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Vehicle Detection for Outdoor Car Parks using IEEE802.15.4

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Abstract—**Cruising for parking has negative impact from the economical and ecological points and view, and in overall traffic slowdown. Effective information about which and how many parking places are free could help to reduce these effects. This is possible only if a per parking place motorization is made, which will require the use of sensors to monitor every parking place. While the placement of sensors in indoor car parks is an easy task, usually are used ultrasonic sensors attached to the ceiling, the same is not true for outdoor car parks. Not having a ceiling or a similar structure over (most) outdoor parks, sensors must be placed on the ground. This means that ultrasonic sensors are not the most suitable for this type of application, because their performance might be compromised by dirt. Another option is the placement of inductive loops, magnetometers, micro-loop probes or pneumatic road tubes, however its placement in all parking places of a city might be very expensive and its placement will imply rather complex works on the pavement. The approach presented in this paper consists in using wireless communications to detect the presence of vehicles. It is based on the attenuation that the presence of a vehicle will cause in the propagation path between two wireless nodes. As Wireless Sensor Network (WSN) technology IEEE802.15.4 was used, and it was successfully tested in the detection of parked vehicles.**

Index Terms—**Vehicle Detection, Propagation, IEEE802.15.4, WSN**

I. Introduction

All major cities face a common problem related with downtown vehicle parking [1]. Before and at the end of each journey there is the needed for a proper place to park the car, which might be a big problem specially in dense urban areas where it is becoming more and more difficult to find a parking place.

The lack of parking places in cities makes drivers to cruise for parking. This has consequences such as higher costs of trips, both in terms of time spend in cruising and fuel, there is an increase of noise and pollutants emission, and it also contributes to the overall traffic slowdown, specially in busy areas [2].

One solution to minimize these negative impacts is to inform, in real-time, drivers about the available parking places. For this to be possible a parking place motorization system is needed. Only then it is possible to broadcast to drivers effective information about how many car parking places are free and where are they located.

While detecting the presence of vehicles in indoor parks can be easily made, using for example ultrasonic sensors placed on the ceiling, the same is not true for outdoor parks. Most outdoor parks are not covered nor have a ceiling like structure were to fixate the sensors, therefore they can only be placed on the ground. In these conditions the performance of ultrasonic sensors might not be the best because dirt could cover the transducers.

There are other options such those that are used to detect vehicles in movement, however they are not suitable to detect cars that are not moving. Detecting stopped cars can be made using for example inductive loops, magnetometers, micro-loop probes or pneumatic road tubes [3]. However such a solution usually involves complex works in the pavement and its costs are rather high specially if we consider that the objective is to count free parking places, and consequently place sensors in a per parking place basis.

In [3] Daubaras and Zilys presented a solution based on a wireless sensor that uses the Earth's magnetic field to detect the presence of vehicles. In this paper it is also presented a solution based on Wireless Sensor Networks (WSN), however, instead of using the WSN only to transport data from the sensors, the WSN itself is used as the sensing element.

Detection of parked vehicles is made by analysing the interference that they make on the propagation of the electromagnetic waves used by the wireless network.

This work makes part of a pilot project to be implemented in the city of Vila Real, in Portugal. It consists of a real time in city traffic and parking motorization, using several types of sensors. In this paper it is presented the technique that has been developed to detect cars in outdoor car parks. It consists on obstruction detection sensors that use electromagnetic waves of a IEEE802.15.4 [4] wireless network. This technology was chosen because of its relatively low cost, its low power consumption and its area of coverage.

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II. Detecting Parked Vehicles using Radio Frequency Waves

While travelling between the transmitting and the receiving antennas electromagnetic waves suffer changes, and the received signal is an attenuated version of the original wave. This means that only a small fraction of the sent energy is picked-up by the receiver. Let us consider that a transmitter as an output power P_t (dBm), the power that will arrive to the input of a remote receiver is given by Eq. 1:

$$P_r = P_t + G_t + G_r - PL_{tot} \quad (1)$$

where P_r is the received power (in dBm), G_t and G_r the gains of the transmitting and the receiving antennas (in dB or dBi) and PL_{tot} is the summation of all losses that the wave suffers while travelling between the transmitter and the receiver (in dB).

We can divide the path loss into two main types: Path loss in free space and attenuation due to propagation medium features (Eq. 2):

$$PL_{tot} = PL_{fs} + A_{env} \quad (2)$$

where PL_{tot} is the total path loss, PL_{fs} the path Loss in free-space and A_{env} the attenuation due to the environment features.

