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High density emulation platform for Wi-Fi performance testing

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ABSTRACT

The IEEE 802.11 standard has become the basis of one of the most successful wireless communication technologies of all time. Originally created to provide wireless connectivity for a few devices, a couple of decades later it may support thousands of users in a single wireless LAN. This fact has made 802.11 a relevant research topic, and as it happens with other wireless technologies, many of the work carried out is based on simulations. In particular, studies for scenarios with high user density are usually performed this way, in many cases leading to conclusions which do not apply to real world situations. This mismatch can be due to multiple factors, such as the specific protocol implementations or the hardware and drivers used. In this article we present a novel 802.11-based testing platform, which aims to bridge the gap between simulations and the real world, in order to carry out research work for typical high density scenarios. The platform is compatible with standard 802.11-based wireless cards on the market and it was tested with two different radios, The validation metrics considered were the TCP throughput, the airtime utilization and the effective data rate, with relative errors ranging from 0 up to 15%. The potential of the tool is illustrated with real world measurements from two example use cases in education facilities: a school classroom and a conference room. The results indicate this might be the first step towards an open platform to enable active Wi-Fi performance testing for large scale scenarios. Further emulation capabilities are shown with different application tests already integrated to the platform, such as QoE tests for YouTube video playback or e-learning platforms.

1. Introduction

In the past decade, the great success of the IEEE 802.11 standard, popularly known as Wi-Fi, has been one of the key factors that has driven the massive deployment of wireless Internet access worldwide. This technology, originally created to provide a wireless solution for small-size LAN environments, now supports thousands of clients in a single WLAN (e.g. large conferences or stadiums [1]), becoming one of the most successful wireless communication technologies of all time [2]. This evolution was obviously supported by much research on the subject, which has also made 802.11-based systems one of the most relevant research topics in wireless networks.

One of the major challenges for the 802.11 evolution is the exponential increase in the number of devices and traffic that it will have to support in the near future. As it was the case in the past, with the explosion of smartphones and tablets in the mass consumer market, the novel Internet of Things (IoT) forecasts a new wave of significant growth in the number of connected devices [3]. Every day new products arise, either wearables or home sensors, and many of them are choosing Wi-Fi as their preferred wireless connectivity technology [4]. This is a tough technical challenge for 802.11-based networks, and many research efforts would be necessary to find efficient solutions to support the larger amount of devices and higher densities expected.

In this research area, as it happens with other wireless technologies, much of the work carried out is based on simulations. In particular, studies for large scale scenarios and high device density are usually performed this way, majorly due to the greater simplicity and scalability against the difficulty of mounting suitable real world testbeds. In many cases this option is suitable, choosing carefully the proper simulator for the particular purpose [5–8]. However, there are also many situations where the results obtained do not match with the performance seen in practice, with real world implementations [9]. This mismatch can be explained by multiple factors such as inaccurate radio channel modeling due to wrong assumptions [10], improper parameters settings for the protocols implementation, or specific hardware and drivers issues which are not considered in typical simulators [11].

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Concerning high-density in 802.11-based networks, it is clear that simulation provides a simpler option because of the large amount of nodes necessary to implement a typical WLAN network. Hence the research carried out on real hardware is usually performed with few devices, but it is very uncommon for large scale scenarios due to the inconveniences involved in managing a large number of devices. We strongly believe that this typical research practice may lead in some cases to quite different results from what happens in real world environments. To illustrate the problem an example is given below.

One of the most studied topics in 802.11 is the performance of the MAC layer, which is based on the CSMA/CA medium access algorithm. In this area, one of the typical questions posed is to find out the protocol scalability as the client count increases [12]. It is well known that when traffic is UDP and there is no RTS/CTS, the transport layer capacity is equivalent to the one at the MAC layer (neglecting the headings overhead), with a continuous drop as the number of client rises. The situation is quite different for TCP traffic, as we have two dynamics which run simultaneously: the CSMA/CA algorithm at the MAC layer and the TCP congestion control at the transport layer. This interaction has a positive effect for high density scenarios, as the TCP congestion control avoids the large number of stations to contend simultaneously, which provides a nice scalability property [13]. This effect seems to be ideal looking at several simulation based research papers [14–16], where the aggregated capacity hardly changes as the client count increases.

