Extended Research on Effects of Encryption and Topology on Performance of IEEE 802.11a Laboratory 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 worldly recognized. Performance is an essential 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 802.11a WPA2 and WPA point-to-multipoint links. Our study contributes to the performance evaluation of this technology, using available equipments (HP V-M200 access points and Linksys WPC600N adapters). New detailed results are presented and discussed, namely at OSI level 4, from TCP and UDP measurements: TCP throughput, jitter and percentage datagram loss. Comparisons are made to corresponding results obtained for WPA2 and WPA point-to-point, and Open links. Conclusions are drawn about the comparative performance of the links.**

***Index Terms*—IEEE 802.11a, Point-to-Multipoint and Point-to-Point Links, Wi-Fi, Wireless Network Laboratory Performance, WLAN, WPA, WPA2.**

I. Introduction

Contactless communications use electromagnetic waves in several frequency ranges, propagating in the air. Wireless fidelity (Wi-Fi) and free space optics (FSO) are typical examples of wireless communications technologies using microwaves and laser light, respectively. Their importance and application have been growing.

Wireless communications are significantly important for their adaptability, mobility and favourable prices. Wi-Fi permits complementing traditional wired networks. Its importance and utilization have been expanding. Both ad hoc and infrastructure modes have been used. In this case an access point (AP), enables communications of Wi-Fi electronic devices with a wired based local area network (LAN), through a switch/router. Thus, a wireless local area network (WLAN) is built, based on the AP. At the personal home level, a wireless personal area network (WPAN) permits communications of personal devices. Point-to-point (PTP) and point-to-multipoint (PTMP) topologies are used both indoors and outdoors, with appropriate directional and omnidirectional antennas. The 2.4 and 5 GHz microwave frequency bands and IEEE 802.11a, b, g, n standards are associated with Wi-Fi [1,2]. The 2.4 GHz band is increasingly used, leading to growing electromagnetic interference. Therefore, the 5 GHz band is an alternative, in spite of larger absorption and shorter ranges. Wi-Fi has nominal transfer rates up to 11 (802.11b), 54 Mbps (802.11 a, g) and 600 Mbps (802.11n). Carrier sense multiple access with collision avoidance (CSMA/CA) is the medium access control. Studies have been published on wireless communications, wave propagation [3,4], practical setups of WLANs [5], performance analysis of the effective transfer rate for 802.11b PTP links [6], 802.11b performance in crowded indoor environments [7].

Performance evaluation has been a fundamentally important criterion to assess communications quality, leading to more reliable and efficient communications and, therefore, improving enterprise information system yield. Requirements for both traditional and new telematic applications have been given [8].

Wi-Fi security is very important, ranging from the personal level to the enterprise information system level. Confidentiality is essential. However, as microwave radio waves propagate in the air, they can be very easily captured. Wired equivalent privacy (WEP) was initially intended to provide confidentiality like 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 cyclic redundancy check 32 (CRC32) checksum used in WEP does not provide a great protection. Besides presenting weaknesses, WEP is still reasonably used in Wi-Fi networks for security reasons, mainly in point-to-point links. More advanced and reliable security methods have been developed to provide authentication such as, by increasing order of security, Wi-Fi protected access (WPA) and Wi-Fi protected access II (WPA2). WPA implements the majority of the IEEE 802.11i standard. It includes a message integrity check (MIC), replacing the CRC used in WEP. WPA2 is compliant with the full IEEE 802.11i standard [1]. It includes Counter Mode with Cipher Block Chaining Message Authentication Code

Manuscript received May 2, 2017. 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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Protocol (CCMP), a new Advanced Encryption Standard (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 Temporal Key Integrity Protocol (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 [9], WEP [10], WPA [11] and WPA2 [12] links, as well as very high speed FSO [13]. It is important to investigate the effects of increasing levels of security encryption, network topology, on link performance and compare equipment performance for several standards. In the present work new Wi-Fi (IEEE 802.11 a) results arise, using WPA2 and WPA links, namely through OSI level 4. Performance is evaluated in laboratory measurements of WPA2 and WPA PTMP links using new available equipments. Comparisons are made to corresponding results obtained for WPA2 and WPA PTP and Open links. The present work complements previous work of the authors [14], by investigating the 5 GHz band, where there was the least electromagnetic interference, WPA2 and WPA.

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 and WPA PTMP links using new available equipments. Comparisons are made to corresponding results obtained for WPA2 and WPA PTP and Open links. This contribution permits to increase the knowledge about performance of Wi-Fi (IEEE 802.11a) 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 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: Section II is about the experimental details i.e. the measurement setup and procedure. Results and discussion are given in Section III. Conclusions are drawn in Section IV.

