

In order to set up the AR Marker, following the steps below:

1. Stick the Marker above the charger in the same height as the robot's camera.
2. Make sure the robot is localized.
3. Teleoperate the robot in front of the sticker.
4. Run in a terminal on the robot:

```
rosservice call /marker_mapping_node/save_maker "id: [] filename: ""
```

The AR Marker is now set up. You can now kill all running processes and restart the robot.

4 RADIO WIRELESS NETWORK

The RADIO Wireless Network is the fundamental infrastructure of the RADIO system that is responsible for seamlessly integrating all the sub – components. Particularly, it provides the required interconnectivity to the three gateways (main controller, smart home and BLE gateways) that take care of the robot control, smart home monitoring and control and localization services. The backbone of the RADIO Wireless Network is the access point/router TP-Link 701nd which is a low-cost AP equipped with a WiFi interface and an ethernet port. On the ethernet port a 5 port 100Mbps switch is attached which provides connectivity to the 3 Raspberry–Pi based gateways. On the other side, the AP operates in client mode and connects to a 3G/4G modem which is the Internet provider for the RADIO Network. This approach allows the 3G/4G modem to be placed inside the house at the location with the optimal broadband coverage, while the router and gateway rack can be installed in the more convenient place regarding BLE and Z-wave coverage, power supply and integration to the rest of the house. During every new installation, the RADIO technician should find the optimal location of the modem and the router based on the respective requirements.

In order to achieve a stable and easy to configurable network environment, the gateways are requesting an IP address from the DHCP server that operates on the router. In that way, the network properties of the gateways can be configured centrally by the router user interface without the need to alter the network properties of each gateway separately. Moreover, the DHCP server is configured to bind each gateway's MAC address with a specific IP address. Hence, in every installation the technician knows a priori the IP address of each gateway, if access is needed along with the IP addresses for the modem and the router user interfaces. The same apply to the robot as well. The IP binding that was applied is as follows:

Table 2. IP addresses of the networked devices

Device	IP Address
Main controller	192.168.2.216
Smart Home gateway	192.168.2.105
BLE gateway	192.168.2.106
Robot	192.168.2.16
4G/3G modem	192.168.2.254
Router	192.168.2.253

During installation of the RADIO network, the technician should find the appropriate location of each component as already described and then power up the devices. *It is important that the following sequence is observed:*

1. Power up 3G/4G modem
2. Power up router
3. Power up gateways

If one of the Wireless components does not meet the expected performance, it might be because of signal interference. We have detected issues with 2.4 GHz Wireless signals and BLE signals. If these issues are too severe, the technician might need to consider switching the router to 5 GHz functionality in order to reduce the signal interference issues between BLE and WIFI. An example signal interference is shown in Figure 27, see also deliverable D4.2. The yellow circles are the advertising frequencies of

BLE and the green rectanlge is the full spectrum of all WIFI channels. If certain WIFI channels are used, they can interfere with the BLE signal and therefore distort the measurements of the BLE nodes.

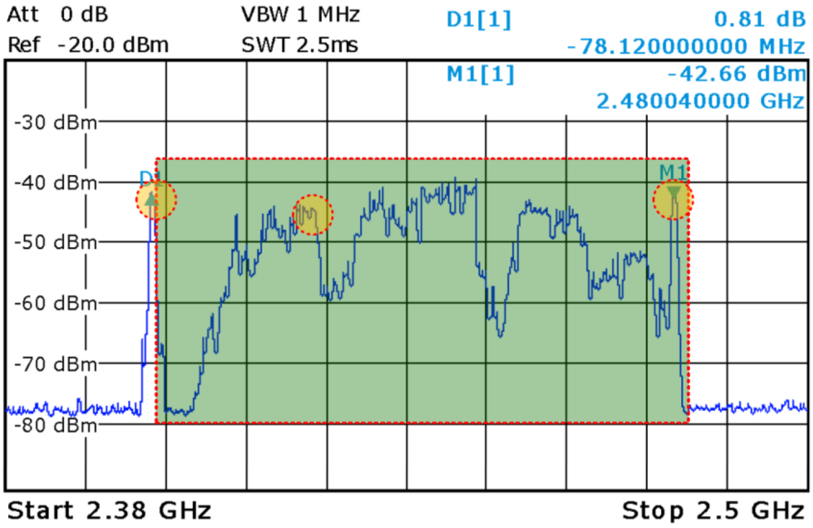

Figure 27. Spectrum BLE and WIFI

4. LOCALISATION MODULE

Localization is performed in various aspects, and it is distinguished in absolute localization and tracking of the robot, and in the relative localization of objects inside the RADIO smart house premises.

