Evaluation of Power Line Communication Equipment in Home Networks

Anna Papaioannou, *Student Member, IEEE*, and Fotini-Niovi Pavlidou, *Senior Member, IEEE*

***Abstract*—In this paper, we examine the performance of power line communication equipments (ethernet–to–powerline adapters) that come from different vendors and are based on different technologies and standards. The scope is to investigate commercially available power line communications (PLC) equipment in their actual working environment under real conditions. Coexistence issues are studied, as well as the possible degradation of performance in case powerline adapters from different manufacturers and technologies are simultaneously operating in the powerline network under consideration. The influence of potential noise sources (ac adaptors, cell phone chargers), as well as plug-in cases that are not recommended by the manufacturers but are, however, convenient in domestic grids (power strips, extension cords), are also examined.**

***Index Terms*—Coexistence, in-home grid, interference, powerline communications (PLC), powerline-to-ethernet adapter.**

I. Introduction

THE recent advances on power line communications (PLC) allow for in-home networking, in-building internet access, home networking, multimedia and triple-play services. Using the existing indoor powerline grid for networking and internet access offers many benefits: no extra wiring is needed, any electrical outlet can easily be turned to an access point by just plugging in the PLC equipment, usually no complicated settings are required and what is more, high speed and reliable communication can be provided achieving rates that are comparable with wireless LAN systems.

Nowadays a large variety of PLC equipment, such as Ethernet–to–powerline adapters, is available at the market. However, not only different technologies, but also PLC adapters of the same technology and different manufacturers cannot ensure interoperability and/or coexistence with each other.

Coexistence is defined [1] as the operation of two or more PLC technologies or applications sharing the same common medium to provide communications services. However, the differing technologies will not communicate between each other. Coexistence is needed between access/in-home and in-home/in-home systems. An example of coexistence is in-premise devices that can recognize the presence of an access service network sharing the same power lines medium. The two technologies recognize that the other exists and therefore do not hinder the communications of the other. Instead, through time or frequency domain, the medium is shared by the two technologies [1].

Interoperability is defined as differing technologies or applications that can not only recognize a different technology sharing the same wire but can also communicate with the differing technology. An example of interoperability is an in-premise device that can communicate with an access network service provider's equipment [1].

However, the road from simple coexistence to full interoperability seems to be long. In [2], the current standards for coexistence in PLC are reviewed and three different coexistence mechanisms are proposed. The authors also describe the objectives of a coexistence solution: these should be to optimize the aggregated performance of the coexisting systems as well as to be vendor independent. It should be physical (PHY) layer independent, should allow quality of service (QoS) and maximize the resources available. It should also minimize the number of cases that coexistence mechanisms are required when interference is low and can be considered as any other present noise.

The Universal Powerline Association (UPA) has published technology specifications for in-home/in-home coexistence on 2005 [1]. Furthermore, the Open PLC European Research Alliance (OPERA) has delivered specification (deliverable D18) for an access/in-home PLC coexistence mechanism and there exists a working group that follows up the influence of the access/in-home coexistence specification [3]. IEEE P1901 Working Group [4] is currently working on the selection of the technical proposal regarding coexistence/interoperability requirements for inclusion as a part of the baseline P1901 draft standard. The recent progress is that the confirmation vote on the CEPCA-SiConnect-HomePlug coexistence proposal was conducted at the meeting of the IEEE P1901 Working Group on December 2008. The proposal received affirmative votes from 100% of the working group and thus passed to become part of the baseline of the draft standard [4].

In-home PLC are also faced with interference and noise from electric appliances and loads that are randomly connected to and disconnected from the powerline grid, thus changing the network topology. The powerline channel suffers from multipath and the channel response varies both with time and frequency. Consequently, the powerline grid does not represent a favorable medium for broadband communications.

With suitable experimental measurements, it is possible to investigate the performance and quality of the medium

Manuscript received November 12, 2008; revised May 09, 2009. First published June 12, 2009; current version published September 16, 2009. This work was supported by the Greek General Secretariat for Research and Technology of the Hellenic Ministry of Development under Grant "PENED 2003".

The authors are with the Department of Electrical and Computer Engineering, Telecommunications Division, Aristotle University of Thessaloniki, Panepistimioupolis of Thessaloniki, 54124 Thessaloniki, Greece (e-mail: anpapai@auth.gr; niovi@auth.gr).

Digital Object Identifier 10.1109/JSYST.2009.2023202

access control (MAC) and PHY layer implementation of different powerline communication equipment [5]. Performance measurements and experimental evaluation of powerline equipment that is today commercially available (such as modems, ethernet to powerline adapters) can be found in the existing literature:

In [6], the transmission limits of the powerline channel are tested between one transmitting and one receiving node, each connected to a power line modem. The interference of electrical devices is evaluated with the use of a testing network, where a low-pass filter was added between the network under test and the outside world in order to block unrelated noises.

