Performance Measurements of Open 5 GHz IEEE 802.11n 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 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 802.11n Open 5 GHz 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 and experiments. TCP throughput is measured versus TCP packet length. Jitter and percentage datagram loss are measured versus UDP datagram size. Data comparisons are made for both point-to-point and point-to-multipoint links. Conclusions are drawn about performance of the links.**

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

I. Introduction

Contactless communications techniques have been developed using mainly electromagnetic waves in several frequency ranges, propagating in the air. The importance and utilization of wireless fidelity (Wi-Fi) and free space optics (FSO) have been growing. They are important 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. Both ad hoc mode and infrastructure mode are possible. In this case an access point, AP, permits Wi-Fi electronic devices to communicate with a wired based local area network (LAN) through a switch/router. Thus a wireless local area network (WLAN), based on the AP, is created. At the personal home level a wireless personal area network (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 increasing use of the 2.4 GHz band is leading to growing electromagnetic interference. Therefore, there is a considerable interest in the 5 GHz band, in spite of larger absorption and shorter ranges. Wi-Fi communications are not significantly sensitive to rain or fog, as wavelengths are in the range 5.6-12.5 cm. On the contrary, FSO communications have been found to be affected by rain or fog, 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). Carrier sense multiple access with collision avoidance (CSMA/CA) is the medium access control. 802.11n offers higher data rates than 802.11a,g. These 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. 802.11n also uses OFDM, permitting, BPSK, QPSK, 16-QAM and 64-QAM. Up to four spatial streams are possible (four antennas), using multiple-input multiple-output (MIMO). MIMO permits to increase the capacity of a wireless link using multiple transmit and receive antennas to take advantage of multipath propagation. Antenna technology also favours 802.11n by introducing beam forming and diversity. Beam forming can be used both at the emitter and the receiver to achieve spatial selectivity to focus the radio signals along the path. Diversity uses, from a set of available multiple antennas, the best subset to obtain the highest quality and reliability of the wireless link. Coding rates up to 5/6 are possible and a 20/40 MHz channel. The standard guard interval (GI) in OFDM is 800 ns. Additional support for 400 ns GI provides an increase of 11% in data rate. Modulation and coding schemes (MCS) vary from 0 to 31. 600 Mbps are possible using MCS 31, four spatial streams, 64-QAM modulation, 5/6 coding rate, 40 MHz channel and 400 ns GI. 802.11n is suitable for transmitting e.g. high definition video and voice over IP (VoIP). It works in the 2.4 and 5 GHz microwave frequency bands.

There are studies on wireless communications, wave propagation [2,3], practical setups of WLANs [4], performance analysis of the effective transfer rate for 802.11b PTP links [5], 802.11b performance in crowded indoor environments [6].

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Performance has been a fundamental issue, resulting in 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 very important. Microwave radio signals can be very easily captured as they travel through the air. 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 made for 2.4 and 5 GHz Wi-Fi Open [8-9], WEP [10-11], WPA [12-13] and WPA2 [14-15] links, as well as very high speed FSO [16]. Performance evaluation of IEEE 802.11 based Wireless Mesh Networks has been given [17]. Studies are published on modelling TCP throughput [18]. A formula that bounds average TCP throughput is available [19].

It is important to investigate 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. In the present work new Wi-Fi (IEEE 802.11 n) results arise, using Open 5 GHz links, 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 investigated. Performance evaluation has been considered 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 5 GHz links using new available equipments. This contribution permits to increase the knowledge about performance of Wi-Fi (IEEE 802.11 n) links. The problem statement is that performance needs to be evaluated under several TCP and UDP parameterizations and link topologies. 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 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 measurements used a HP V-M200 access point [20], with three external dual-band 3x3 MIMO antennas, IEEE 802.11 a/b/g/n, software version 5.4.1.0-01-16481 and a 100-Base-TX/10-Base-T Allied Telesis AT-8000S/16 level 2 switch [21]. 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 [22], to enable three-node PTMP (PTMP) links to the access point. In every type of experiment, communication channels were used having no interference (ch 36 for 802.11a). This was mainly checked through a portable computer, equipped with a Wi-Fi 802.11 a/b/g/n adapter, running Acrylic WiFi software [23]. 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 close.