II. Experimental Details

The equipments selected for the measurements comprised a HP V-M200 access point [15], having 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 Allied Telesis AT-8000S/16 level 2 switch [16]. Two out of three PCs were used having a PCMCIA IEEE.802.11 a/b/g/n Linksys WPC600N wireless adapter with three internal antennas having gains of 2.7 dBi at 2.4 GHz and 1.2 dBi at 2.4 GHz [17], to enable three-node PTMP (PTMP) links to the access point. In setting up the links, an interference free communication channel was used (ch 36). This was mainly checked through a portable computer, equipped with a Wi-Fi 802.11 a/b/g/n adapter, running Acrylic WiFi software [18]. WPA2 and WPA encryptions with AES were activated in the AP and the wireless adapters of the PCs, with keys composed of twenty six hexadecimal characters. The experiments were made under far-field conditions. No power levels above 30 mW (15 dBm) were used, 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 can involve up to three wireless links to the AP. At OSI level 4, measurements were made for TCP connections and UDP communications using Iperf software [19]. For a TCP client/server connection (TCP New Reno, RFC 6582, was used), TCP throughput was obtained. For a UDP client/server communication with a given bandwidth parameter, UDP jitter and percentage loss of datagrams were determined. TCP packet size and window size were 8k bytes. UDP datagram size and buffer size were 1470 bytes and 8k bytes, respectively.

One PC, with IP 192.168.0.2 was the Iperf server and the others, with IP 192.168.0.6 and 192.168.0.50, could be the Iperf clients (client1 and client2). Jitter, which gives the root mean square of the differences between consecutive transit times, was continuously computed by the server, as specified by the real time protocol RTP, in RFC 1889 [20]. Another PC, with IP 192.168.0.20, was mainly used to control the settings in the AP. The laboratory setup permitted three types of experiments to be made: PTP, using the client1 and the control PC as server; PTMP, using the client1 and the 192.168.0.2 PC as server; four-node PTMP (4N-PTMP), using simultaneous connections/communications between the two clients and the 192.168.0.2 PC as server.

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 was the operating system. They were prepared to optimize the resources assigned to the present work. Batch command files have been re-written to enable the new TCP and UDP tests.

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

III. Results and Discussion

The wireless network adapters of the PCs were manually configured for IEEE 802.11 a with typical nominal transfer rates (6, 9, 12, 18, 24, 36, 48, 54 Mbps). For every fixed transfer rate, data were obtained for comparison of the laboratory performance of WPA2 and WPA PTMP and PTP links and Open links at OSI levels 1 (physical layer) and 4 (transport layer) using the setup of Fig. 1. For every nominal fixed transfer rate, an average TCP throughput was calculated from a set of experiments. This value was fed in as the bandwidth parameter for every corresponding UDP test, resulting in average jitter and average percentage datagram loss [14].

At OSI level 1, signal to noise ratios (SNR, in dB) and noise levels (N, in dBm) were measured. Signal indicates the strength of the radio signal the AP receives from a client PC, expressed in dBm. Noise indicates how much background noise, due to radio interference, exists in the signal path between the client PC and the AP, expressed in dBm. The lower (more negative) the value is, the weaker the noise. SNR indicates the relative strength of client PC radio signals versus noise in the radio signal path, expressed in dB. SNR is a good indicator for the quality of the radio link between the client PC and the AP. The measured data were similar for all types of experiments. 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 WPA2, WPA and Open, PTP and PTMP links. The statistical analysis, including calculations of confidence intervals, was carried out as in [21].

In Figs. 3-8 polynomial fits were made (shown as y versus x), using the Excel worksheet, to the 802.11a TCP throughput data for WPA2, WPA and Open PTP and PTMP links, where R2 is the coefficient of determination, which 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 by descending order for Open, WPA and WPA2 PTP links (Table I), with variations close to the experimental error. This is also the case considering Open, WPA and WPA2 PTMP links (Table I). This is due to increase in data length arising from WPA and WPA2 encryptions. However, TCP performance gets significantly degraded in passing from PTP to PTMP links, as now the processing requirements for the AP are higher so as to maintain links between PCs.

In Figs. 9-14, the data points representing jitter and percentage datagram loss were joined by smoothed lines. It was found that, on average, the best jitter performances are by descending order for Open, WPA and WPA2 PTP links (Table I). For PTMP links, the best jitter performance is also for Open links (Table I). But average jitter performance for PTMP gets degraded when compared to PTP links. Figs. 9-11 show decreases in jitter with increasing nominal transfer rate.

