UWB network recognition based on impulsiveness of energy profiles

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***Abstract*—Two important functionalities in cognitive networking are network detection and recognition. Previous investigations showed that MAC sub-layer technology-specific features may offer a simple and direct way of performing such tasks; in particular they allow to by-pass complex physical layer feature extraction based on a simple energy detection scheme, capable of producing a time-varying profile reflecting the presence vs. absence of packets on the air interface. Beyond summarizing previous experimental evidence that confirmed the validity of the approach for technologies in the ISM band, the purpose of this work is to investigate the possibility of extending the network recognition concept to underlay networks such as Ultra Wide Band. Results show that short-term energy profiles may highlight the peculiar impulsive characteristic of IEEE 802.15.4a-like signals. Continuous vs. impulsive signals may be correctly classified based on a simple but important feature such as short-term energy statistics. Moreover short-term energy statistical features, as a function of increased window duration, seem to highlight a multi-static vs. continuous behavior for impulse vs. continuous-wave radio transmissions.**

Keywords—Cognitive networking; network discovery; automatic network classification; UWB underlay network; impulsive energy profile

I. INTRODUCTION

In the context of cognitive radio and cognitive networking, the automatic network recognition and classification assume a very important role. In fact the first step a cognitive radio must be able to do, is to recognize the environment, i.e. to discover if there is any wireless network in the environment in which it is set. Without this primary and important step, it is impossible to have a device that is able to adapt itself to the environment.

The project in which this work is involved, called "AIR-AWARE Project", has a goal: to reach automatic network classification through MAC sub-layer network-specific features. The choice to use this kind of features is due to the need to obtain a simple device, which can recognize the wireless technologies eventually present in the environment through simple steps and simple behaviors.

This work aims to describe this project, to report the results obtained since now [1, 2] and to extend the set of recognizable wireless technologies introducing an underlay network; the choice was to use an Ultra Wide Band (UWB) underlay network. The characteristics of this kind of network are analyzed, and the energy profile of this impulsive signal technology is compared to the energy profile of a traditional continuous signal telecommunications system. This work has the goal to report the situation of this "work-in-progress".

The paper is organized as follows. In Section II it is explained the AIR-AWARE Project, and the results obtained in previous works [1, 2] are reported, in order to better describe the current situation of the project. Section III introduces the characteristics of a UWB network, considered in this work as an example of underlay network. An analysis of its energy profile, compared to traditional technologies energy profiles, and how this affects recognition and classification is taken into account in Section IV. Section V contains the conclusions and indicates the future directions of the investigation and work in the AIR-AWARE Project.

II. AIR-AWARE AND THE CURRENT SITUATION

The goal of the AIR-AWARE Project is to obtain wireless network recognition and automatic technology classification in a simple way. This means that all can be done with a very simple device, for example an energy detector, and with a low computational load. Therefore MAC sub-layer features were selected, that can emphasize the MAC behavior of each considered technology. In fact, based on the study of the Standards that define the different technologies MAC behaviors, some features were chosen; through these features it was possible to identify the wireless technologies present over the air and to proceed with automatic classification. The project focuses on the ISM 2.4 *GHz* unlicensed band, exploited by a lot of widespread wireless technologies.

The AIR-AWARE module analyzes the presence vs. absence of energy, and from this reconstructs a packet sequence diagram; then the chosen features can be extracted and it can proceed with the classification.

A. Wi-Fi vs. Bluetooth automatic classification

In [1] the Wi-Fi technology (IEEE 802.11) was taken into account. Two features were identified and proposed: a) the Short Inter-Frame Space (SIFS), which is set to 10 μs for the Wi-Fi by the Standard; b) the duration of the longest packet

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between two consecutive SIFS. Real Wi-Fi traffic was captured in different situations, in order to have an exhaustive data set, using a Sniffer Station and a specific-developed software. A Bluetooth data-ACK packet sequence was then simulated. These packet sequences were used as training set for four linear classifiers: Pocket, Perceptron, Least Mean Squares Method (LMS), and Sum of Errors Squares Estimation (SOE). After that, the classifiers were tested using other known packet sequences and mixed traffic, i.e. where both Wi-Fi and Bluetooth packets were present.

