Performance Evaluation of Customer Premises Equipment (CPE) in FTTH Networks

Alex Vidigal Bastos, Natã Goulart da Silva, Rone Ilidio da Silva,
Sérgio de Oliveira, Fernando A. Teixeira

***Abstract*— Fiber To The Home (FTTH) networks are becoming the common technology to connect clients to Internet Service Providers. Optical fiber arrives at clients' homes and provides connections with Gbps speed. This paper presents a Customer Premises Equipment (CPE) analysis in FTTH networks. Our experiments are based on Sensitive Analysis, which provides methodologies to evaluate parameter importance on device performance. The results show characteristics that influence the FTTH network's final performance and must be considered to provide better services.**

***Keywords*— FTTH networks, Customer Premises Equipment, Internet Services Provider.**

I. Introduction

The reduction in implementation costs allowed the growth of fiber optic networks that directly connect Internet Services Providers (ISP) to their customers' homes. These networks are called Fiber To The Home (FTTH) and allow speeds up to gigabits per second. FTTH networks meet the growing demand for quality of service in various applications such as games, videos, and other entertainment systems. However, the data transmission speed offered to the user is dependent on the Customer Premises Equipment (CPE) provided by ISP. We consider CPE devices that are installed in homes and perform the switching of networks FTTH to wired (Ethernet) or wireless (Wi-Fi) networks, with emphasis on the latter. With FTTH networks popularization, CPEs become a critical point for a high-speed Internet. Choosing CPE model that meets customers' and ISPs' needs is essential.

Some studies, *e.g.* [1], [2], describe methodologies for evaluating CPEs performance in scenarios similar to those found in networks FTTH, that is, in ISP clients' houses. Such scenarios present physical obstructions that hinder the propagation of the signal Wi-Fi, installations on multiple floors, and interference from other transmissions in the same frequency range. Kofler *et. al* [1] analyzed the performance of three Wi-Fi routers for multimedia services. However, they did not consider the interference of other transmissions and analyzed only one metric: useful data transmitted rate (goodput). Sui *et. al* [2] analyzed Wi-Fi scenarios with a high density of access points. However, these proposes do not consider whole communication between the ISP consumer and core network.

Alex Vidigal Bastos, e-mail: alexvbh@ufsj.edu.br; Natã Goulart da Silva, e-mail: ngoularts@ufsj.edu.br; Rone Ilidio da Silva, e-mail: rone@ufsj.edu.br; Sérgio de Oliveira, e-mail: sergiool@ufsj.edu.br; Fernando A. Teixeira, e-mail: teixeira@ufsj.edu.br; Departamento de Tecnologia em Engenharia Civil Computação e Humanidades, Universidade Federal de São João del-Rei, Ouro Branco - MG.

This article describes the result of the performance analysis of 21 CPEs from different models and manufacturers. The topology used in this analysis is based on an FTTH network infrastructure, from the provider to the customer's home. The proposed scenarios reflect conventional situations encountered by end-users. We evaluated throughput, latency, signal strength, and signal-to-noise ratio for Wi-Fi networks (IEEE 802.11.ac), at 2.4 and 5.8 GHz frequencies.

The main contributions of this work are:

- proposal of Wi-Fi test scenarios that allow exploring the limits of CPEs;
- proposal for the network topology necessary to carry out the tests, including equipment that reflects the traffic from the content server to the final client through FTTH and Wi-Fi networks;
- experimental evaluation results of 21different CPE of nine distinct manufacturers.

This paper is organized as follows: Section II presents an overview of the technologies used in this work. Information about the infrastructure of the test laboratory is presented in Section III. Section IV presents the experiments and results. The V Section presents some related works. In section VI we present the final considerations and conclusions.

II. Overview of FTTH and 802.11ac networks

The increased offer of bandwidth to customers found in the technology FTTH one of the best cost-benefit ratios [3]. The concept of FTTH is based on passive optical network technologies, or Passive Optical Networks (PON), which enable a network up to 20 km away, without active repeaters. PON technologies allow a single fiber to serve up to 128 customers, with transfer rates up to 40 Gbps.

