Extended Research on Performance of IEEE 802.11 a, b, g Laboratory WPA2 Point-to-Multipoint Links

J. A. R. Pacheco de Carvalho, H. Veiga, C. F. Ribeiro Pacheco, A. D. Reis

Abstract—**The increasing importance of wireless communications, involving electronic devices, has been widely recognized. Performance is a crucial issue, leading to more reliable and efficient communications. Security is also critically important. Laboratory measurements were performed about several performance aspects of Wi-Fi (IEEE 802.11 a, b, g) WPA2 point-to-multipoint links. Our study contributes to the performance evaluation of this technology, using available equipments (DAP-1522 access points from D-Link and WPC600N adapters from Linksys). New detailed results are presented and discussed, namely at OSI levels 4 and 7, from TCP, UDP and FTP experiments: TCP throughput, jitter, percentage datagram loss and FTP transfer rate. Comparisons are made to corresponding results obtained for WPA2 point-to-point and Open point-to-multipoint links. Conclusions are drawn about the comparative performance of the links.**

Index Terms—**IEEE 802.11 a b and g, Wi-Fi, Wireless Network Laboratory Performance, WLAN, WPA2 and Open Links.**

I. Introduction

Contactless communications techniques have been developed using mainly electromagnetic waves in several frequency ranges, propagating in the air. Wi-Fi and FSO, whose importance and utilization have been recognized and growing, are representative examples of wireless communications technologies.

Wi-Fi is a microwave based technology providing for versatility, mobility and favourable prices. The importance and utilization of Wi-Fi has been increasing for complementing traditional wired networks. It has been used both in ad hoc mode and in infrastructure mode. In this case an access point, AP, permits Wi-Fi electronic devices to communicate with a wired based LAN through a switch/router. By this means a WLAN, based on the AP, is formed. At the personal home level a WPAN allows personal devices to communicate. Point-to-point (PTP) and point-to-multipoint (PTMP) 2.4 and 5 GHz microwave links are used, with IEEE 802.11a, 802.11b, 802.11g and 802.11n standards [1]. The intensive use of the 2.4 GHz band is resulting in increasing interferences. Therefore, the 5 GHz band is receiving considerable attention, in spite of larger absorption and shorter ranges.

Nominal transfer rates up to 11 (802.11b), 54 Mbps (802.11 a, g) and 600 Mbps (802.11n) are specified. CSMA/CA is the medium access control. There are studies on wireless communications, wave propagation [2]-[3], practical implementations of WLANs [4], performance analysis of the effective transfer rate for 802.11b PTP links [5], 802.11b performance in crowded indoor environments [6].

Performance has been seen as a very important issue, resulting in more reliable and efficient communications. New telematic applications are specially sensitive to performances when compared to traditional applications, Requirements have been given [7].

Wi-Fi security is very important. Microwave radio signals travel through the air and can be easily captured by virtually everyone. Therefore, several security methods have been developed to provide authentication such as, by increasing order of security, WEP, WPA and WPA2. WEP was initially intended to provide confidentiality comparable to that of a traditional wired network. A shared key for data encryption is involved. The communicating devices use the same key to encrypt and decrypt radio signals. The CRC32 checksum used in WEP does not provide a great protection. However, in spite of its weaknesses, WEP is still widely used in Wi-Fi communications for security reasons, mainly in PTP links. WPA2 is compliant with the full IEEE 802.11i standard [1]. It includes CCMP, a new AES-based encryption mode with enhanced security. Either personal or enterprise modes can be used. In this latter case an 802.1x server is required. Both TKIP and AES cipher types are usable and a group key update time interval is specified.

Several performance measurements have been made for 2.4 and 5 GHz Wi-Fi open [8]-[9], WEP [10], WPA [11]-[12] and WPA2 [13]-[14] links, as well as very high speed FSO [15]. It is important to investigate the effects of network topology, increasing levels of security encryption on link performance and compare equipment performance for several standards. In the present work new Wi-Fi (IEEE

Manuscript received December 3, 2014. Supports from University of Beira Interior and FCT (Fundação para a Ciência e a Tecnologia)/PEst-OE/FIS/UI0524/2014(ProjectoEstratégico-UI524-2014) are acknowledged.

