TCP, UDP and FTP Performance Measurements of IEEE 802.11 a, g Laboratory WEP and WPA Point-to-Point Links

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Abstract—**The importance of wireless communications, involving electronic devices, has been growing. Performance is a crucial issue, leading to more reliable and efficient communications. Security is equally important. Laboratory measurements were performed on several performance aspects of Wi-Fi (IEEE 802.11 a, g) WEP and WPA point-to-point 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, mainly, open links. Conclusions are drawn about the comparative performance of the links.**

Keywords-IEEE 802.11a, g Point-to-Point Links; WEP; WPA; Wireless Network Laboratory Performance.

I. INTRODUCTION

Contactless communication techniques have been developed using mainly electromagnetic waves in several frequency ranges, propagating in the air. Wireless fidelity (Wi-Fi) and free space optics (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. Wi-Fi has been considerably expanding to complement the traditional wired networks. It has been used both in ad hoc mode and in infrastructure mode. In this case, a wireless local area network (WLAN), based on an access point (AP), permits Wi-Fi electronic devices to communicate with a wired based local area network (LAN) through a switch/router. At the personal home level, a wireless personal area network (WPAN) permits personal devices to communicate. Point-to-point and point-to-multipoint 2.4 and 5 GHz microwave links are used, with IEEE 802.11a, 802.11b, 802.11g and 802.11n standards [1]. Nominal transfer rates up to 11 (802.11b), 54 Mbps (802.11 a, g) and 600 Mbps (802.11n) are specified. Carrier sense multiple access with collision avoidance (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 point-to-point links [5], 802.11b performance in crowded indoor environments [6].

Performance has been a very important issue, resulting in more reliable and efficient communications. In comparison to traditional applications, new telematic applications are especially sensitive to performances. Requirements have been pointed out [7].

Wi-Fi security is very important. Microwave radio signals can be very easily captured as they travel through the air. Therefore, several security 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). 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 cyclic redundancy check 32 (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 point-to-point links. WPA implements the majority of the IEEE 802.11i standard [1]. It includes a message integrity code (MIC), replacing the CRC used in WEP. 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 advanced encryption standard (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 links [11], as well as very high speed FSO [12]. It is important to investigate the effects of increasing levels of security encryption on link performance. Therefore, in the present work new Wi-Fi (IEEE 802.11 a, g) results arise, using personal mode WPA, through OSI levels 4 and 7. Performance is evaluated in laboratory measurements of WPA point-to-point links using new available equipments. Comparisons are made to corresponding results obtained for WEP and open links.

The rest of the paper is structured as follows: Section II describes the state of the art, the problem and the solution.

Section III presents the experimental details i.e. the measurement setup and the procedure. The results and discussion are presented in Section IV. Conclusions are drawn in Section V.

II. State of the Art, Problem and Solution

In prior and actual state of the art, several Wi-Fi connections have been studied and implemented. Performance evaluation has been considered as a fundamentally important criterion to assess communications quality. The motivation of this work is to evaluate performance in laboratory measurements of WPA point-to-point links using new available equipments. Comparisons are made to corresponding results obtained for WEP and open links. This contribution permits to increase the knowledge about performance of Wi-Fi (IEEE 802.11 a,g) point-to-point links [4-6]. The problem statement is that performance needs to be evaluated under security encryption. 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).

III. Experimental Details

The measurements used a D-Link DAP-1522 bridge/access point [13], 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 [14]. The wireless mode was set to access point mode. The firmware from the manufacturer did not make possible a point-to-point link with a similar equipment. Therefore, a personal computer (PC) was used having a PCMCIA IEEE.802.11 a/b/g/n Linksys WPC600N wireless adapter with three internal antennas [15], to enable a PTP link to the access point. In every type of experiment, interference free communication channels were used (ch 36 for 802.11a; ch 8 for 802.11g). This was checked through a portable computer, equipped with a Wi-Fi 802.11 a/b/g/n adapter, running NetStumbler software [16]. WPA personal encryption was activated in the AP and the PC wireless adapter using AES and a shared key with 26 ASCII characters. WEP encryption was activated in both equipments, using 128 bit encryption and a 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 access points were close.