The PON architecture has an optical concentrator known as Optical Line Terminal (OLT), located next to the provider backbone, and multiple CPEs, located in the customers' homes. The OLT connects to CPEs through optical fibers, in a tree topology. The fibers are divided through passive elements called Optical splitter, in Time Division Multiplexer (TDM) system [4]. CPEs currently used by ISPs include routing and wireless access point functionality, incorporating the functions of distributing network access to customer equipment. Gigabit Ethernet network interfaces (IEEE 802.3z) and protocols of the IEEE 802.11 family for Wi-Fi access are present in CPEs considered in this work.

For the customer to take full advantage of the bandwidth provided by FTTH networks, their equipment must have a network interface capable of connecting to CPE at a speed compatible with the contracted speed. Most current residential devices access the Wi-Fi network, which becomes the main interface for access. However, unlike wired interfaces, the IEEE 802.11 standard shares the medium among users by dividing bandwidth between connected devices and is also sensitive to factors such as interference, obstacles, and signal strength. Currently, the IEEE 802.11ac standard presents itself as an alternative to the growing demand for Internet access speed with plans up to gigabits per second.

The IEEE 802.11ac standard supports several configurations: in frequency, 2.4 GHz and 5.8 GHz; in channel width, from 20 to 160 MHz; in modulation, up to 256 QAM, with 8 bits per carrier; and the number of spatial flows MIMO, up to 8, in the MIMO 8x8 configuration. Theoretically, at the maximum of each configuration, the transfer rate could reach 4900 Mbps [5]. However, the equipment available at a cost compatible with commercial plans, only offers transfer rates in the range of 750 to 1733 Mbps, adding the flows in frequencies 2.4 and 5.8 GHz.

In this article, we present results of experiments carried out with 21 CPEs that demonstrate that, in practice, it is difficult to reach all this theoretical potential with a good part of the current CPEs.

III. Infrastructure for Experiments

To carry out the experiments, the basic infrastructure of an FTTH network was created in the laboratory. The topology reflects the network structure from the content server, through the Internet access provider, to the customer's home (Figure 1). The test scenarios reflect common conditions found in urban regions, with interference and obstructions. The test environment was implanted in one of the blocks of the Campus Alto Paraopeba (CAP) of Federal University of São João del-Rei (UFSJ), formed by two floors and constituted mainly by teachers' offices. Figure 2 shows the floor plan of one of the blocks in the block, scenario of the tests, with the respective divisions of the rooms. Data collections took place on the block's two floors. The points at which the signal strength measurements and Signal-Noise Ratio (SNR) took place are identified by the letters A to J. The test environment was set up on the second floor, in the room that contains the E and F points. In all tests, CPE remained located at E, on the second floor of the block.

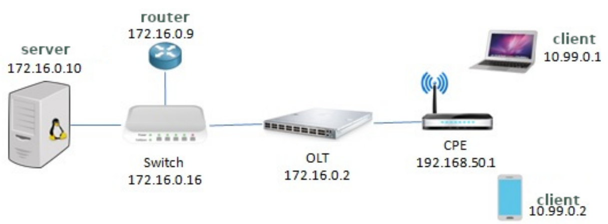

Fig. 1. Network topology used in the experiments.

To carry out the experiments, user devices, and infrastructure equipment that form the FTTH network were used.

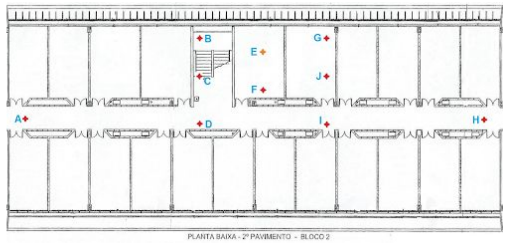

Fig. 2. Floor Plan of Block 2 of the Alto Paraopeba Campus of the Federal University of São João del-Rei (UFSJ) - Ouro Branco - MG.

As user devices, a MacPro notebook with a macOS Mojave operating system and four smartphones with Android and iOS operating systems were used. The network infrastructure equipment was a Gigabit switch, an OLT, a router that performs the authentications and a test server with a Linux operating system on which the Iperf server [6] was run iperf.Figure 1 shows a schematic with all the equipment and the network topology that configure the test environment.

The 21 CPEs evaluated are from different manufacturers, namely: Huawei, FiberHome, Sagemcom, TP-Link, DLink, Chima, Technicolor, Nokia, and Cig-Technology. The equipment will have their brands and models anonymized for *CPE 1* to *CPE 21*. Two of the evaluated equipment had support for Mesh networks (CPE 12 and CPE 15).

