Radio Frequency Mapping using an Autonomous Robot: Application to the 2.4 GHz Band

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Radio Frequency Mapping using an Autonomous Robot: Application to the 2.4 GHz Band

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Abstract. Radio signal strength measurement systems are essential to build a Radio Frequency (RF) mapping in indoor and outdoor environments for different application scenarios. This paper presents an autonomous robot making the construction of a radio signal mapping, by collecting and forwarding different useful information related to all access point devices and inherent to the robot towards the base station. A real case scenario is considered by measuring the RF field from our department network. The RF signal mapping consistency is shown by fitting the measurements with the radio signal strength model in two-dimensional area, and a path-loss exponent of 2.3 is estimated for the open corridor environment.

1. Introduction

Radio Frequency (RF) mapping is generally performed in wireless site surveys in order to monitor the coverage of a wireless network. Systems and methods for surveying a wireless network site are presented in [1]. The RF coverage is generally based on measurements taken by a mobile human user. Measurement consists of repetitive tasks which are time consuming and can lead to measurement errors regarding the coordinate information. Other measurement campaigns are done with sensor nodes placed on transport vehicles such as [2], however this method does not enable a controllable path by the sensor node itself.

An autonomous mobile robot is proposed as a measurement technique to avoid these drawbacks. Measurements are also taken for different positions since the robot can move inside an environment and record its path. The data are transferred in real-time to the base station using a wireless transmission. Then the robot actual location and the data exploitation can be directly observed by the user. The advantages of this method are the fact that measurements are performed in an autonomous way and the mapping is done in real-time. The user's presence on the site is only needed at the beginning of the measurement process.

Furthermore, RF mapping can be used to find and identify the different RF sources available in the environment. This automated system can then be exploited for other projects which aim at harvesting RF energy. Jabbar presents the overview and progress achieved in RF energy harvesting field in [3]. The amount of harvested energy is still low, so it is important to know where the most amount of energy is available. The automated system can also produce RSSI (Received Signal Strength Indicator) fingerprinting of an area, which is used for WiFi localisation in some studies [4],[5]. Our main contribution is the automation of a reliable RF mapping by a robot with the RF distribution displayed in real-time.

2. Robot Hardware

The robot, illustrated in figure 1, is based on the BOE Shield-Bot from Parallax Inc. The BOE Shield-Bot kit is actually composed of a Board of Education (BOE) Shield, a metal chassis, servo motors and wheels. An Arduino Uno is plugged in underneath the Shield. Arduino is an open-source electronics platform based on easy-to-use hardware and software. The Arduino Uno is a micro-controller board that controls all the components connected to the robot. An ultrasonic distance sensor is mounted at the front of the robot so that it can detect obstacles. Then, a gyroscope is fixed to the chassis in order to measure the angular velocity of the robot during its rotation. Concerning the wireless communication, two kinds of modules are used. The Arduino WiFi shield is used to measure signal strength from the different access points. The other wireless transmission is through an Xbee module mounted on the Xbee shield, providing data transmission from the robot to the base station. The robot has a size of 120x160x130 mm and a weight of 0.6 kg. Finally, the batteries allow the robot to work more than 4 hours, corresponding to a 2 km navigation.

3. Principle and Algorithm

The RF mapping principle is to let the robot move within a defined area and to frequently make a scan of the available RF signals. For practical applications, the 2.4 GHz band is selected for the case study. WiFi access points are then considered as RF sources for the study. The robot has to make scans of the available WiFi networks at different positions. The SSID (Service Set Identifier), RSSI and encryption types of the different access points are given by the scans. Even if the 13 channels can be scanned, only the five strongest signals are recorded here in order to keep data in a uniform size. The robot is also constrained to avoid obstacles while it is moving. Random rotations of the robot have been added during the travel in order to have a better coverage of the measured area. The algorithm used by the robot is defined in figure 1.

