Performance Evaluation of Commercially Available PLC Modems

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Abstract: This paper discusses the performance evaluation of two sets of commercially available PLC modems. The two sets are tested in various locations within the power distribution network of TEI Patras, in offices and labs equipped with heavy machinery in active condition. The results under normal and severe conditions show the average throughput achieved in low and high intensity operating conditions as well as corresponding performance limitations. The process involved provides valuable information on the usage of such devices in power distribution networks of residential, office and light industry environments.

Key–Words: Powerline communications, Network Throughput Performance

1 Introduction

Power distribution networks provide an extremely hostile channel for communication purposes. Load switching as well as operation of a multiplicity of electrical appliances and machinery create a highly non-stationary environment where electrical parameters vary unpredictably in time. The bus topology of the network also injects multipath components to the signal and existing power transformers in the network can increase highly the path attenuation [5].

In commercially available power line communication systems the above problems have been overcome to some extent by the development of sophisticated modulation and coding techniques, particularly in the area of broadband communication systems. This is an area of active development that combines work in a) better understanding of the structure and properties of existing power distribution networks and b) adaptation of advanced broadband communication techniques to this area. The goal is to develop robust and high throughput devices in the market that can be employed in as many parts of the power grid as possible.

Some systematic performance evaluation methods have already been published for narrowband [2], [3] as well as broadband [4] PLC modems. In this paper we mostly follow the guidelines set in [1] to characterize performance of two commercially available modem kits in an environment that combines aspects of residential, office and light industry.

The simplest TCP/IP network can be set up between two PLC modems attached to two controlling computers and performance can be evaluated with standard network traffic measurements at the TCP/IP level. The two PLC modems that are to be evaluated in this work are the Devolo MicroLink DLAN Ethernet Starter Kits, regular (nominal throughput 14 Mbps) and highspeed (nominal throughput 85 Mbps) versions that follow the HomePlug 1.0 and Turbo specifications.

The performance evaluation of these two devices will show the benefits/tradeoffs due to the difference between specifications of regular and high speed PLC modem versions. The evaluation process itself will also demonstrate a testing procedure that could be carried out prior to the final installation of such types of devices.

2 Testing environment

The testing/performance evaluation takes place at the Technical Education Institute (TEI) of Patras, Electrical Engineering Department, within and between offices and labs running heavy duty machinery typical of a light industry environment.

The power infrastructure in Greece typically utilizes both single phase and three phase grids depending on user power requirements. TEI Patras is similar to a light industry complex as it has its own power substation that feeds all campus buildings. The labs of the Electrical Engineering Department have heavy power requirements due to the machinery and other equipment that are employed for student training. Control panels supply both three phase and single phase power to the available power outlets typically through 3 or 2.5 mm^2 standard wiring. Most test cases were connected to outlets at the Power Electronics Lab which were also protected with isolation transformers. Table 1 describes the test cases involved.

Table 1: Test Cases

Case	Description
AB	Nodes within power systems lab, distance $\sim$ 6 m, outlets protected by isolation transformers at different phase
AC	Nodes within power systems lab, distance $\sim$ 15 m, outlets protected by isolation transformers at same phase
AE	One node within power systems lab, other node within nearby office. Distance $\sim$ 20 m
AF	One node within power systems lab, other node within technical measurements lab. Distance $\sim$ 35 m
NET	Network case. Four nodes within power systems lab, two with the 14 Mbps devices and two with the 85 Mbps ones. Communication scheme 14 $\leftrightarrow$ 14 and 85 $\leftrightarrow$ 85 concurrently.
TG	Compatibility case. Check 14 $\leftrightarrow$ 14, 85 $\leftrightarrow$ 14 and 85 $\leftrightarrow$ 85 in a residential environment.

