Wi-Green: Optimization of the Power Consumption of Wi-Fi Networks Sensitive to Traffic Patterns

Invited paper

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Abstract— **Enterprise Wi-Fi networks have been increasingly considering energy efficiency. In this paper, we present the Wi-Green project wherein we are investigating new techniques and innovative solutions that will allow the minimization of the energy consumption in Wi-Fi networks. In Wi-Green we will consider an enterprise network, in which there is equipment from different vendors, with different ages and different consumption profiles.**

Keywords—energy consumption; wireless network; access point; energy efficiency; wi-fi.

I. INTRODUCTION

The volume of traffic transported in mobile networks is growing exponentially majorly due to an increasing number of mobile services and applications running on top of it. In the next coming years, the number of network-connected devices and its corresponding traffic is anticipated to increase due to recent technological advancements such as the Internet of Things (IoT) and the Tactile Internet, making it impossible for current mobile networks to provide enough capacity to support the expected traffic growth. Due to these facts, it is necessary to adapt existing wireless technologies to cater for future traffic needs. Also, this increased volume of traffic will result in a higher energy bill, hence the need to find mechanisms to reduce the energy consumption.

The Wi-Green project is part of the SooGREEN European project under the CELTIC – Plus program (Eureka cluster for Telecommunications). The major objective of SooGREEN is to develop new solutions to increase the energy efficiency of mobile networks, including traffic offloading mechanism from cellular networks to Wi-Fi networks.

Wi-Green aims to develop new solutions enabling further reduction of the energy consumption in the mobile networks,

focusing on Wi-Fi networks in indoor environments. The main innovation of the Wi-Green project lies on the optimization of the energy consumption from the access point (AP) point of view. The Wi-Green approach includes the use and adoption of mechanisms for analyzing and detecting incoming and outgoing traffic from APs in order to enable a dynamic and traffic-aware configuration of the operation of Wi-Fi networks in the following setup: a) Basic Service Set (BSS) consisting of a single AP; b) Extended Service Set (ESS) consisting of more than one AP, without compromising its network performance.

This paper introduces the Wi-Green project, its activities and approach to develop solutions that will allow the reduction of the energy consumption of Wi-Fi networks.

The rest of this paper is organized as follows. In Section II, we state the problem. In Section III the Wi-Green project goals are detailed. Next, in Section IV we describe the use case that will be used as a basis for developing the solution. Section V shows in which components Wi-Green concept is based on and the innovative advances that we want to achieve. In Section VI we describe the current status of the project. Section VII concludes the paper and points out the next steps.

II. PROBLEM DESCRIPTION

The energy consumption of mobile devices is increasing exponentially due to the growing popularity of new applications that increase the wireless traffic – e.g. video streaming and social networking [1]. Approximately 3.2 billion people were using the Internet at the end of 2015 [2], which corresponds to a 5000% increase from the year 2000. On the other hand, the mobile broadband market had a significant growth, where it reached 47.2% of the telecommunications market share, a figure that has increased approximately twelve-

fold since 2007. Globally, the proportion of domestic customers with Internet access has increased from 18% in 2005 to 46% in 2015 [2]. A relevant aspect to be considered is that mobile devices are battery dependent and crucial to minimize the energy consumption of wireless networks; however, the technological development of batteries has not been in line with the energy requirements of the applications [3].

It is important to develop new techniques and innovative solutions that allow minimizing the energy consumption of wireless networks. There are several factors that influence the energy consumption, and it is necessary to understand the energy impact of each one.

Moreover, it is already evident that new mechanisms will be needed to implement on ad hoc network protocols in order to reduce energy consumption [4]. One of the drawn conclusions is that energy consumption and bandwidth utilization are not directly proportional, so it will be necessary to consider not only the cost of transmitting a packet but also the cost of receiving and discarding a packet. In this sense, it is necessary to consider the transmission ratios and the point-to-point traffic used by the protocol, since the cost of transmitting small payloads is high [4].