4.1 Robot Localization Module

The robot localization module is running in different parts of the whole system, as shown in Figure 28. We install and run a ROS application in order to obtain the location of the robot according to its own map. In turn, the obtained location gets forwarded to the RADIO Gateway, for preprocessing and finally transmitted to the RADIO IoT Platform, where the main localization services are running. Finally, the virtual location of the Robot is calculated from localization services and send to the Web Interface for visualization.

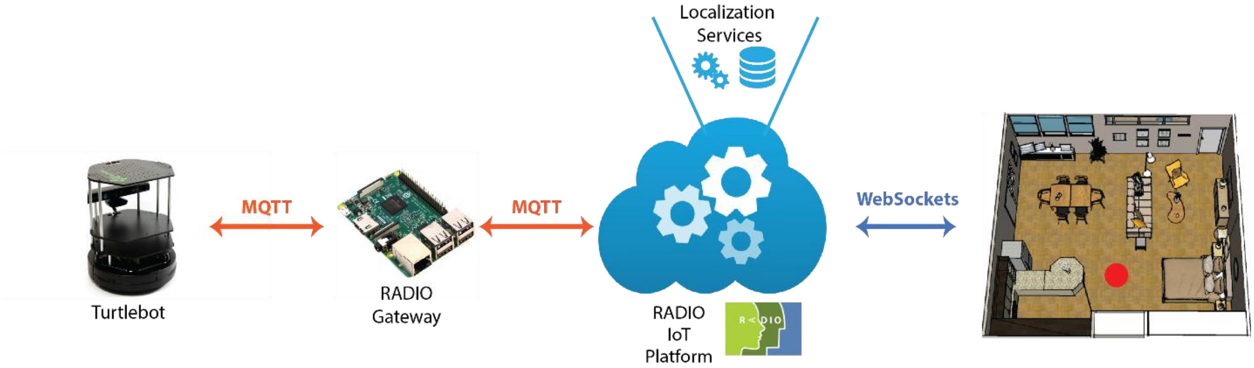

Figure 28. Robot localization module

ROS Application
The ROS application is subscribing and receiving ROS messages from */amcl_pose* ROS topic, which gives the location of the Robot according to its own map. Furthermore, the application establishes a MQTT connection with the RADIO Gateway, which in turn, forwards the messages from /amcl_pose to the MQTT topic robot/location.

RADIO Gateway
The RADIO Gateway is the main aggregation point for the positions of the robot. When a new robot position gets received from the Gateway, it is transformed to an appropriate format that can be handled by the RADIO IoT Platform services, and sends the message to the following MQTT topic aalhouses/gateway/{gatewayId}/robot/{robotId}/location

RADIO Platform Localization Service
The Localization service analyzes the received robot positions with those existing in a database. The robot position can be determined from the MQTT topic placeholder, *{robotId}*. Knowing the identity of the robot, the service can determine the house that the robot is installed in and retrieve the corresponding house fingerprints. The relationships of robot, house and fingerprints can be extracted from the following schema.