A versatile laboratory setup has been planned and implemented for the PTMP measurements, as shown in Fig. 1. It can use up to three wireless links to the AP. At OSI level 4, measurements were made for TCP connections and UDP communications using Iperf software [24]. 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 IP 192.168.0.6 and 192.168.0.50, were the Iperf clients (client1 and client2). Jitter, which represents 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 [25]. 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; 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 configured to maximize the resources allocated to the present work. Batch command files have been re-written to enable the new TCP, UDP and FTP 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 R&D Unit network, via switch.

III. Results and Discussion

The wireless network adapters of the PCs were manually configured for best rate. No encryption was used, since Open links were chosen. 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 Open 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 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.

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 means 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, both for Open PTMP and PTP links. The statistical analysis, including calculations of confidence intervals, was carried out as in [26].

In Fig. 3 polynomial fits were made (shown as y versus x), using the Excel worksheet, to the TCP throughput data for PTMP and PTP links, where R2 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 PTP links (Table I). There is a very significant degradation of 49% 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. Fig. 3 also shows that there is a fair increase in TCP throughput with packet size. For small packets the overhead is large, 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 generally better for PTP than for PTMP links (Table I). Jitter performance degrades, on average, by 33% 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. Fig. 4 also shows that the difference between PTP and PTMP is not, on average, so pronounced as for TCP throughput. 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. For PTMP the initial oscillatory behaviour of the curve is difficult to explain.

Concerning average percentage datagram loss, performances were found as better for PTP than for PTMP links (Table I). This is, again, due to increase of processing requirements for the AP, so as to maintain links between two PCs. Fig. 5 shows large percentage datagram losses for small sized datagrams, when the amounts of data to send are small in comparison to the protocol components. For larger datagrams, percentage datagram loss decreases. The best performance is on average for PTP links. For PTMP links percentage datagram loss degrades, on average, by 64 %.

TCP throughput, jitter 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.

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

Other experiments were made using 802.11a and Open links for nominal transfer rates varying from 6 to 54 Mbps. TCP packet size and window size were 8k bytes. UDP datagram size and buffer size were 1470 bytes and 8k bytes, respectively. Average results were found as follows: TCP throughput of 15.0 +- 0.5 Mbps for PTP and 8.1 +- 0.2 Mbps for PTMP; Jitter of 2.2 +- 0.1 for PTP and 2.6+- 0.2 for PTMP; percentage datagram loss of 1.4 +- 0.1 for PTP and 1.7 +- 0.5 for PTMP. Although these experiments are not directly comparable with the previous ones, it is however worthwhile mentioning some performance trends: for 802.11n TCP performance is higher; jitter performance is lower and percentage datagram loss is also lower (mainly due to influence of large losses for small datagram size in 802.11n results); performances for PTMP are lower than for PTP.

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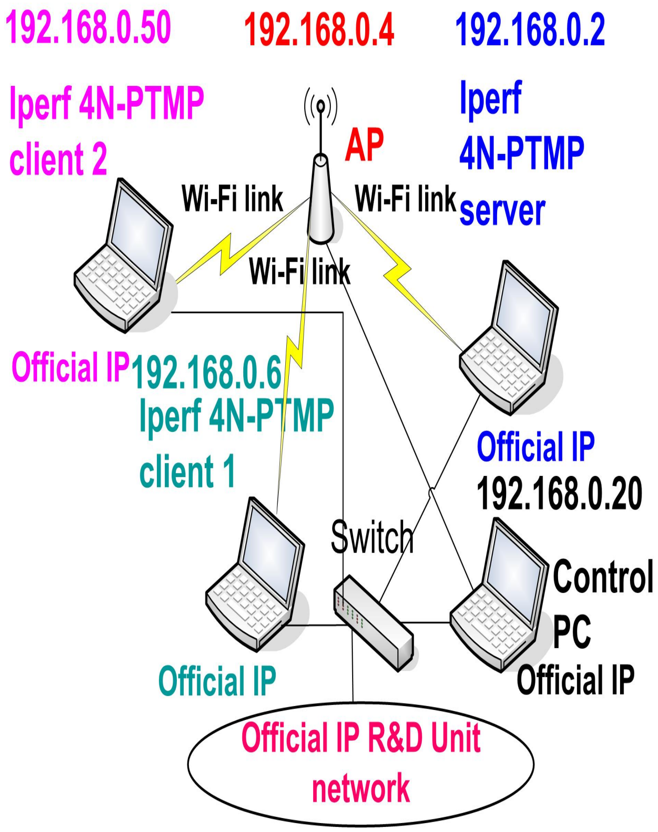

Fig. 1- Laboratory setup scheme.

