# 1 Purpose

Mapping signal strength for NB-IoT gives an idea of how to best make use of IoT devices. Since IoT devices depends on connectivity to the internet, placing such a device in a location without sufficient signal strength to connect, would be infeasible.

To map indoor signal strength of NB-IoT a setup with two LIDAR sensors and an antenna is used to find position as well as signal strength. The two LIDAR sensors are controlled by an arduino while the antenna is controlled by a Rohde and Schwarz TSMW Universal Rodio Network Analyzer. By capturing measurements while moving, indoor placement can be related to signal strength.

# 2 Manual

The following describes how to used the test setup. You will need:

- **Digital resources:**
  - The `i2c_scanner.ino` arduino script.
  - The `Lidar.ino` arduino script.
  - The `I2C_Rev5.zip` library for arduino.
  - The `LidarLite_Arduino_labrary-master.zip` library for arduino.
  - The `arduinoTest.m` Matlab script.
  - The `readDistance.m` Matlab script.
  - The `takeRange.m` Matlab script.
  - The `waitForBusy.m` Matlab script.
  - The `GPSmapping.m` Matlab script.
  - The `lldistkm.m` Matlab script.
  - The `simple_kml_writer.m` Matlab script.
  - The `get_power_measurements.m` Matlab script.
  - The `postprocess.m` Matlab script.
  - Installed and running MATLAB R2018b.
  - Installed and running MATLAB R2015a.
  - Installed and running Arduino Software (IDE).
- **Physical resources:**
  - The arduino board with the two LIDAR sensors attached.
  - Laptop with all the digital resources on.

  - Powersource (a car battery with the suitable adapter).
  - Rohde & Schwarz TSMW Universal Radio Network Analyzer.
  - Means of fastening (a metal plate and clamps or similar).
  - A trolley or simiar, that can support the equipment.

All the scripts can be found in the github repository INSERT GITHUB HERE.

## 2.1 Record metadata

Before starting a proper scenario must be chosen. Scenarios are further explained in section 3. The recordings of metadata is done by writing all metadata in directly in the matlab script `arduinoTest.m`. Here the `metaData` struct must updated to fit the scenario. These informations are later stored in a `.mat` format.

## 2.2 Setup

To setup a measurement follow the steps below accordingly:

- Start the Arduion IDE.
- Make sure that Tools→Board is set to Arduino Mega 2560
- Install the `.zip` libraries (Sketch→Include library→Add .ZIP library...).
- Disconnect one of the LIDARs (the blue and green wire)
- Run `i2c_scanner.ino`, changing the address of the connected one from the default `0x62` to `0x61`. By opening the serial monitor (found under tools) and setting the baud rate to 9600, the connected components addresses can be identified.
- Now connect the other LIDAR to the board.
- The other LIDAR should now be connected and have address `0x62`.
- Remember to close the serial monitor.
- Run the `Lidar.ino` now. To ensure it works, open the serial monitor and change the baud to 115200 and follow the instructions. This step is not always mandatory, but on some systems a necessity to enable the matlab script.
- Close the serial monitor.
- Set up the equipment on a rolling table or similar. An example sketch can be seen in figure 1.

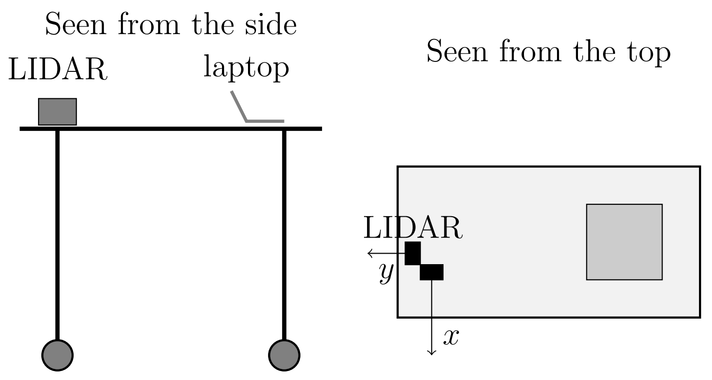


Figure 1: Example setup.

