Performance Assessment of IEEE 802.11a 54 Mbps WEP Laboratory Links

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Abstract – **The importance of wireless communications, involving electronic devices, has been widely recognized. Performance is a fundamental issue, resulting in more reliable and efficient communications. Security is also critically important. Laboratory measurements were performed about several performance aspects of Wi-Fi IEEE 802.11a 54 Mbps WEP links. Our study contributes to performance evaluation of this technology, using available equipments (HP V-M200 access points and Linksys WPC600N adapters). New results are presented and discussed, namely at OSI level 4, from TCP and UDP experiments. TCP throughput is measured versus TCP packet length. Jitter and percentage datagram loss are measured versus UDP datagram size. Results are compared for both point-to-point and four-node point-to-multipoint links. Conclusions are drawn about performance of the links.**

Keywords – **IEEE 802.11a, Multi-Node WEP Links, TCP packet size, UDP datagram size, Wi-Fi, WLAN Laboratory Performance.**

I. INTRODUCTION

Electromagnetic waves in several frequency ranges, propagating in the air, have made possible the development of contactless communication technologies. Wireless fidelity (Wi-Fi) and free space optics (FSO) are examples of such technologies. Microwaves and laser light are used, respectively. Their importance and utilization have been growing worldwide.

Wi-Fi completes traditional wired networks. The main configuration is infrastructure mode. Here, a WLAN (wireless local area network) is formed where an access point, AP, enables communications of Wi-Fi electronic devices with a wired based LAN, through a switch/router. At the private home level a WPAN (wireless personal area network) permits personal devices to communicate. Frequency bands of 2.4 and 5 GHz are usable, with IEEE 802.11a, b, g, n standards [1]. Nominal transfer rates up to 11 (802.11b), 54 Mbps (802.11 a, g) and 600 Mbps (802.11n) are stated. Carrier sense multiple access with collision avoidance (CSMA/CA) is the medium access control. Point-to-point (PTP) and point-to-multipoint (PTMP) microwave links are applied. The intensive use of the 2.4 GHz band has caused growing interference. The 5 GHz band solves this problem, at the expense of higher absorption and shorter range.

802.11a,g use a multi-carrier modulation scheme called orthogonal frequency division multiplexing (OFDM) that allows for binary phase-shift keying (BPSK), quadrature phase-shift keying (QPSK) and quadrature amplitude modulation (QAM) of the 16-QAM and 64-QAM density types. One spatial stream (one antenna) and coding rates up to 3/4 are possible and a 20 MHz channel.

There are studies on wireless communications, wave propagation [2],[3], practical setups of WLANs [4], performance analysis of the effective transfer rate [5], performance in crowded indoor environments [6].

Communication performance is a crucial issue, giving higher reliability and efficiency. Requirements are given for new and traditional telematic applications [7].

Wi-Fi security is critically important for confidentiality. Several encryption methods have been developed to provide authentication such as, by increasing order of security, wired equivalent privacy (WEP), Wi-Fi protected access (WPA) and Wi-Fi protected access II (WPA2).

Several performance measurements have been published for 2.4 and 5 GHz Wi-Fi Open [8], WEP [9], WPA[10] and WPA2 [11] links, as well as very high speed FSO [12]. Studies are published on modelling TCP throughput [13]. A formula that bounds average TCP throughput is available [14]. Studies have been given for 5 GHz 802.11n and 54 Mbps 802.11a Open links [15],[16].

The motivation of this work is to evaluate and compare performance in laboratory measurements of WEP PTP and four-node point-to-multipoint (4N-PTMP) 802.11a links at 54 Mbps using new available equipments. This new contribution permits to increase the knowledge about performance of Wi-Fi (IEEE 802.11 a) links [16]. The problem statement is that performance needs to be evaluated under several TCP and UDP parameterizations and link topologies under WEP encryption. The solution proposed uses an experimental setup and method, permitting to monitor signal to noise ratios (SNR) and noise levels (N), measure TCP throughput (from TCP connections) versus TCP packet size, and UDP jitter and

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percentage datagram loss (from UDP communications) versus UDP datagram size.