The performance of power line modems developed for use in residential communication networks is investigated in [7], where electrical loads were not taken into account in the evaluation process since the main goal was to extract information regarding the power distribution networks themselves.

In [8], the influence of the cell-phone chargers on PLC adapters representing different technologies from different vendors is studied and the UDP throughput for the various PLC adapters on the power line channels while charging the cell phone is presented. A noise cut transformer is used in the measurement system.

The work presented in [9] aims to verify if the specifications of pre-established service quality parameters of commercial Broadband Power Line (BPL) technology agree with practical results. The paper presents and discusses some measurement carried out from medium- and low- voltages networks when commercially available PLC terminals are used for data transmission in both indoor and outdoor environments.

Using an isolated basic powerline reference network [5], five pairs of commercially available Ethernet-to-powerline adapters are tested with respect to their ability to recover from a white noise overload, and one pair of adapters with respect to a pulsed noise overload. As the authors mention, what is missing from the existing literature is some coexistence measurements with two or more simultaneously operating powerline adapters.

In this paper we investigate the performance of PLC equipments when they operate in an actual indoor powerline network. The Ethernet–to–powerline adapters under test come from different vendors and represent different technologies, namely HomePlug 1.0, UPA Digital Home Specification (DHS) [1], and High Definition Power Line Communication (HD-PLC) [10].

In comparison to the existing literature, the presented measurements refer to real in-home environments, where no special changes have been made to the power line grid and both the existing topology and common domestic loads were present during the tests. In this way, the scope is to investigate commercially available PLC equipment in their actual working environment under real conditions. Furthermore, coexistence issues are studied, as well as the possible degradation of performance in case PLC adapters from different manufacturers and technologies are simultaneously operating in the powerline network under consideration. The influence of potential noise sources (ac adaptors, cell phone chargers), as well as of plug-in cases that are not recommended by the manufacturers, but are however convenient in domestic grids (power strips, extension cords), are also examined.

TABLE I
DESCRIPTION OF POWERLINE EQUIPMENT

Vendor	Model	Standard	Speed
Netgear	XE102	HomePlug 1.0	14 Mbps
Netgear	HDX101	UPA Digital Home Specification (DHS)	200 Mbps (real more than 80 Mbps)
Panasonic	BL-PA100A	HD-PLC	190 Mbps (70 Mbps real regarding UDP)

II. POWERLINE EQUIPMENT

A detailed description of the powerline equipment used for the measurements is given in the following and on Table I. The selection of powerline equipment was indicative regarding different technology classifications and families of equipment, rather than exhaustive as new PLC products are being available at the market with increasing rates.

The wall-plug Ethernet Extender Kit (Netgear XE102G) includes two XE102 powerline Ethernet adapters, which can deliver up to 14 Mbps wired speed covering up to 5000 square feet home area and are HomePlug 1.0 compatible. As the manufacturer notes, an XE102 may coexist with HomePlug 1.0 products, but it is not compatible or interoperable with Netgear HDX101 Ethernet adapter. The frequency band of operation is 4.3 MHz to 20.9 MHz.

The Netgear HDX101 powerline Ethernet adapters follow the UPA DHS and can offer up to 200 Mbps (with real throughput greater than 80 Mbps) for high-quality video, gaming and Voice over IP (VoIP). The power consumption is 6.3 W and the frequency band of operation 2 MHz to 32 MHz. An HDX101 may coexist with HomePlug 1.0 products, but it is not compatible or interoperable with Netgear XE102 and XE103 adapters [11]. By default, HDX101 devices check for the existence of HomePlug Ethernet units (for example XE102). If such device is detected by an HDX101 device, then all HDX101 units will switch to a mode where the HDX101 network will operate without interfering with HomePlug network. However, the ability to coexist with a HomePlug network comes with some performance cost.

The BL-PA100A Panasonic adapters follow the HD-PLC standard specification. They operate at the frequency band of 4 MHz to 28 MHz and use wavelet orthogonal frequency division multiplexing (OFDM). The actual maximum data transmission speed is about 70 Mbps (UDP) and the communication distance that can be covered is about 150 m (490 ft.) depending on the electrical environment. The power consumption is 4 W.

Potential noise sources, as it is mentioned at the product's instructions, are ac adaptors, cell phone chargers and battery chargers that may interfere with the performance of the adapter. It is recommended to plug the adapters directly to wall outlets and when this is impossible, to use a power strip without noise filter or surge protector and with as short ac cord as possible. It is also noted that the PLC adapters may interfere with PLC adapters which do not use the HD-PLC standard.