In Wi-Fi network, APs are continually consuming power due to beacon frames, which periodically need to be broadcast to announce its availability to potential clients. This mechanism is defined as mandatory in the IEEE 802.11 standard [5], meaning that the radio module is continuously transmitting signals when the AP is switched on. In certain locations, due to the lack of users (e.g., night time business areas, weekends), permanent switched on APs results in a waste of energy and consequently higher bill costs. If the APs were switched off or put in a different mode of operation, for example, in standby, this would result in a reduction of energy consumption.

In recent years the number of APs has grown substantially worldwide due to increased use of mobile devices. In Portugal from 2011 to 2014 the growth was 133.7% [6]. According to the study conducted in [7], the power consumption of a Wi-Fi AP varies according to the manufacturer of the device, as well as whether the Wi-Fi AP is single or dual-band. For example, the Cisco Aironet 1130AG model that does not support the IEEE 802.11n standard consumes 12.2 W, while the Cisco Aironet 1250 Series models, which supports the IEEE 802.11n [7] standard, consumes 18.5 W. In this way, the study and use of energy-saving techniques becomes relevant. Also, in [7] it was demonstrated that the use of an energy-saving algorithm could reduce the consumption of a Wi-Fi AP by 17%, though the mechanism defined was rather simplistic – the AP was switched off in the absence of users and the transmission power was adaptively changed when a user was detected.

Considering that the average consumption of a Wi-Fi AP is 10 Wh this leads to 87.60 kWh of consumption per year per AP. Knowing that the number of Wi-Fi APs in Portugal in the year 2014 was approximately 1,144,914 hotspots [6], assuming a 20% reduction in energy consumption per AP and a market share of 20%, for one year it would be possible to save energy costs of approximately 500,000 € – assuming that in Portugal the average kWh cost is 0.11 €.

III. PROJECT OBJECTIVES

The Wi-Green project aims at developing solutions that will allow for the reduction of the energy consumption of Wi-Fi indoor networks, focusing on energy efficiency in Wi-Fi APs. To achieve this goal, Wi-Green considers the following objectives:

● Study the mechanisms of analysis and detection of traffic currently used in cellular networks for the energy management, and adapt them to Wi-Fi networks;

● Develop a simulation platform based on the ns-3 open source simulator, which will allow the validation of different solutions for energy efficiency of Wi-Fi networks, in different communication and operation scenarios;

● Develop an energy management solution for Wi-Fi access points, in order to provide a dynamic adaptation to the traffic and the services supported by the network;

● Realize experimental testing in a controlled environment for comparison with the results obtained in simulation;

● Perform a proof of concept at Eurico Ferreira's facilities with commercial equipment, in order to evaluate in real-world environment the proposed solution and compare the results with those obtained in simulation and controlled environment.

IV. USE CASES

Our use case will focus on the development of mechanisms to optimize the usage of each AP in an indoor environment, aiming at reducing the energy consumption of a Wi-Fi network as a whole, without affecting the network performance, neither in terms of throughput nor coverage. The scenario considers an enterprise network, in which there are several APs of different vendors, ages, and energy consumption profiles. In the first phase, mechanisms will be developed to recognize and categorize the traffic in the Wi-Fi network's AP, based on a set of existing parameters such as distance to the AP, throughput, the received signal strength indicator (RSSI) and the modulation coding schemes. The goal of this phase is to collect and develop measures that allow the mechanisms to be implemented across new and existing Wi-Fi networks, independent of equipment vendors. This mechanism or Decision Maker will be smart with minimal response time (Intelligent Manager – IM), and will allow enabling and disabling of APs (via minimization of overlapping Wi-Fi cells) based on several criteria, including the individual APs' energy consumption, percentage of use, and coverage area. For that, the ON and OFF states, that currently exist in Wi-Fi will have to be extended, with the creation of intermediate states/modes of operation. This first phase is represented in Fig 1.
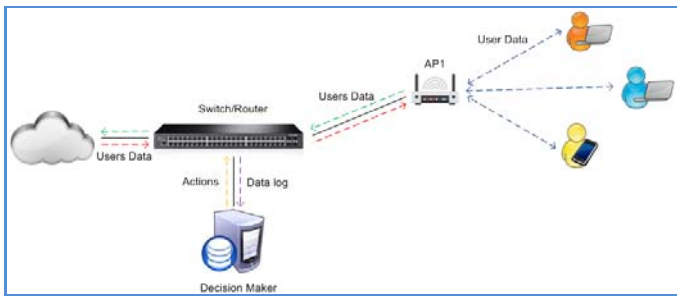
Fig 1 – Use case of the first phase.