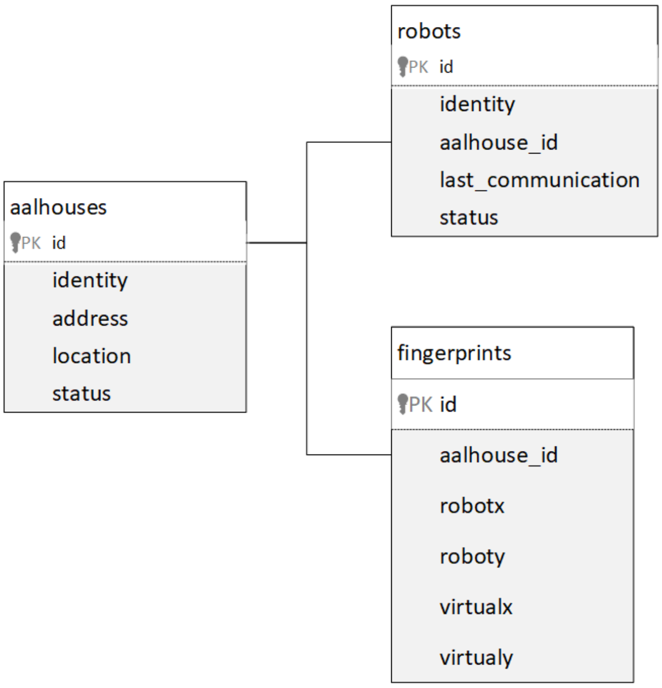

Figure 29. Relationship between robot, house and fingerprints

In this schema we have the houses, represented by the aalhouses entity, the robots entity, where each robot belongs to an AALhouse, (aalhouse_id), and finally for each AALHouse we have the fingerprints, which represented robot position to a virtual map, where in our case is the Web Interface showing an AALHouse view.

The installation of the localization module requires the following steps,

1. Run the application (ros_mqtt_subscriber) on the robot.
2. Place the robot on multiple position inside the house and for each position
   2.1. Save the position coordinates of the robot, as exposed from /amcl_pose
   2.2. Save the virtual coordinates, by clicking on the corresponding location on the Web Interface.
3. Finally, import all the gathered coordinates into the database.

4.2 Object Relative Localization Module

Relative localization aims to identify the presence of a BLE enabled object and report the space it lives to the RADIO system. It consists of three sub–components.

1. The mobile BLE node which is attached (localization-wise) to the object of interest. With additional sensors, the robot is able to also localize other objects of interest. This can be accomplished with the Bluetooth devices that are positioned within the house. Thus the robot can also help the end-user to search for an item which is outfitted with a BLE transmitter. Because Bluetooth beacons only broadcast their ID, the received signal strength indication (RSSI) is used in order to extract position information out of the beacons signal. The RSSI value can then be converted into a distance measurement.
2. The static BLE nodes are installed in predefined locations in the house. With static BLE nodes, the robot can estimate its position within the RADIO home environment or use a thresholding

approach to annotate the rooms in which the robot is currently located. The thresholding approach is shown in Figure 30.

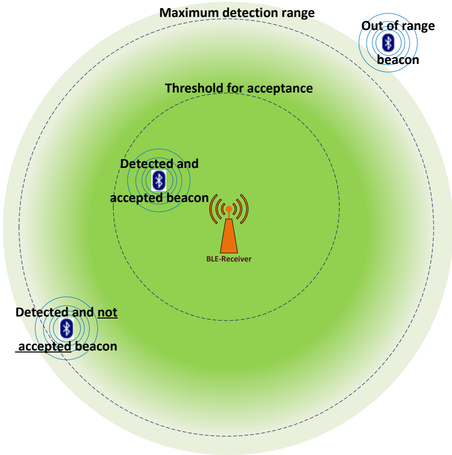

Figure 30. Thresholding of range determined through the RSSI values of BLE beacons

The BLE nodes should be located at places with a clear view of the room and not be hidden behind or inside furniture. This severely impacts the signal strength of the nodes and reduces accuracy and performance. The technician should test all BLE signals and determine the best placement for the BLE nodes. He/she can follow these guidelines:

- The BLE node should be in clear view of most of the room
- No metal construction (e.g. cages) should be near the BLE position
- The position should be static, so not on the door of a cupboard or a closet.
- The position should be easily measureable.

If these guidelines are followed, the BLE node should perform as expected.

3. The BLE gateway that collects all the BLE localization reports by the static nodes.

For accurate position estimation through trilateration, three measurements at different positions have to be performed. Each position generates a circle with a certain radius which describes the measured distance to the BLE beacon. In the case of three measurement positions, 27 circle constellations exist. These 27 constellations contain redundant constellations which do not need to be analyzed separately. Then, these 27 constellations can be reduced to 10 different circle arrangements. We assume that no circle is contained within another circle except if several measurement errors occur. Therefore, we discard the circle arrangements where circles are included in other circles. Then, we receive four valid arrangements as seen in Figure 31. They are used to determine the region of interest (ROI) with the help of multi lateration[1].

In the first arrangement, each circle has no intersection with the other circles. In this case, the center of the shortest connection for every circle pair is determined. These three calculated points are the triangle out of which the position estimation can be calculated for the BLE beacon. The region of interest is the circumcircle of the triangle with the radius being the uncertainty of the measurement.