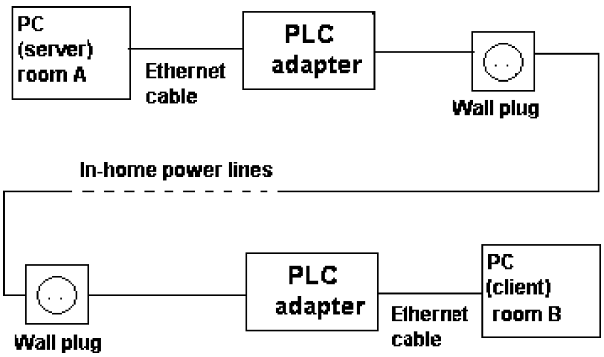

Fig. 1. Experimental measurement setup.

The transmission power levels of the PLC equipment under study should also be taken into consideration in order to present a detailed description of the powerline equipment under test. In [8], the power spectra of Panasonic and Netgear 200 Mbps adapters were measured at the frequency range up to 35 MHz, where it can be observed that generally the Netgear adapters present greater transmission power levels than Panasonic.

III. Performance Evaluation

A. Measurement Set-Up

The measurements took place in a 120 m^2 area apartment which is fed by a single-phase power installation in a seven-apartment building with a three-phase power installation, which is part of the residential power distribution network.

No noise filters or low-pass filters are used and all measurements were made considering the real deployment of an indoor PLC grid, whose parameters vary with time as domestic electrical loads are randomly connected and disconnected.

A desktop computer in room A of the apartment was considered as the server and a laptop computer (client) was connected to electrical wall outlet in room B that is crossways opposite to room A (or room C that is next to room A for one measurement as described at Section III-B3). Two powerline modems are used in order to establish communication between the two computers. The experimental measurement set-up can be seen at Fig. 1 and the powerline topology of the apartment at Fig. 9 (Appendix).

The Iperf tool [12] is used for the measurement of bandwidth, jitter and packet loss regarding UDP traffic. UDP traffic does not employ flow or error control mechanisms and it is used for real-time services such as video streams and VoIP. Jitter is calculated by Iperf as follows: the server computes the relative transit time as [server's receive time] minus [client's send time]. Jitter is the smoothed mean of differences between consecutive transit times.

B. Measurement Results

For varying sending data rates (offered load), the actual throughput, jitter and packet loss are measured. The maximum targeted sending rate is 100 Mbps. Each measurement is the average value of a one minute test when 1470-byte UDP datagrams are sent.

1) Netgear XE102: Figs. 2 and 3 present the measured throughput as a function of the offered load that varies from 1 to 16 Mbps at 2-Mbps intervals. The transmission time is 60 s for every offered load and the presented values are the average of the 60-s measurement.

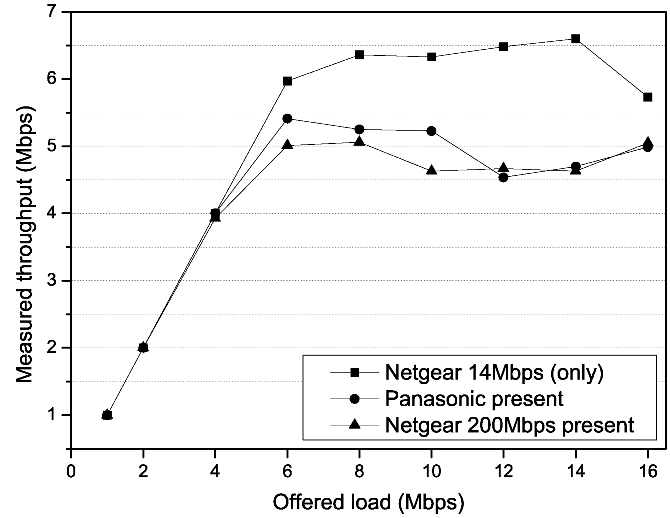

Fig. 2. Measured throughput as a function of offered load for the Netgear XE102 adapters regarding coexistence with other adapters.

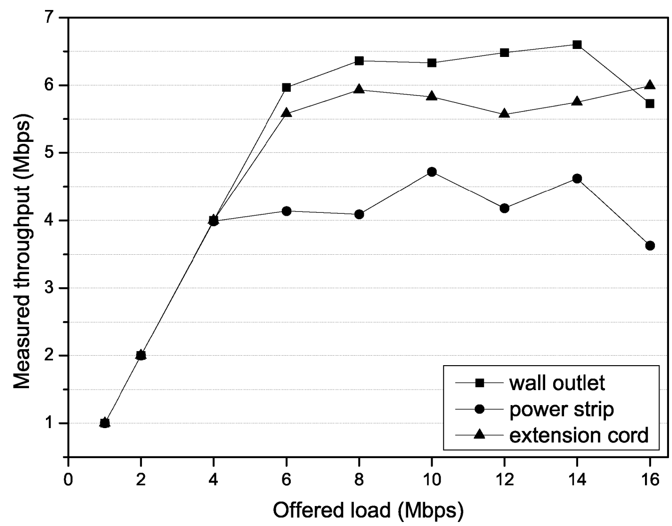

Fig. 3. Measured throughput as a function of offered load for the Netgear XE102 adapters regarding not recommended plug-in cases.