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(Advance online publication: 17 February 2015)

802.11 a,b,g) results arise, using personal mode WPA2, namely through OSI levels 4 and 7. Performance is evaluated in laboratory measurements of WPA2 PTMP links using new available equipments. Comparisons are made to corresponding results obtained for WPA2 PTP links and Open PTMP links. The present work is an extension of [14].

In prior and actual state of the art, several Wi-Fi links have been investigated. Performance evaluation has been considered as a crucially important criterion to assess communications quality. The motivation of this work is to evaluate performance in laboratory measurements of WPA2 PTMP links using available equipments. Comparisons are made to corresponding results obtained for PTP links and Open PTMP links. This contribution permits to increase the knowledge about performance of Wi-Fi (IEEE 802.11 a, b, g) links [4]-[6]. The problem statement is that performance needs to be evaluated under security encryption and several topologies. The solution proposed uses an experimental setup and method, permitting to monitor, mainly, signal to noise ratios (SNR) and noise levels (N) and measure TCP throughput (from TCP connections) and UDP jitter and percentage datagram loss (from UDP communications).

The rest of the paper is structured as follows: Chapter II is about the experimental details i.e. the measurement setup and procedure. Results and discussion are given in Chapter III. Conclusions are drawn in Chapter IV.

II. Experimental Details

The measurements used a D-Link DAP-1522 bridge/access point [16], with internal PIFA *2 antenna, IEEE 802.11 a/b/g/n, firmware version 1.31 and a 100-Base-TX/10-Base-T Allied Telesis AT-8000S/16 level 2 switch [17]. The wireless mode was set to access point mode. Two PCs were used having a PCMCIA IEEE.802.11 a/b/g/n Linksys WPC600N wireless adapter with three internal antennas [18], to enable PTMP links to the access point. In every type of experiment, interference free communication channels were used (ch 36 for 802.11a; ch 8 for 802.11b, g). This was checked through a portable computer, equipped with a Wi-Fi 802.11 a/b/g/n adapter, running NetStumbler software [19]. WPA2 encryption was activated in the AP and the wireless adapters of the PCs, using AES and a shared key composed of 26 ASCII characters. The experiments were made under far-field conditions. No power levels above 30 mW (15 dBm) were required, as the wireless equipments were close.

A versatile laboratory setup has been planned and implemented for the PTMP measurements, as shown in Fig. 1. It involves two wireless links to the AP. At OSI level 4, measurements were made for TCP connections and UDP communications using Iperf software [20]. For a TCP connection, TCP throughput was obtained. For a UDP communication with a given bandwidth parameter, UDP jitter and percentage loss of datagrams were determined. Parameterizations of TCP packets, UDP datagrams and window size were as in [11]. One PC, with IP 192.168.0.2 was the Iperf server and the other, with IP 192.168.0.6, was the Iperf client. Jitter, which is the smooth mean of differences between consecutive transit times, was continuously computed by the server, as specified by the real time protocol RTP, in RFC 1889 [21]. Another PC, with IP 192.168.0.20, was used to control the settings in the AP. The scheme of Fig. 1 was also used for FTP measurements, where FTP server and client applications were installed in the PCs with IPs 192.168.0.2 and 192.168.0.6, respectively. The server and client PCs were HP nx9030 and nx9010 portable computers, respectively, running Windows XP. They were configured to optimize the resources for the present work. Batch command files have been written to enable the TCP, UDP and FTP tests [14].

The results were obtained in batch mode and written as data files to the client PC disk. Each PC had a second network adapter, to permit remote control from the official IP University network, via switch.