The term for the Path Loss in free space is well known and can be given by Eq. 3, which expresses the Path Loss as a function of the distance [5]:

$$PL(d) = PL(d_0) + 10Nlog\left(\frac{d}{d_0}\right) + X_\sigma \quad (3)$$

where N represents the Path Loss exponent and d_0 is an arbitrary distance, X_σ denotes a Gaussian variable with zero mean and standard deviation σ.

This is the expected attenuation in a wireless communications link when there is no obstacle between the transmitting and the receiving antennas. When the Line-of-Sight between the antennas is obstructed (including the Fresnel zone) there will be an additional attenuation in the link, A_{env}.

While in most applications this additional attenuation of electromagnetic waves is faced as a major disadvantage, in the present work it is used as the working principle of the sensor itself, as it was presented by the authors in [6] to detect the presence of vegetation.

There are several propagation models to predict the value of this attenuation, both for indoor (e.g. COST231[7]) and outdoor (e.g. Okumura-Hata model [8], COST-Walfisch model [9] and Two-slope model [10]) environments. However these modes might not be very effective for very short range communications such as the ones used in WSN [6], [11].

However, precise values for the attenuation due to vehicles is not necessary because the objective is to detect the presence of vehicles. Therefore it is only needed to do the comparison between the values of the received power when a vehicle is parked and when the parking place is free. Since vehicles have a large amount of metal it is expected that they will cause a significant attenuation in the path, when compared with the attenuation in free space considered alone.

In Fig. 1 is presented the working principle of the proposed system. There are two elements: the remote sensors that will be placed on the ground and a base station that will be placed on a high place (e.g. in a pole). The base station must be placed in a location where other parked, or moving, vehicles do not influence the readings.

Remote sensors must periodically send data frames to the base station that will record the value of the received power and sends it to a remote server. On this remote server this information is stored in a database and it is processed. The result of this data processing is the information about the parking place status.

If no vehicle is parked over the remote sensor, the power received by the base station will be at its maximum. When a vehicle is parked over a sensor the received power will decrease.

There are some cases where the attenuation is so high that the base station is unable to receive data sent by the the remote sensor. In these cases, after a timeout without receiving frames from a sensor, the base stating attributes to that particular sensor a received power value lower than me minimum value that the transceivers can detect. In the case of the prototype presented in this paper that value is -100dBm.

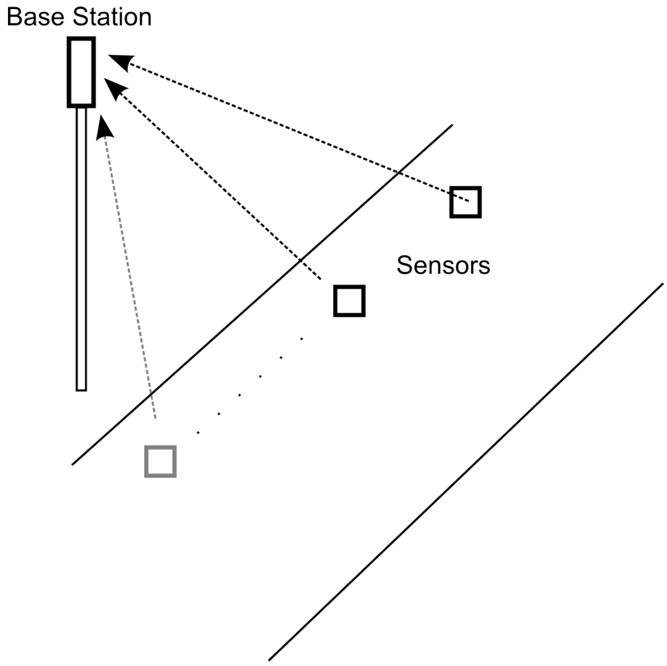

Figure 1. Working principle of the vehicle detection system.

III. The Implemented Prototype

A. Hardware

As above mentioned there are two main components of the proposed system: the remote sensor that will be placed on the ground and the base station that will receive the data frames from the remote sensor.

Both these systems are based on a low power microcontroller, a PIC18F2620 from Microchip [12], and an IEEE802.15.4 transceiver. For this project XBee or XBee

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Pro IEEE802.15.4 transceivers from Digi [13] have been selected. XBee transceivers have an output power of $0dBm$ and XBee Pro $10dBm$.

Although these components have been chosen for this project any other low power microcontroller (with a minimum of 2KBytes of RAM for the base station) or IEEE802.15.4 transceivers could be used.