A laboratory setup has been planned and implemented for the measurements, as shown in Fig. 1. At OSI level 4, measurements were made for TCP connections and UDP communications using Iperf software [17]. For a TCP connection, TCP throughput was obtained. For a UDP communication with a given bandwidth parameter, UDP throughput, jitter and percentage loss of datagrams were determined. Parameterizations of TCP packets, UDP datagrams and window size were as in [10]. 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, representing 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 [18]. The scheme of Fig. 1 was also used for FTP measurements, where the FTP server and the client applications were installed in the PCs with IPs 192.168.0.2 and 192.168.0.6, respectively. The server PC also permitted manual control of the settings in the access point.

The server and client PCs were HP nx9030 and nx9010 portable computers, respectively, running Windows XP. They were configured to optimize the resources allocated to the present work. Batch command files have been written to enable the TCP, UDP and FTP tests. 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.

IV. Results and Discussion

The access point and the PC wireless network adapter were manually configured, for both standards IEEE 802.11 a, g, with typical fixed 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 the links at OSI layers 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 several experiments. This value was used as the bandwidth parameter for every corresponding UDP test, giving average jitter and average percentage datagram loss.

At OSI level 1, noise levels (N, in dBm) and signal to noise ratios (SNR, in dB) were monitored and typical values are shown in Fig. 2 and Fig. 3 for WPA and WEP links, respectively. They are similar to those obtained for open links.

The main average TCP and UDP results are summarized in Table I, both for WPA and open links. The statistical analysis, including calculations of confidence intervals, was carried out as in [19]. In Figs. 4-5, polynomial fits were made (shown as y versus x), using the Excel worksheet, to the 802.11 a, g TCP throughput data for WPA and open links, respectively, where R^2 is the coefficient of determination. It provides information about the goodness of fit. If it is 1.0, it indicates a perfect fit to data. It was found that the best TCP throughputs are for 802.11 a, for every link type, where the best SNR values were measured. The 802.11 a, g average data are reasonably close for all link types. The best average 802.11g TCP throughput is for open links. In Figs. 6-10, the data points representing jitter and percentage datagram loss were joined by smoothed lines. The jitter data show some fluctuations in some cases, mainly for 802.11a, as seen in Figs. 6 and 8. It was found that, on average, the best jitter performances are for 802.11 g for all link types. On average, for both 802.11 a and 802.11 g, the jitter performances were not found significantly sensitive, within the experimental errors, to link type. In Figs. 9-10, where percentage datagram loss data are shown, the error bars are well visible.

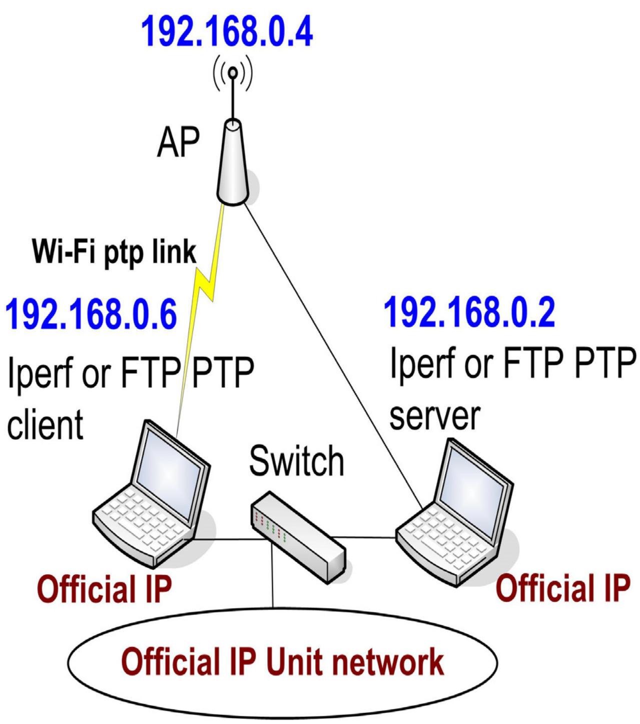

Figure 1. Laboratory setup scheme.

