Wi-Fi Intruder Detection

An experimental approach

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Abstract - **In a society where monitoring and security are one of the most important concerns, this system represents a convenient and interesting low-cost solution in terms of intruder detection. Using widely spread infrastructure such as Wi-Fi routers and laptops, we proposed an innovative alternative, capable of detecting intruders by sensing the different electromagnetic interference caused. These perturbations are sensed by the system through the changes in the acquired Wi-Fi Received Signal Strength Indicator (RSSI), in the presence of obstacles/targets between the transmitter and receiver.**

Keywords-*Wi-Fi; RF Signature; Wavelet Transform; Intruder Detection; RSSI, Security; Wireless.*

I. Introduction

A wide number of solutions for intrude detection are available nowadays. From the simple and low cost infrared and Passive Infrared (PIR) sensors [1][2] that detect the heat radiated from the human body, up to the high-end RADAR security [3] systems, a large variety of effective solutions are available to fulfil the various needs of different scenarios.

Among all the mentioned solutions are the requirement to introduce or install extra components in the medium under surveillance. The goal of this work is to propose an innovative and pertinent alternative suitable for modern scenarios.

With a sense of practicality in mind, our system reutilizes the widely spread Wi-Fi infrastructures, taking leverage of easy implementation, turning suitable for both domestic and industrial environments. Utilizing only a standard Wi-Fi router, connected wirelessly to a laptop with dedicated software, this security system can be a simple solution for the actual intruder detection problem. This work mostly tries to show the concept of Wi-Fi intruder detection with results in a controlled scenario. Despite that, some considerations and challenges to adapt this prototype to a real scenario are addressed.

This paper is divided in six sections. The first two sections are dedicated to provide an overview of the develop work and the state of the art applications. The third section, unveils the system operation modules and provides a brief explanation of the concepts of Wavelet Transform and the RSSI in the scope of the designed prototype. The fourth and fifth sections address the experimental set up and the results obtained, with an additional presentation of considerations regarding the set up used and its consequent analysis. Finally, the last section draws some conclusions and indicates the future work proposed by the group.

II. Related Work

In the last decades, with the proliferation of mobile phones and Wi-Fi Access Points (AP), a set of ground breaking applications were developed to demonstrate the large capacity of wireless networks.

An example of this trend is presented by the concept of Wi-Fi localization [3][4][5]. This concept exploits RSSI data from different AP's to reassemble innovative and accurate localization systems, providing an attractive solutions and complement to the Global Positioning System (GPS). So parallel to the development of these applications, studies were conducted focusing on the Received Signal Strength Indicator (RSSI) characteristics and practical concerns [3][4].

Recently, in the monitoring scope, WiSee [6] and WiVi [7] displayed the large tracking detail that can be obtained from Wi-Fi signals when proper signal processing tools are applied.

The WiSee showed the capacity of Wi-Fi based systems to recognize human gestures by extracting the signals frequency Doppler shifts [6]. The WiVi using a Multi Input Multi Output (MIMO) interference nulling [7], detects human movement through walls by the elimination of the static objects reflections.

More in the context of this work, a detection system based on the RSSI was presented with the goal of monitoring pedestrian and automobile traffic [6]. The differentiation of the targets was obtained through the different RSSI changes triggered by the cars and the humans. To achieve this objective a moving mean and variance technique was adopted to analyze the data.

We proposed a less complex system inspired in the previously mentioned works that through the RSSI, senses the alterations of intruders on a static environment. To refine the detection and to possibly avoid false alarms, the Wavelet Transform is applied to the RSSI data. This signal processing technique is characterized to have a time and frequency multiresolution being utilized in diverse image and video processing procedures [9][10][11][12][13].

III. System

This section is dedicated to the system characterization. As mentioned before, the RSSI and the Wavelet Transform are the core of the operation principle, so due to their

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importance an introduction of these concepts is presented in the following subsections.

A. RSSI

The RSSI is a Radio Frequency (RF) measure, which indicates in dBm, a reference value of the received signal power in the receiver antenna.

Nevertheless, the RSSI is a precise indicator of the received signal strength and quality of the connection in real time, it was proven that the RSSI used on its own needs to pass through a calibration process to overcome the environment factors that influence the signal quality [4][14][15].

The RSSI was addressed in this paper as a measure that indicates the effects on the received signal of the presence of intruders or other targets.

B. Wavelet Transform

The Wavelet Transform is a multiresolution signal processing method capable of adjusting the window length to get a desirable precision in different signal regions, allowing long time windows where low frequency information is needed and short windows for high frequency.