Concerning average percentage datagram loss, the best performances were found by descending order for Open, WPA and WPA2 PTP links (Table I). This also applies for PTMP links (Table I). Percentage datagram loss performance gets degraded in passing from PTP to PTMP links.

Generally, in passing from Open links to WPA and WPA2 links, TCP throughput, jitter and percentage datagram loss were found to show performance degradations, as data lengths are increased due to encryption. Still, TCP throughput was not found very significantly affected by encryption, considering the experimental error. However, in passing from PTP to PTMP, TCP throughput gets visibly degraded, as in PTMP the 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.

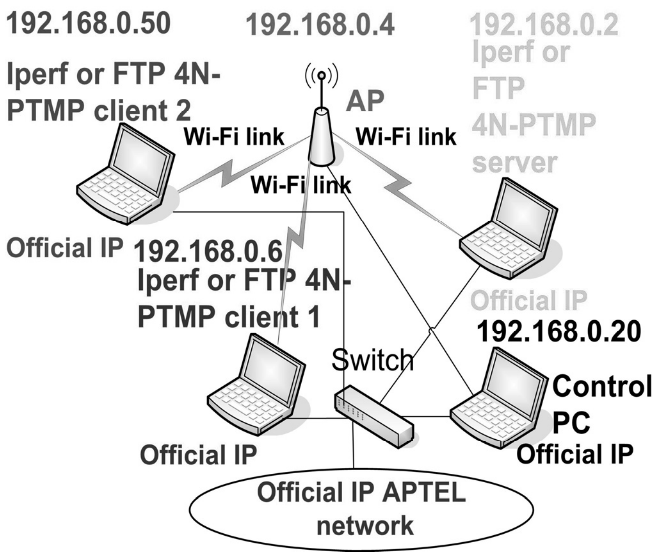

Fig. 1- Laboratory setup arrangement.

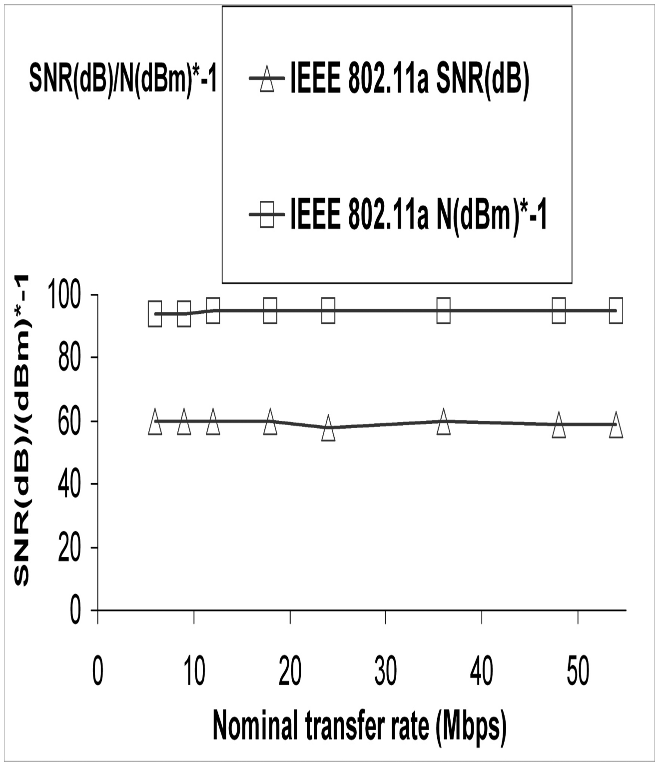

Fig. 2- Typical SNR (dB) and N (dBm). WPA2.

TABLE I
AVERAGE IEEE 802.11 A WPA2, WPA AND OPEN RESULTS: PTP; PTMP

Encryption	WPA2		WPA		OPEN	
Parameter/ Link type	**PTP**	**PTMP**	**PTP**	**PTMP**	**PTP**	**PTMP**
TCP throughput (Mbps)	14.8+-0.5	7.9+-0.2	14.6+-0.4	8.0+-0.2	15.0+-05	8.1+-0.2
UDP-jitter (ms)	2.6+-0.3	3.0+-0.6	2.3+-0.2	2.4+-0.5	2.2+-0.1	2.6+-0.2
UDP-% datagram loss	1.9+-0.1	2.9+-0.1	1.9+-0.3	2.6+-0.2	1.4+-0.1	1.7+-0.5