In the second phase, a platform that associates a Wi-Fi network with a motion sensor is aimed to be developed to help the IM to keep APs in lower energy consumption state. This IM will have processing capability and memory to create a decision-making table where it aggregates all the analyzed parameters, based on the historic of use and decisions, as represented in Fig 2.
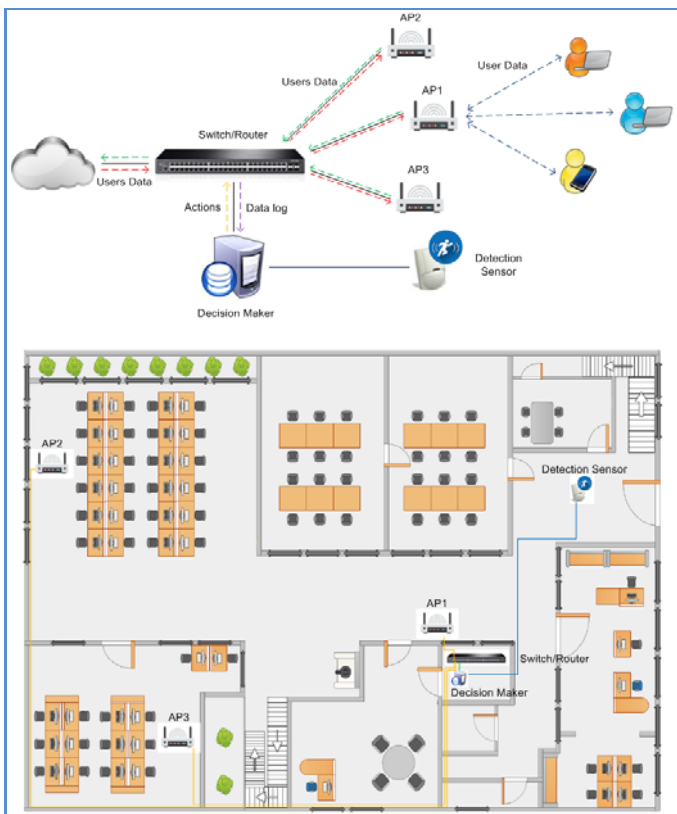