According to Misiti et al. [10], “A wavelet is a waveform of effectively limited duration that has an average value of zero.”. However in contrast with the sinusoids, basis of the Fourier analysis, the wavelets tend to have irregularities and “unpredictable” shape.

The Wavelet Transform uses shifted and scaled versions of the main wavelet to separate the signal under analysis. So, the choice of an adequate wavelet is an important step in the analyzing process.

The Wavelet Transform is represented in mathematical terms by:

$$C(a,p) = \int_{-\infty}^{+\infty} f(t)\Psi(a,p,t)dt \qquad (1)$$

where a represents the scale factor and p the shifted position. The Continuous Wavelet Transform (CWT) is a sum over time of the multiplication of the signal with a scaled and shifted version of the main wavelet. Each coefficient evaluates the comparison between the original signal and the wavelet, where the higher the value of the coefficient the more similarities exist between the signal and the wavelet.

In the proposed system, the interference generated by intruders is analyzed applying the Wavelet Transform over the RSSI stream of data. The core of the analysis process comes from the correct choice of a wavelet and scale function, giving great importance and detail to find the best match between wavelet and the pattern to be detected.

The wavelet chosen was the Haar wavelet (step function) with a scale factor of 30. This decision was made taking in consideration the similarities of the step function with the human interference and the better results obtained after several wavelets tested, the ones presented in Figure 1.

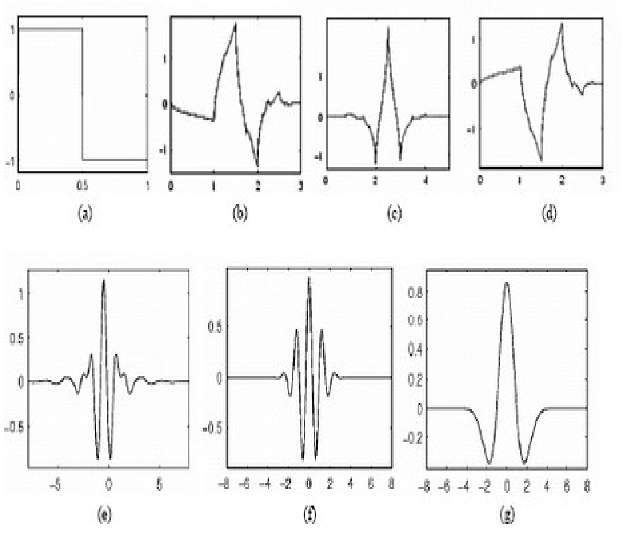

Fig. 1. Example of Wavelet families. (a)Haar, (b) Daubechie4, (c) Coiflet1, (d)Symlet2, (e) Meyer, (f) Moelet, (g) Mexican Hat [8]

C. System Architecture

The system architecture is divided in three interconnected modules: radio, data and processing module.

a) Radio module

The radio module is responsible for emitting and receiving the data using the Wi-Fi protocol. It is constituted by a router in the transmitter side and a laptop with a receiver antenna connected to a network card in the receiver side.

The designed prototype utilizes a Samsung laptop model NP350V5C, an Asus LAN Wireless Router model WL-500n and an external network card from the manufacturer TPLINK, model TL-WN722N (see Figure 4).

This hardware module is responsible for both generating and receiving electromagnetic signals in the 2.4 GHz operation band.

Our system is influenced by the inherent characteristics of wireless communication protocols, being the most relevant the multipath path fading, packets collision and the natural interference from other AP’s.

b) Data Module

The data module is both software and hardware based and has the role to be the communication bridge between the radio and processing module. Connected with the PHY layer through the network card, the data module selects the packets applying network filters, discarding packets from undesirable network address. When this filtering process is completed, the stream of RSSI data is sent to the processing module (Figure 2).

The software used was the Microsoft Network Monitor 3.4, responsible for gathering all the RSSI values and selecting the correct network address.