The remaining of the paper is organized as follows: Section II is about the experimental conditions i.e. the measurement setup and procedure. Results and discussion are given in Section III. Conclusions are drawn in Section IV.

II. Experimental Details

In here we have used a HP V-M200 access point [17], with three external dual-band 3x3 MIMO antennas, IEEE 802.11 a/b/g/n, software version 5.4.1.0-01-16481, a 1000-Base-T/100-Base-TX/10-Base-T layer 2 3Com Gigabit switch 16 and a 100-Base-TX/10-Base-T layer 2 Allied Telesis AT-8000S/16 switch [18]. Three PCs were adopted having a PCMCIA IEEE.802.11 a/b/g/n Linksys WPC600N wireless adapter with three internal antennas [19], to enable 4N-PTMP links to the access point. In every type of experiment, an interference free communication channel was used (ch. 36). This was centrally checked through a portable computer, equipped with a Wi-Fi 802.11 a/b/g/n adapter, running Acrylic WiFi software [20]. WEP encryption was turned on in the AP and the wireless adapters of the PCs, with 128 bits and a key composed of twenty six hexadecimal characters. The experiments were made under far-field conditions. Power levels of 30 mW (15 dBm) were not exceeded, as the wireless equipments were proximate.

A functional laboratory arrangement has been planned and set up for the measurements, as shown in Fig. 1. Up to three wireless links to the AP are viable. At OSI level 4, measurements were made for TCP connections and UDP communications using Iperf software [21]. For a TCP client/server connection (TCP New Reno, RFC 6582, was used), TCP throughput was obtained for a given TCP packet size, varying from 0.25k to 64k bytes. For a UDP client/server communication with a given bandwidth specification, UDP jitter and percentage loss of datagrams were determined for a given UDP datagram size, varying from 0.25k to 64k bytes.

One PC, with IP 192.168.0.2 was the Iperf server and the others, with IPs 192.168.0.6 and 192.168.0.50, were the Iperf clients (client1 and client2, respectively). Jitter, which is the root mean square of differences between consecutive transit times, was constantly computed by the server, as specified by the real time protocol RTP, in RFC 1889 [22]. A control PC, with IP 192.168.0.20, was mainly intended to control the AP configuration. The net mask of the wireless network was 255.255.255.0. Three types of measures are feasible: PTP, using the client1 and the control PC as server; PTMP, using the client1 and the 192.168.0.2 server PC; 4N-PTMP, using simultaneous connections/communications between the two clients and the 192.168.0.2 server PC.

The server and client PCs were HP nx9030 and nx9010 portable computers, respectively. The control PC was an HP nx6110 portable computer. Windows XP Professional SP3 was the operating system. The PCs were arranged to provide maximum resources to the present work. Batch command files have been re-written for the new TCP and UDP tests.

The results were obtained in batch mode and recorded as data files to the client PCs disks. Every PC had a second Ethernet adapter, to permit remote control from the official IP APTEL (Applied Physics and Telecommunications) Research Network, via switch.

III. Results and Discussion

The wireless network adapters of the PCs were manually configured for a nominal rate of 54 Mbps. WEP encryption was activated in the AP and the wireless network adapters of the PCs. Transmit and receive rates were typically 54 Mbps, as monitored in the AP. For every TCP packet size in the range 0.25k-64k bytes, and for every corresponding UDP datagram size in the same range, data were acquired for WEP 4N-PTMP and PTP links at OSI levels 1 (physical layer) and 4 (transport layer) using the setup of Fig. 1. For every TCP packet size an average TCP throughput was calculated from a series of experiments. This value was taken as the bandwidth parameter for every corresponding UDP test, giving average jitter and average percentage datagram loss.