A. Testing Scenarios

For the experiments with Wi-Fi, 24 scenarios were evaluated where the frequency was varied (2.4 GHz or 5.8 GHz), the customer's floor (same floor as the CPE or not), the distance between the client and CPE, whether or not the hotspot service via CPE was activated and how many users used the client network or the hotspot service network. Table I presents the characteristics of each of these test scenarios' Wi-Fi. Scenarios 1 to 12 used frequency 2.4 GHz and scenarios 13 to 24 frequency 5.8 GHz. In scenarios 1 to 6 and 13 to 18, in addition to the usual network, an additional network, hotspot, was configured for public access. In the table, we have the scenario number shown in the first column, the floor on which the client device was located, in the second column. In the third column, we have the distance between the client and CPE. In the fourth column we have the information if the hotspot network was used and in the fifth column the number of users who shared the network. From the sixth to the tenth column, we have the same distribution for scenarios 13 to 24.

B. Procedures Used in the Experiments

In the experiments, the programs iperf, wget, and ping were used. The iperf [6] was configured to generate traffic with the UDP protocol because it sought to record the maximum flow regardless of the additional costs that could be derived from the TCP protocol. To obtain an additional result, tests were performed using an HTTP server (Apache / Linux) and the program wget which is an HTTP client. Thus, results were obtained considering all network layers and eventual losses caused by the operating system related to HTTP access.

TABLE I

SCENARIOS USED IN WI-FI NETWORK EXPERIMENTS.

#	nº floor	dist. (m)	hotspot	nº users	#	nº floor	dist. (m)	hotspot	nº users
1	2	0	YES	1	*13*	2	0	YES	1
2	2	12	YES	1	*14*	2	8	YES	1
3	1	0	YES	1	*15*	1	0	YES	1
4	2	0	YES	5	*16*	2	0	YES	5
5	2	12	YES	5	*17*	2	8	YES	5
6	1	0	YES	5	*18*	1	0	YES	5
7	2	0	NO	1	*19*	2	0	NO	1
8	2	12	NO	1	*20*	2	8	NO	1
9	1	0	NO	1	*21*	1	0	NO	1
10	2	0	NO	5	*22*	2	0	NO	5
11	2	12	NO	5	*23*	2	8	NO	5
12	1	0	NO	5	*24*	1	0	NO	5

Concerning latency, the command ping was used, whose output was processed, statistically analyzed, and summarized.

To check the Wi-Fi coverage capacity of the CPEs, signal level collections were performed using the Netspot [1] program at 10 distributed points on each floor of block 2, on the UFSJ campus. The positions of these points, A to J, are defined in the map of Figure 2.

IV. EXPERIMENTS AND RESULTS

We present the results obtained according to the following aspects: (i) evaluation of the network coverage through signal strength and SNR; (ii) flow measurement; (iii) latency values and (iv) impact of a second network (hotspot) on CPE.

A. Clients Wi-Fi

For the analysis of the flow of the Wi-Fi network, tests were carried out in twelve scenarios for each frequency and the distance, the number of users using the network, and the provision or not of a hotspot service were varied. In Figures 3 to 6, the horizontal axis corresponds to the scenarios and the vertical axis, the network flow in Mbps. The flow rate obtained in each scenario at the 5.8 GHz frequency can be seen in Figure 3 (flow measured using the command iperf) and Figure 4 (flow measured using the command wget). For the 2.4 GHz frequency the results are shown in Figure 5 (flow measured using the command iperf) and Figure 6 (flow measured using the command wget). Information from CPEs that did not transmit data has been deleted. In Figures 7 and 8, the horizontal axis corresponds to the scenarios and the vertical axis, the latency in ms. Figure 7 shows the latency results for the 5.8 GHz frequency and in Figure 8 the results for the 2.4 GHz frequency.