To setup the TSMW box, simple connect it to the power source and the computer. When the measurement is to be carried out, run the `get_power_measurements.m` script and terminate by ressing `ctrl+c`.

Pictures of a setup can be seen in figure 2 and 3.

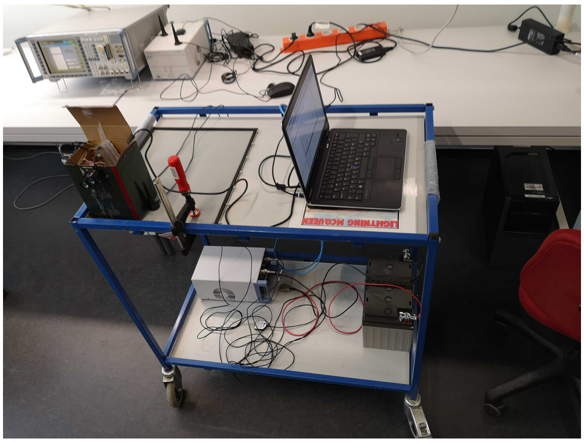

Figure 2: Picture of a setup from the 25th of January.

## 2.3 Recording

To record data, perform the setup procedure, place yourself in the desired location and run the matlab script `arduinoTest.m` in the R2018b release and the `get_power_measurements.m` in the R2015a release. To stop the arduino press any bottom and to stop the TSMW use `ctrl +c`. While recording to map the room, move the sensors around. In [1] it is proposed to have a grid of 0.5m by 0.5m at a height of 2m above the floor. While the height depends on the specific setup, the movement can be done freely and thus is a 0.5m spacing a good idea. The pattern could be done in a "lawnmover" style as shown in figure 4.

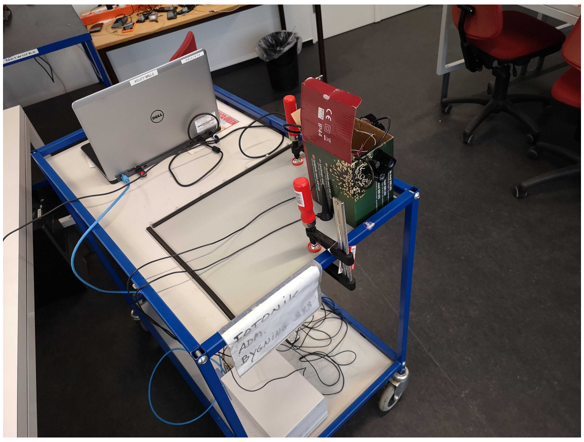

Figure 3: Picture of a setup from the 25th of January.

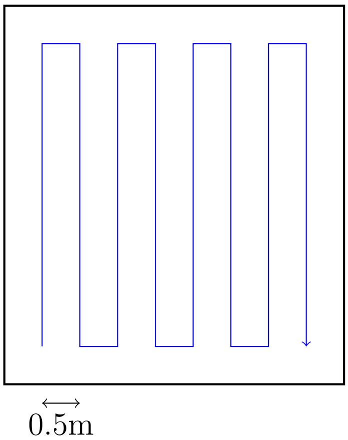


Figure 4: Proposed movement pattern

Furniture and people moving around in a room disturbs the measurements. To avoid furniture and most people the sensors could be raised to 2m or above, while keeping the antenna at the same height or moving it up. Remeber to note it in the metadata.

## 2.4 Postprocessing

As the data is saved to a `.mat` file all one would have to do is to run the`GPSmapping.m` function with the proper filename. Then two sets of plots are made for a quick sanity check and then the GPS coordinates (in decimal degrees) and a `.kml` file is saved. For the function to work, two GPS coordinates are needed as reference. One to map the origin and another one to map the angle of the wall. An illustration of how two GPS coordinates helps map a room can be seen in figure 5. To find GPS coordinates, google map is here used and google earth is used to plot the measured coordinates.