Fig 2 – Use case second phase

Finally, in order to optimize the energy consumption of the enterprise network, a network of sensors will be developed, which will allow the detection of new users in the network and add the related information to the IM. With this, the Wi-Fi network performance is expected to be even better. This phase is represented in Fig 3.
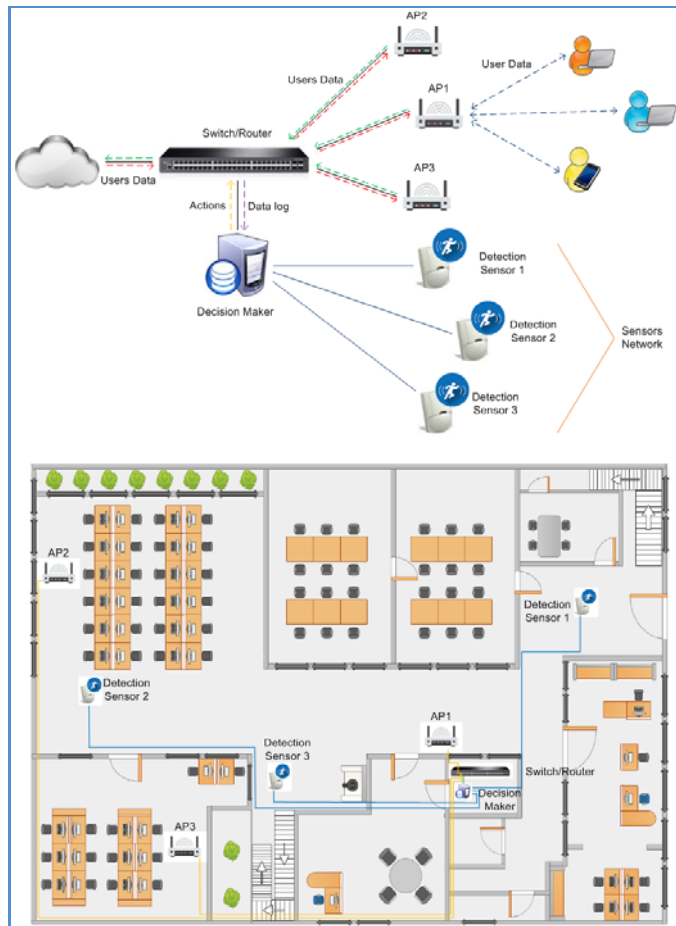

Fig 3 – Use case third phase

V. APPROACH AND INNOVATIVE ADVANCES

The Wi-Green concept is based on the following fundamental components:

● A new approach to increase the energy efficiency of a Wi-Fi AP based on the adaptation of techniques defined in literature for mobile networks considering the energy consumption model recently proposed in [9].

● Dynamic configuration of the operation mode of a Wi-Fi AP based on the user traffic, which provides the increase of energy efficiency without compromising performance, taking into account the dynamic adaptation of configuration parameters, including channel bandwidth, SISO vs MIMO, transmission power, bit rate, size of the packets, and dispatch of beacons.

● Energy consumption optimization mechanism that will use traffic forecast models and/or existing algorithms for detection and analysis of incoming and outgoing traffic from a Wi-Fi AP defining the operational mode for the AP (in addition to ON/OFF) and adjusting configuration parameters accordingly. This mechanism will be considered to optimize the energy consumption of a network consisting of an AP (BSS) and a network consisting of a set of APs (ESS).

● Intelligent manager for APs configuration that will include the proposed energy consumption mechanism as well as the needed interfaces to the software integration that is part of the Wi-Fi AP.

The solution to be developed is based on minimizing energy consumption of enterprise Wi-Fi networks. In this sense, the project aims to deepen the study of the state of the art when it comes to energy efficiency in these networks, making tests and simulations with the existing techniques, as well as with the different operational modes in which an AP can operate (example: sleep mode /standby). In this way, these techniques will be evaluated and adapted to the scenarios of interest, in order to reduce the energy consumption of the APs. As the first step, the work will focus on reducing the energy consumption of a BSS. In the following stage, based on the results of the first stage, the focus will be on reducing the energy consumption of an ESS.

To compare simulation and experimental results, prototypes will be developed to evaluate the different energy saving mechanisms in a controlled environment. Later, the prototypes will be installed as a pilot at Eurico Ferreira's facilities, in order to evaluate the industrial application of the developed solution in a real-world environment.

The Wi-Green project novelty lies on the definition of new operation modes for APs, including high/low load mode and standby/sleep mode, against the existing ON/OFF mode. Also, it proposes the use of IEEE 802.11k/v and the SDN/CAPWAP extensions, or equivalent technologies already supported by the Aps, to enable the optimization of the energy consumption of BSS and ESS, without degrading performance.

Finally, the approach of introducing a grid of sensors on a Wi-Fi network to help the IM decide the APs state is new in the Wi-Fi network industry and we believe it will a good approach for new and legacy networks.