Relatively to the power supply two options have been taken into consideration, for both the base station and the remote sensors:

- External power supply - These sensors are to be used in a larger project that also involves the use of in ground LED to signal the parking place status (free, paid, residents-only, etc). So in some parking places there are already low voltage DC power lines that can be used to power the sensors and/or the base station;
- Battery powered - In this case rechargeable batteries with a solar panel can be used, so it was also developed a NiMH battery charger based on MAX712CPE. This solution in intended mainly for the base station.

In the case of battery powered systems the battery voltage is monitored by the microcontroller, so another requirement for the microcontroller is the need for an internal Analog-to-Digital Converter (ADC).

Both systems (sensor and base station) are therefore very similar at the hardware level, the only physical difference between them is the used antenna type. For the base station it is used an external dipole half-wave articulated antenna (2.1 dBi). For the sensor, to achieve a better form factor, were tested chip antennas (-1.5 dBi) and attached monopole whip antenna (1.5 dBi). In Fig. 2 it is presented the base station main board.

Figure 2. Base station main board.

B. Working Procedure

Because the sensing principle is based on the received power, the base station must be permanently listening for incoming communications from the sensors, and the sensors must periodically send data frames.

The base station can receive at any time information about the sensors it should listen to. This information is transmitted from the Operations Control Centre (OCC) using IEEE802.15.4 The type of messages that the Base Station can receive from the OCC include ”sensor add” and ”sensor remove”.

On the other hand the sensors periodically send data frames, broadcasting the status of its power supply. These messages are collected by the nearby Base Stations that store the power supply/battery information and the received signal strength.

The interval between these data frames can be programmed and it is dependant on the needed temporal resolution and end applications. For example in paid parks there is the need to detect when a car leaves the parking place, to effectively calculate the fees, therefore a very short interval between frames is needed. On the other hand if the the application is simply intended to monitor available parking places, there is no needs for a very short interval between samples.

A great advantage of using IEEE802.15.4 is that a transmitter can send data without the need for any kind of association with a remote peer or coordinator. Sensors can simply broadcast their information without needing to know which base stations will listen to their frames. This is very useful because:

- There is no need to individually program the sensor for a given base station;
- For debugging our motorization purposes there can be more than one base station listening to the sensor frames;
- The base station associated to a sensor can be changed without the need to reconfigure the sensor.

C. Data Visualization

Data sent to the OCC is processed by a decision algorithm and the result is sent to a database. One of the options that was implemented to visualize these data is a web application, based on a iterative map, where the user can easily visualize which are the free parking spaces.

In Fig. 3 is presented a screen-shot of that web application, which is based on the Google Maps API. The presented map corresponds to the parking places, that are being used during the development phases, at the University of Trás-os-Montes and Alto Douro.

In this web application the status of the parking place is represented by two possible colours indicating its status: green for free parking places and red for occupied places. The user can also access to additional information about the sensor and the base stations to which it is associated. These information are: the battery voltage (or the indication that it has an external power supply), the sensor MAC (Medium Access Controller) address and the base station MAC address.

This web application is also used to add new sensors to the system and to associate them to a base station.

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Figure 3. Screen-shot of the web application (based on the Google Maps(TM) API).

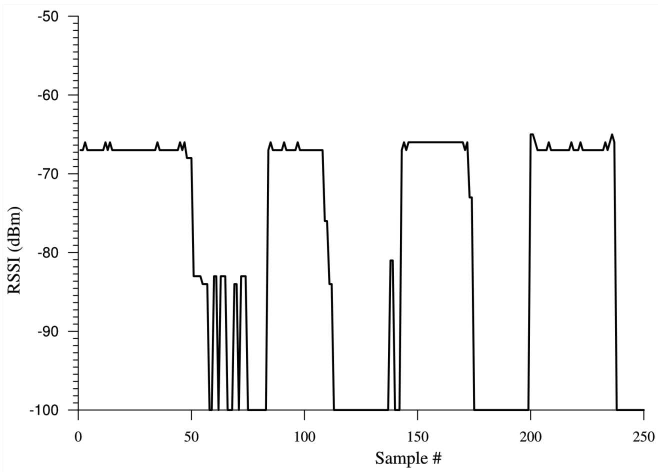

Figure 4. Values of the received power for sensor S0 (XBee with chip antenna).