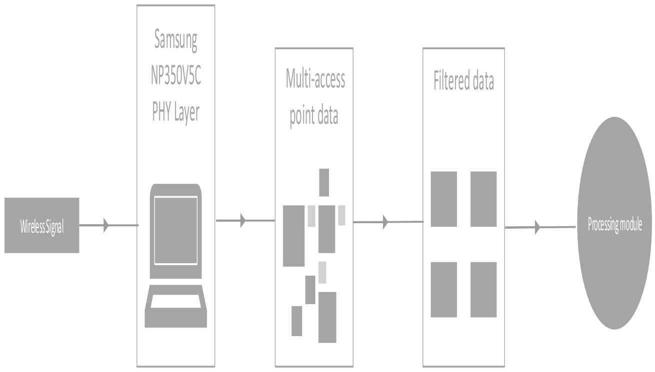

Fig. 2. Simplification of the Data Module operation principle

c) Processing Module

The processing module is completely software based and is implemented in a MATLAB platform (Figure 3). This module has the important task of filtering the noise from the received signals and applying signal processing methods to detect and distinguish the different targets.

The filtering process is simply used to eliminate noise due to multi path and collision components inherent in Wi-Fi connections. This noise appears in the received signals, in the form of notches of one sample duration, with 20 to 30 dB of attenuation, in comparison with the trend of the signal. To filter these undesirable samples, was adopted a simple scheme that detects and discards packets, having always in mind the concern of maintaining the original signal response. Then, the Wavelet coefficients are computed and the human presence is analyzed. The application of the Wavelet Transform also guaranties an additional filtering process, because turns the system insensitive to the variance of quality of the received signal in a wireless channel, having the coefficients values oscillating around zero. This last feature can be very interesting for example to create/design an automatic target identification method. This would be based on the thresholds of the coefficient values generated from different targets, which is very difficult to be implemented directly from the RSSI data.

Connecting all the modules, the system works in the following manner: the radio module generates the signals in the emitter side; the signals propagate in the medium, affected by the intruder presence. When received, the signals are handled in the receiver side of the radio module. Then, the data module gathers from the PHY layer the RSSI data and selects the correct network address, sending posteriorly the data to the processing module. Here, the data is filtered and then the Wavelet Transform is applied. With Wavelet coefficients computed, the data is analyzed with the goal to see if an intruded is detected.

IV. EXPERIMENTAL SET UP

The experiments were elaborated in a domestic indoor scenario. The line of sight between the transmitter and receiver was intentionally clear in a radius of approximately 3 meters. The directional antennas used, were set at a height of 1 meter with 1.8 meters distance to the ceiling (Figure 4). The receiver and transmitter were separated by 3 meters being the targets inserted in half distance, i.e., 1.5 meters (Figure 4).

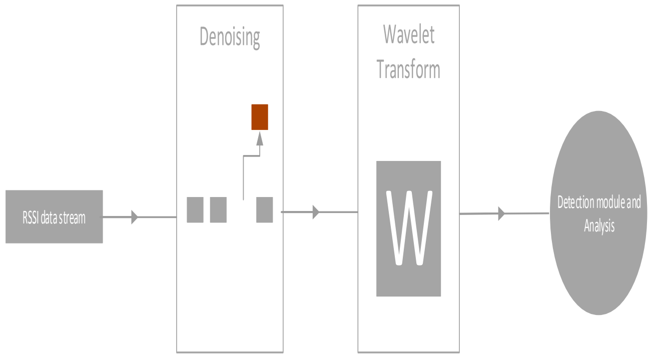

Fig. 3. Simplification of the Data Module operation principle

The half distance was adopted after the testing of several set up’s with the targets more close to the Tx or to the Rx. These asymmetrical arrangements proved that the results are dominated by the smaller distance between the target and the Tx or Rx. Also, when the targets are inserted close to the transmitter or receiver end of the system the signals are highly attenuated. The minimum acceptable distance between the target and the Tx or Rx obtained for our system was of 20 cm. In distances below that threshold, the received signal is very low and with large power fluctuations.

The system was also evaluated for more Tx and Rx distances between the 0.2 to 10 meters interval. With this study it was concluded that the distance does not affect much the performance until the 6 meters distance mark, in this controlled environment experiments, generating only a decreased of the mean value of the received signals in order of 1 to 6 dB. After this distance, the presence of the human is more difficult to identify.

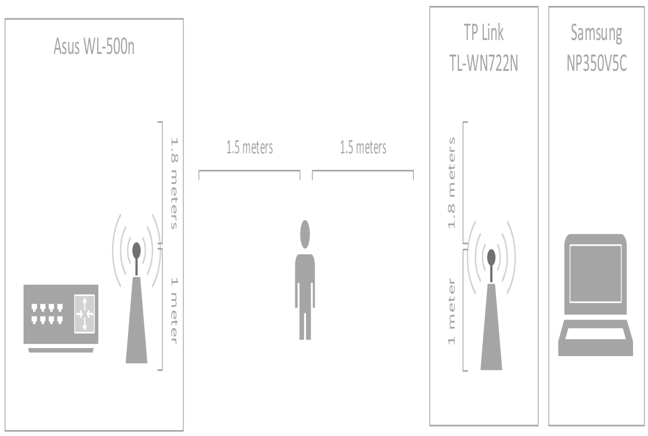

Fig. 4. Schematic of the experimental set up.