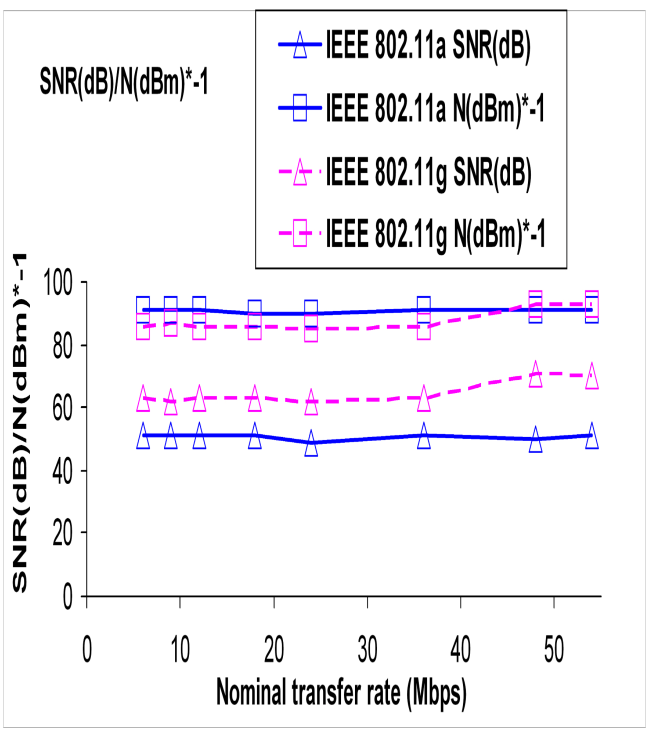

Figure 2. Typical SNR (dB) and N (dBm). WPA links.

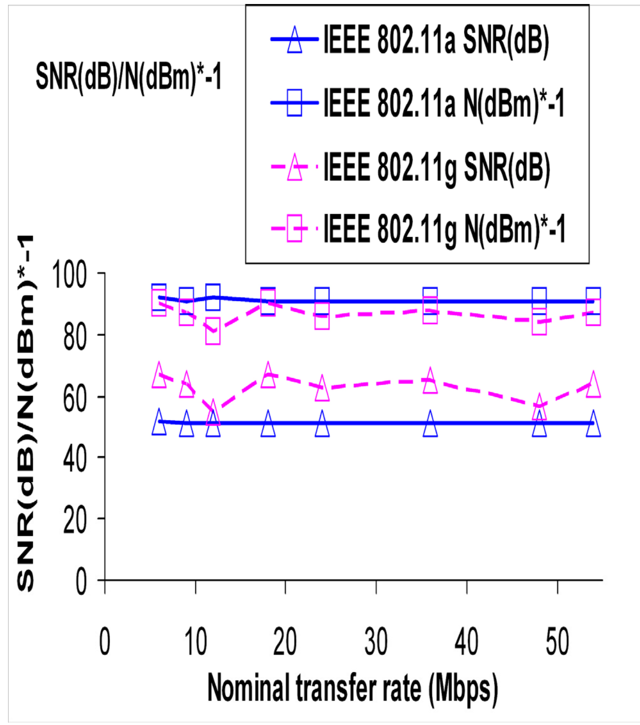

Figure 3. Typical SNR (dB) and N (dBm). WEP links.