Three cases regarding the coexistence of the Netgear 14 Mbps adapters are examined at Fig. 2: when the Netgear 14-Mbps pair is the only operating pair in the considered powerline grid and while the Panasonic or the Netgear 200-Mbps pairs are simultaneously plugged in the grid but in other rooms of the apartment. It can be seen that the coexistence causes a decrease of throughput that is almost the same for Panasonic and the Netgear 200-Mbps pairs, with mean decrease values 19.3% and 22.17%, respectively.

Fig. 3 presents three cases regarding the various connection possibilities of the adapters: when they are plugged into an electrical wall outlet as it is recommended and when the not allowed power strip or extension cord are used. It can be observed that the extension cord affects slightly the operation of the Netgear 14 Mbps by decreasing a little the measured throughput (mean

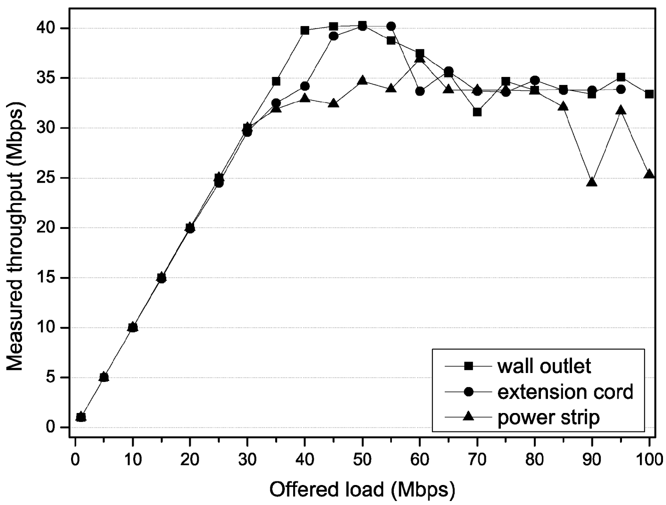

Fig. 4. Measured throughput as a function of offered load for the Netgear HDX101 adapters regarding not recommended plug-in cases.

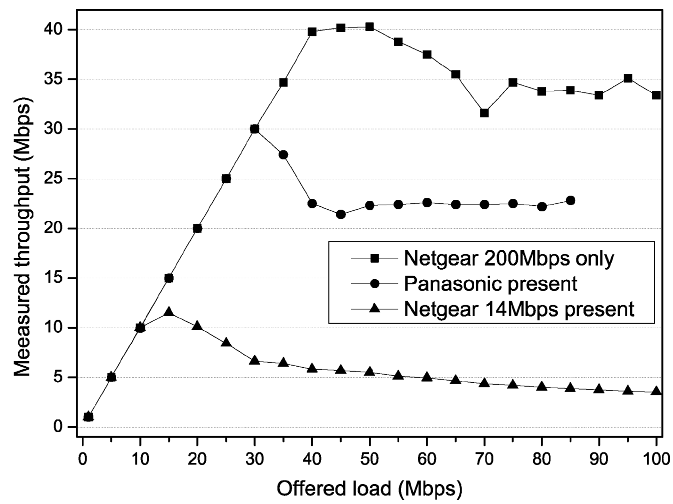

Fig. 5. Measured throughput as a function of offered load for the Netgear HDX101 adapters regarding coexistence with other adapters.

decrease value 9.62%). On the contrary, the use of the power strip deteriorates significantly the throughput and the observed mean decrease is 32.32%.

Regarding the packet loss, it remains very low for all test cases whereas the measured jitter values can be found at Table II (Appendix). It can be seen that the maximum average jitter value (4.892 ms) occurred when Panasonic adapters were operating simultaneously (coexistence case).

2) Netgear HDX101: The installation instructions advise users not to connect the HDX101 to a power strip, extension cord or surge protector as this may prevent them from working properly or degrade the network performance. However, these not-recommended plug-in cases could be convenient solutions in residential in-home environments, where the number of available wall outlets may be limited. For this reason, we tested three possible plug-ins of the Netgear adapters as shown at Fig. 4, namely into an electrical outlet, an extension cord of 5 m length or a power strip. The offered load varies from 1 Mbps to 100 Mbps at 5-Mbps intervals. It can be observed that the measured throughput is mostly affected by the use of the power strip with mean decrease 11.27%, whereas the mean throughput decrease due to the use of the extension cord is 4.82%.

The coexistence of Netgear 200 Mbps adapters is examined at Fig. 5, where two different pairs of adapters are operating simultaneously and not at the same rooms as the HDX101.

Regarding coexistence with Panasonic, the throughput stops to vary linearly with respect to the offered load when reaching 30 Mbps; after that point, throughput decreases (mean decrease value 36.92%).