The recordings include timestamps, and thus can position and signal recordings be compared.

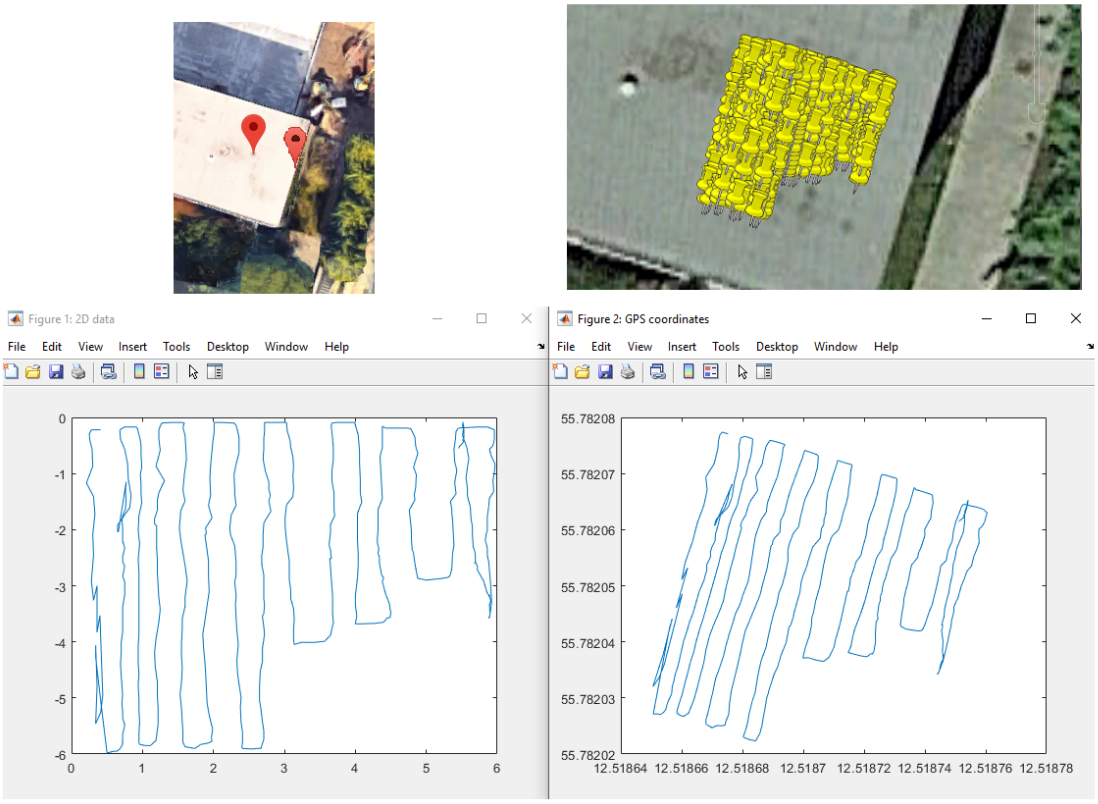


Figure 5: Example of mapping from 2D to GPS

The measured signal power is stored in a `.txt` file, also with timestamps, making associations to the distance measurements possible.

## 2.5 Errors

Errors will happen and they can easily be removed if identified. When approaching the 40m limit the sensors are prone to output 0cm instead of the actual distance, espicially if the surface is glass. This can be solved by removing all samples of 0cm. Also if the difference in distance suddenly changes a lot, for example due to a collegue walking by or an overlooked piece of furniture, that measurement could be removed as all movement should be slow and smooth. However when walking through a door or similar, the measured distances will rapidly change. In general avoid glass as the measurements jumps between the actual distance and the distance plus around 3m.