TABLE I. AVERAGE WI-FI (IEEE 802.11 A, G) RESULTS; WPA AND OPEN LINKS

Link type	**WPA**		**Open**	
Parameter/ IEEE standard	***802.11a***	***802.11g***	***802.11a***	***802.11g***
TCP throughput (Mbps)	15.9 +-0.5	13.4 +-0.4	15.7 +-0.5	14.5 +-0.4
UDP-jitter (ms)	2.5 +-0.5	2.3 +-0.1	2.8 +-0.2	2.3 +-0.1
UDP-% datagram loss	1.2 +-0.2	1.8 +-0.2	0.7 +-0.1	1.2 +-0.1
FTP transfer rate (kbyte/s)	1765.4 +-70.7	1450.6 +-58.0	1745,2 +-69.8	1526.9 +-61.1

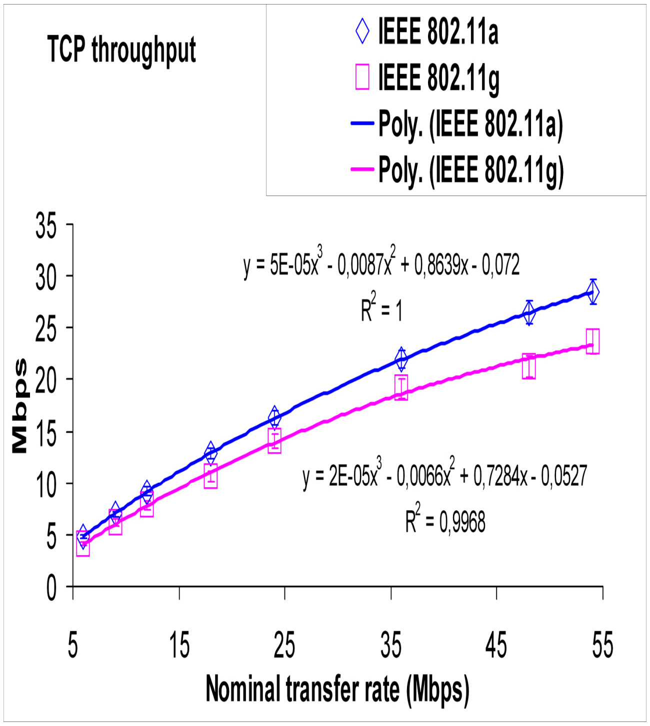

Figure 4. TCP throughput (y) versus technology and nominal transfer rate (x). WPA links.

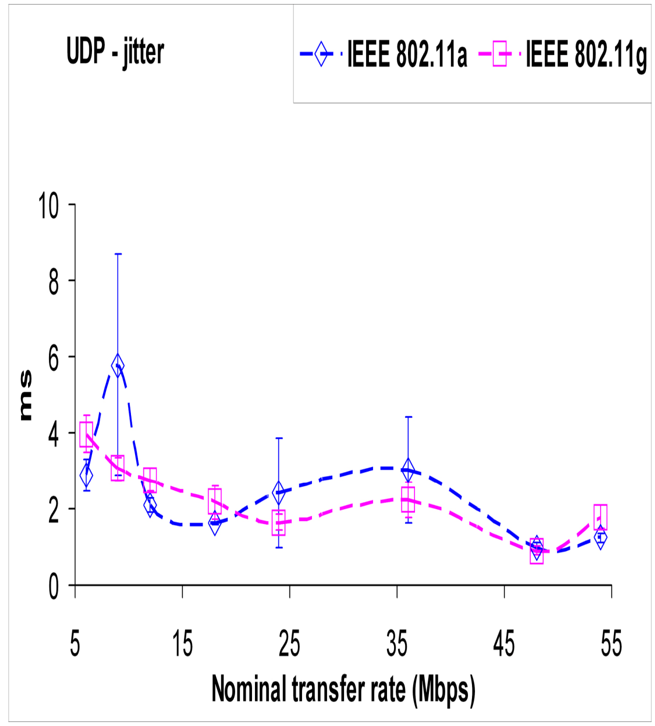

Figure 6. UDP – jitter results versus technology and nominal transfer rate. WPA links.

