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Performance Evaluation of IEEE 802.11a 54 Mbps Open Laboratory Links

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***Abstract*—The increasing importance of wireless communications, involving electronic devices, has been widely recognized. Performance is a fundamental 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 54 Mbps Open links. Our study contributes to 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 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 point-to-multipoint links. Conclusions are drawn about performance of the links.**

***Index Terms*—Wi-Fi; WLAN; IEEE 802.11a; TCP packet size; UDP datagram size; Point-to-Point and Point-to-Multipoint Open Links; Wireless Network Laboratory Performance.**

I. Introduction

Electromagnetic waves in several frequency ranges, propagating in the air, have decisively contributed to the development of contactless communication technologies. Typical examples of wireless communications technologies are wireless fidelity (Wi-Fi) and free space optics (FSO), using microwaves and laser light, respectively. Their importance and utilization have been growing worldwide.

Wi-Fi uses microwave technology. It gives versatility, mobility and favourable prices. The importance and utilization of Wi-Fi have been increasing. It is a complement to traditional wired networks. Both ad hoc and infrastructure modes are used. In this latter case a wireless access point, AP, provides communications of Wi-Fi electronic devices with a wired based local area network (LAN) through a switch/router. In this way a wireless local area network (WLAN), based on the AP, is set. At the home level, personal devices are permitted to communicate through a wireless personal area network (WPAN). Point-to-point (PTP) and point-to-multipoint (PTMP) microwave links are used in the 2.4 and 5 GHz bands, with IEEE 802.11a, 802.11b, 802.11g and 802.11n standards [1]. The increasing use of the 2.4 GHz band has led to considerable electromagnetic interference. Therefore, the use of the 5 GHz band is interesting, in spite of larger absorption and shorter ranges. Wi-Fi communications are not significantly affected by rain or fog, as wavelengths are in the range 5.6-12.5 cm. On the contrary, rain or fog significantly degrade FSO communications, as the typical wavelength range for the laser beam is 785-1550 nm.

Wi-Fi has nominal transfer rates up to 11 (802.11b), 54 Mbps (802.11 a, g) and 600 Mbps (802.11n). The medium access control of Wi-Fi is carrier sense multiple access with collision avoidance (CSMA/CA). 802.11a,g. provide 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. 802.11a and 802.11g work in the 2.4 and 5 GHz bands respectively.

Studies are available on wireless communications, wave propagation [2,3], practical realizations 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 increase has been a fundamental issue, giving more reliable and efficient communications. New telematic applications are specially sensitive to performances when compared to traditional applications. Requirements have been published [7].

Wi-Fi security is critically important. Microwave radio signals travel through the air and can be very easily captured. 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).

Several performance measurements have been published for 2.4 and 5 GHz Wi-Fi Open [8-9], WEP [10], WPA[11] and WPA2 [12] links, as well as very high speed FSO [13]. Performance evaluation of IEEE 802.11 based Wireless Mesh Networks has been given [14]. Studies are published on modelling TCP throughput [1]. A formula that bounds average TCP throughput is available [16].

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It is worthwhile investigating the effects of TCP packet size, UDP datagram size, network topology, increasing levels of security encryption, on link performance and compare equipment performance for several standards. Studies have been published for 5 GHz 802.11n Open links [17]. In the present work new Wi-Fi results arise from measurements on 802.11a Open links at 54 Mbps, namely through OSI level 4. Performance is evaluated and compared in laboratory measurements of Open PTP and three-node point-to-multipoint (PTMP) links using new available equipments. TCP throughput is measured versus TCP packet length. Jitter and percentage datagram loss are measured versus UDP datagram size.

In prior and actual state of the art, several Wi-Fi links and technologies have been researched. Performance evaluation has been pointed out as a crucially important criterion to assess communications quality. The motivation of this work is to evaluate and compare performance in laboratory measurements of Open PTP and PTMP 802.11a links at 54 Mbps using new available equipments. This contribution permits to increase the knowledge about performance of Wi-Fi (IEEE 802.11 a) links. The problem statement is that performance needs to be evaluated under several TCP and UDP parameterizations and link topologies under no security 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 percentage datagram loss (from UDP communications) versus UDP datagram size.