At OSI level 1, signal to noise ratios (SNR, in dB) and noise levels (N, in dBm) were obtained in the AP. Typical values are shown in Fig. 2. The links had good, high, SNR values. The main average TCP and UDP results are summarized in Table I, for WEP 4N-PTMP and PTP links. The statistical analysis, including calculations of confidence intervals, was made as in [23]. In Fig. 3 polynomial fits were made (shown as y versus x), using the Excel worksheet, to the TCP throughput data both for both links, where R^2 is the coefficient of determination. It gives the goodness of fit. It is 1.0 for a perfect fit to data. It was found that, on average, the best TCP throughputs are for PTP links (Table I). In passing from PTP to 4N-PTMP throughput reduces to 23%. This is due to increase of processing requirements for the AP, so as to maintain links between the PCs. Fig. 3 shows a fair increase in TCP throughput with packet size. Small packets give a large overhead, due to small amounts of data that are sent in comparison to the protocol components. Frame has a very heavy role in Wi-Fi. For larger packets, overhead decreases; the amount of sent data overcomes the protocol components.

In Figs. 4 and 5, the data points of jitter and percentage datagram loss were joined by smoothed lines. The vertical axes have log 10 scales. It was found that, on average, the best jitter performance is for PTP links. There are large error bars mainly in the 8k, 16k, 32k data points of the 4N-PTMP curve (Fig. 4), needing further investigations. For PTP it can be seen that, for small sized datagrams, jitter is small. There are small delays in sending datagrams. Latency is also small. For larger datagram sizes jitter increases.

Concerning average percentage datagram loss, performances were found on average significantly better for PTP than for 4N-PTMP links (Table I). There are large error bars mainly in the 16k, 32k data points of the 4N-PTMP curve, needing further investigations. Fig. 5, mainly for 4N-PTMP, shows larger percentage datagram losses for small sized datagrams, when the amounts of data to send are small in comparison to the protocol components. There is considerable processing of frame headers and buffer management. For larger datagrams, percentage datagram loss is lower. However, large UDP segments originate fragmentation at the IP datagram level, leading to higher losses.

TCP throughput, jitter and percentage datagram loss were generally found to show performance degradations due to link topology, in passing from PTP to 4N-PTMP, where processing requirements for the AP are higher so as to maintain links between PCs. As CSMA/CA is the medium access control, the available bandwidth and the air time are divided by the nodes using the medium. In comparison to Open links [16], TCP throughput did not show significantly sensitive to WEP within the experimental error. In passing from Open to WEP links, where data length increases due to encryption, jitter and percentage datagram loss have shown considerable performance degradations.

In comparison to previous results for 5 GHz 802.11n Open links [15] the present results show that 5 GHz 802.11n gives better TCP, jitter and datagram loss performances than 802.11a.

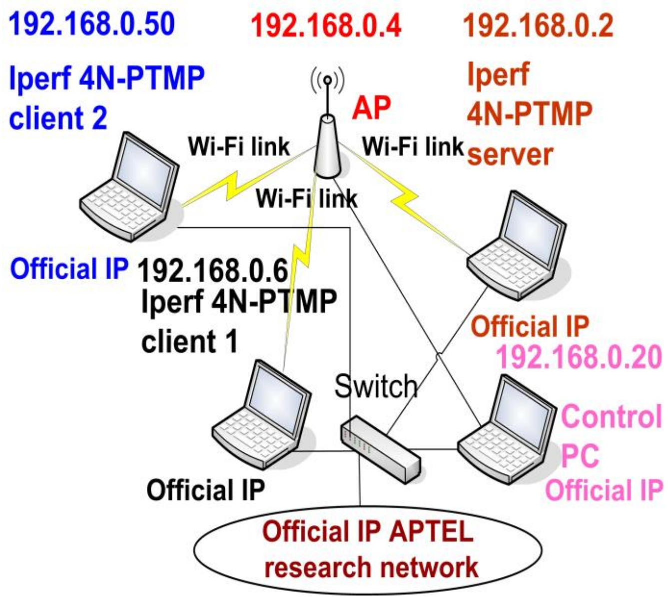

Fig. 1. Wi-Fi laboratory arrangement.