III. Results and Discussion

The access point and the wireless network adapters of the PCs were manually configured for each standard IEEE 802.11 a, b, g with typical nominal transfer rates (1, 2, 5.5, 11 Mbps for 11b; 6, 9, 12, 18, 24, 36, 48, 54 Mbps for 11a,g). For every fixed transfer rate, data were obtained for comparison of the laboratory performance of the WPA2 PTMP and PTP links at OSI levels 1 (physical layer), 4 (transport layer) and 7 (application layer) using the setup of Fig. 1. For each standard and every nominal fixed transfer rate, an average TCP throughput was determined from a set of experiments. This value was used as the bandwidth parameter for every corresponding UDP test, resulting in 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 measured. The measured data were similar for all experiment types. Typical values are shown in Fig. 2.

The main average TCP and UDP results are summarized in Table I, both for WPA2 PTMP, PTP and Open PTMP links. The statistical analysis, including calculations of confidence intervals, was carried out as in [22]. In Figs. 3-4 polynomial fits were made (shown as y versus x), using the Excel worksheet, to the 802.11a, b, g TCP throughput data for WPA2 PTMP and PTP links, respectively, where R^2 is the coefficient of determination. It gives information about the goodness of fit. If it is 1.0 it means a perfect fit to data. It was found that, on average, the best TCP throughputs are for 802.11 a and PTP links (15.9+-0.5 Mbps). Fig. 5 shows TCP throughput results for Open PTMP links. Average data for 802.11 a are the same (7.6+- 0.2 Mbps) as for WPA2 PTMP links. In Figs. 6-11, the data points representing jitter and percentage datagram loss were joined by smoothed lines. It was found that, on average, jitter performances are better for WPA2 PTP than for WPA2 PTMP links. The average jitter performances for Open PTMP links were found as better than for WPA2 PTMP links. Concerning average percentage datagram loss, performances were, generally, found as better for WPA2 PTP than for WPA2 PTMP links. The best performance was found for 802.11a and Open PTMP links (1.0+-0.1 %). In comparison to WPA2 PTP links, TCP throughput, jitter and percentage datagram loss were found to show performance degradations for WPA2 PTMP links, where the AP has to maintain links between PCs. In comparison to Open PTMP links and except for TCP throughput, where performances were the same for 802.11 a, jitter and percentage datagram loss were, generally, found to show performance degradations for WPA2 PTMP, where data length is increased.

At OSI level 7 we measured FTP transfer rates versus nominal transfer rates, configured in the access point and the wireless network adapters of the PCs, for the IEEE 802.11a,b, g standards. The result for every measurement was as calculated in [14]. The FTP results show the same trends found for TCP throughput.

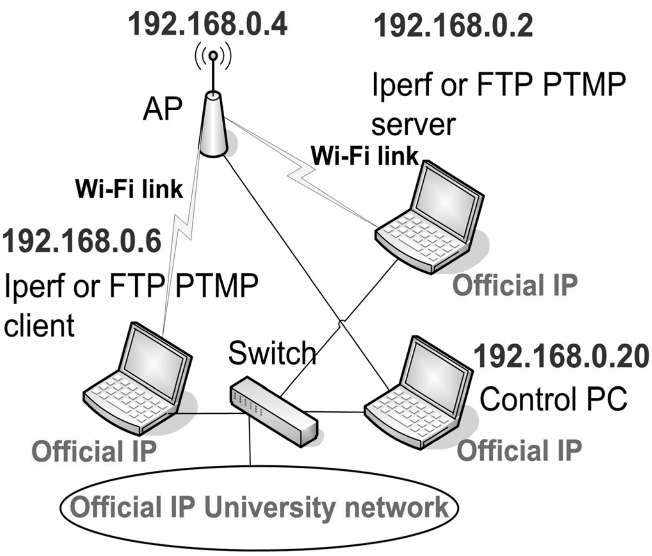

Fig. 1- Laboratory setup scheme.