In scenario 19, at zero meters from CPE with a user and frequency of 5.8 GHz, average flow rates of 669 Mbps were observed for the command wget, maximum values obtained. The CPEs 8 and 17 had a flow rate of approximately 500 Mbps and another five CPEs, a flow rate of around 400 Mbps. For scenario 20, 8 meters from CPE and with one user, CPE 2 had an average throughput of 475 Mbps. Another three CPEs showed values slightly above 300 Mbps. Scenarios 21 and 24 were performed with customers on a different floor than CPE and only 5 CPEs were able to transmit data. Among them, the

[1]https://www.netspotapp.com/pt/

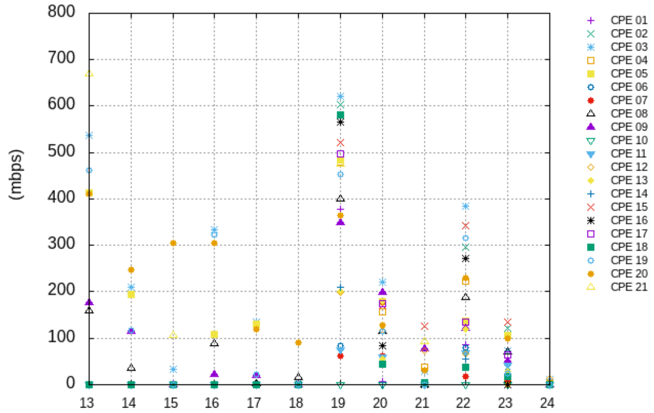

Fig. 3. Flow rate at 5.8 GHz - command iperf.

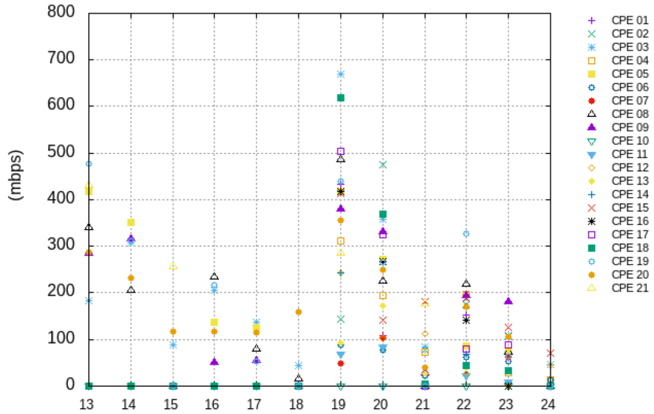

Fig. 4. Flow rate at 5.8 GHz - command wget.

two that support Mesh technology (15 and 12) and CPE 3. With 5 users connected to the network (scenarios 22 and 23) the CPEs 3 and 19 obtained throughput of about 300 Mbps with the customer at zero meters and of about 100 Mbps with the customer at eight meters.

For tests at 2.4 GHz frequency, the best flow results obtained are in the order of 100 Mbps with the client at zero meters from the CPE and only one client using the network (Figure 5). With 5 customers at zero meters from CPE, the maximum throughput was around 60 Mbps (scenario 5). For tests on the 5.8 GHz frequency, the results for tests at zero meters from CPE with one user-provided a maximum throughput of 650 Mbps and with 5 clients, 380 Mbps.

a) Clients on the private network and the hotspot simultaneously: Experiments with scenarios one to six (2.4 GHz) and thirteen to eighteen (5.8 GHz) evaluated the impact on the customer's network due to the availability of the hotspot service using the same CPE. The objectives of these experiments were to evaluate: (i) the impact of using the hotspot on the customer's network when both networks operate at 2.4 GHz (scenarios 1 to 6); and ii) impact of the use of the hotspot when the customer's private network operates at 5.8 GHz and the hotspot operates at 2.4 GHz. Of the 21 CPEs tested, six are capable of providing support for the hotspot service, namely: 3, 5, 8, 9 (*dual band*), 10 (operates only on 2.4GHz), and 19. On average, experiments have shown that

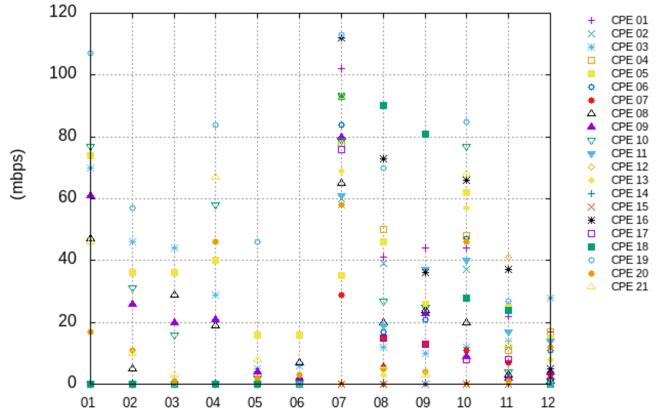

Fig. 5. Flow rate at 2.4 GHz - command iperf.