The rest of the paper is structured 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

Here we have used a HP V-M200 access point [18], 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 [19]. 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 [20], to enable three-node PTMP (PTMP) links to the access point. In every type of experiment, interference free communication channels were used (ch 36 for 802.11n). This was essentially verified through a portable computer, equipped with a Wi-Fi 802.11 a/b/g/n adapter, running Acrylic WiFi software [21]. No encryption was activated in the AP and the wireless adapters of the PCs. The experiments were made under far-field conditions. No power levels above 30 mW (15 dBm) were used, as the wireless equipments were nearby.

A versatile laboratory setup has been planned and implemented for the PTMP measurements, as shown in Fig. 1. Up to three wireless links to the AP are possible. At OSI level 4, measurements were made for TCP connections and UDP communications using Iperf software [22]. 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 parameter, 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 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 [23]. A control PC, with IP 192.168.0.20, was mainly used to control the settings of the AP. Three types of experiments are possible: 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 was the operating system. The PCs were prepared to enable 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 written as data files to the client PCs disks. Every PC had a second network adapter, to permit remote control from the official IP University network, via switch.

III. Results and Discussion

The wireless network adapters of the PCs were manually configured for a nominal rate of 54 Mbps. No encryption was used. Transmit and receive rates were monitored in the AP during the experiments. They were typically 54 Mbps. 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 WPA2 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 considered 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. Signal gives the strength of the radio signal the AP receives from a client PC, in dBm. Noise means how much background noise, due to radio interference, exists in the signal path between the client PC and the AP, in dBm. The lower the value is, the weaker the noise. SNR indicates the relative strength of client PC radio signals versus noise in the radio signal path, 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 exhibited good, high, SNR values.

The main average TCP and UDP results are summarized in Table I, for Open PTMP and PTP links. The statistical analysis, including calculations of confidence intervals, was made as in [24].

In Fig. 3 polynomial fits were made (shown as y versus x), using the Excel worksheet, to the TCP throughput data both for PTMP and PTP links, where R^2 is the coefficient of determination. It gives 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 PTP links (Table I). There is a very significant degradation of 45% in passing from PTP to PTMP. This is due to increase of processing requirements for the AP, so as to maintain links between two PCs. In comparison to Fig. 3 shows that there is a fair increase in TCP throughput with packet size. For small packets there is a large overhead, as there are small amounts of data that are sent in comparison to the protocol components. The role of the frame is very heavy in Wi-Fi. For larger packets, overhead decreases; the amount of sent data overcomes the protocol components

In Figs. 4-5, the data points representing jitter and percentage datagram loss were joined by smoothed lines. It was found that, on average, jitter performances are not very significantly different between PTP and PTMP links, considering two large error bars in the 8k and 16k data point of the PTMP curve (Fig. 4). Although the average values for PTMP are lower than for PTP. But we would expect a decrease of jitter performance in passing from PTP to PTMP due to increase of processing requirements for the AP, for maintaining links between two PCs. 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. Jitter increases for larger datagram sizes.

Concerning average percentage datagram loss, performances were found on average significantly better for PTP than for PTMP links (Table I). This is due to increase of processing requirements for the AP, for maintaining links between two PCs. Fig. 5 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 and percentage datagram loss were generally found to show performance degradations due to link topology, in passing from PTP to 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.

TCP and UDP performance aspects versus TCP packet size and UDP datagram size were found as given above.

In comparison to previous results for 5 GHz 802.11n Open links [17] the present results show that 5 GHz 802.11n gives better TCP, jitter and datagram loss performances than 802.11a.