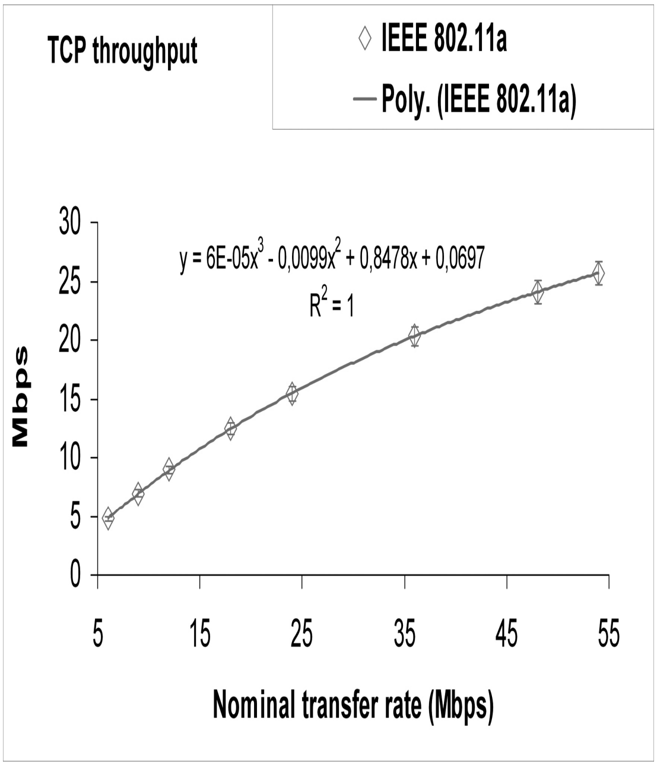

Fig.3- TCP throughput (y) versus nominal transfer rate (x). WPA2 PTP.

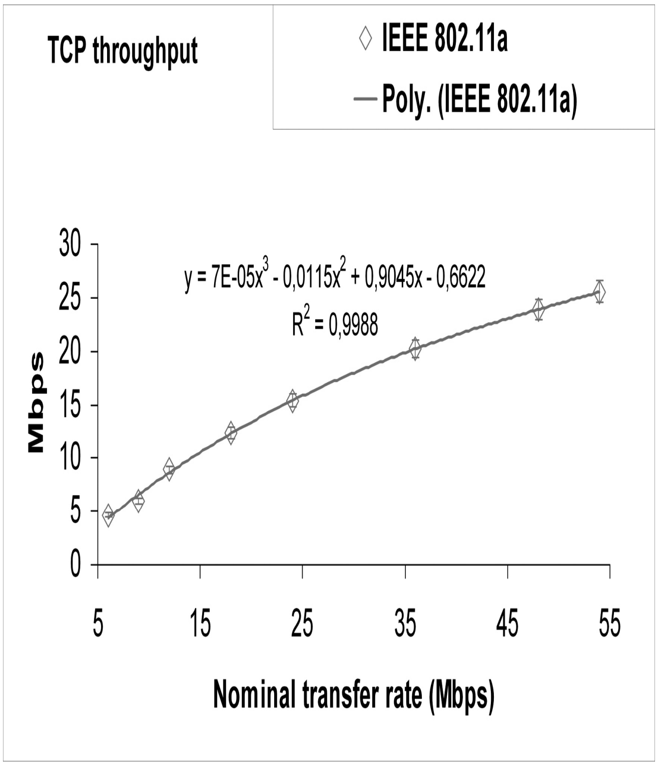

Fig. 4- TCP throughput (y) versus nominal transfer rate (x). WPA PTP.