TABLE I. WI-FI VS. MULTI-SLOT BLUETOOTH, CLASSIFICATION RESULTS (FROM [1])

Classifier	Input Network	Classification into Wi-Fi	Classification into multi-slot Bluetooth
Pocket	Bluetooth	0% [0/462]	100% [462/462]
Pocket	Wi-Fi	98.86% [348/352]	1.14% [4/352]
Perceptron	Bluetooth	0.43% [2/462]	99.57% [460/462]
Perceptron	Wi-Fi	98.86% [348/352]	1.14% [4/352]
LMS	Bluetooth	34.85% [161/462]	65.15% [301/462]
LMS	Wi-Fi	99.43% [350/352]	0.57% [2/352]
SOE	Bluetooth	29.87% [138/462]	70.13% [324/462]
SOE	Wi-Fi	99.72% [351/352]	0.28% [1/352]

TABLE II. MULTI-NETWORK ENVIRONMENT, CLASSIFICATION RESULTS (FROM [1])

Classifier	Input Network	Classification into Wi-Fi	Classification into multi-slot Bluetooth
Pocket	Bluetooth predominant	17.10% [133/778]	82.90% [645/778]
Pocket	Wi-Fi predominant	86.07% [315/366]	13.93% [51/366]
Pocket	Balanced	41.34% [210/508]	58.66% [298/508]
Perceptron	Bluetooth predominant	17.22% [134/778]	82.78% [644/778]
Perceptron	Wi-Fi predominant	86.07% [315/366]	13.93% [51/366]
Perceptron	Balanced	41.53% [211/508]	58.47% [297/508]

As reported in Tables I and II, Pocket and Perceptron classifiers reached almost perfect classification rate with a single network as input, and obtained a good classification rate with mixed traffic. This shows the validity of the approach and of the chosen features.

B. Bluetooth characterization

In [2] the analysis and the tests considered the Bluetooth technology (IEEE 802.15.1). In that work the selected features were: a) the packet duration; b) the packet inter-arrival interval. A Software Defined Radio (SDR) called Universal Software Radio Peripheral (USRP, in particular the 2nd version) was used as energy detector, in order to calculate the short-term energy. From it a packet diagram can be derived, and the features can be extracted.

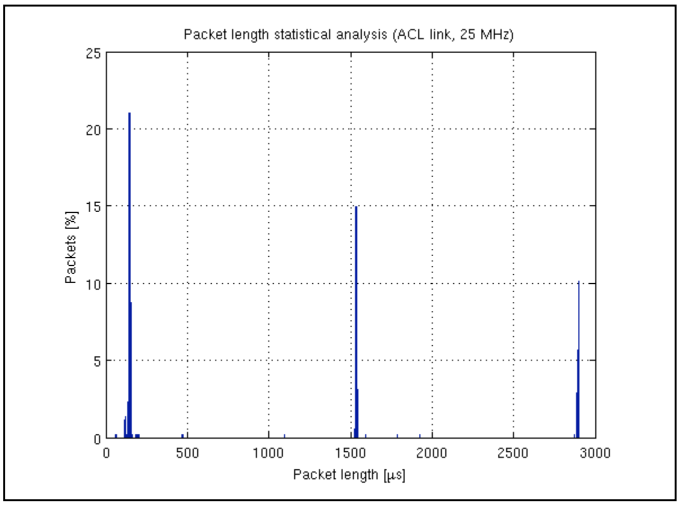

Figure 1. Bluetooth, distribution of packet duration (from [2])

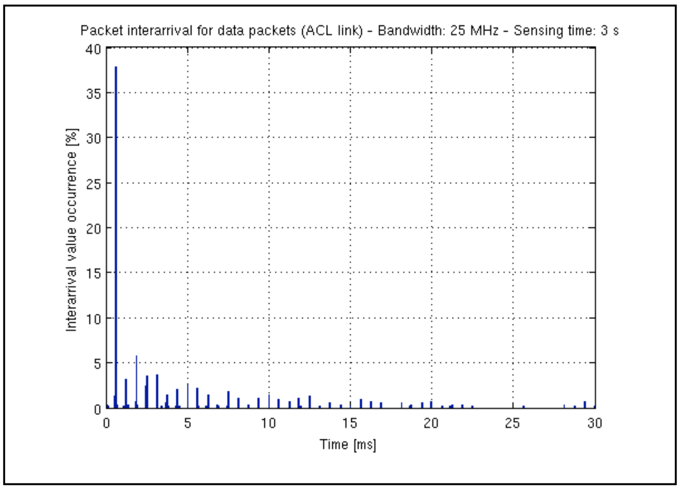

Figure 2. Bluetooth, distribution of packet inter-arrival interval (from [2])

In Figure 1 the distribution of packet duration (1st feature) is reported, while Figure 2 shows the distribution of packet inter-arrival interval (2nd feature). These two figures clearly show how the selected features permit to point out a MAC behavior specific of the Bluetooth technology, even in a visual way. In fact the values in both figures are extremely concentrated in peaks. This means that these features reflect a Bluetooth-specific behavior, which can be useful for recognition and classification.