As far as coexistence with the Netgear 14 Mbps pair is investigated, the HDX101 adapters are switch to a mode that allows them not to interfere with the Homeplug network, i.e., the Netgear 14 Mbps adapters. This setting option is available using the software that comes together with the HDX101 adapters. However, as was mentioned in Section II, this setting results in a performance cost and the throughput is severely degraded (mean decrease value 79.75%), since the maximum measured value is only about 11 Mbps.

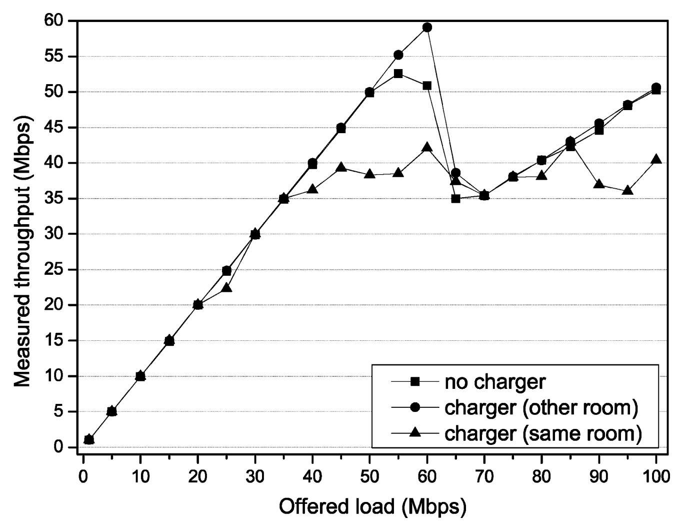

Fig. 6. Measured throughput as a function of offered load for the Panasonic BL-PA100A adapters regarding interference from a cell phone charger.

The measured packet loss is presented in Table III (Appendix). In general, it can be observed that the worst packet loss occurred when the Panasonic adapters were coexisting. The lowest packet loss occurred when the Netgear 14-Mbps pair was also present, but it should be mentioned that the respective measured throughput was extremely low as shown at Fig. 4.

3) Panasonic BL-PA100A: Figs. 6–8 present the measured throughput as a function of the offered load that varies from 1 Mbps to 100 Mbps at 5 Mbps intervals, while the transmission time is 60 s for every offered load and the presented values are the average of the 60-s measurement.

In Fig. 6, the Panasonic adapters are examined in terms of their robustness against the interference caused by a cell phone charger that operates simultaneously. It is shown that the performance depends on the distance from the interference source, i.e., the cell phone charger in this case. The deterioration of the measured throughput is considerable when the charger is plugged

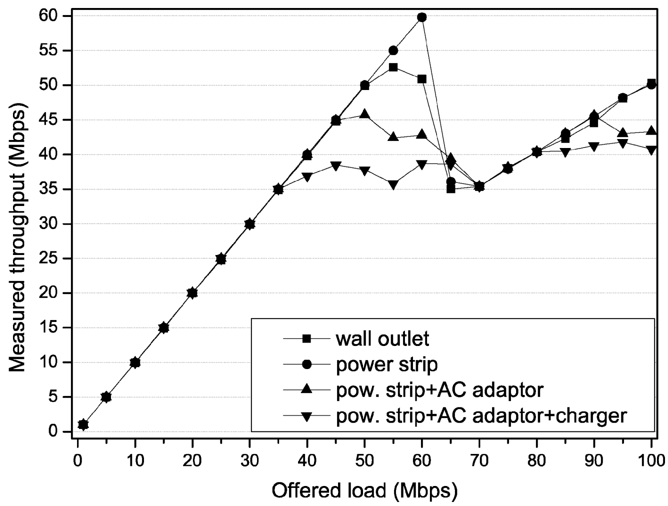

Fig. 7. Measured throughput as a function of offered load for the Panasonic BL-PA100A adapters regarding some not recommended plug-in cases.

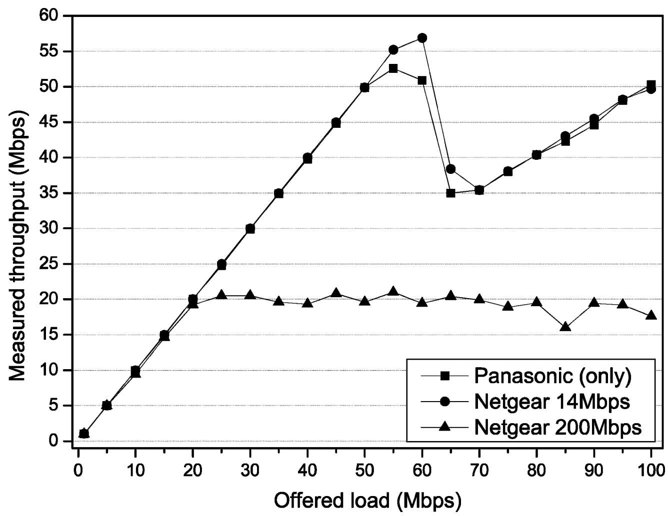

Fig. 8. Measured throughput as a function of offered load for the Panasonic BL-PA100A adapters regarding coexistence with other adapters.

into a wall outlet in the same room with the adapter, with mean observed decrease 16.65%.