IV. Tests and Results

In this section are presented three sets of tests that were made to assess the feasibility of the proposed technique to detect of parked vehicles. These tests included the comparison of transceiver and antenna types combinations, different distances between the base station and the remote sensors, and, the detection of different vehicles.

A. Transceiver and Antenna Type Test

In this set of tests four combination of transceiver types (XBee and XBee-Pro) and antennas (whip and chip) were used. These combination were:

- Xbee with whip antenna (sensor S0);
- XBee with chip antenna (sensor S1);
- Xbee Pro with whip antenna (sensor S2);
- XBee Pro with chip antenna (sensor S3);

In the base station it was used a XBee Pro with a dipole external antenna.

These sensors were all placed in the same parking place, next to each other, the base station was placed in a pole. The distance between the pole and the sensors was $16,5m$ and the base station was at $2,80m$ high. For these tests a single vehicle was used.

Results obtained with these tests are presented in Fig. 4, Fig. 5, Fig. 6 and Fig. 7, for sensors S0, S1, S2 and S3, respectively. In these plots are presented the Received Signal Strength Indicator (RSSI) in dBm for 250 samples. An interval of 6 seconds between samples was used for these tests.

It is visible the effect that the vehicle has on the received signal. As it was already expected there is a decrease on the received power when it is parked over the sensor. In some cases the attenuation is so high that communications are lost and the base station is unable to detect the sensor. In these case, as it was above mentioned, the base station communicates a received power level of -100dBm.

Observing the plot for the XBee Pro with the whip antenna (S2) it can be concluded that this is the sensor that was

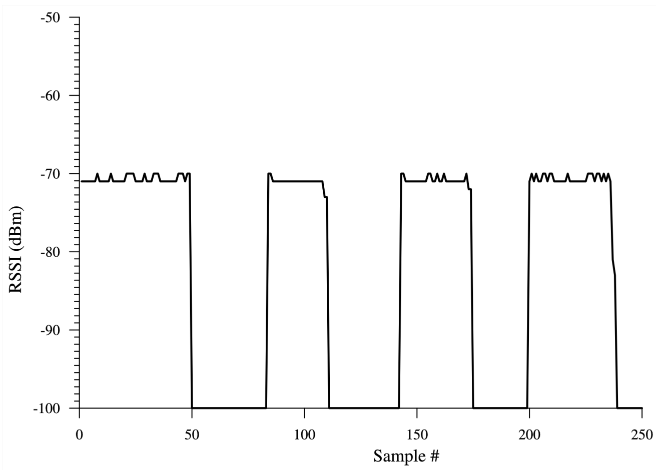

Figure 5. Values of the received power for sensor S1 (XBee with whip antenna).

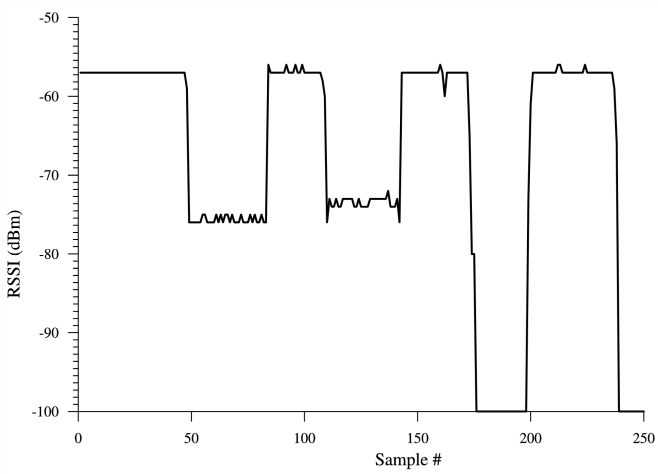

Figure 6. Values of the received power for sensor S2 (Xbee Pro with chip antenna).

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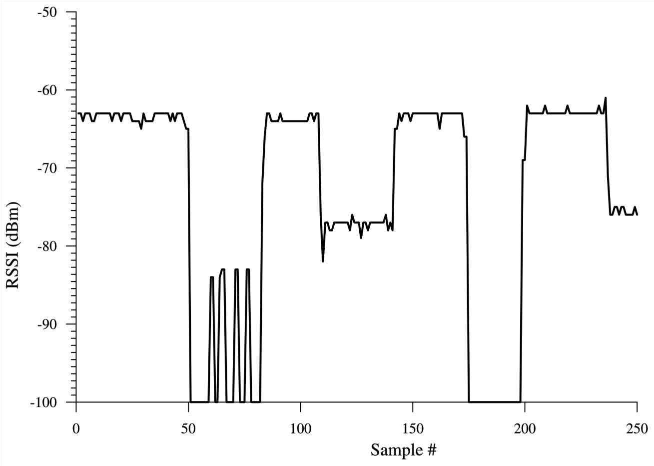

Figure 7. Values of the received power for sensor S3 (XBee Pro with whip antenna).