Is also worth to mention that the system works with the presence of obstacles in the nearby, with only the special attention to the line of sight Tx and Rx. With the experiments elaborated by the group, it can be preliminary concluded that the presence of objects with similar size to the human body blocking the line of sight influence the system performance, especially metallic objects.

a) Detection Experiments

The system detection performance was tested in two different scenarios: presence of one and two humans.

To avoid false alarms, the response of the system with the presence of domestic animals, in particular cats and dogs, was evaluated. The dimensions of the different targets are presented in Table 1.

TABLE I. TARGET DIMENSIONS

	Human 1	Human 2	Dog	Cat
Height (m)	1.70	1.68	0.68	0.3
Width (m)	0.45	0.40	0.45	0.57

Regarding the testing procedure, the experiments consisted on taking samples of the environment in a silent scenario, for approximately 20 seconds, inserting then the targets during the same interval. In the animal detection, the accuracy of the sampling intervals dropped due to the unpredictable animal reaction.

The angle of detection in the 3 meters experiments was approximately ± 30° in the longitudinal plane.

V. RESULTS AND ANALYSIS

The results are presented in two subsections. The first one evaluates the human detection and the second one the domestic animal response. In both sections, the first graphic shows the RSSI data and the second one the Wavelet Coefficients plot.

A. *Human detection*

The human detection results are presented in Figures 5 and 6. In both plots, the moments of intruder presence are easily distinguished. Specifically, is visible the attenuation of approximately 10 dB of the received signal in the RSSI data and the increase values of Wavelet coefficients with a consequently oscillation of the pattern.

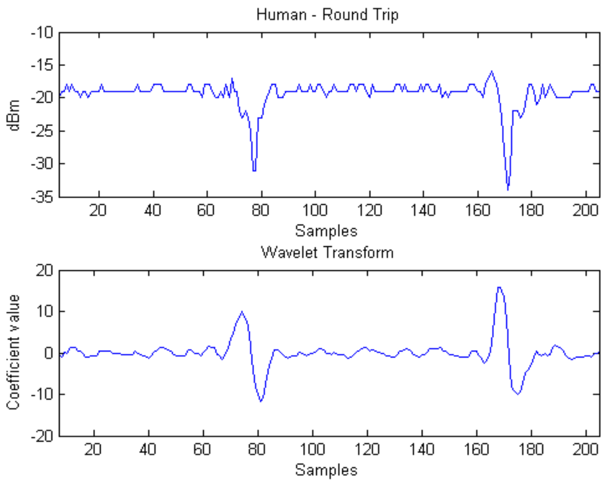

Fig. 5. Human walking; Up) RSSI data; Down) Wavelet coefficients

The experiment with the presence of two humans side by side shown a similar interference in comparison to the single human experiment, presenting only a wider attenuation interval (Figure 6).

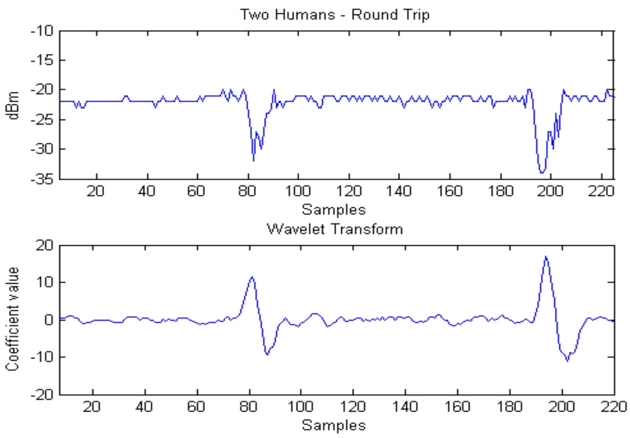

Fig. 6. Two humans walking side by side, Up) RSSI data; Down) Wavelet Coefficients

B. *Animal detection*

The results from animal detection are presented in Figure 7 and 8. The interference of a dog presented to be smaller in comparison with the human's. Both signal attenuation and Wavelet coefficient alterations are reduced but perceptible in both patterns.