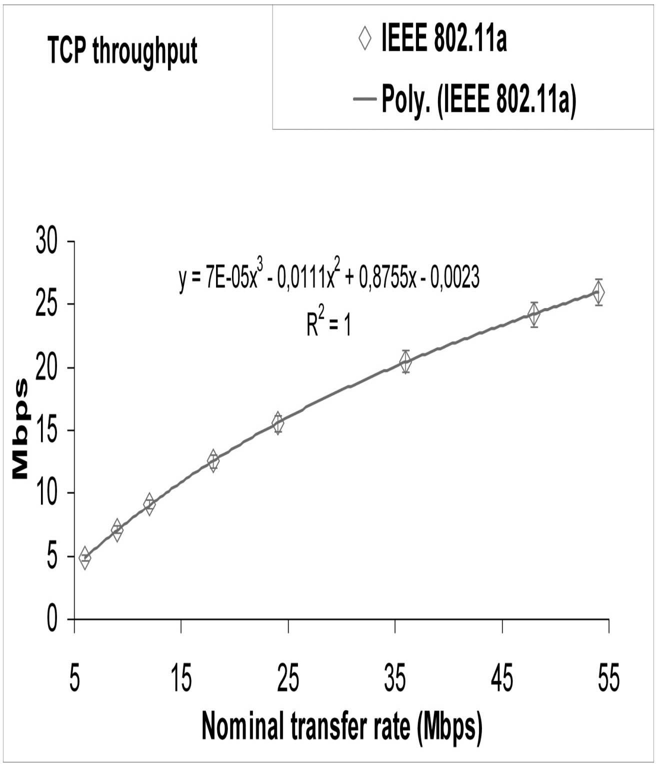

Fig. 5- TCP throughput (y) versus nominal transfer rate (x). Open PTP.

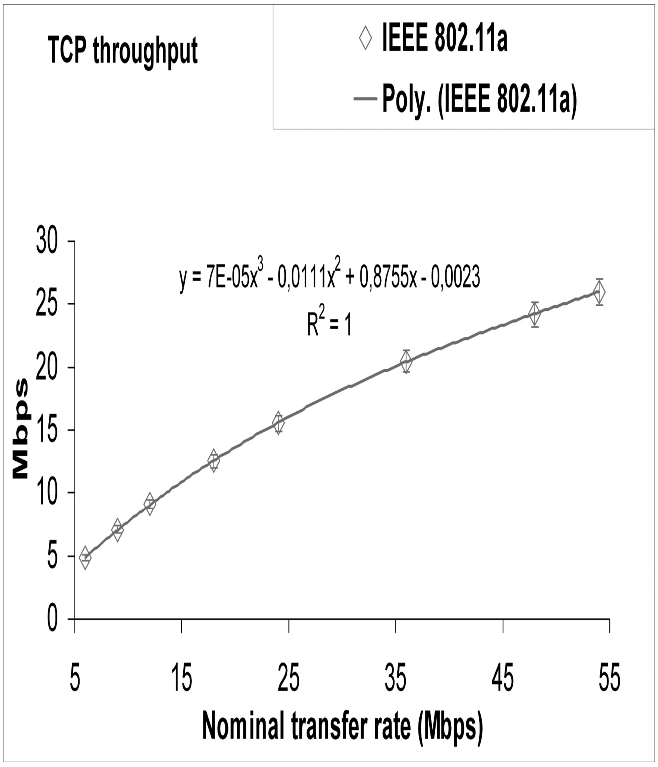

Fig. 7- TCP throughput (y) versus nominal transfer rate (x). WPA PTMP.

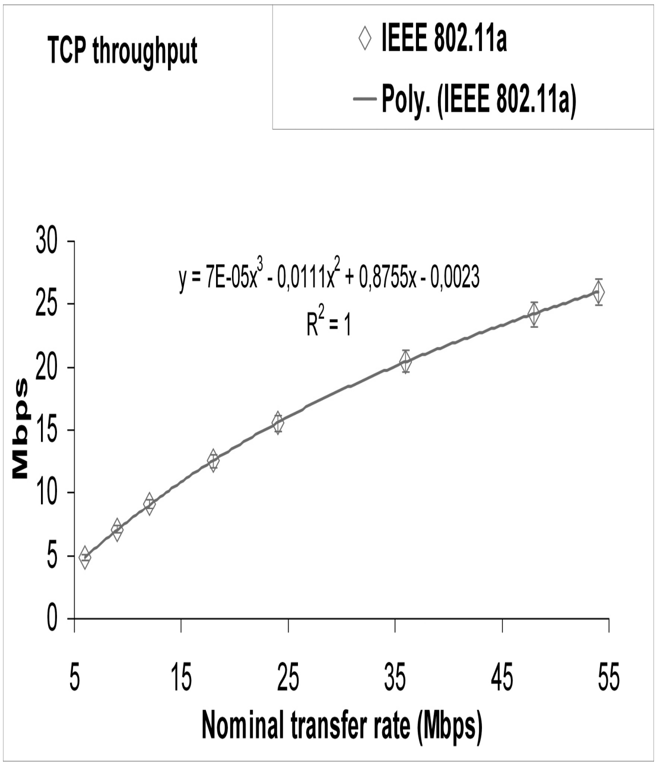

Fig. 6- TCP throughput (y) versus nominal transfer rate (x). WPA2 PTMP.