A number of computers (labelled A,B,C,E,F,T,G) were employed, all running Windows XP professional SP2 with firewall disabled. The main software used was PCAUSA's port of the standard unix TTCP application to Windows Sockets, version V2.01.01.08. The command `pcattcp -t -f m -l 8760 -b 65535 -n 5000 <ip addr of destination PC>` was used on the transmitter node PC, while the command `pcattcp -r -f m -l 8760 -b 65535 -n 5000` was used on the receiver node PC for tcp packets. The addition of the `-u` option in both commands makes the application utilize udp packets. The `-t` and `-r` options indicate transmit or receive mode, `-f m` indicates that throughput results are in Mbit/s, `-l 8760` is the length of the buffers read from or written to the network, `-b 65535` is the socket buffer size (64k) and `-n 5000` is the number of source buffers written to the network. This means that each run of pcattcp involves the transmission of about 42 Mbytes of test data. In addition to that, and in order to have a spread of results that enables us to calculate the measurement σ, the above commands were incorporated in a script file that looped 10 times without any lag between loops. On average each loop took about a minute to complete. [1]

PC A was connected to a reference outlet in the Power Lab while PC's B,C and G were connected to other outlets within the Lab. PC's E and F were connected to outlets within a neighbouring office and the Measurements Technology Lab. Finally, in the last test case, PC's T and G were connected to outlets in two different rooms of a residential apartment in order to provide a comparison between the TEI environment and a typical residence.

3 Results

Table 2 presents the measured throughput of the first set of test cases while figures 1, 2, 3 and 4 display the actual measurements.

Table 2: Throughput between nodes in Mbit/s

Set	tcp85	udp85	tcp14	udp14
AB	8.51 ± 0.04	9.92 ± 0.40	2.68 ± 0.16	3.33 ± 0.41
	11.27 ± 0.18	–	3.05 ± 0.13	3.35 ± 0.17
BA	11.29 ± 0.18	66.48 ± 0.16	3.10 ± 0.13	3.33 ± 0.17
	8.49 ± 0.04	10.06	2.60 ± 0.19	3.52
AC	19.11 ± 0.30	21.57 ± 2.41	5.77 ± 0.03	6.93 ± 0.39
	18.00 ± 0.58	–	5.53 ± 0.08	6.77 ± 1.38
CA	18.05 ± 0.59	56.6 ± 0.65	5.61 ± 0.07	6.89 ± 0.86
	19.06 ± 0.28	22.99 ± 0.38	5.46 ± 0.23	7.15 ± 0.45
AE	4.67 ± 0.07	5.59 ± 0.16		
	6.14 ± 0.13	7.12 ± 0.09		
EA	6.15 ± 0.13	7.00 ± 0.24		
	4.65 ± 0.08	5.69		
AF	2.35 ± 0.03	2.67 ± 0.03	0.15 ± 0.12	0.66 ± 0.13
	6.40 ± 0.08	8.17 ± 0.02	1.59 ± 0.03	2.07 ± 0.19
FA	6.41 ± 0.08	7.90 ± 0.74	4.78 ± 2.32	2.41 ± 0.30
	2.34 ± 0.03	2.62	0.02	–

The first letter designates the transmitting PC while the second letter the receiving PC. Results shown are measured on the transmitting PC. The second line with blank **Set** shows the reverse situation where the previous receiver becomes transmitter and the results are measured on the receiver PC. Often, at low connection rates on the receiver side, especially for udp packets, there were packets missing (no error bars on table) or miscounted (fewer packets in shorter time leading to large measured throughputs). Such outliers were not included in the σ calculations.

Nodes for test case $A \leftrightarrow B$ were between different phases while nodes for $A \leftrightarrow C$ were on the same phase which explains the difference in throughput even though the distance was shorter for the first case.

In reference [4] it is mentioned that the lower nominal throughput devices are more stable (smaller σ) that the higher ones. We did not observe this in our tests within our environment. The σ's seem to be similar.

An interesting observation occurred when most equipment in the lab were turned on (test under load),

[1] Actually it was $\sim 20 - 25$ s for connections utilizing 85 $\leftrightarrow$ 85 devices and $\sim$ 90 s for connections utilizing 14 $\leftrightarrow$ 14 devices with other cases in between.