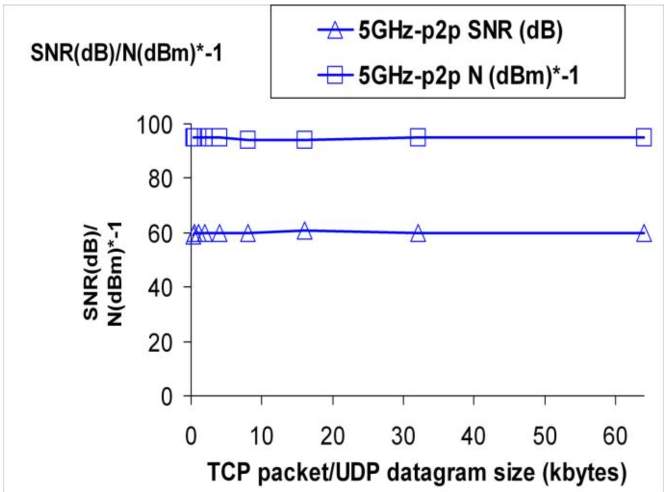

Fig. 2. Typical SNR (dB) and N (dBm).

TABLE I
AVERAGE WI-FI (IEEE 802.11A) RESULTS
WEP PTP AND 4N-PTMP LINKS

Parameter/Link type	PTP	4N-PTMP
TCP throughput (Mbps)	23.2 +- 0.7	5.4 +- 0.2
UDP-jitter (ms)	3.7 +- 0.3	28.6 +- 17.6
UDP-% datagram loss	1.3 +- 0.1	30.4 +- 9.5

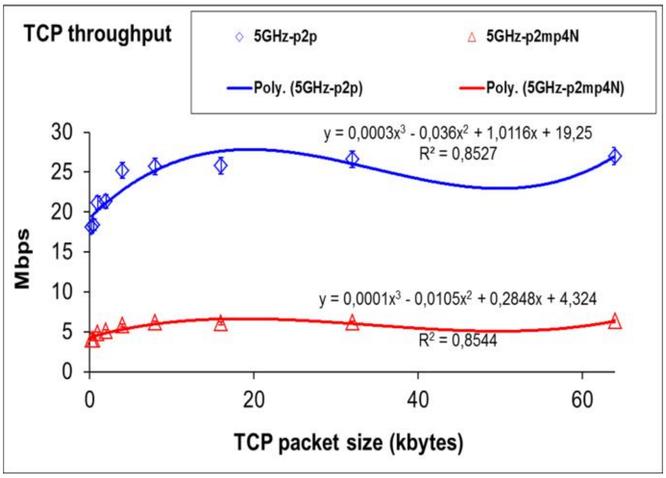

Fig. 3. TCP throughput (y) versus TCP packet size (x). WEP links.

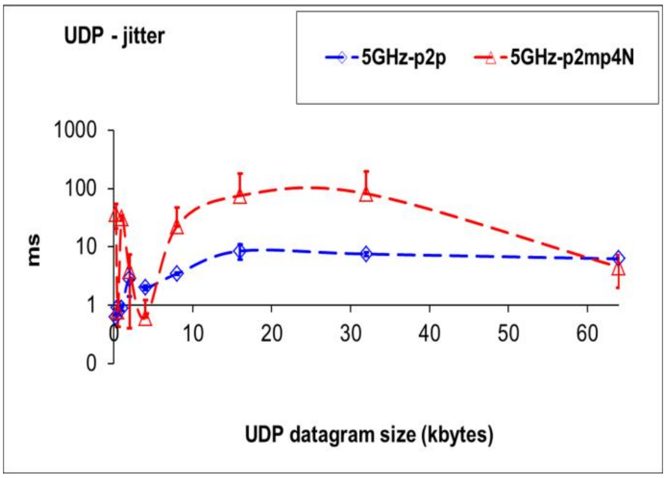

Fig. 4. UDP - jitter versus UDP datagram size. WEP links.