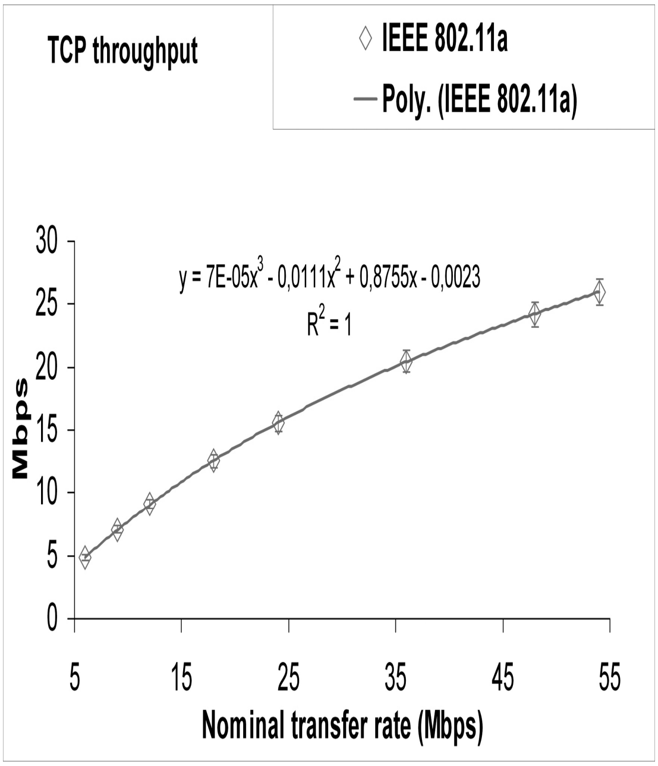

Fig. 8- TCP throughput (y) versus nominal transfer rate (x). Open PTMP.

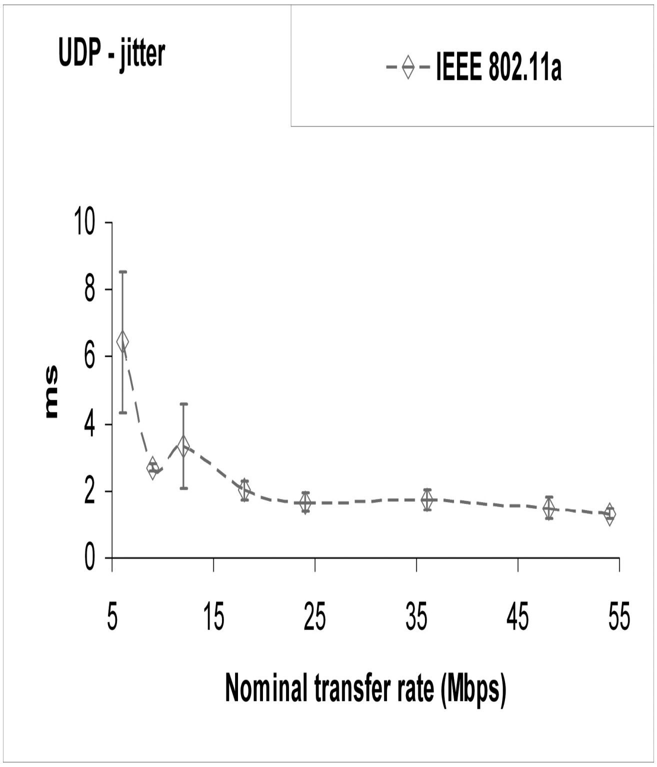

Fig. 9- UDP – jitter results versus nominal transfer rate. WPA2 PTP.