III. ULTRA WIDE BAND AS UNDERLAY NETWORK

Since now the considered technologies operate in the ISM 2.4 *GHz* band. Even though the most widespread devices operate in this band, there can be other networks that exploit a wider range of frequencies, and that include the frequencies in the ISM band. The fact they share the same frequency range, even if it is only a part of the frequency spectrum used by this kind of technology, can have effects on the recognition and classification of Wi-Fi and Bluetooth. This is the case of Ultra Wide Band networks.

UWB communication systems obtained using impulse radio [3] are adopted in the Standard IEEE 802.15.4a. In the U.S. the Federal Communications Commission (FCC) defined two emission spectral masks, one for indoor and one for outdoor. Considering the frequency spectrum range that includes the ISM 2.4 *GHz* band, the limits on the Power Spectral Density (PSD) imposed by the masks are -51.3 *dBm/MHz* for indoor and -61.3 *dBm/MHz* for outdoor.

The important aspect of UWB, in this context of cognitive radio and network recognition, is the impulsive nature of this kind of signal. In fact, while the other traditional communications systems (as Wi-Fi and Bluetooth) use continuous signals, UWB uses very short pulses, in order to reach such a high bandwidth. The term "very short" means 700 *ps* to 1 *ns*. The different nature of these signals can be a useful feature, that can be exploited for the recognition of UWB networks.

IV. EXTENDING DETECTION AND RECOGNITION: ENERGY PROFILES

In this work, a first analysis on constant vs. impulsive energy profiles is carried out. The Bluetooth technology is taken as example of system that exploits a continuous waveform, since it uses a GFSK modulation. The UWB technology is, instead, taken into account for its impulsive signal.

In order to maintain the initial goal of the AIR-AWARE Project, i.e. to obtain network recognition through simple features, the short-term energy is calculated for the two signals, and these energy profiles are compared. Our expectations is to find a constant energy profile for Bluetooth, since it uses a continuous signal, while we expect a UWB energy profile with a lot of discontinuities, that reflects the impulsiveness of its signal, if the short-term energy windowing is sufficiently short.

Both Bluetooth and UWB signals are simulated using MATLAB. For Bluetooth signal generation the model included in Simulink was used; for UWB it was used a 2PPM-TH modulation technique [3], with the following parameters: number of pulses per bit $N_S = 1$, frame time $T_S = 3$ *ns*, chip time $T_C = 1$ *ns*, PPM time shift $\varepsilon = 0.5$ *ns*, pulse duration $T_M = 0.5$ *ns*, pulse shaping factor $\tau = 0.25$ *ns*.

Figures 3 and 4 show the Bluetooth short-term energy profiles, with different values of window duration. The wider the window length, the smaller the fluctuation of the short-term energy gets. In Figure 3 three window values are considered, and Figure 4 highlights that, as the window length increases, the short-term energy becomes flatter. This is due to the continuous nature of Bluetooth signal.