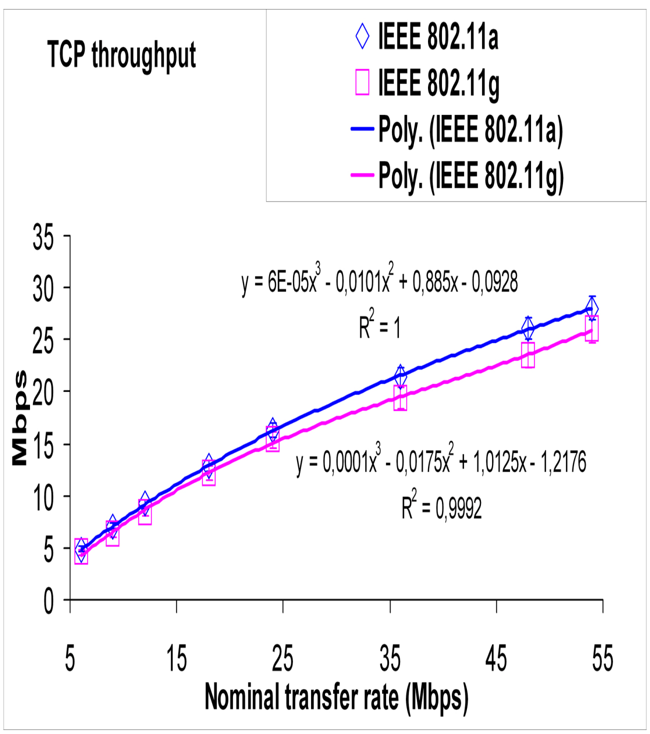

Figure 5. TCP throughput (y) versus technology and nominal transfer rate (x). Open links.

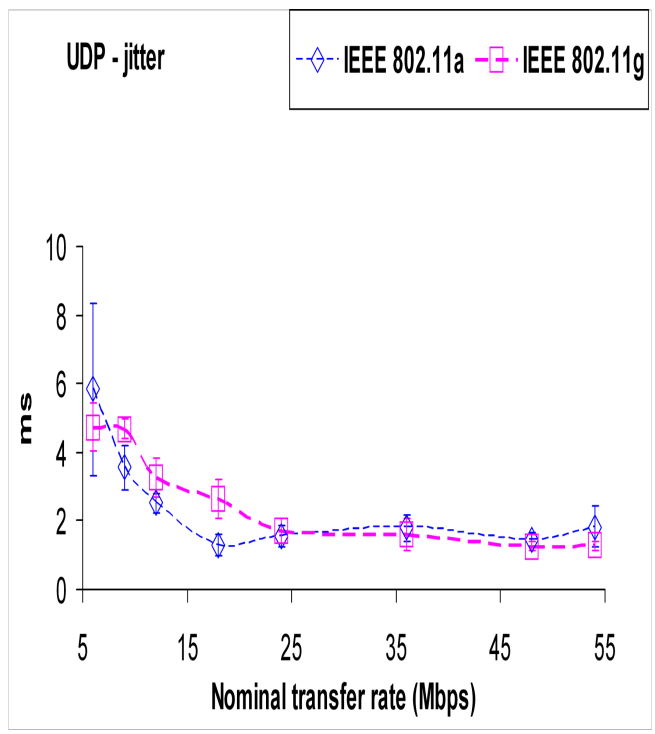

Figure 7. UDP – jitter results versus technology and nominal transfer rate. WEP links.