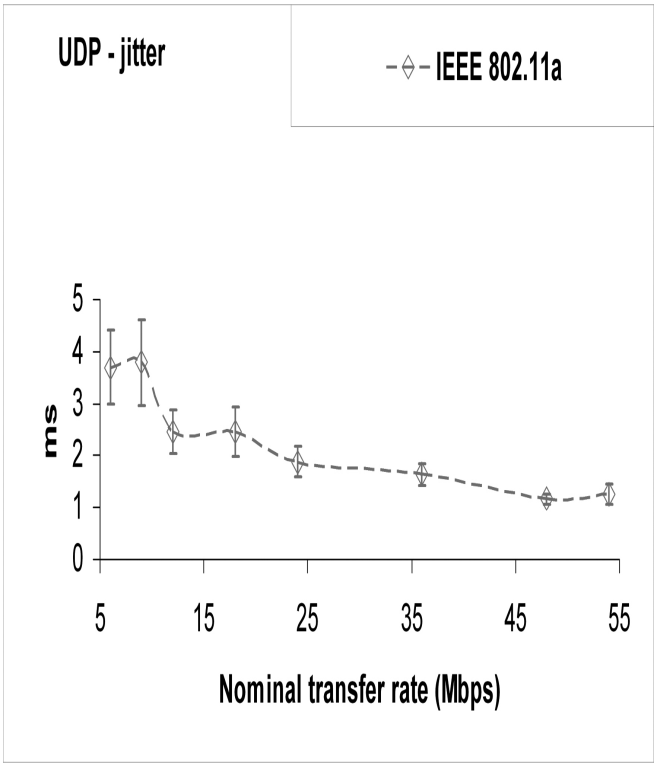

Fig. 10- UDP – jitter results versus nominal transfer rate. WPA PTP.

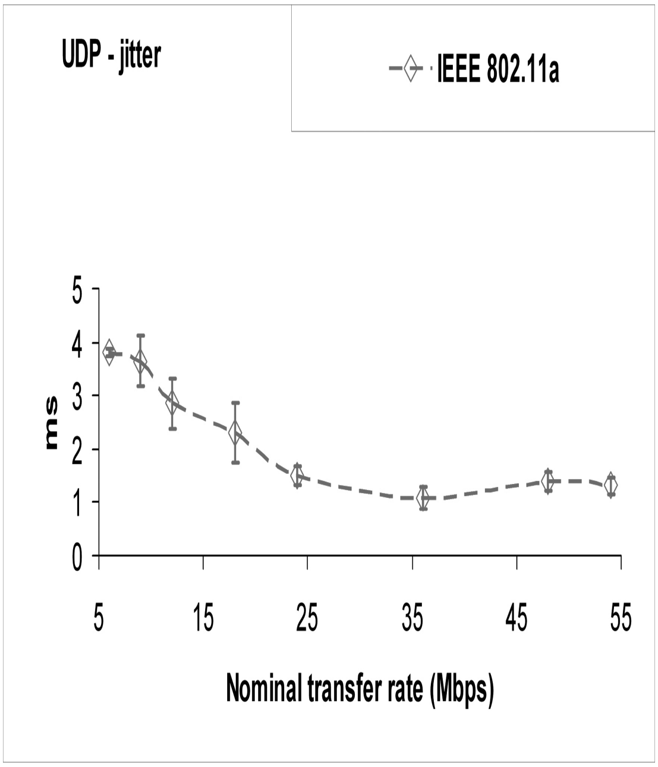

Fig. 11- UDP – jitter results versus nominal transfer rate. Open PTP.

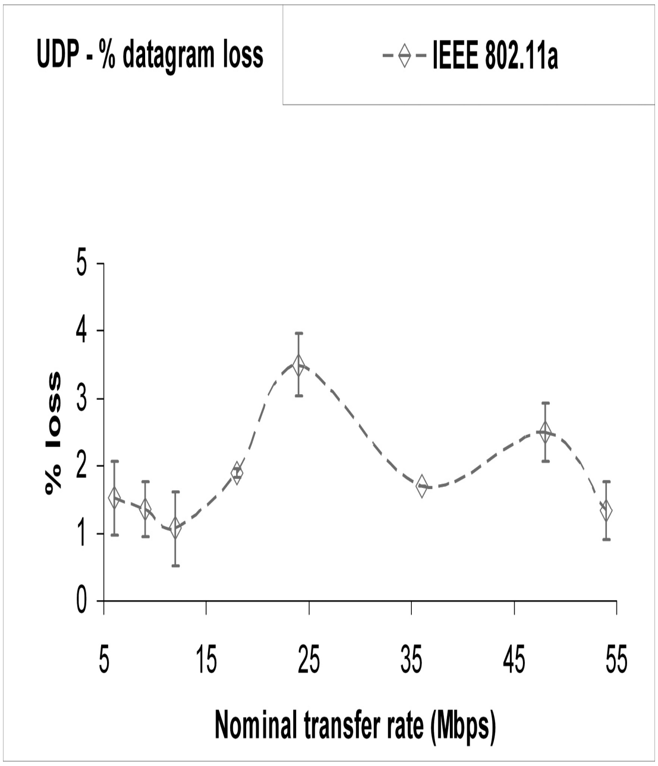

Fig. 12- UDP – percentage datagram loss results versus nominal transfer rate. WPA2 PTP.