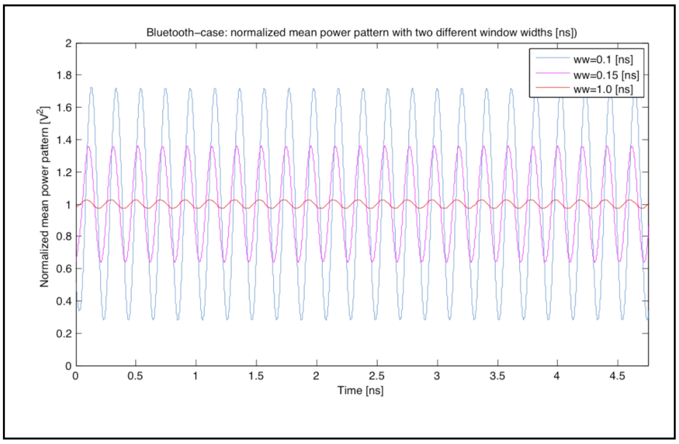

Figure 3. Bluetooth short-term energy with three window lengths

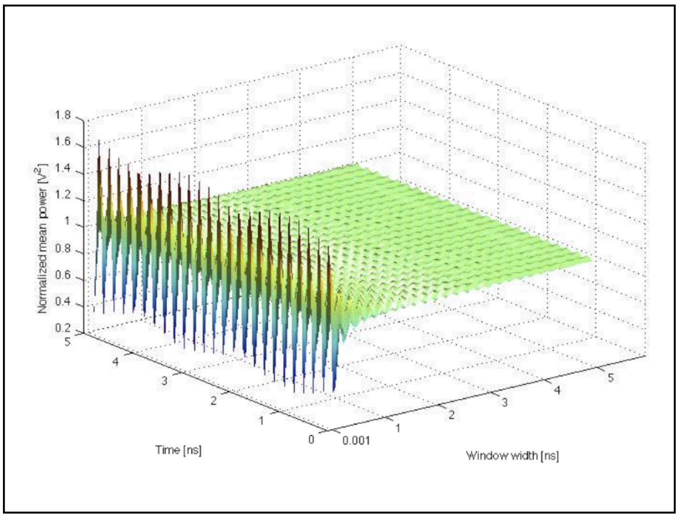

Figure 4. Bluetooth short-term energy, function of time and window length

Figures 5 and 6 show that the short-term energy profile of UWB signal is very different: with a short window length it has impulsive nature, shown by the presence of peaks; as the windows length increases, it does not assume a smoother behavior, but it presents even higher peaks. To be more precise, the short-term energy is extremely concentrated in very few discrete values, as shown in Figure 7. Cardinality of this set of values increases with window length.

These first results show that, with a proper window length, the short-term energy of a continuous waveform is approximately flat, while the one of an impulsive signal is multi-static and very discontinuous.

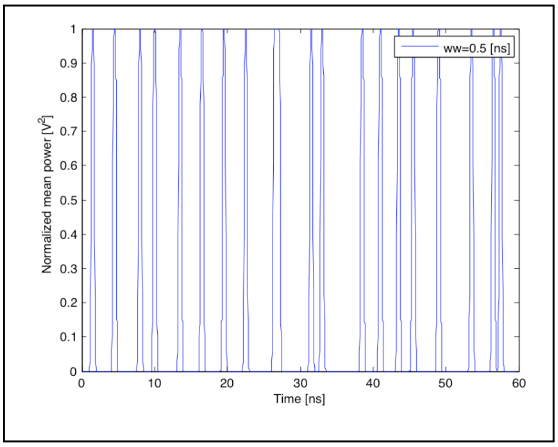

Figure 5. UWB short-term energy with a window length equal to one pulse duration

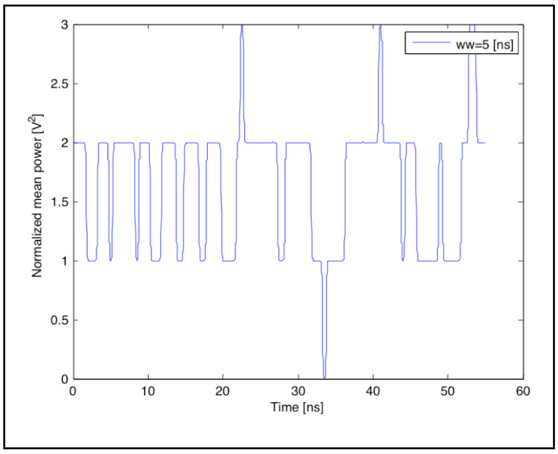

Figure 6. UWB short-term energy with a window length equal to ten pulse duration

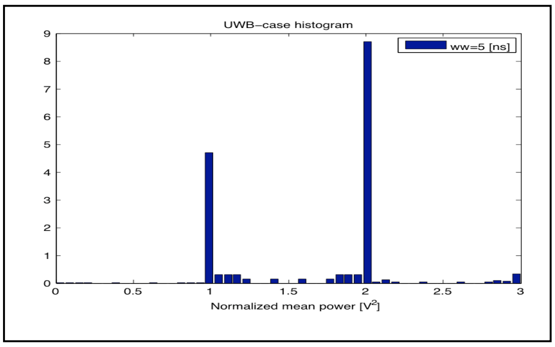

Figure 7. Histogram of UWB short-term energy, with a window length of 5 ns

As it can be seen, the two energy profiles appear very different, as expected. The Bluetooth one is constant, while the UWB one shows significant discontinuities, derived from the impulsive nature of the signal. This difference can be exploited for the UWB network detection, and this can be important because even in this case only simple operations, with very low complexity, are done. In other words, through simple features it is possible to reach network detection and recognition.

V. Conclusions and Future Work

In this work the AIR-AWARE Project was presented and the results obtained since now were showed. Wi-Fi vs. Bluetooth automatic recognition was reached through simple MAC sub-layer features, and Bluetooth technology-specific significant features were found. The analysis was then extended to UWB underlay networks. The impulsive nature of its signal, completely different from the continuous waveform of traditional telecommunications systems, was exploited with an analysis of the energy profiles. The first investigations show that through the continuous vs. discontinuous energy profile, the presence of a UWB network can be pointed out.

Further studies on this feature must be done. Different types of windows could be tested, and the other parameters could be changed, in order to find the optimal values, that can lead to detection. A classification test should be done, in an environment with multiple networks as well as the UWB network.

Acknowledgment

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