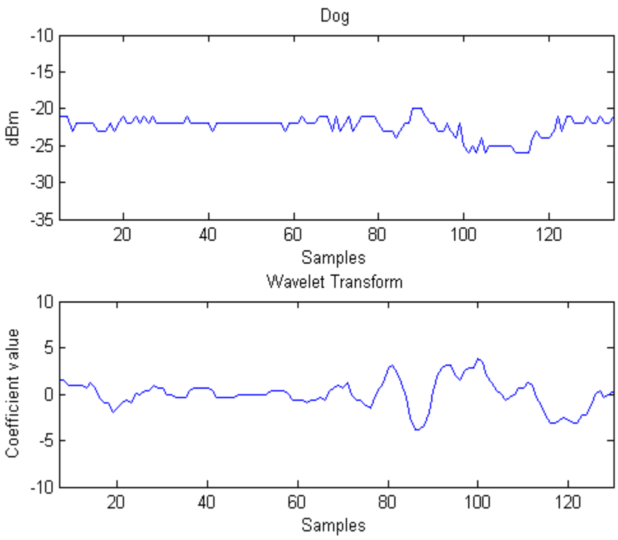

Fig. 7. Dog, Up) RSSI data; Down) Wavelet coefficient

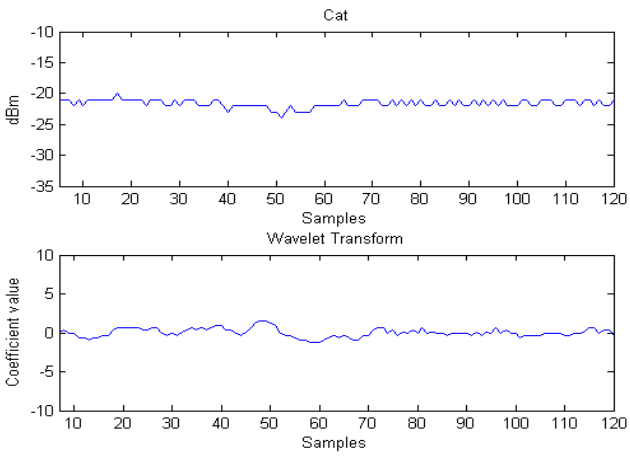

Fig. 8. Cat, Up) RSSI data; Down) Wavelet coefficient

The cat detection results are shown in Figure 8. Due to the smaller dimensions of the cat, principally in height, the signal attenuation is only around 1 to 3 dB which presents to be out of the system detection range.

VI. CONCLUSION AND FUTURE WORK

This work presented an innovative security system able of detecting intruders based on the RF interference generated in a static environment. The proposed Wavelet Transform based technique exhibited a good detection capability and enhanced the target identification performance of the system.

The Wavelet Transform coefficient analysis shows to be a good complement to the RSSI data, with suitable characteristic to improve the system to autonomously identify the targets (recalling the processing module subsection) and possibly avoiding false alarms like neglecting a car or a dog detection.

The Wavelet Transform improvements are also noticeable in the detection of moving targets with significant speed, e.g., running human, where the interference triggered can be mistaken with noise/oscillations in the RSSI raw data. In contrast, the patterns obtained with the Wavelet coefficients are similar to those presented in this paper, where the detections moments are easily seen. Additionally, to enhance the system detection capacity, the adjustment of the scale factor of the Wavelet Transform can be used to detect/neglect smaller RSSI signal interference/patterns. These two last topics are not addressed in detail in this paper because are currently under study, with only preliminary results.

To support the system, an evaluation experiment exposed the different effects on the received signals of the domestic animals presence. The domestic animals proved to have a reduced influence in the system performance, except when the emitter and receivers are very close to the animal (less than 0.75 meters).

The results proved the feasibility and performance of this interesting low-cost solution, achieving in a total of 500 experiments, a 95% human detection in a domestic scenario ratio comparable to other RSSI based systems [5][8]. In [5][8], the authors claim to achieve 100% human detection ratio in similar conditions, i.e., line of sight.

Under study are methods to distinguish different targets more efficiently, the adaptation of the system to perform a real-time detection, the introduction of additional antennas to improve the system coverage area and the use of dual frequency mode available in the 802.11 standard. In terms of propagation, the influence of linear and circular polarized antennas in the system performance are also under analysis.

In the experimental set up it is also under study the influence of the presence of obstacles, the intruder detection outside the line of sight and to conclude, test our system in a real environment to further prove our concept and to isolate the improvements needed.

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