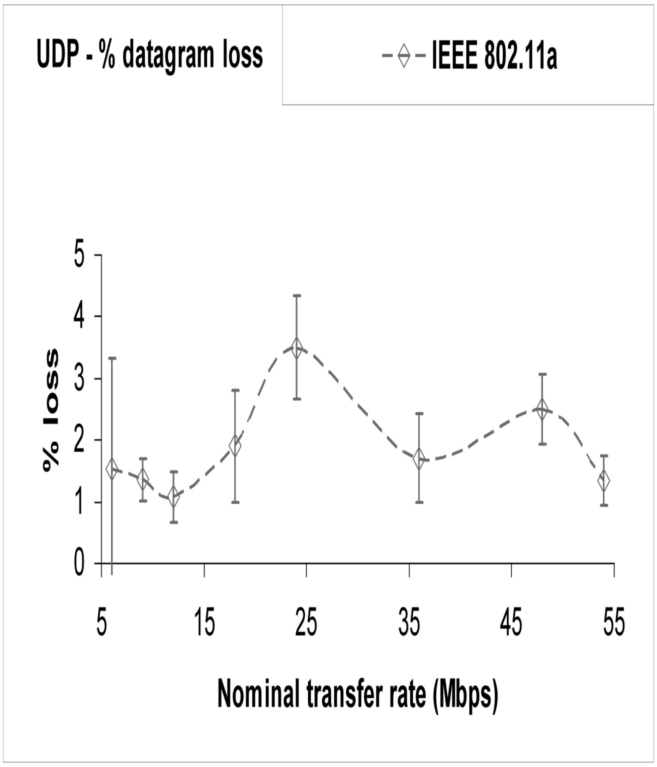

Fig. 13- UDP – percentage datagram loss results versus nominal transfer rate. WPA PTP.

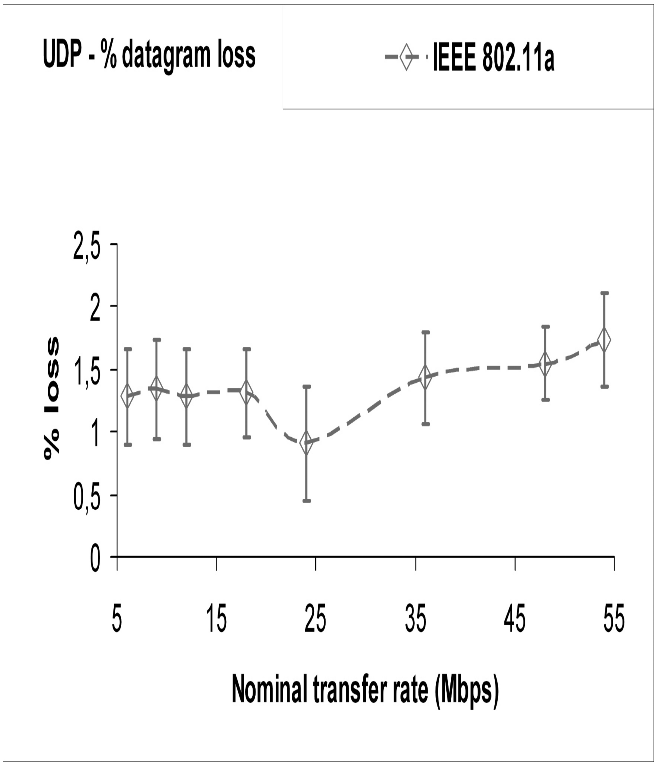

Fig. 14- UDP – percentage datagram loss results versus nominal transfer rate. Open PTP.

IV CONCLUSION

In the present work a versatile laboratory setup arrangement was planned 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 WPA and WPA2 encrypted links, and PTP and PTMP topologies.

Through OSI layer 4, TCP throughput, jitter and percentage datagram loss were measured and compared to corresponding results obtained for Open PTP and PTMP links.

In comparison to Open links, generally, TCP throughput, jitter and percentage datagram loss were found to show performance degradations for WPA and, to a larger extent, for WPA2 links. Data length is increased due to encryption. However, performance decreases in TCP throughput were found to be within the experimental error.

In passing from PTP to PTMP links, more significant performance degradations were found for TCP throughput, jitter and percentage datagram loss, where the processing requirements for the AP are higher so as to maintain links between two PCs. As CSMA/CA is the medium access control, the available bandwidth and the air time are divided by the nodes using the medium. Topology effects on performance were found far more significant than WPA and WPA2 encryption effects.

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.

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