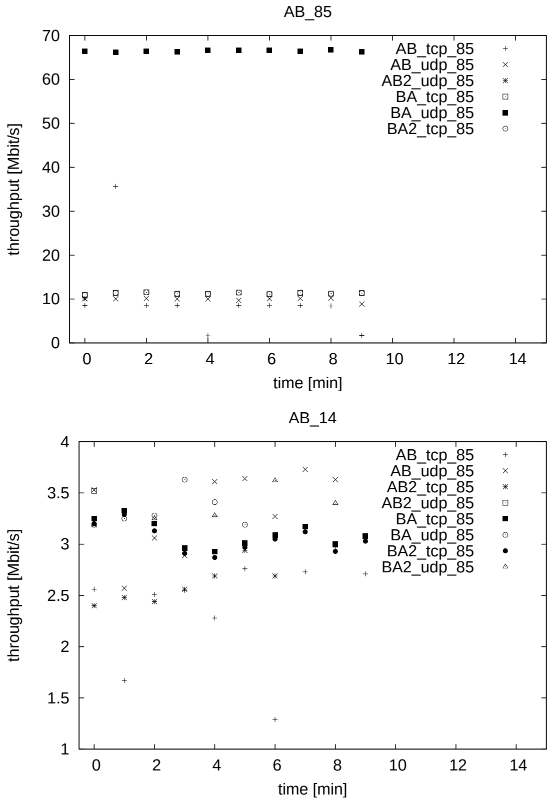

Figure 1: $A \leftrightarrow B$ tcp and udp measurements.

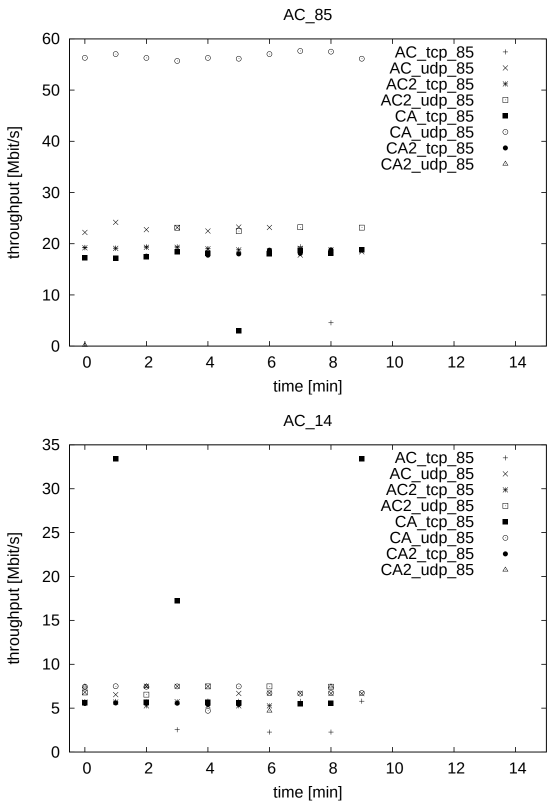

Figure 2: $A \leftrightarrow C$ tcp and udp measurements.

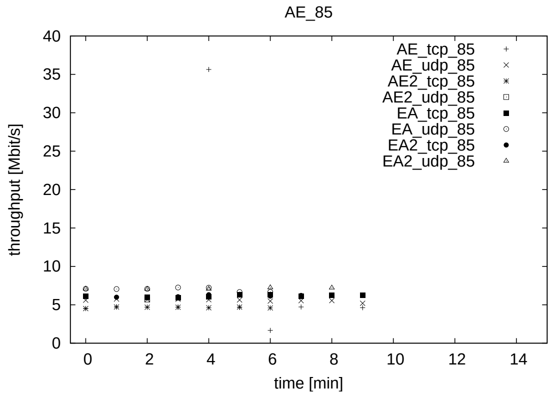

Figure 3: $A \leftrightarrow E$ tcp measurements.