# 3 Scenarios

To best map the signal quality in terms of position a number of scenarios will have to be adressed. In [1] a parking lot, with 4 floors including ground floor, is examined.

Besides varyring the floor, the line of sight is also varyed by having different transmitters. With a range limit of less than 40m, large "open" indoor areas are hard to map. The following is a list of possible scenarios and combinations of these to map the signal indoor.

- Floors
  - -2nd to 3rd floor.
- LOS
  - LOS
  - NLOS
  - no LOS
- Walls, material
  - Wood
  - Bricks
  - Concrete
  - Glass - thermo windows, double layer, etc.
- Walls, layers
  - 1-10 Layers

## 3.1 Getting above 40m

As the LIDAR is limited to 40m, a solution to this has to be found to map hallways corretly. The ideas include the following:

- Place a piece of cardboard (or similar) for each 40m and add that as an offset between measurements. Remember to do it in the right direction.
- Only do a few refference measurements in the hallways with manual input.

## 3.2 Glass

When measurering the distance to a window of glass, the LIDARs adds around 3m sometimes and sometimes not. It is very uncertain and not recommended to do distance mesurements up against a glass wall/window.

# 4 Uncertanties

There are some uncertanties to take into account.

- Height above ground, measured with ruler ±0.5cm
- The GPS reference coordinates. As long as it is done by point and click on google maps there is an potential uncertainty of several meters. This can be minimized be having a reference measurement of the GPS position out of a window or door as a refference.
- Wether or not LOS or NLOS is achieved is also quite unsure. Fair estimates can be made from calculating the fresnel zone and investigating the terrain.
- When adding an offset, if measured with a ruler an uncertainty of ±0.5cm is likely.
- If the angle of the LIDAR sensors change, the uncertainty is large. By change the angle $\theta$ slightly the measured distance $x'$ becomes $\frac{x}{\cos\theta}$ instead of $x$.

To asses the measured values more accurately these uncertainties should be handled in a suitable manner. The uncertainties of the signal measurements should also be taken into account.

# 5 Results

By comparing timestamps of the TSMW and arduino measueremnets the results can visualized as showed in figure 6 and 7. A rather simple postprocessing script extracted the measured power and distance and connected the two with the timestamps, such that a single point had the mean of 600ms (± 300ms) of power measurements associated. By rotation the position measurements and inverting their axis the movement can be mapped to a displacement in GPS coordinates and as such is the results produced.
As one can see from the figures (6 ans 7), the signal strength drops close to the walls and are "best" in the middle of the rooms.

As the measurements are dependent on smooth walls, no glass walls and prefereably no furniture or people, finding easy-to-map rooms prooved difficult. Thus is the resulting measurements somewhat uneven. Furthermore is the size of the rolling table a limiting factor as to which corners can be entered as the entire table has to be able to fit. The table also hindered wall to wall measurements, since the extent of the table were larger that the entire setup (see figures 2 and 3).

Some of these limitation could be reduced by introducing a diffrent setup. The LIDAR sensors and the antennas is not required to be at same altitude and a setup with the