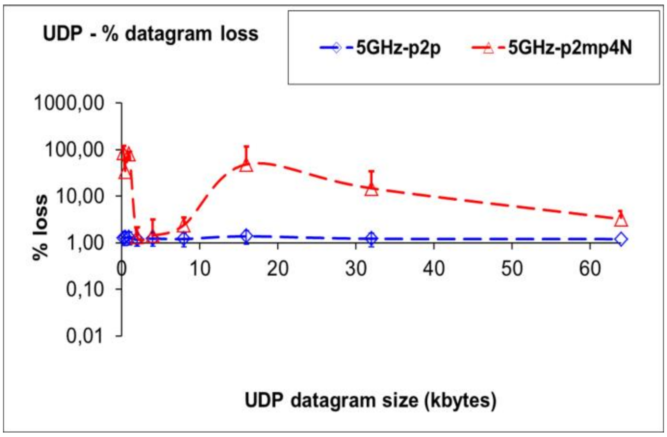

Fig. 5. UDP – percentage datagram loss versus UDP datagram size. WEP links.

IV. Conclusion

In the present work a versatile laboratory setup arrangement was devised and implemented, that permitted systematic performance measurements using new available wireless equipments (V-M200 access points from HP and WPC600N adapters from Linksys) for Wi-Fi (IEEE 802.11 a) in 54 Mbps WEP PTP and 4N-PTMP links. Through OSI layer 4, TCP and UDP performances were measured versus TCP packet size and UDP datagram size, respectively. TCP throughput, jitter and percentage datagram loss were measured and compared for WEP PTP and 4N-PTMP links. TCP throughput was found to increase with packet size. For PTP jitter, for small sized datagrams, is found small. It increases for larger datagrams. Concerning percentage datagram loss, it was found high for small sized datagrams. For larger datagrams it diminishes. However, large UDP segments originate fragmentation at the IP datagram level, leading to higher losses. In comparison to PTP links, TCP throughput, jitter and percentage datagram loss were found to show significant performance degradations for 4N-PTMP links, where the AP experiments higher processing requirements for maintaining links between PCs. Unlike jitter and percentage datagram loss, TCP throughput has not shown significant sensitivity to WEP. The present results show that 5 GHz 802.11n gives better TCP, jitter and datagram loss performances than 802.11a.

Further performance studies are planned using several standards, equipments, topologies, security settings and noise conditions, not only in laboratory but also in outdoor environments involving, mainly, medium range links.

Acknowledgement

Supports from Universidade da Beira Interior and FCT (Fundação para a Ciência e a Tecnologia)/PEst-OE/FIS/UI0524/2014 (Projecto Estratégico-UI524-2014) are acknowledged.

References

[1] Web site http://standards.ieee.org Web site; IEEE 802.11a, 802.11b, 802.11g, 802.11n, 802.11i standards; accessed 10 Jan 2017.

[2] J. W. Mark, W. Zhuang, Wireless Communications and Networking, Prentice-Hall, Inc., Upper Saddle River, NJ, 2003.

[3] T. S. Rappaport, Wireless Communications Principles and Practice, 2nd ed., Prentice-Hall, Inc., Upper Saddle River, NJ, 2002.

[4] W. R. Bruce III, R. Gilster, Wireless LANs End to End, Hungry Minds, Inc., NY, 2002.

[5] M. Schwartz, Mobile Wireless Communications, Cambridge University Press, 2005.

[6] N. Sarkar, K. Sowerby, "High Performance Measurements in the Crowded Office Environment: a Case Study", In Proc. ICCT'06-International Conference on Communication Technology, Guilin, China, 27-30 November 2006, pp. 1-4.

[7] F. Boavida, E. Monteiro, Engenharia de Redes Informáticas, 10th ed., FCA-Editora de Informática Lda, Lisbon, 2011.

[8] J. A. R. Pacheco de Carvalho, H. Veiga, C. F. Ribeiro Pacheco, A. D. Reis, "Extended Performance Research on Wi-Fi IEEE 802.11 a, b, g Laboratory Open Point-to-Multipoint and Point-to-Point Links", in Transactions on Engineering Technologies, Sio-Iong Ao, Gi-Chul Yang, Len Gelman, Eds. Singapore: Springer, 2016, pp. 475-484.