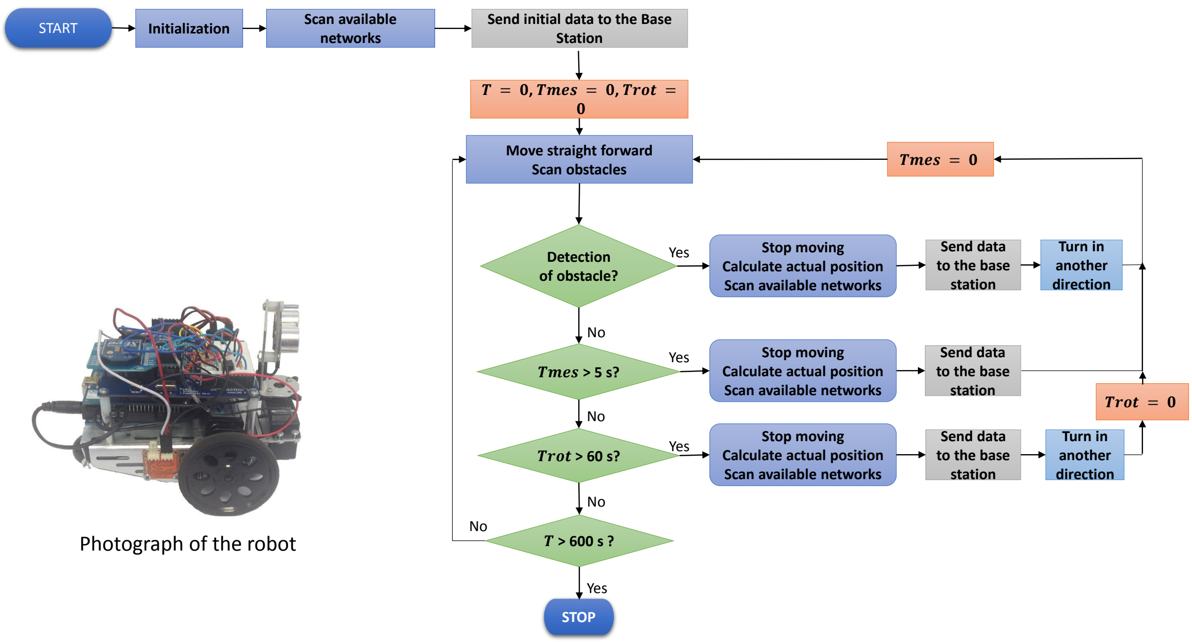

Figure 1. Flowchart of the algorithm used by the robot to perform a RF mapping of an area.

4. Measurement campaign

A RF mapping of our department was performed. The floor plan is illustrated in Figure 2 and the access points locations are represented as well. The network deployment and configuration have been done by the department and no specific change is done for the measurement process in order to study the network state. The results are presented in figure 2, which shows the mapping obtained after 45 minutes of operating time. The robot moved along the corridor of the building and the path is represented in the upper-left sub-figure. At each point, the robot measured the RSSI from five access points since only the five highest signal strengths are considered.

Besides, the robot travelled within an area of 400 m^2. It was located upstairs, so measurements could not be obtained in the middle of the area and signal strengths are only represented in the corridor. The RSSI distribution related to the different sources is represented in figure 2. It shows a reliable mapping for the first three sources, which were the closest access points to the robot path. For all of them, the RSSI distribution is consistent since high signal strengths are observed next to the related access point locations. The same signal strength levels are also obtained from these sources, which is consistent with their location toward the robot path. Then, some data have been collected for two other sources, but they were not close enough to get a reliable map. Therefore, the robot can carry out a good RF mapping of a network in a real case study. The entire mapping process can be viewed in [6].