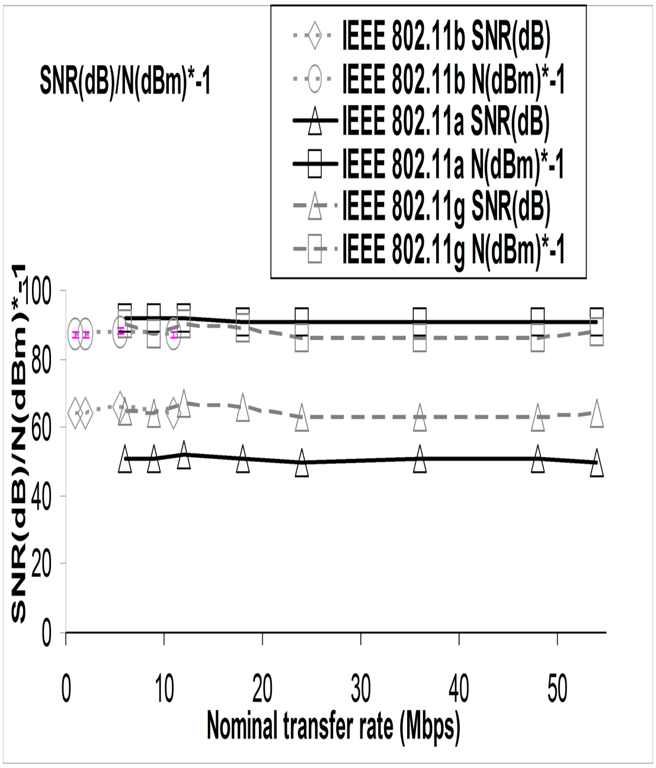

Fig. 2- Typical SNR (dB) and N (dBm).

TABLE I -AVERAGE WI-FI (IEEE 802.11 A, B, G) RESULTS: WPA2 PTMP; PTP; OPEN PTMP

Exp type	WPA2 PTMP			WPA2 PTP			Open PTMP		
Parameter/ IEEE standard	802.11b	802.11a	802.11g	802.11b	802.11a	802.11g	802.11b	802.11a	802.11g
TCP throughput (Mbps)	1.1 +-0.0	7.6 +-0.2	5.9 +-0.2	3.0 +-0.1	15.9 +-0.5	13.7 +-0.4	1.2 +-0.0	7.6 +-0.2	6.0 +-0.2
UDP-jitter (ms)	8.8 +- 1.8	3.9 +-0.7	4.4 +-0.7	6.3 +-0.7	2.7 +-0.4	2.6 +-0.3	5.4 +-0.4	3.1 +-0.3	3.5 +-0.4
UDP-% datagram loss	1.2 +-0.2	1.6 +-0.2	1.7 +-0.1	1.5 +-0.5	1.2 +-0.2	1.2 +-0.2	1.3 +-0.2	1.0 +-0.1	1.8 +-0.2

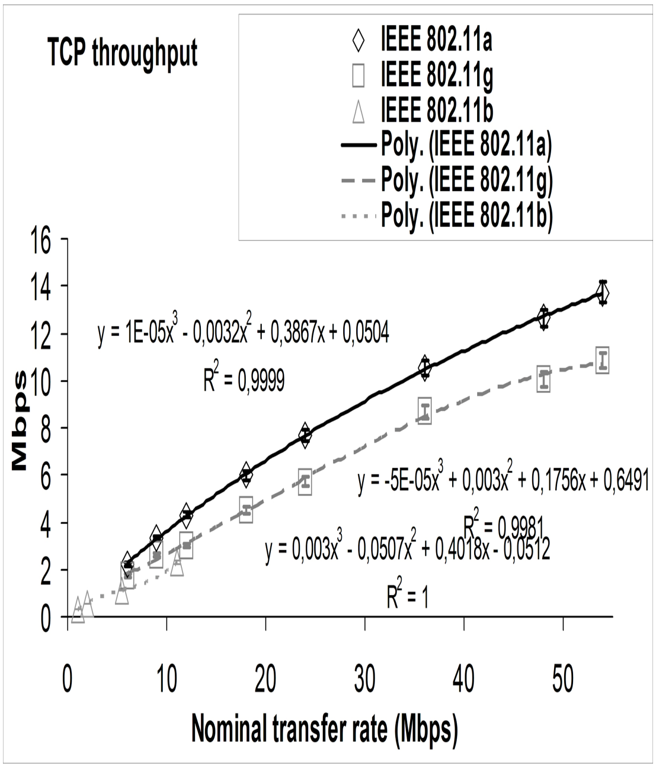

Fig.3- TCP throughput (y) versus technology and nominal transfer rate (x). WPA2 PTMP.