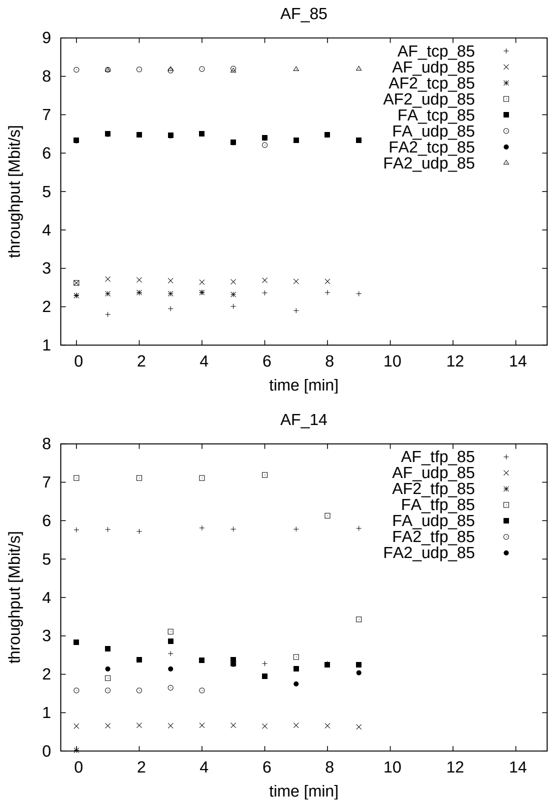

Figure 4: $A \leftrightarrow F$ tcp and udp measurements.

Table 3 and figure 5. The forward direction $A \leftrightarrow B$ tcp and udp traffic throughput improved by ~ 4 Mbps. The reverse tcp throughput deteriorated by ~ 5 Mbps while the reverse udp throughput remained the same. It may be that the equipment provided alternate paths for the packets to travel through between nodes.

Table 3: Throughput between nodes in Mbit/s under extra load

Set	tcp85 load	udp85 load
AB	12.75 ± 0.54	14.25 ± 1.16
	6.43 ± 0.56	–
BA	6.44 ± 0.56	66.22 ± 0.07
	12.52 ± 0.43	–

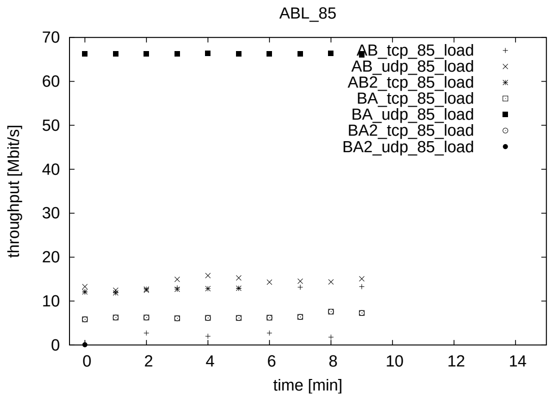

Figure 5: $A \leftrightarrow B$ tcp and udp measurements under extra load.

In the deployment of such devices there will certainly be cases when both low and high nominal throughput devices will be operating at the same time in a network. Such a case was tested when $A \leftrightarrow B$ (14 Mbps devices) and $G \leftrightarrow C$ (85 Mbps devices) were operating concurrently. It was observed that the lower rate devices "froze" until the higher rate traffic was finished (figure 6). Performance otherwise was somewhat less but not significantly so.

Table 4: Network coexistence case

Set	tcp14	udp14
AB	2.31 ± 0.53	2.90 ± 0.55
	2.30 ± 0.54	0.94 ± 1.22
Set	**tcp85**	**udp85**
GC	9.77 ± 1.50	15.57 ± 0.89
	9.76 ± 1.50	15.56 ± 1.00

Finally, a test is made in a residential environment (two different rooms in a apartment) between two PC nodes T and G utilizing 14 Mbps and 85 Mbps devices. Table 5 and figure 7 show the observed measurements.