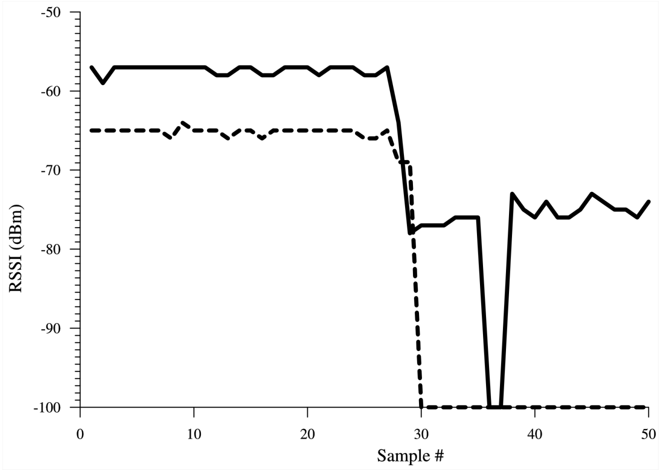

Figure 9. Test using XBee (dashed line) and XBee Pro (solid line) with whip antenna at 15 meters from the Base Station.

detected more often when the car was parked.

Apparently any of the combinations could be used for vehicle detection, however observing the received power levels it can be concluded that the ones with the best values are S0 and S2, i.e., those that have a whip antenna. Based on these tests this type of antenna was selected over the chip antenna, even though this last one has a better form factor.

The decision about choosing a XBee or a XBee Pro for the sensor is dependent on the distance between the transmitter and the receiver. Since XBee Pro has an output power higher 10dBm than XBee (which can be confirmed in the above plots) it will be detected at farther distances.

B. Distance Test

In this second set of tests the sensors with the whip antenna (S0 and S2) were placed at two distances from the base station ($3m$ and $15m$), and data was collected with and without a car parked over the sensor. For these tests both sensors were placed at the same parking place, next to each other.

Results of the test at a distance of $3m$ is presented on Fig. 8 and for $15m$ in Fig. 9. In these plots the dashed lines correspond to the XBee and the solid line to XBee Pro.

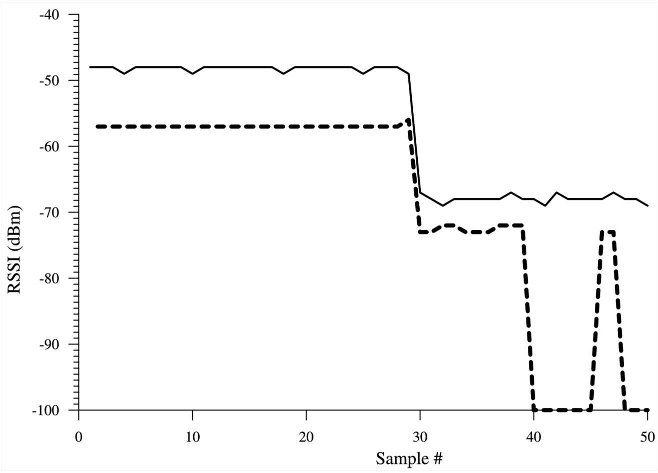

Figure 8. Test using XBee (dashed line) and XBee Pro (solid line) with whip antenna at 3 meters from the Base Station.

While at $3m$ both types of transceivers can be used without any problem, at $15m$ the noise margin for S1 starts to be too low. The maximum received power values are too low therefore a minimal fluctuation on the RSSI values due external factors (e.g. a person passing between the sensor and the base station) could lead to a loss of communications. This would lead to a false detection of a vehicle.

C. Several Vehicles

In this set of test it was used only sensor S2 and several vehicles were parked over the sensor. This test was recorded in the same sampling conditions as the above tests, and the results are presented in Fig. 10.