Fig. 7 presents measurements results for some of the not recommended plug-in cases according to the instructions given by the manufacturer. The measured throughput is shown when the adapters are powered through an electrical wall outlet (recommended) and when a power strip is used with interference sources (such as an ac adapter and charger) also plugged into the power strip. It can be observed that the greater decrease (mean value 16.13%) of the measured throughput is caused when both an ac adaptor and a mobile phone charger are plugged into the power strip together with the Panasonic adapter. With only the ac adaptor present the mean throughput decrease is 13.65%.

The coexistence of Panasonic adapters with the Netgear equipment is tested and the results are shown in Fig. 8. It can be observed that there is a severe degradation (mean decrease 43.32%) of the performance regarding the measured throughput when the Netgear 200-Mbps adapters are also operating at the same time in other rooms of the apartment. It should also be mentioned that the minimum possible distance between wall outlets is chosen for this measurement (the client PC was in room C instead of room B), since the communication was impossible when the two computers were at a greater distance. On the contrary, the Netgear 14-Mbps adapters do not seem to affect the function of the Panasonic adapters.

Tables IV and V (Appendix) present the measured packet loss. It can be observed that from all tested cases, the greater packet loss values were measured when coexistence measurements took place, i.e., when the Netgear 200 Mbps were operating at the same time.

As a general comment regarding Figs. 6–8, it can be noted that there is a linear relation between the measured throughput and offered load until about 60 Mbps. Then, throughput decreases suddenly when the offered load is 65 Mbps, with a simultaneous decrease of the packet loss as it can be seen at Tables IV and V. From that point and above, the measured throughput is about the half of the offered load following again a linear relation.

IV. Discussion

In this section, an attempt to discuss the obtained results regarding measured throughput, jitter and packet loss is made. Such observations are useful since the PLC equipment can provide multimedia services with specific QoS requirements. Specifically, video streams require as low packet losses as possible, while minimum delay and jitter are required for VoIP services. In general, multimedia applications require packet loss probability that is less than 0.01.

As a general conclusion from all measurements, it should be mentioned that the max measured rate ($\sim$ 6.5 Mbps) for the Netgear XE102 pair is half of the nominal (14 Mbps) and the greater throughput decrease is observed when a power strip is used.

Regarding the Netgear HDX101 pair, the max measured rate ($\sim$ 40 Mbps) is half of the nominal (80 Mbps) and the operation mode for avoiding interference with Homeplug networks results in a considerable performance cost. Finally, the max measured rate ($\sim$ 60 Mbps) for the Panasonic pair is quite close to the nominal (70 Mbps).

In [8], it is mentioned that the degradation regarding UDP throughput for the Panasonic adapters is not crucial because HD-PLC specification has the ability to mitigate cyclo-stationary noise. The HD-PLC physical layer uses wavelet OFDM that features greater speed efficiency and forms a deeper "flexible notch" in order to prevent interference. This is achieved by appropriate modulating the sub-carriers and by including no guard interval. The BL-PA100 adapters detect fluctuations in the data transmission path caused by noise or other factors, and determine the optimal data transmission method in order to enable maximum throughput [10]. However, the results regarding measured throughput for the Panasonic pair in this work are not as optimistic as those presented in [8] without charger, perhaps due to the fact that the latter were performed in a controlled powerline environment and not an actual one, which is the objective of the study presented here.

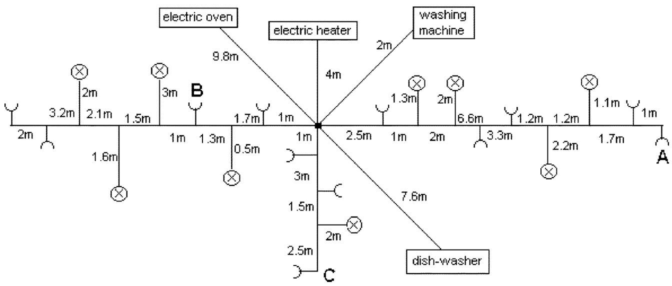

Fig. 9. Powerline topology of the apartment with wall outlets that were used for measurements in rooms A, B, and C.