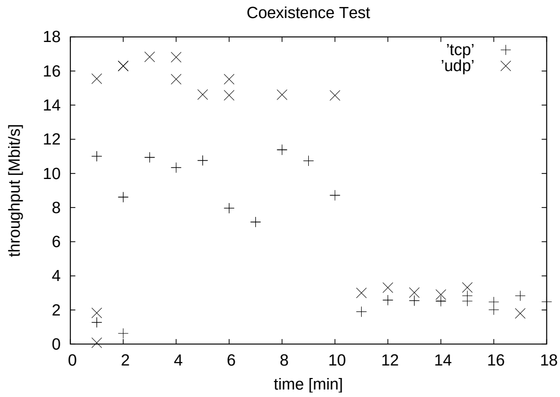

Figure 6: Network coexistence test. Notice that the the lower rate devices "freeze" until the higher rate traffic is finished.

Table 5: Compatibility case.

Set	T14G14	T85G14	T85G85
TGtcp	3.56 ± 0.04	4.35 ± 0.70	15.29 ± 0.31
	5.16 ± 0.04	5.20 ± 0.02	16.35 ± 0.43
GTtcp	5.17 ± 0.04	5.20 ± 0.02	16.32 ± 0.43
	3.56 ± 0.03	4.01 ± 0.03	15.09 ± 0.41
TGudp	4.10 ± 0.03	4.66 ± 0.05	18.11 ± 0.06
	6.62	6.67 ± 0.13	19.67 ± 0.13
GTudp	6.59 ± 0.24	6.50 ± 0.34	19.59 ± 0.16
	4.10 ± 0.03	4.66 ± 0.05	18.11 ± 0.06

We see that communication is possible between different nominal throughput devices at the rate of the lower one. In this particular test the devices should be first configured by the manufacturer's supplied utility so as to comprise a network.

A test under more normal conditions was also performed in which the four devices, two 85's and two 14's, were deployed in a small LAN. One of the devices was connected directly to the output of an ADSL router and the other three to three different PC's that comprised the powerline LAN. The ADSL line was nominally 768 kbit/s although in actual practise with no LAN, the observed throughput was ~ 40 kbit/s. With the PLC devices connecting the three PC's together, to the Internet, there was no significant performance deterioration observed. Under rather heavy Internet traffic for about a week the three users expressed satisfaction with this PLC based HomeLAN.

The method of video streaming with the VLC server/client [1] was also tested where one VLC server "served" audio and video to VLC clients on the other two PCs. Any type of audio stream worked fine (mp3, wav, etc.). Low definition video streams also work fine but with higher definition ones the dropped frames, "freezing" and other imperfections are painfully visible (hence the "need" for the Homeplug AV standard with nominal rate 200 Mbps).