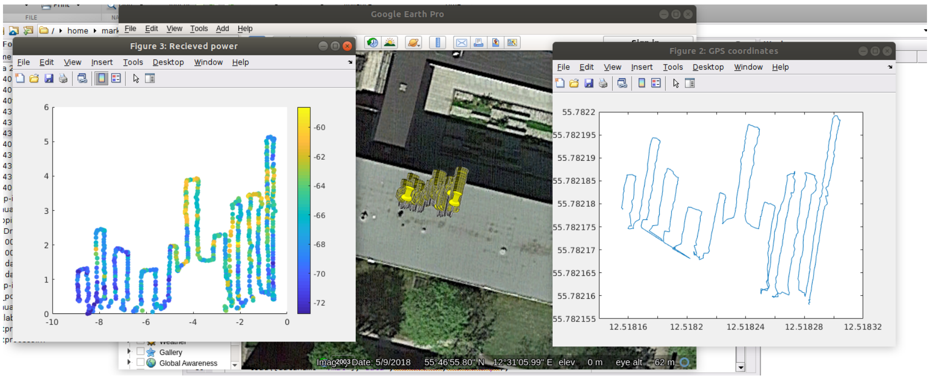


Figure 6: Measurements from the inside the databar, room 009 in building 343. The room had a lot of furniture, making a complete coverage mapping of the room inpractical with the simple setup. The signal quality drops as one moves closer to the walls and further away from the windows. The databar is located at the north side of the building and is thus closer to the transmitter compared to the measurement done on the south side of the building such as the ones described in figure 7. Still LOS is not achieved as building 340 is blocking. The displayed power is in dB.

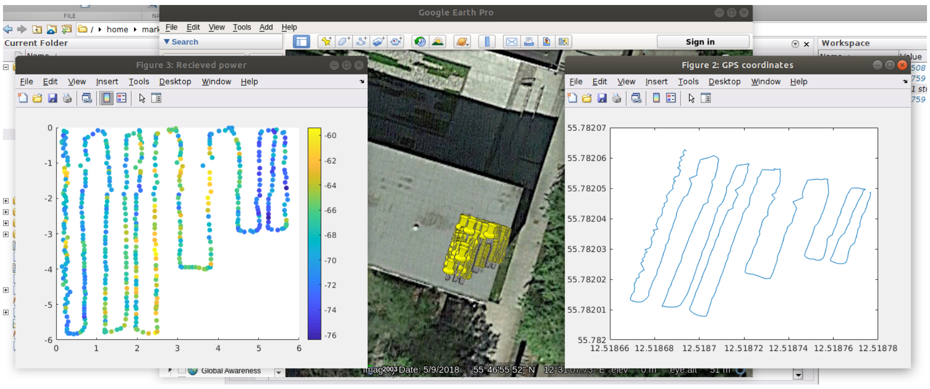


Figure 7: Measurements from the basement at the stairs in the east end of 343. When moving closer the the west wall or under the stairs to the east, the signal is weakned, while in the middle it is at its best. In the middle there is free space all the way up as the stairs revolve around some free space. These measurements are closest the the southern wall and thus further away from the transmitter to the north compared to the measurements described in figure 6. The displayed power is in dB.

LIDAR sensors elevated to a heigth above furniture, possibly on a smaller rolling table (or similar) would improve the agility and mapping robustness of the setup.

In terms of precision in relating the measured positions to GPS coordinates, other methods should be considered. For the measurements shown in figure 6 and 7 the corresponding refference point and the callibration points (for calculating the angle relative to north) are found by estimating a position on google maps and sanity checking it, by plotting in google earth. A more solid (and faster) approach could be to use the GPS module of TSMW to find a starting point. The GPS will not work while indoor, but by placing it at a known distance to the LIDAR an offset can be added to the measurements and provide more accurate mapping.

# 6 Conclusion

By using the described test setup, indoor measurements relating signal power of NB IoT and position can be carried out. To map an indoor location to GPS coordinates estimates can give a fair idea, but actual measurement could improve accuracy. The setup has the potential to execute deep indoor measurements of NB IoT in a number of cases, but has some limitations. Some limitations, such as range, can be omitted without much effort, while others require more extensive measures, like handling glass walls and/or uneven walls etc.

By reasonable postprocessing, measurements can be illustrated and exported. The measurements shows stronger signal in the middle of a room compared to the walls further away from the transmitter.

# References

[1] S. Gangakhedkar, O. Bulakci, and J. Eichinger. Addressing deep indoor coverage in narrowband-5g. In *2017 IEEE 86th Vehicular Technology Conference (VTC-Fall)*, pages 1–5, Sep. 2017.