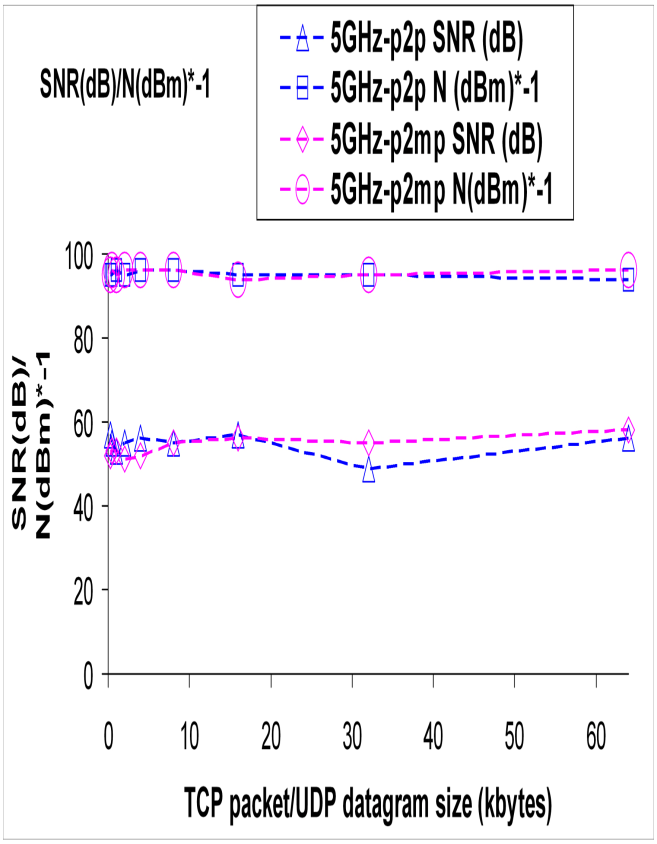

Fig. 2- Typical SNR (dB) and N (dBm).

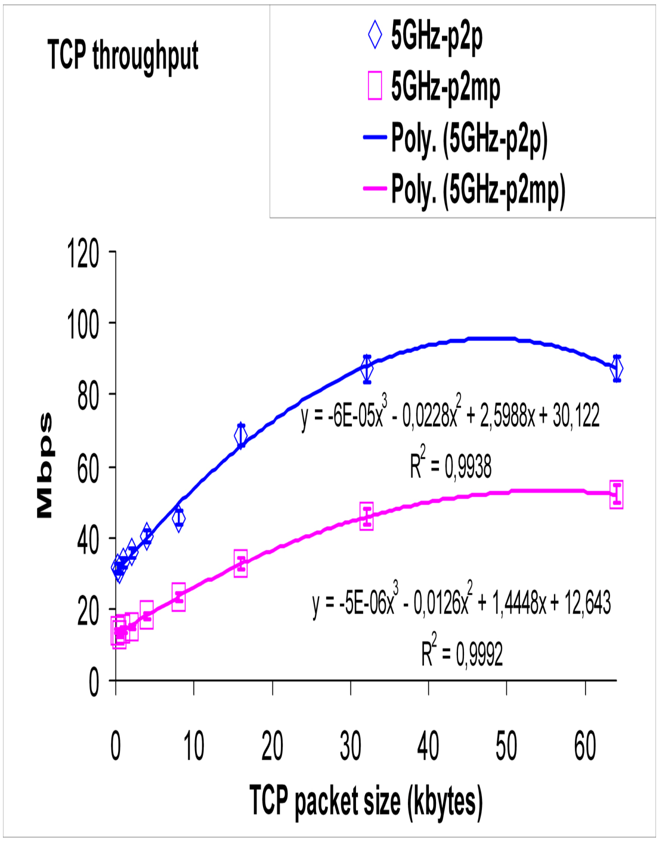

Fig.3- TCP throughput (y) versus TCP packet size (x).