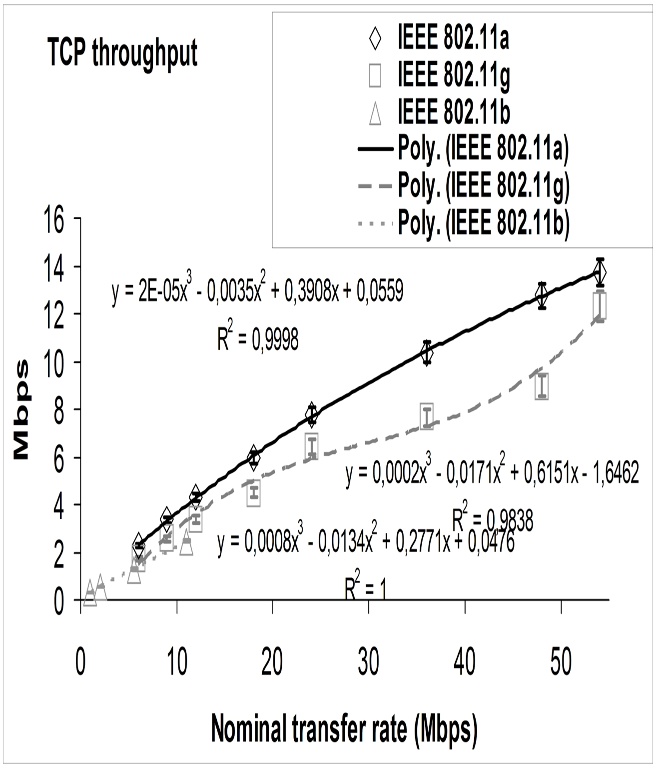

Fig. 5- TCP throughput (y) versus technology and nominal transfer rate (x). Open PTMP.

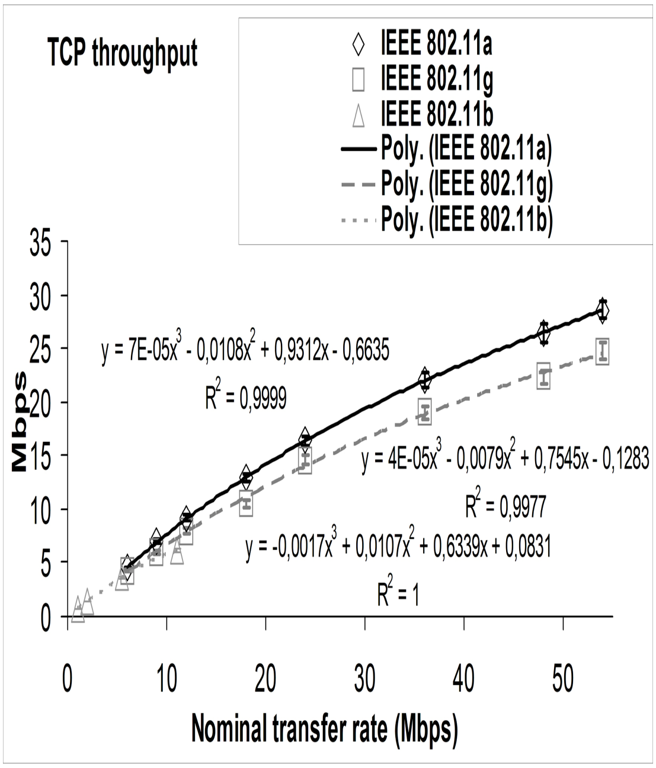

Fig. 4- TCP throughput (y) versus technology and nominal transfer rate (x). WPA2 PTP.