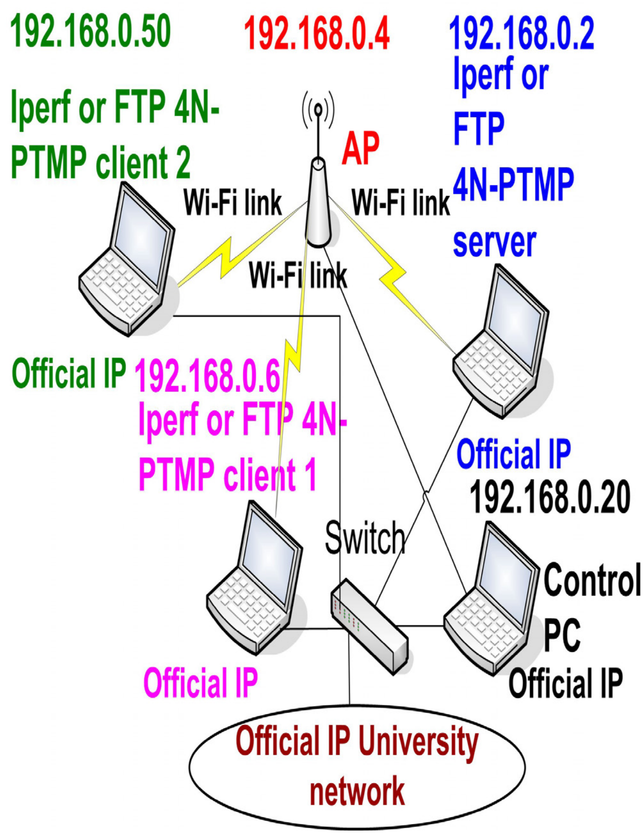

Fig. 1- Laboratory setup scheme.

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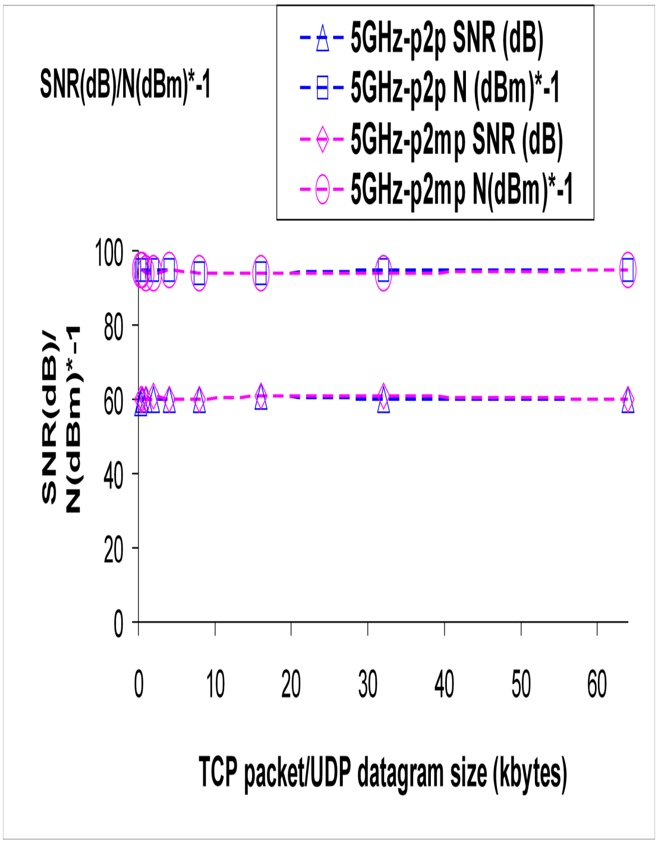

Fig. 2- Typical SNR (dB) and N (dBm).

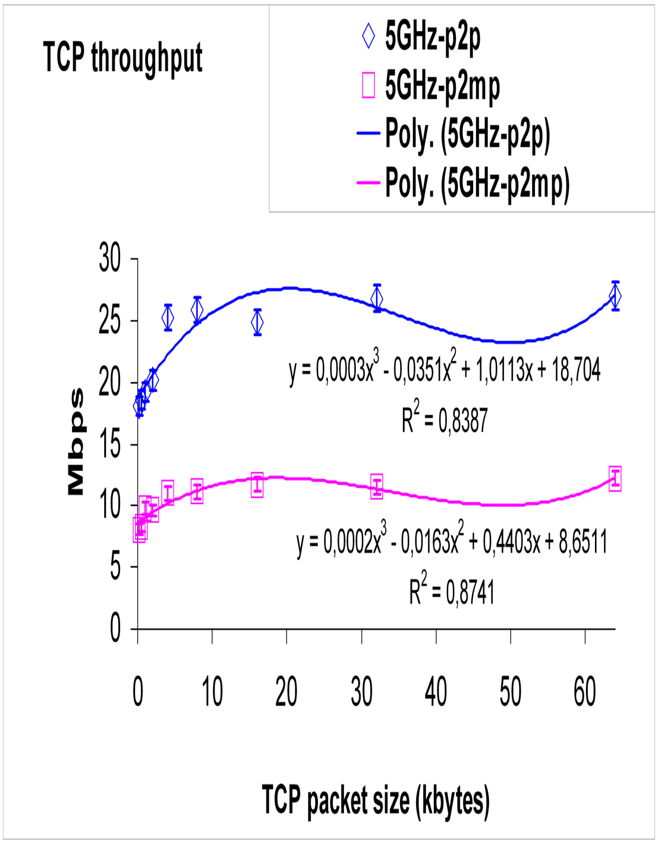

Fig.3- TCP throughput (y) versus TCP packet size (x).