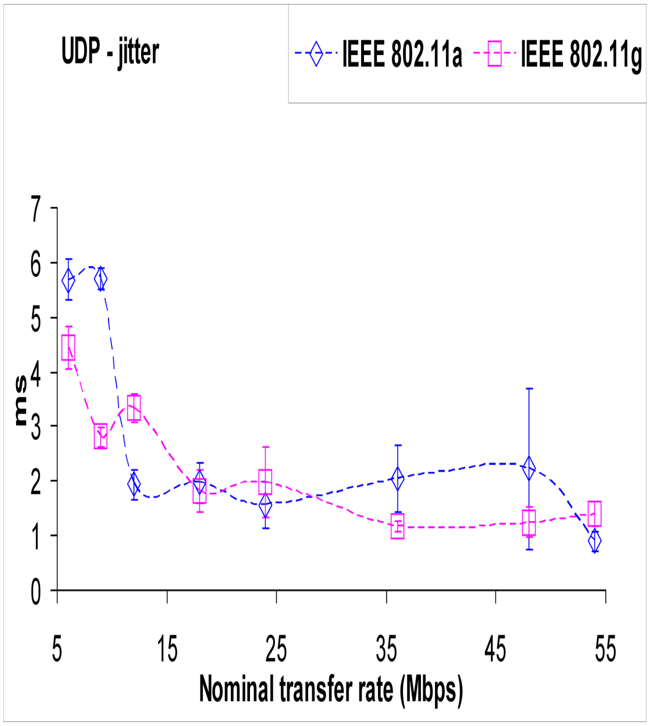

Figure 8. UDP – jitter results versus technology and nominal transfer rate. Open links.

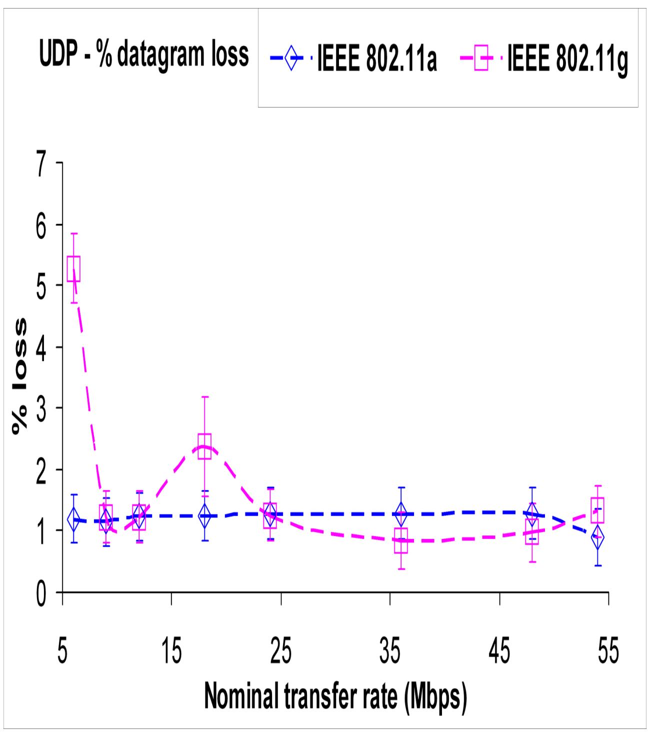

Figure 9. UDP – percentage datagram loss results versus technology and nominal transfer rate. WPA links.