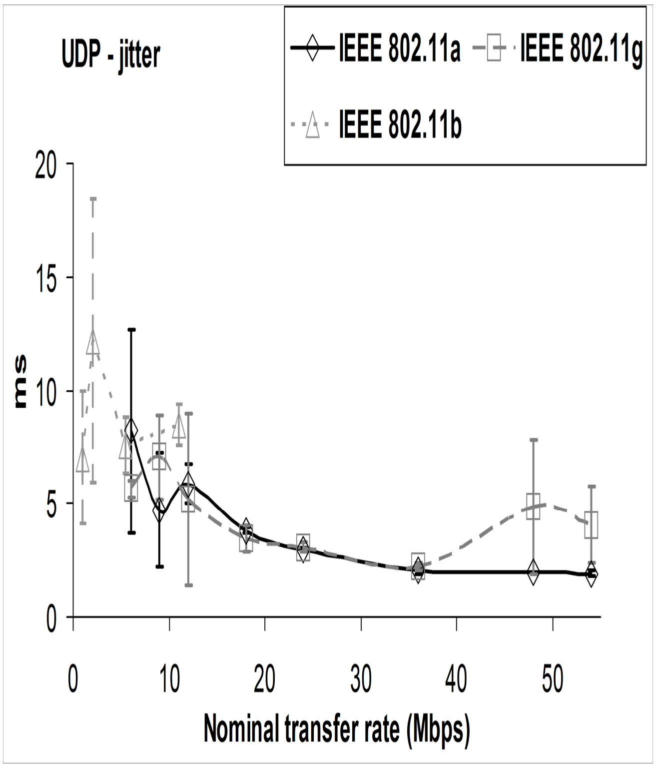

Fig. 6- UDP – jitter results versus technology and nominal transfer rate. WPA2 PTMP.

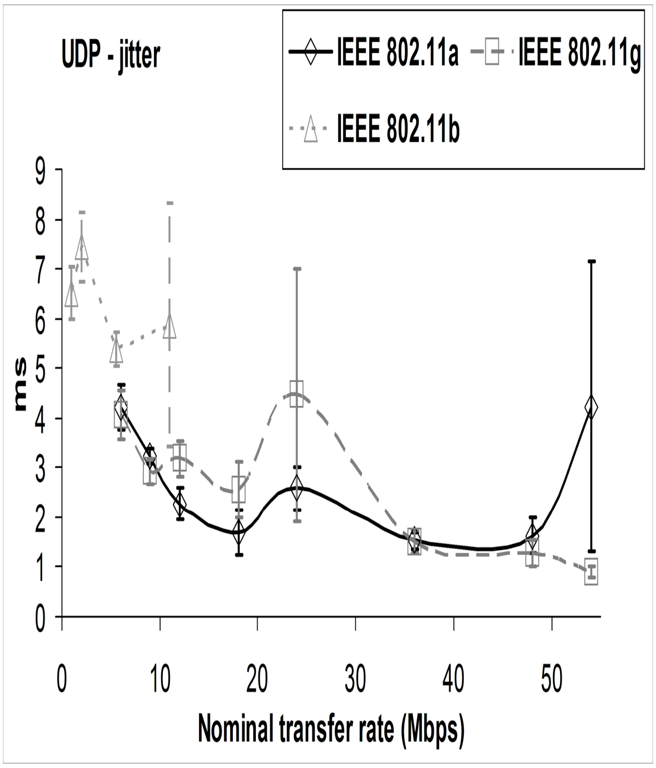

Fig. 7- UDP – jitter results versus technology and nominal transfer rate. WPA2 PTP.