TABLE II
JITTER IN MILISECONDS FOR NETGEAR 14 MBPS

Offered load (Mbps)	Netgear	Panasonic present	Netgear 200Mbps present	Power strip	Extension cord
1	7.794	0	4.069	0	7.788
2	0	8.026	1.483	0	8.031
4	2.701	5.664	0.104	5.768	5.902
6	3.829	4.608	5.484	5.72	1.676
8	2.777	5.191	4.633	3.55	5.833
10	3.914	5.433	4.918	5.962	3.889
12	3.917	5.833	3.611	2.949	4.002
14	1.367	4.029	5.246	5.213	2.637
16	3.443	5.248	4.63	4.675	3.85
mean	3.305	4.892	3.797	4.165	4.405

TABLE III
PACKET LOSS (%) FOR NETGEAR 200 MBPS

Offered load (Mbps)	Netgear	Panasonic present	Netgear 14Mbps present	Power strip	Extension cord
1	0	0	0	0	0
5	0	0	0	0	0
10	0	0.47	0.016	0	0.0098
15	0	0.012	0.082	0.026	0.68
20	0	0.0088	0.0039	0	0.52
25	0.00078	0.015	0.024	0.0086	0.056
30	0.0026	0	0.012	0.012	0
35	0.76	21	0.53	8.7	6.7
40	0.45	44	0.93	17	14
45	11	52	2.7	28	13
50	19	55	11	31	19
55	30	59	17	38	43
60	37	62	26	38	43
65	0.63	34	0.076	12	1.5
70	10	36	0.042	4.2	4.6
75	8.5	41	0.055	11	11
80	16	45	0.041	16	14
85	21	47	0.099	25	21
90	27	49	4.4	46	26
95	27	50	12	34	30
100	34	51	15	50	32

As far as the measurements presented at Tables III–V are concerned, we can conclude that the packet loss becomes greater as the offered load increases. The packet loss for the Netgear adapters reaches higher values more quickly in comparison to other test cases when coexistence with the Panasonic pair is considered. In general, the critical value of offered load, where

TABLE IV
PACKET LOSS (%) FOR PANASONIC

Offered load (Mbps)	Panasonic	Netgear 200Mbps present	Netgear 14Mbps present	Charger (other room)	Charger (same room)
1	0	3.3	0	0	0
5	0	0.62	0	0	0
10	0.47	5.9	0.053	0	0.0078
15	0.83	3	0	0.01	0.052
20	0.2	4.3	0.018	0.2	0.026
25	0.93	18	0.025	0.42	11
30	0.41	32	0.0085	0.2	0.025
35	0.37	44	0.00056	0.0006	0.099
40	0.47	51	0.002	0.032	9.3
45	0.45	54	0.0087	0.0074	13
50	0.28	61	0.24	0.041	23
55	4.7	62	0.005	0.015	30
60	14	68	4.7	1.1	29
65	3.4	47	0.013	0.028	1.1
70	0.025	44	0.0033	0	0.08
75	0.027	50	0.0088	0.013	0.064
80	0.06	52	0	0.021	5.6
85	1.6	63	0.012	0	0.11
90	2.2	57	0.2	0.014	13
95	0.056	60	0.0028	0.025	25
100	0.58	65	1.8	0.011	20

TABLE V
PACKET LOSS (%) FOR PANASONIC

Offered load (Mbps)	Panasonic (wall outlet)	Power strip	Power strip + AC adaptor	Power strip + AC adaptor + charger
1	0	0	0	0
5	0	0	0	0
10	0.47	0	0	0
15	0.83	0.017	0.0078	0.039
20	0.2	0	0	0
25	0.93	0	0.0039	0
30	0.41	0.0098	0	0.013
35	0.37	0.0056	0	0.0062
40	0.47	0.015	0.0083	7.5
45	0.45	0.0035	0.16	14
50	0.28	0.0023	8.6	24
55	4.7	0.41	23	35
60	14	0.21	29	35
65	3.4	0	2.5	4.2
70	0.025	0	0	0
75	0.027	0.36	0.013	0.0046
80	0.06	0.039	0.0087	0.0083
85	1.6	0.021	0.0059	5.7
90	2.2	0.26	0.01	9.4
95	0.056	0.0073	11	13
100	0.58	1.1	14	19

packet loss is at its maximum, is 60 Mbps; then packet loss drops and increases again.

Regarding the Panasonic pair, coexistence with the Netgear HDX101 causes an increased packet loss even for low values of the offered load. The presence of charger in the same room of the Panasonic adapters is also responsible for greater packet loss. Moreover, it should be mentioned that in all other cases the packet loss becomes greater than the acceptable limit when the offered load reaches 60 Mbps. Then, after the drop of measured throughput which can be observed at about 65 Mbps, packet loss decreases again to acceptable values and perhaps this is the reason for the throughput drop.

Netgear HDX101 adapters follow the UPA DHS that uses adaptive bit loading, where modulation parameters for each transmitter/receiver pair are adapted in real-time depending on channel quality of each carrier. The optimum modulation (bits per carrier) is chosen, with the objective of achieving the maximum transmission speed while maintaining the desired bit error rate (BER). DHS MAC also provides flexibility, including different scheduling transmission formats depending on impulsive noise and channel impedance [1]. As can be seen, there is a cooperation, interaction and information exchange between the two layers PHY and MAC, a form of cross-layer design of the adapters, aiming at improving the performance. It is therefore preferable to lower the throughput (transmission speed) in order to keep BER at acceptable values regarding multimedia services. This fact can be observed at a certain extent at Table III, where the throughput drop when the offered load reaches about 60 Mbps serves as a way to keep packet loss at a lower level.