[9] J. A. R. Pacheco de Carvalho, H. Veiga, N. Marques, C. F. Ribeiro Pacheco, A. D. Reis, "Wi-Fi WEP Point-to-Point Links-Performance Studies of IEEE 802.11 a,b,g Laboratory Links", in Electronic Engineering and Computing Technology, Series: Lecture Notes in Electrical Engineering, Sio-Iong Ao, Len Gelman, Eds. Netherlands: Springer, 2011, Vol. 90, pp. 105-114.

[10] J. A. R. Pacheco de Carvalho, H. Veiga, C. F. Ribeiro Pacheco, A. D. Reis, "Extended Performance Studies of Wi-Fi IEEE 802.11a, b, g Laboratory WPA Point-to-Multipoint and Point-to-Point Links", in Transactions on Engineering Technologies: Special Volume of the World Congress on Engineering 2013, Gi-Chul Yang, Sio-Iong Ao, Len Gelman, Eds. Gordrecht: Springer, 2014, pp. 455-465.

[11] J. A. R. Pacheco de Carvalho, H. Veiga, C. F. Ribeiro Pacheco, A. D. Reis, "Performance Evaluation of IEEE 802.11 a, g Laboratory WPA2 Point-to-Multipoint Links", Lecture Notes in Engineering and Computer Science: Proceedings of the World Congress of Engineering 2014, WCE 2014, 2-4 July 2014, London, U. K., pp. 699-704.

[12] J. A. R. Pacheco de Carvalho, N. Marques, H. Veiga, C. F. F. Ribeiro Pacheco, A. D. Reis, "Performance Measurements of a 1550 nm Gbps FSO Link at Covilhã City, Portugal", Proc. Applied Electronics 2010 - 15th International Conference, 8-9 September 2010, University of West Bohemia, Pilsen, Czech Republic, pp. 235-239.

[13] J. Padhye, V. Firoiu, D. Towsley, J. Kurose, "Modeling TCP Throughput: A Simple Model and its Empirical Validation", Proc. SIGCOMM Symposium Communications, Architecture and Protocols, August 1998, pp. 304-314.

[14] M. Mathis, J. Semke, J. Mahdavi, "The Macroscopic Behavior of the TCP Congestion Avoidance Algorithm", ACM SIGCOMM Computer Communication Review, vol. 27, Issue 3, July 1997, pp. 67-82.

[15] J. A. R. Pacheco de Carvalho, H. Veiga, C. F. Ribeiro Pacheco, A. D. Reis, " Performance Measurements of Open 5 GHz IEEE 802.11n Laboratory Links", Lecture Notes in Engineering and Computer Science: Proceedings of the World Congress on Engineering 2016, WCE 2016, 29 June-1 July, 2016, London, U.K., pp. 607-611.

[16] José A. R. Pacheco de Carvalho, Cláudia F. F. P. Ribeiro Pacheco, Hugo Veiga, António D. Reis, "A New Performance Determination of IEEE 802.11a 54 Mbps Open Laboratory Links", *Proc. ICEST 2017 – LII International Scientific Conference on Information, Communication and Energy Systems and Technologies*, P28.6, pp. 257-260, Nis, Serbia, 28-30 June, 2017.

[17] Web site http://www.hp.com; HP V-M200 802.11n access point management and configuration guide; 2010; accessed 3 Jan 2018.

[18] Web site http://www.alliedtelesis.com; AT-8000S/16 level 2 switch technical data; 2009; accessed 10 Dec 2016.

[19] Web site http://www.linksys.com; WPC600N notebook adapter user guide; 2008; accessed 10 Jan 2012.

[20] Acrylic WiFi software; 2016; http://www.acrylicwifi.com; accessed 8 Jan 2018.

[21] Iperf software; 2016; http://iperf.fr; accessed 16 Feb 2018.

[22] Network Working Group. "RFC 1889-RTP: A Transport Protocol for Real Time Applications", http://www.rfc-archive.org; 1996; accessed 13 Apr 2018.

[23] P. R. Bevington, Data Reduction and Error Analysis for the Physical Sciences, Mc Graw-Hill Book Company, 1969.