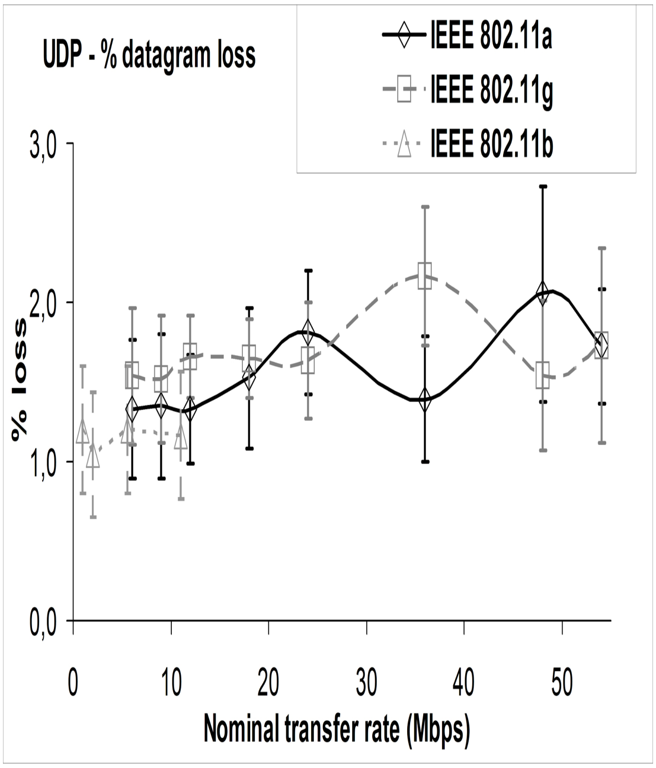

Fig. 9- UDP – percentage datagram loss results versus technology and nominal transfer rate. WPA2 PTMP.

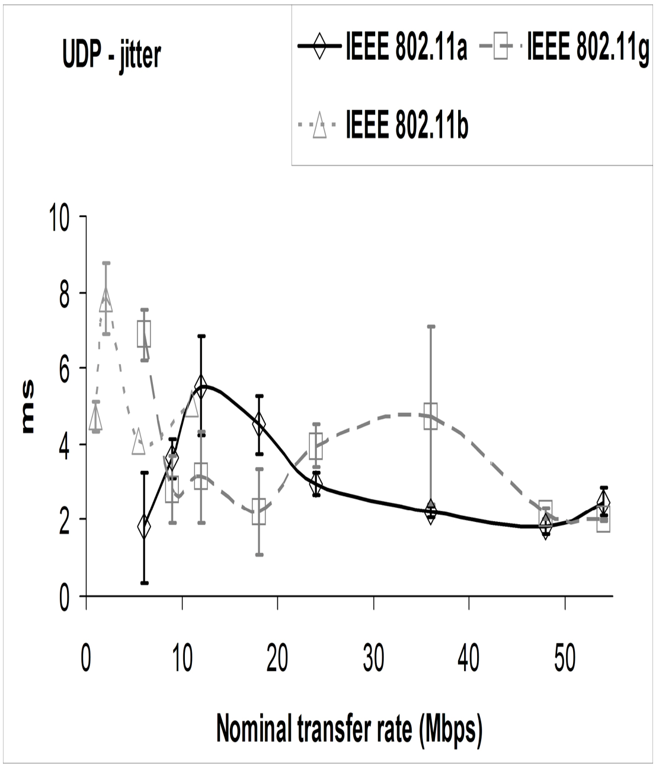

Fig. 8- UDP – jitter results versus technology and nominal transfer rate. Open PTMP.