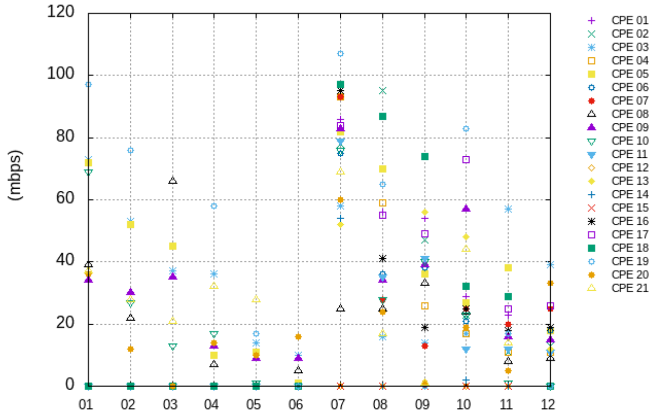

Fig. 6. Flow rate at 2.4 GHz - command wget.

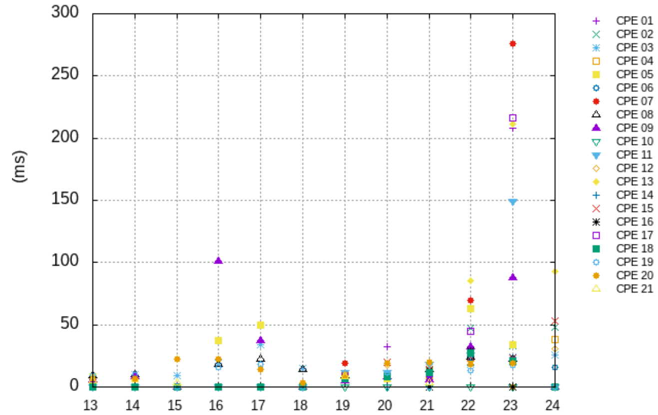

Fig. 7. Latency in the frequency of 5.8 GHz

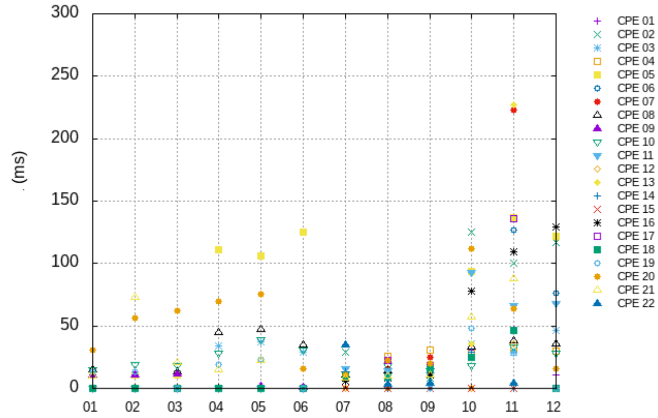

Fig. 8. Latency in the frequency of 2.4 GHz

providing the hotspot service via CPE has an impact on the customer's network for maximum throughput, but this impact is limited to 20 % in most scenarios.

Considering the experiments with the command iperf (Figure 3), the CPEs 8, 9, and 10 showed a greater loss of flow with the hotspot network, while for CPE 3, the drop in flow was smaller, from 621 Mbps to 536 Mbps.

b) CPEs Wi-Fi Signal Level: The graph in Figure 9 shows the average signal level for the 10 points and each CPE on the 1st and 2nd floor for the 5.8 GHz frequency measured with the Netspot tool. The red bars correspond to the average values obtained on the 1st floor and the blue bars on the 2nd floor. The devices that presented the best average signal level are the two with Mesh technology. The CPE 12 showed an average signal level of -47 dBm, while the CPE 15, -44 dBm. Signal levels greater than -50 dBm are considered excellent [7] and five CPEs showed an average signal level of the order of -50 dBm. However, the communication at 5.8 GHz frequency was not viable between the CPE on the 2nd floor and the client devices on the 1st floor.