The above mentioned observation holds also for the Panasonic pair, where packet loss and throughput increase until the offered load reaches 60 Mbps; then there is a sharp drop of both the measured packet loss and throughput. Therefore, we can conclude that the effort to limit packet loss as the offered load increases comes with a cost at throughput.

V. Conclusions

This paper discusses in-home coexistence of PLC equipment that comes from different vendors, technologies and standards. The presented measurement results provide a number of valuable remarks, indicating that there are indeed coexistence problems to be faced. However, the powerline adapters have built-in mechanisms in order to show some kind of robustness and to present a more stable performance despite interference and noise sources. Further studies of PLC equipment coexistence as well as the progress on related standardization issues will enable the wide use of PLC equipment in domestic networks.

References

[1] *UPA Digital Home Specification (DHS)*, [Online]. Available: www.upaplc.org

[2] D. Arlandis, J. Barbero, A. Matas, S. Iranzo, J. C. Riveiro, and D. Ruiz, "Coexistence in PLC networks," in *Proc. IEEE Int. Symp. Power Line Communications and Its Applications (ISPLC)*, Apr. 2005, pp. 260–264.

[3] *Open PLC European Research Alliance (OPERA)*, [Online]. Available: www.ist-opera.org

[4] *IEEE P1901 Working Group*, [Online]. Available: http://grouper.ieee.org/groups/1901

[5] B. Jensen, "Experimental studies of the noise recovery ability of in-house powerline equipment," in *Proc. IEEE Int. Symp. Power Line Communications and Its Applications (ISPLC)*, Apr. 2008, pp. 269–273.

[6] C.-K. Lin, S.-C. Yeh, and H. H. Chen, "Bandwidth estimation of in-home power line networks," in *Proc. IEEE Int. Symp. Power Line Communications and Its Applications (ISPLC)*, Mar. 2007, pp. 413–418.

[7] G. T. Andreou, I. G. Dimoulkas, M. I. Mazneikou, T. A. Papadopoulos, and D. P. Labridis, "Performance of commercially available residential PLC modems," in *Proc. IEEE Int. Symp. Power Line Communications and Its Applications (ISPLC)*, Mar. 2007, pp. 116–120.

[8] D. Umehara, T. Hayasaki, S. Denno, and M. Morikura, "The influence of time-varying channels synchronized with commercial power supply on PLC equipments," in *Proc. IEEE Int. Symp. Power Line Communications and Its Applications (ISPLC)*, Apr. 2008, pp. 30–35.

[9] E. A. Teixeira, F. S. Marques, S. G. de Araújo, E. M. de Souza, T. M. Johnson, and M. V. Ribeiro, "Modeling and performance analysis of PLC channels with external interference in outdoor and indoor environments," in *Proc. IEEE Int. Symp. Power Line Communications and Its Applications (ISPLC)*, Apr. 2008, pp. 222–227.

[10] *High Definition Power Line Communication (HD-PLC)*, [Online]. Available: http://www.hd-plc.org/

[11] *HDX101 Powerline HD Ethernet Adapter User Guide*, [Online]. Available: www.netgear.com

[12] *Iperf – The TCP/IP Bandwidth Measurement Tool*, [Online]. Available: http://dast.nlar.net/Project/Iperf

Anna Papaioannou (S'02) received the Diploma degree in electrical and computer engineering in 2003 from the Aristotle University of Thessaloniki, Thessaloniki, Greece, where she is currently pursuing the Ph.D. degree in the Division of Telecommunications, Department of Electrical and Computer Engineering.

Her research interests include coding and modulation techniques for powerline communications, space-time coding, cooperative diversity systems, and phy-mac cross-layer design.

Ms. Papaioannou is a member of the Technical Chamber of Greece.

Fotini-Niovi Pavlidou (S'86–M'87–SM'00) received the Diploma and Ph.D. degree in electrical engineering from the Aristotle University of Thessaloniki (AUTh), Thessaloniki, Greece, in 1979 and 1988, respectively.

She is with the Department of Electrical and Computer Engineering, AUTh, where her research interests are in the fields of mobile and satellite communications, multiple-access systems, routing, and traffic flow in networks. She has published more than 100 papers in refereed journals and conferences.

Dr. Pavlidou has participated in many national and international projects and has served as member of the Technical Program Committee for many IEEE/IEE conferences. She is a permanent reviewer and has served as guest editor or editor for many journals. She is currently Chair of the joint IEEE VT and AES Chapter in Greece.