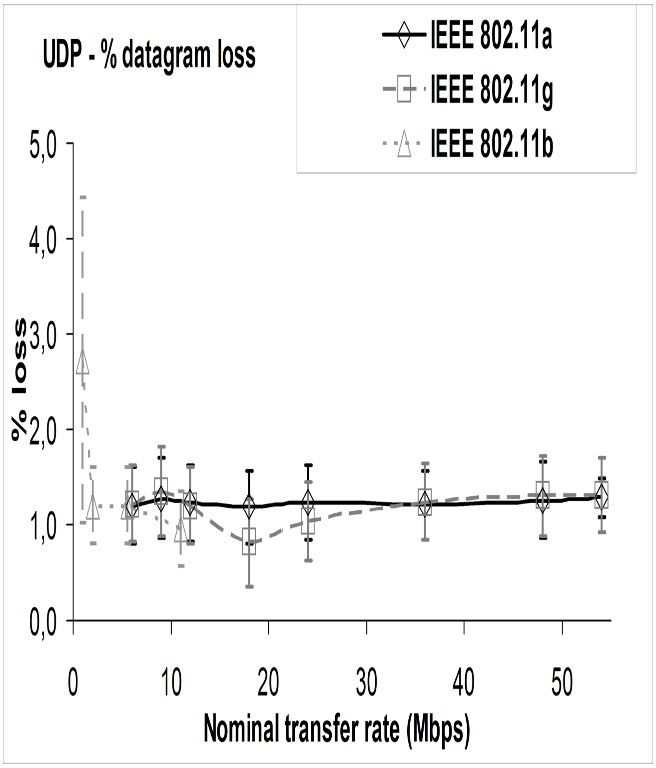

Fig. 10- UDP – percentage datagram loss results versus technology and nominal transfer rate. WPA2 PTP.

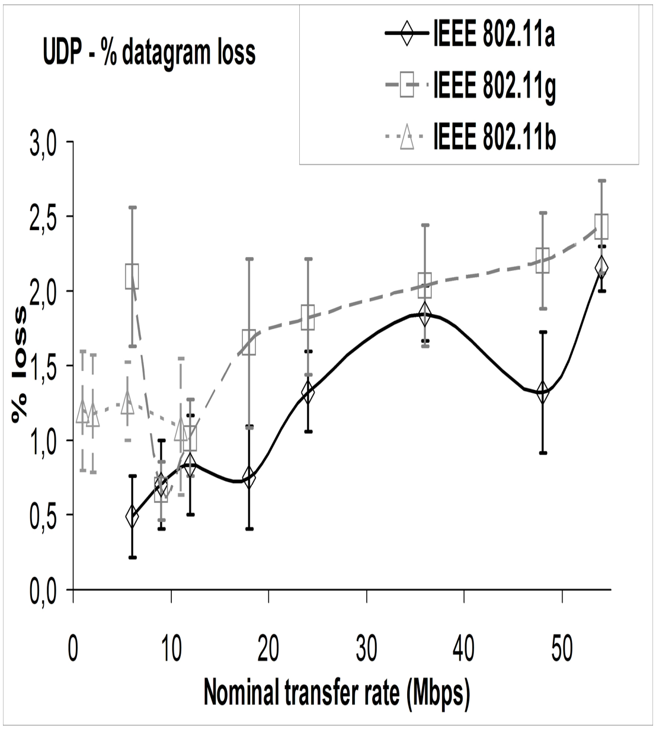

Fig. 11- UDP – percentage datagram loss results versus technology and nominal transfer rate. Open PTMP.

IV CONCLUSION

In the present work a versatile laboratory setup arrangement was planned and implemented, that permitted systematic performance measurements of new available wireless equipments (DAP-1522 access points from D-Link and WPC600N adapters from Linksys) for Wi-Fi (IEEE 802.11 a, b, g) in WPA2 PTMP links.

Through OSI layer 4, TCP throughput, jitter and percentage datagram loss were measured and compared for every standard to corresponding results obtained for WPA2 PTP and Open PTMP. On average, jitter performances are better for WPA2 PTP than for WPA2 PTMP links. The average jitter performances for Open PTMP links were found as better than for WPA2 PTMP links. Concerning average percentage datagram loss, performances were, generally, found as better for WPA2 PTP than for WPA2 PTMP links. In comparison to WPA2 PTP links, TCP throughput, jitter and percentage datagram loss were found to show performance degradations for WPA2 PTMP links, where the AP has to maintain links between PCs. In comparison to Open PTMP links and except for TCP throughput, where performances were the same for 802.11 a, jitter and percentage datagram loss were, generally, found to show performance degradations for WPA2 PTMP, where data length is increased. At OSI layer 7, FTP performance results have shown the same trends found for TCP throughput.

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

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