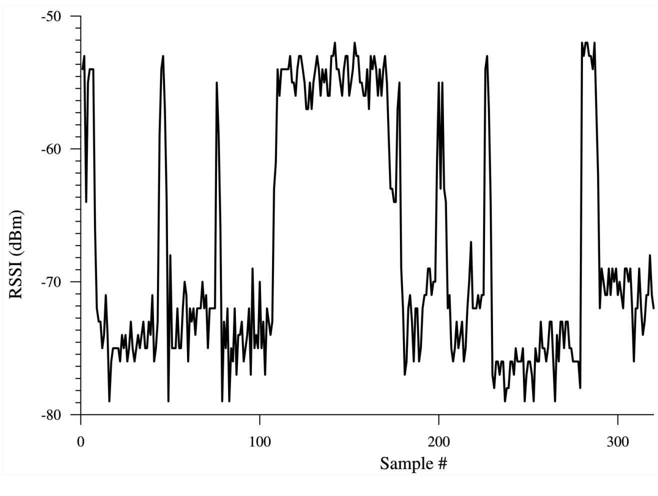

Figure 10. RSSI values obtained for S2 in the detection of different vehicles.

Observing the plot it can be concluded that the presence of a car can be correctly detected by analysing the values of RSSI. For all cars it is possible to detect when they were parked or not.

This detection can be made using a simple threshold, which for the above presented values would be between $-64dBm$ and $-68dBm$.

Another conclusion that can be drawn from the presented results is that RSSI values are not stable. Whichever the situation or the technology these values will always be floating randomly. This might affect the performance of a

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detection system. A simple technique that can be used is to reduce such noise is to use for example a simple sliding average. In Fig. 11 are presented the results for a window with size 4. Please notice that the in this case the first four sample cannot be considered.

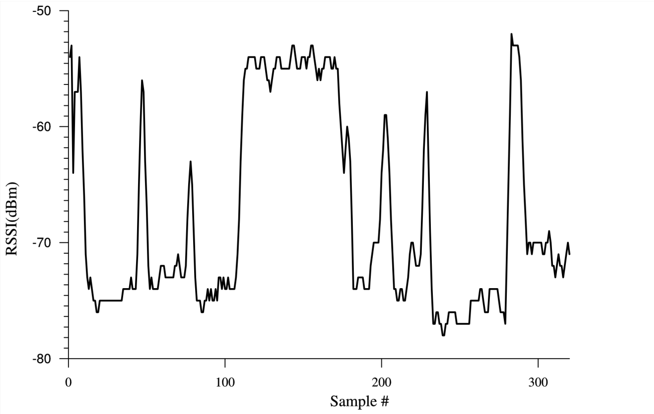

Figure 11. Effect of applying a sliding average with size 4 to the data.

As it can be observed there is an apparent increase in the quality of the signal that is processed. However there is a drawback of such a technique: it makes harder to detect cars that are not parked for a long time. The feasibility of this technique is subject to the project needs and the interval between samples.

If a comparator with hysteresis is used instead of a simple threshold comparator, it will not impose any additional computational effort to the sensors and the detection is more accurate and less prone to errors due to RSSI fluctuations. Considering values presented in the plot of Fig. 10, the comparator limits were set to $-58dBm$ and $-70dBm$.

V. Conclusion and Future Work

In this paper it was presented a sensor for detecting vehicles on parking places. This sensor is aimed for outdoor applications where solutions that are traditionally used for indoor parks, such as those based on ultrasonic sensors, cannot be used. It is based on the attenuation that wireless signals suffer when there are objects covering the Line-of-Sight between the transmitter and the receiver. In the proposed solution the WSN is not used only to transmit data from the sensor, we can consider that the WSN is sensor itself.

Some tests were made to assess the feasibility of the proposed approach to vehicle detection, and the obtained results were presented. From these results we can conclude that the used of electromagnetic waves can be used for the proposed application. These tests also allowed to select the best combination of transceiver and antenna (among the ones tested) for use in vehicle detection.

In the tests presented in the previous section, for the detection of a single vehicle and the detection of multiple (different) vehicles, a success rate of 100% was obtained.

All the presented tests were made in a controlled environment in a car parking at the University of Trás-os-Montes and Alto Douro and will now be tested in a real life scenario. Further work will involve also the analysis of data fusion and data classification techniques to compute data from the sensors.

Although in this work it was used only one sensor to detect the vehicle, this system will now be tested using more than one sensor per parking place The output of the decision algorithm will be therefore based on the value of several sensors. This aims the reduction on possible detection errors. Several combination will be tested, trying to maximize the success rate of vehicle detection and at the same time minimizing the number of needed sensors.

Nevertheless that this system has been developed to detect vehicles in parking places, this technology can also be used to detect vehicles moving too slow, for example in the detection of traffic congestion.

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