However, the real world results show something different. In spite of the good scalability, there is still a non-negligible capacity loss as the number of stations rises [17,18]. In this empirical observations coming from the Wi-Fi industry, the explanation for the drop in the aggregate capacity seems to be the rise of control packets when the number of devices increases. Those control packets are related to energy saving issues and it remains unclear if the effect has to do with the particular devices involved in the tests, or if it is something which is possible to generalize for any other Wi-Fi devices. This gap between simulations (and the analytical models derived from them) against what reality shows, has a more significant impact with the evolution of the IEEE 802.11 standard, due to the higher data rates available and the larger densities supported by today WLANs. An error in the capacity estimation of the WLAN cells may lead to wrong sizing decisions and underperforming networks.

The previous is just an example of the possible wrong conclusions induced by working with simulators. Other real world issues such as capture effect or the carrier sense algorithm implementation, typically omitted by simulators or analytical models, are also found in the literature [19]. This problem becomes evident looking at the Wi-Fi industry, where large-scale testing is required to verify the networks operation [20], because it is not possible to trust in any simulation to guarantee that things will work in the same way in practice. This kind of stress tests serve to analyze the network performance in a high-density high-load situation, in order to determine how many clients and which applications the network would be able to support. It is a suitable way to address extensive real world testing, except for one point: managing hundreds of devices each time you perform a test. This fact implies several inconvenient aspects: the logistics to transport the devices and other additional equipment (e.g. spectrum analyzer), tens of technicians and several hours of field work.

In this work we present a novel platform for effective and reproducible performance analysis of 802.11-based systems, which enables to easily generate a high number of clients in the network. We believe that the proposed solution is a contribution in order to bridge the gap between simulations and the real world, in order to carry out research work for typical high density scenarios. The low-cost portable solution presented offers a flexible setup that can emulate dynamic topologies which classical testbeds cannot due to their fixed design. The platform proposed could be useful not only as a research tool, but also as a performance testing solution for real world Wi-Fi infrastructure. The tool enables to conduct stress tests in a much easier way and also helps to reduce costs and simplify the work of the technicians involved. Moreover, the flexibility to integrate test automation for different applications just developing the proper new software module, allows to adapt the tool for other specific requirements.

The platform performance, considered as the ability to emulate the real devices behavior, was evaluated in a laboratory environment with two different models of 802.11 radio cards. The validation was carried out considering transport layer metrics such as the TCP throughput, and lower layers metrics such as the airtime usage and the effective data rate. The results show an accurately emulation of the real devices, with relative errors between 0 up to 15%, which indicate this might be the first step towards an open platform to enable active Wi-Fi performance testing for large scale scenarios. The potential of the tool is illustrated with real world field measurements from two example use cases in the educational context: a school classroom and a conference room. In the field of Wi-Fi networks deployment, the last years have shown a switch between coverage-based design into a capacity-based approach, particularly focused on the quality of experience (QoE) [21–23] of users. The tool not only proved to be a useful solution to perform high density Wi-Fi tests, but also enables future customization for different purposes because of the system modular design. An example of this possibility is shown below, with the integration of an open-source software to estimate QoE for playback of YouTube videos [24].

The rest of this article is structured as follows. In the next section we present other works related to testbed development and a short review of 802.11 emulation solutions. In Section 3 the problem addressed is presented, defining the main requirements for the platform development. Next, Section 4 illustrates the design and development of the solution proposed, with one subsection dedicated to the platform hardware and the other to the software architecture and its main modules. In Section 5 we present the procedure and test results carried out to validate the accurate performance of the platform. Two example use cases are presented in Section 6 which illustrate the potential of the tool. Finally, Section 7 concludes the article and presents several new research lines.

2. Related work

Several approaches are typically used to carry out research in wireless networks, ranging from analytical models and simulation, to testbed developments, emulation and real world field tests. For example, a lot of academic research in 802.11-based networks is based on the popular open source simulator ns-3,[1] with a large community involved and available implementations for almost any relevant wireless standard. There is a clear advantage of using simulation, which is the possibility to generate hundreds of nodes in a network with only several lines of code and execute tests in a short period of time. However, simulators are typically developed for specific purposes with many assumptions and simplifications of real world scenarios [25]. Depending on the particular research purposes, simulation may become an unsuitable option because of its limitations [26,27], or in other cases still very difficult to develop the proper simulator [28,29].

[1] ns-3: https://www.nsnam.org/.