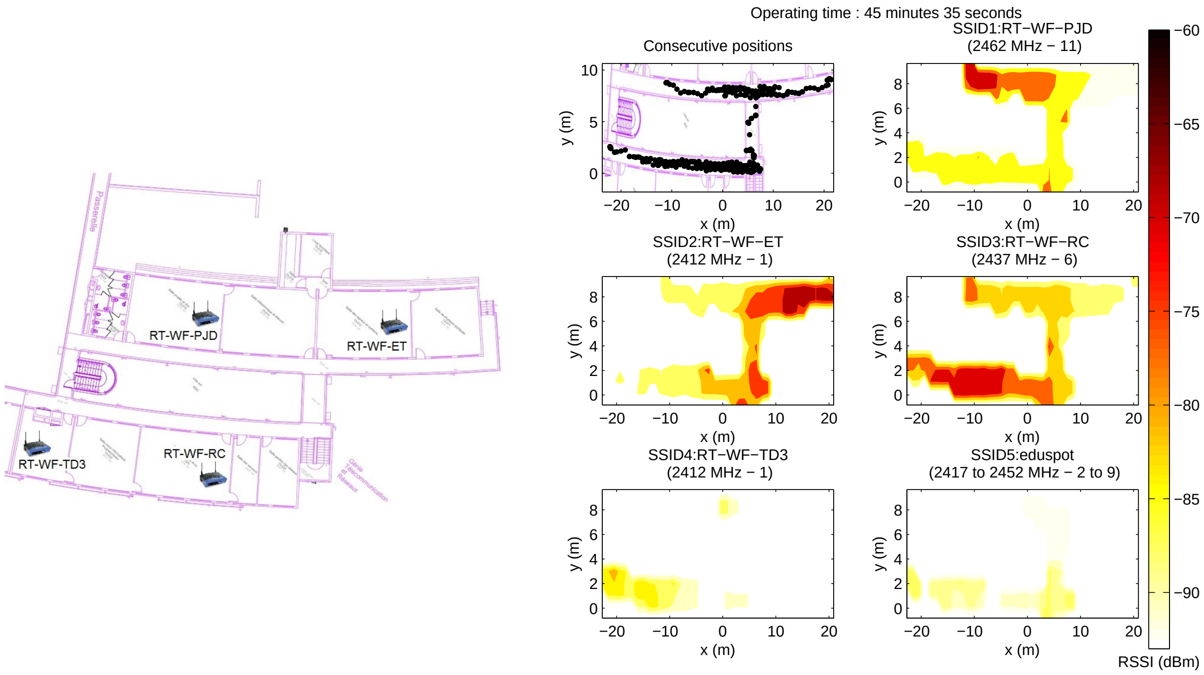

Figure 2. RF mapping of the department obtained after 45 minutes of measurement.

5. Application to the propagation model characterization

The measurements performed by the robot can also be exploited to estimate the parameters of the radio signal propagation, which is studied according to the log-normal path loss model [7]:

$$P_{dBm} = P_0 - 10n\log(||X - X_s||) + Z_\sigma \tag{1}$$

where P_0 is the received power at 1 meter from the source, n is the path loss exponent, X and X_s are respectively the positions of the receiver and transceiver, Z_σ is a normally distributed variable with a standard deviation σ and a zero-mean value ($Z_\sigma \sim \mathcal{N}(0, \sigma)$). Z_σ not only represents the shadowing and multipath fading related to the signal propagation, but also the measurement errors from the device.

A least-square method is applied to fit the measurements with equation (1) in order to estimate P_0 and n. A received power P_0 of -53.6 dBm and a path loss exponent n of 2.3 are estimated, which is relevant for this type of environment. So this new path loss exponent can be referred as the path loss exponent in an open corridor environment. The standard deviation σ is then calculated through equation 1, resulting in $\sigma = 5.7$ dBm. The signal strength attenuation is plotted in figure 3 using the model with estimated parameters or measured data. The measured data fit to the model even though there is a significant noise, which is inherent to a radio signal propagation.

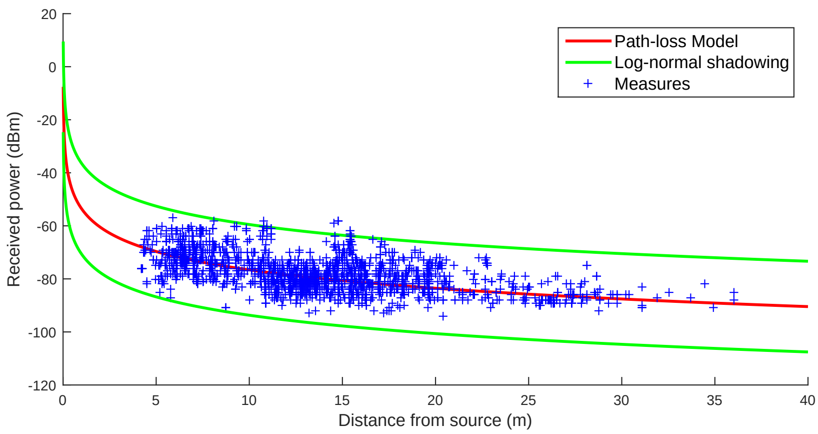

Figure 3. Signal strength attenuation model fitted to the measurements.

6. Conclusion

This paper shows that an accurate RF mapping can be performed by an autonomous robot, avoiding a user to walk around for collecting data. The measured data is also used to estimate the propagation model parameters of the environment, providing the path loss exponent of the environment. As our research project is concerned by RF energy harvesting, the map provided by the robot depicts the location where the most energy is available. It is useful for a future network deployment of sensor nodes with energy harvesting capabilities.

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