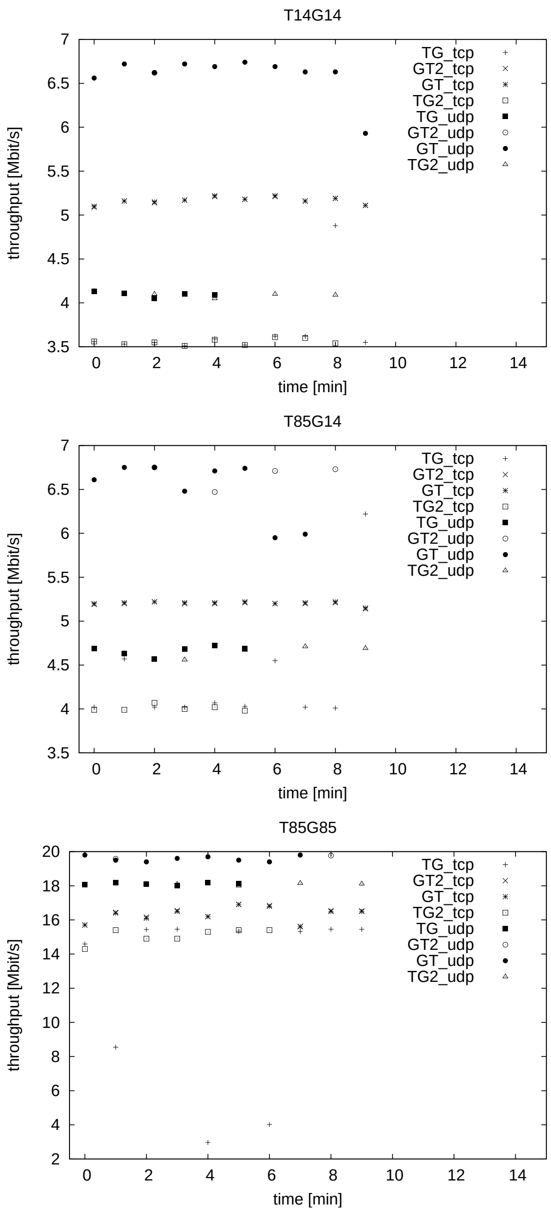

Figure 7: Measurements between two nodes both utilizing 14 Mbps devices, 85 Mbps devices or one node utilizing a 14 Mbps device and the other utilizing a 85 Mbps device.

4 Conclusion

Two pairs of commercially available PLC modem devices were tested and their performance evaluated under a variety of conditions. The two pairs were made by the same manufacturer, one of them with nominal throughput 14 Mbps following the Homeplug 1.0 specification and the other with nominal throughput 85 Mbps following the same specification with Turbo enhancements.

A variety of locations and operating conditions in light industry and residential environments were utilized and the tcp and udp network traffic throughput was measured for point-to-point links between similar and different throughput devices.

As expected the throughput depended on distance and noise conditions on the powerline medium with increasing deterioration on larger distance, added noise and different power phase. Interestingly enough, on one of the cases where additional loads were turned on, the tcp and udp forward traffic throughput improved by ~ 4 Mbps. The reverse tcp throughput deteriorated by ~ 5 Mbps while the reverse udp throughput remained the same.

A compatibility test between two sets of similar throughput devices operating concurrently under demanding traffic conditions showed that the lower throughput devices "freeze" until the high throughput traffic is finished when they "unfreeze" and continue on until their traffic is finished too.

The devices were also tested in a residential environment by building a HomeLAN that shared Internet access through an ADSL router. The three LAN users expressed their satisfaction with this setup showing that the residential PLC modems achieve their intended goal of providing exactly such capabilities to residential users.

Work is continuing at the Laboratories of Power Electronics and Powerline Communications of TEI Patras to test out network performance with more nodes of such devices as well as integrating them with additional powerline based control and automation systems.

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References:

[1] *Intellon PLC Performance Testing whitepaper*, `http://www.intellon.com/pdfs/whitepaper_PLCPerformanceTesting.pdf`.

[2] T.G. Chang, N.H. Ahn and H. Kim, "A systematic evaluation method for the operation and communication reliabilities of the PLC net-

worked home appliances", *IEEE Trans. on Consumer Electronics*, 48(3):765-769,2002.

[3] D. Liu, E. Flint, B. Gaucher and Y. Kwark, "Wide band AC power line characterization", *IEEE Trans. on Consumer Electronics*, 45(4):1087-1097,1999.

[4] G.T. Andreou, I.G. Dimoulkas, M.I. Mazneikou, T.A. Papadopoulos and D.P.Labridis, "Performance of Commercially Available Residential PLC Modems", *IEEE International Symposium on Power Line Communications and Its Applications, ISPLC'07*, 116-120,2007.

[5] D. Anastasiadou and T. Antonakopoulos, "An experimental set-up for characterizing the residential power grid variable behaviour", *IEEE International Symposium on Power Line Communications and Its Applications, ISPLC'02*, 2002.

[6] *PCAUSA*, `http://www.pcausa.com/Utilities/pcattcp.htm`.