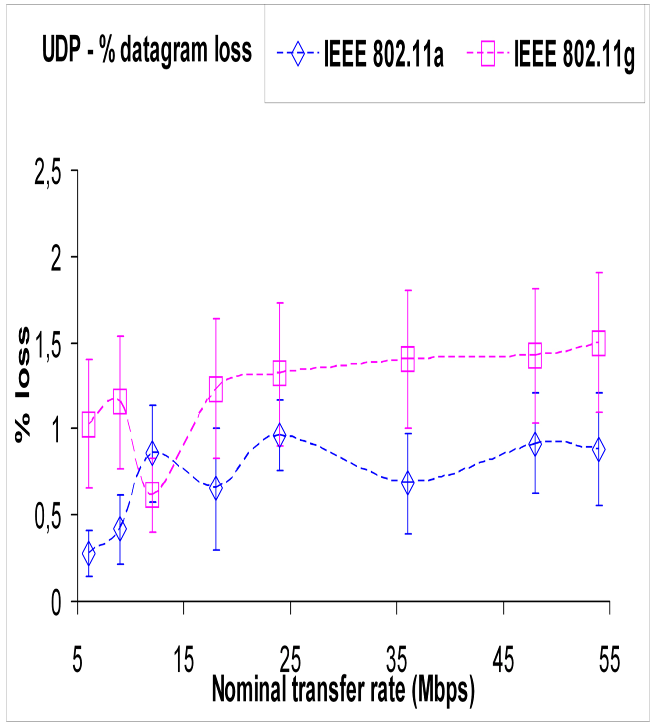

Figure 10. UDP – percentage datagram loss results versus technology and nominal transfer rate. Open links.

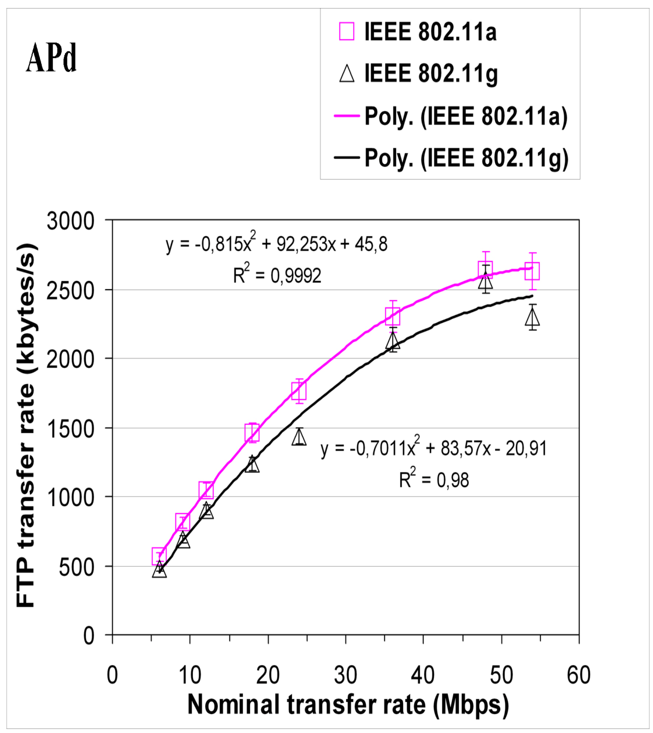

Figure 11. FTP transfer rate (y) versus technology and nominal transfer rate (x). WEP links.

The best performances were for 802.11 a for both link types. Increasing security encryption was found to degrade performance for both standards 802.11 a,g. This is expected due to increased data length.

At OSI level 7, we measured the FTP transfer rates versus nominal transfer rates configured in the access points for IEEE 802.11 a, g as in [11]. The average results thus obtained are summarized in Table I, both for WPA and open links. In Fig. 11 polynomial fits are shown to 802.11 a, g data for WEP links. The results show the same trends found for TCP throughput.

Generally, except for 802.11g TCP throughput and 802.11 a,g percentage datagram loss, where increasing security encryption was found to degrade performances, the results measured for WPA links were found to agree, within the experimental errors, with corresponding data obtained for all link types.

V. Conclusion and Future Work

A new laboratory setup arrangement has been 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 b,g) in WPA point-to-point links.

Through OSI layer 4, TCP throughput, jitter and percentage datagram loss were measured and compared for WPA, WEP and open links. It was found that the best TCP throughputs were found for 802.11a, for every link type. Generally, except for 802.11g TCP throughput and 802.11 a,g percentage datagram loss, where increasing security encryption was found to degrade performances, the results measured for WPA links were found to agree, within the experimental errors, with corresponding data obtained for all link types. Jitter performances were not found significantly sensitive, within the experimental errors, to link type.

At OSI layer 7, FTP performance results have shown the same trends found for TCP throughput.

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

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