In the second arrangement, exactly two circles intersect with each other. Then two intersection points exist. One of the intersection points has a larger distance to the third circle than the other intersection point. The intersection point with the larger distance is discarded and the resulting region of interest is a circle with the center point being the center of the shortest connection

[1] Kuruoglu, G.S., Erol, M., Oktug S. (2009) — Localization in Wireless Sensor Networks with Range Measurement Errors, Fifth Advanced International Conference on Telecommunications, Istanbul.

between the remaining intersection point and the third circle while the radius of the circle and thus the uncertainty is half the length of the connection.
In the third arrangement, one circle serves as connector to the two other circles. The two other circles do not share any intersection while the circle in the middle has two intersections with the respective circle. In order to determine the region of interest, all intersection points have to be calculated and the four distances between the intersection point pairs from the different circles have to be determined. The intersection point pair with the smallest distance is chosen and the center of this connection is the center point of the region of interest circle with the radius being half the length of the connection.

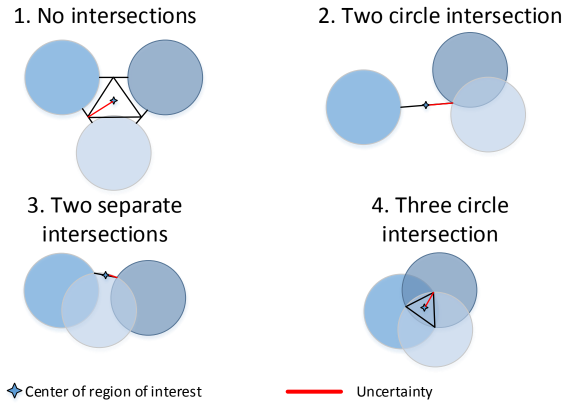

Figure 31. Four possible circle arrangements

In the fourth arrangement, all circles intersect with each other. The distance to the remaining circle is calculated for each intersection point. The intersection point with smallest distance to the remaining circle is chosen as final point for the resulting triangle. Just as in the first case, our region of interest is formed by the circumcircle of the resulting triangle.
If more than three measurements are performed, this approach is also valid. Then we consider four triples of circles (1, 2, 3), (1, 2, 4), (1, 3, 4), and (2, 3, 4) separately. The triple with the smallest measurement error determines then the final region of interest.
This process is done automatically by the localisation app.

For configuration, it is very important to exactly know the positions of the static BLE nodes, otherwise the localzation results will not meet the expected accuracy. Otherwise is the developed methodology very robust and can be used as additional localisation information for the RADIO robot platform.

During the installation of the module a specific procedure needs to be applied before operating the relative localization module. Initially, the mobile BLE node needs to be applied to the object of interest. The mobile BLE node differentiates to the rest of the BLE nodes of the relative localization module (static nodes) only on the firmware. The mobile node performs only the advertising of its presence. The specific firmware should be applied to the board before attaching to the objects. Afterwards, the BLE board needs to be attached to the object in the more convenient way and special care should be given in avoiding blocking the wireless components of the BLE board (e.g. avoid packing the board in cases, etc.). An indicative installation is given in Figure 32.
Static nodes are the BLE nodes that scan for the presence of the mobile object of interest and report the strength of the received signals to the gateway. Firmware–wise, the static nodes are responsible to scan for mobile nodes and advertise periodically, therefore, their firmware should be uploaded to the boards prior to any other installation procedure. The second step of the procedure considers placing the nodes at the locations that should be installed. Particularly, the technician should decide based on the requirements for granularity of the localization reports and define the final number of the static BLE

nodes that will be used. The technician must identify the optimal places where the static nodes will be able to scan and report flawlessly the presence of mobile nodes. The technician should avoid places that might deteriorate the wireless operation of the nodes (e.g. inside cupboards). Moreover, since the beacons used for embedding the localization information, are propagated in an opportunistic fashion, the virtual graph formed by the BLE nodes should be connected. An indicative installation of such nodes is depicted in Figure 32.

Figure 32. Installation of BLE nodes

Finally, the gateway is the localization component that glues the BLE local network to the backend of the RADIO system. Gateway scans for localization reports by the static nodes and performs all the needed actions needed to extract the location of the mobile object. The gateway must adhere to two mandatory requirements. Firstly, it should be placed in a location where it can collect the data forwarded by the static nodes and secondly, the internet availability should be guaranteed (whether delivered by the RADIO internet gateway or not). No further care is needed by the technician apart from powering up the device. The gateway needs around 5 minutes to load the required software and start reporting objects' locations.