The graph in Figure 10 shows signal level information for the 2.4 GHz frequency on the two floors. It appears that the signal levels for this frequency were, on average, better than those of the 5.8 GHz. Again, equipment with Mesh, CPEs 12 and 15 , presented the best results. The other equipment approached the signal level classified as acceptable, -70 dBm.

V. Related Works

The authors at [1] analyzed the performance of three routers Wi-Fi for home use (Linksys WRT54, TP-Link TLWR, and Ubiquity RSPRO), all based on Linux platforms. The focus of the experiments was to analyze the stack of applications implemented in the devices with the provision of multimedia services. Despite the wireless transmission capacity of the devices, only the wired interface was used and the only metric analyzed was the amount of useful data transmitted.

In [2], the performance of corporate Wi-Fi networks was evaluated with a focus on increasing the density of access points. The experiments were carried out in real settings, using students from Tsinghua University in China as users. It was found that the higher density of access points improves the performance of the network and that the use of Wi-Fi with higher transmission power reduces performance. However, the focus of the experiments was the density of access points.

The authors at [8] evaluated the transfer rate of three IEEE 802.11ac/n access points from different manufacturers (Buffalo, I-O Data, and NEC), both indoors and outdoors. In external experiments, they analyzed the variation of the transfer rate with the variation of the distance. In internal experiments, the density of access points and the existence of obstacles varied.

The authors at [9] analyzed the performance of networks

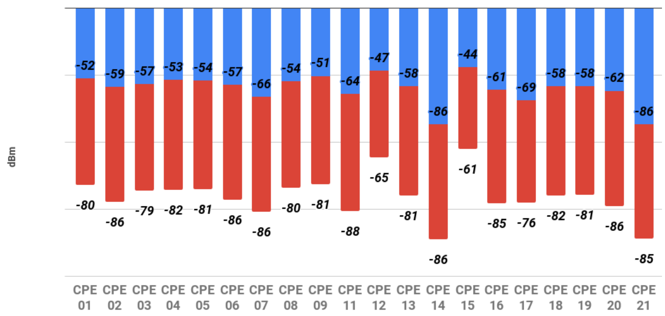

Fig. 9. Signal Level at 5.8 GHz, 1st (red bars) and 2nd floor (blue bars).

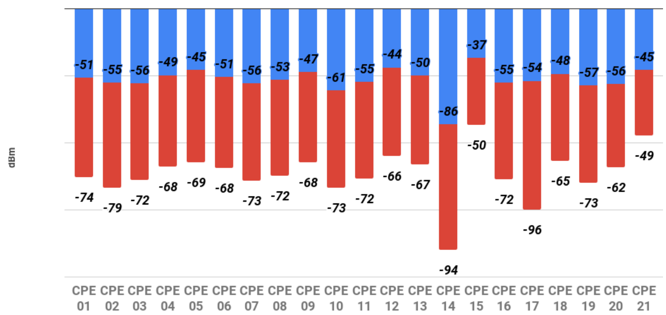

Fig. 10. Signal Level at 2.4 GHz, 1st (red bars) and 2nd floor (blue bars).

Wi-Fi using information collected on users' devices, using scripts accessed via the browser. In [10], the download speed was evaluated using the TCP protocol in scenarios with high user density. In [11] was analyzed the performance of networks Wi-Fi versus the positioning of users. All Wi-Fi access points in these jobs were from a fixed set of manufacturers.

In [12] was analyzed the performance of two Ethernet network cards and two different frameworks for packet processing (Netmap and PF Ring). The authors used sensory analysis of parameters that seeks to determine the effect of the variation of a given item on its total value.

In [13] tests were carried out to assess the benefits of using the standard with 802.11ac versus the 802.11n standard. The speed obtained with the client near the router was 700 Mbps (MIMO 3 x 3). It was not possible to carry out communication in scenarios in which there were two or more walls between the connection pairs. In [14], the authors evaluated the use of beamforming technology that directs the signal and energy of communication using an omnidirectional antenna to directions in which the greatest volume of traffic is occurring. The authors found that despite the gain obtained in download rates using beamforming, the use of multiple traditional 802.11n devices offered a better result and cost.

These works focused on specific aspects of the Wi-Fi protocols while our work prioritizes the customers' final experience with the network. Our experiments consider not only local Wi-Fi networks but also communications between servers and final clients trough OLT, CPE, routers, and splitters in an infrastructure similar to an ISP's FTTH network.