VI. PROJECT STATUS

Wi-Green is still in its early stage. The project team is currently doing the preliminary studies and characterizing the power consumption of an AP. The power consumed by an AP (Linksys WRT54GL) has been obtained using two digital loggers (UNI-T UT71B) to measure the current and voltage in three operation modes – i.e idle, receive (RX) and transmit (TX). One of the loggers was used to measure the DC current, while the other measured the DC voltage. To analyze the measured values, the digital logger sends them to a computer that calculates the used power by the AP.
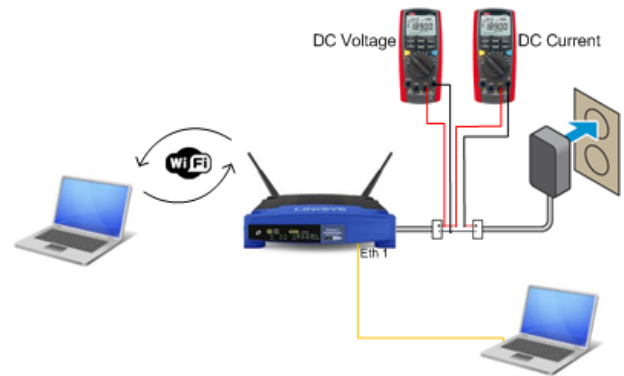

Fig 4 – Testbed

The characterization of the power consumption depends on the adopted standard (e.g., IEEE 802.11 a/b/g/n/ac) and the modulation coding scheme. For more flexibility to change the AP parameters, the firmware was changed to OpenWRT.

Next, we will characterize the power consumption of the AP, based on the energy consumption model defined in [9], taking into account some adjustments that may be needed.

VII. CONCLUSION

As wireless traffic continues to grow and dominate the Wi-Fi networks, mechanisms are needed to minimize the energy consumption of a Wi-Fi network. The management of Wi-Fi APs from the energy efficiency point of view is possible with commercial equipment using IMs. It allows the reduction of the energy consumption of the equipment and improves the energy efficiency of the networks. However, the configuration is typically manual, static, and specific to each manufacturer. For this reason, an intelligent configuration mechanism that is less dependent on each manufacturer is vital in order to have a more efficient Wi-Fi network, while having higher flexibility in optimizing the energy consumption of any Wi-Fi network.

VIII. ACKNOWLEDGMENT

REFERENCES

[1] Xiao, Yu. et al. "Modeling energy consumption of data transmission over wi-fi."Mobile Computing, IEEE Transactions on 13.8 (2014): 1760-1773.

[2] Sanou, Brahima. "The World in 2015: ICT facts and figures." International Telecommunications Union (2015).

[3] Feeney, Laura Marie, and Martin Nilsson. "Investigating the energy consumption of a wireless network interface in an ad hoc networking environment." INFOCOM 2001. Twentieth Annual Joint Conference of the IEEE Computer and Communications Societies. Proceedings. IEEE. Vol. 3. IEEE, 2001.

[4] H. Singh, S. Saxena, and S. Singh. "Energy consumption of tcp in ad hoc networks," Wirel. Netw., vol. 10, pp. 531–542, Sep. 2004.

[5] IEEE 802.11-2007 IEEE standard for information technology - telecommunications and information exchange between systems - local and metropolitan area networks - specific requirement. Part 11: wireless LAN medium access control (MAC) and Physical layer (PHY) specifications.

[6] Instituto Nacional de Estatística (INE), Hotspots - wi-fi (N.º); Anual, 20 de julho de 2015.

[7] Chiaravalloti, S., Filip Idzikowski, and L. Budzisz. "Power consumption of WLAN network elements." Tech. Univ. Berlin, Tech. Rep. TKN-11-002 (2011).

[8] Xiao, Yang. "IEEE 802.11 n: enhancements for higher throughput in wireless LANs." Wireless Communications, IEEE 12.6 (2005): 82-91.

[9] Pablo Serrano, Andres Garcia-Saavedra, Giuseppe Bianchi, Albert Banchs, Arturo Azcorra. Per-Frame Energy Consumption in 802.11 Devices and Its Implication on Modeling and Design, IEEE/ACM Transactions on Networking, vol. 23, no. 4 (2015): 1243-1256.