TABLE I
AVERAGE IEEE 802.11A 5 OPEN RESULTS: PTP, PTMP

Parameter/ Link type	PTP	PTMP
TCP throughput (Mbps)	22.9+-0.7	10.4+-0.3
UDP-jitter (ms)	4.1+-0.6	2.9+-1.4
UDP-% datagram loss	1.2+-0.1	7.4+-0.5

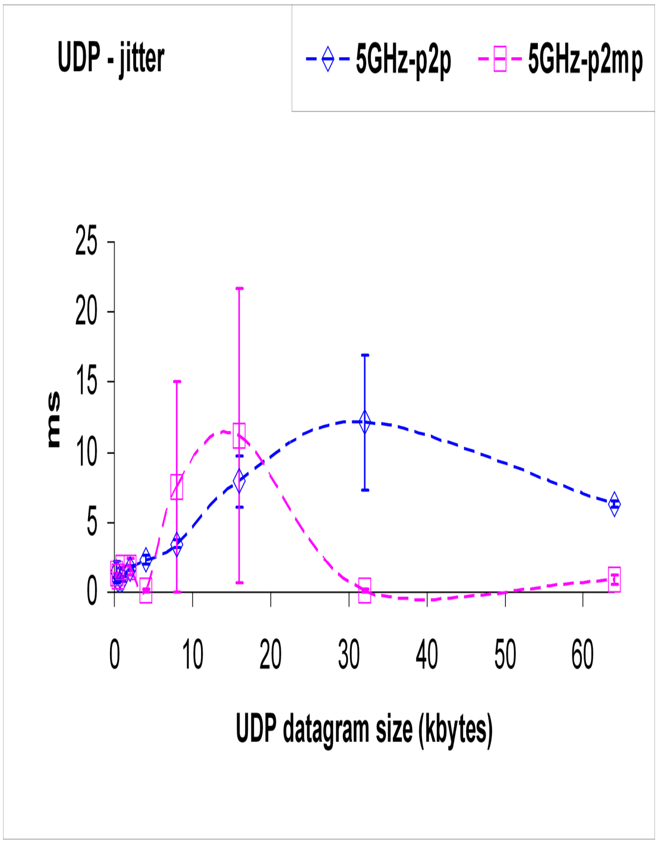

Fig. 4- UDP - jitter versus UDP datagram size.

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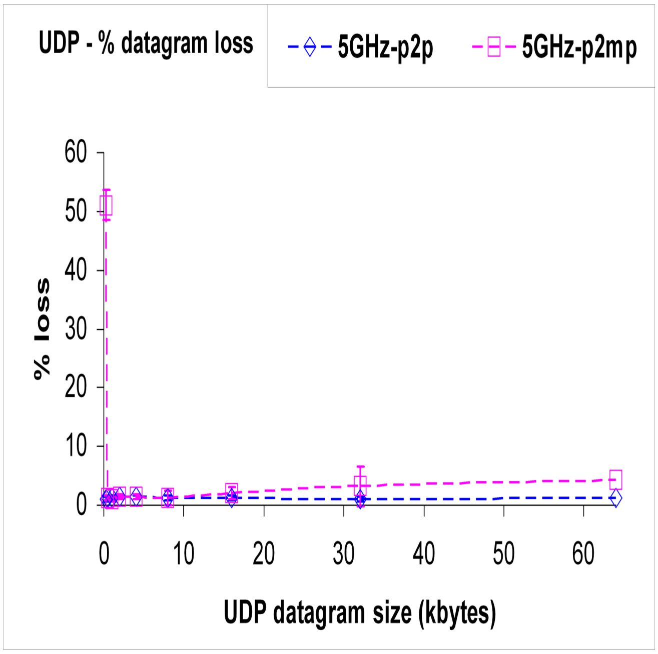

Fig. 5- UDP – percentage datagram loss versus UDP datagram size.

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 Open PTP and 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 Open PTP and 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 and percentage datagram loss were found to show significant performance degradations for PTMP links, where the AP experiments higher processing requirements for maintaining links between PCs. 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.

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