TABLE I
AVERAGE IEEE 802.11N 5 GHZ OPEN RESULTS: PTP; PTMP

Link type	**Open PTP**	**Open PTMP**
TCP throughput (Mbps)	51.2 +-1.5	25.3 +-0.8
UDP-jitter (ms)	1.8 +-0.1	2.4 +-0.2
UDP-% datagram loss	3.3 +-0.3	5.4 +-0.2

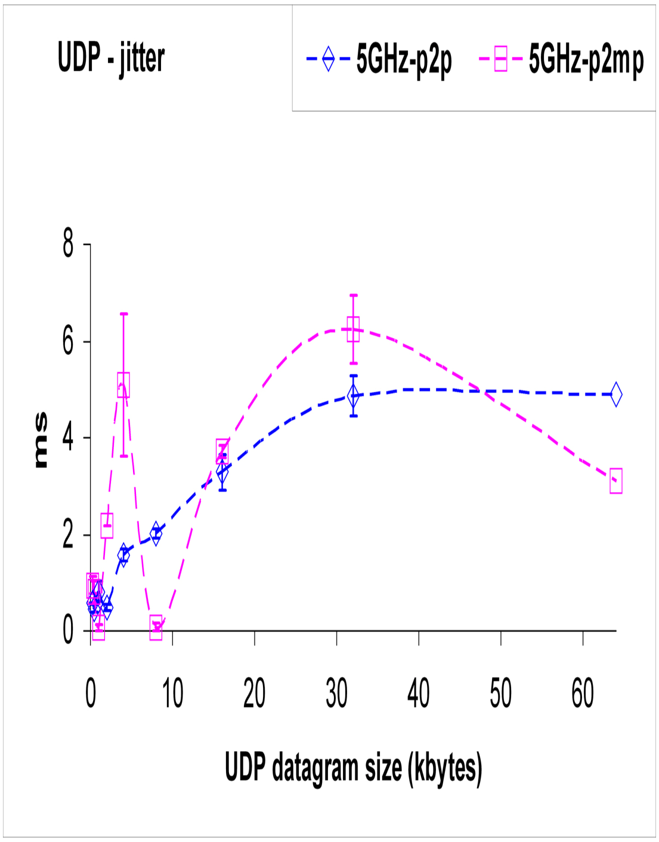

Fig. 4- UDP - jitter versus UDP datagram size.

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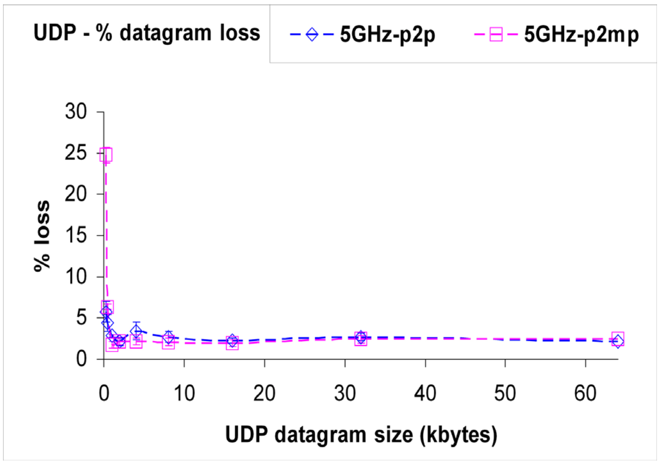

Fig. 5- UDP – percentage datagram loss versus UDP datagram size.

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 n) in 5 Ghz 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. Generally 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. In comparison to PTP links, TCP throughput, jitter and percentage datagram loss were found to show significant performance degradations for PTMP links, where the AP experiments higher processing requirements so as to maintain links between PCs. 802.11n results were found to show larger TCP throughput performance than for 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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