VI. Conclusions

This work presents results of performance analysis of 21 different CPEs models and manufacturers, used as cutting edge equipment in FTTH networks. Based on the experiments, we can point out that: i) CPEs 2, 3 and 5 obtained throughput greater than 500 Mbps; ii) impact of using the hotspot service on the customer's network was around 20% on average; iii) communication was not viable over 8 meters at 5.8 GHz frequency; iv) communication on the 2.4GHz frequency was possible between floors and at distances up to 20 m; and v) CPEs are the FTTH network bottleneck due to the limits of local processing and Wi-Fi Networks, therefore must be carefully chosen to guarantee ISPs' quality of service.

Acknowledgments

We would like to thank Daniel Dayrell, Carlos Vilhena, Thierry Braga, and João Queiroz for work on experiments. This study was financed in part by Vero Internet, CNPq, CAPES, FAPEMIG and DTECH/UFSJ.

References

[1] I. Kofler, R. Kuschnig, and H. Hellwagner. Evaluating the networking performance of linux-based home router platforms for multimedia services. In *2011 IEEE International Conference on Multimedia and Expo*, pages 1–6, July 2011.

[2] Kaixin Sui, Siqi Sun, Yousef Azzabi, Xiaoping Zhang, Youjian Zhao, Jilong Wang, Zimu Li, and Dan Pei. Understanding the impact of ap density on wifi performance through real-world deployment. In *2016 IEEE International Symposium on Local and Metropolitan Area Networks (LANMAN)*, 2016.

[3] Gerd Keiser. *Comunicações por Fibras Ópticas-4*. AMGH Editora, 2014.

[4] Mohd Syuhaimi AbRahman, BC Ng, and K Jumari. Engineering a network management system for ftth access network. *J. Appl. Sci.*, 9:2390–2398, 2009.

[5] Cisco and its affiliates. 802.11ac: The Fifth Generation of Wi-Fi Technical White Paper. Technical report, Cisco Systems, Inc., 2018.

[6] A. TIRUMALA. Iperf : The tcp/udp bandwidth measurement tool. *http://dast.nlanr.net/Projects/Iperf/*, 1999.

[7] Rohan Murty, Jitendra Padhye, Ranveer Chandra, Alec Wolman, and Brian Zill. Designing high performance enterprise wi-fi networks. In *NSDI*, volume 8, pages 73–88, 2008.

[8] Chang Chew, Nobuo Funabiki, and Tutut Herawan. A common measurement method for throughput experiment of ieee 802.11ac and ieee 802.11n wi-fi under variable condition. *International Journal of Grid and Distributed Computing*, 11:93–112, 07 2018.

[9] V. Kokkinos, K. Stamos, N. Kanakis, K. Baumann, A. Wilson, and J. Healy. Wireless crowdsourced performance monitoring and verification: Wifi performance measurement using end-user mobile device feedback. In *2016 8th International Congress on Ultra Modern Telecommunications and Control Systems and Workshops (ICUMT)*, pages 432–437, Oct 2016.

[10] Mukulika Maity, Bhaskaran Raman, and Mythili Vutukuru. Tcp download performance in dense wifi scenarios: Analysis and solution. *IEEE Transactions on Mobile Computing*, 16(1):213 – 227, 2017.

[11] Marta Fernandez, David Guerra, Unai Gil, Inigo Trigo, Ivan Pena, and Amaia Arrinda. Measurements and analysis of temporal and spatial variability of wifi exposure levels in the 2.4ghz frequency band. *Measurement: Journal of the International Measurement Confederation*, 149, 2020.

[12] Paulo Rocha, Thiago Pinheiro, Ricardo Macedo, and Francisco Airton Silva. 10gbe network card performance evaluation: A strategy based on sensitivity analysis. In *Inproceedings of IEEE Latin-American Conference on Communications*. IEEE, November 2019.

[13] M. Dianu, J. Riihijärvi, and M. Petrova. Measurement-based study of the performance of ieee 802.11ac in an indoor environment. In *2014 IEEE International Conference on Communications (ICC)*, pages 5771–5776, June 2014.

[14] M. Naghibi and M. Ghaderi. Characterizing the performance of beamforming wifi access points. In *39th Annual IEEE Conference on Local Computer Networks*, pages 434–437, Sep. 2014.