Throughput Analysis on BPL Networks

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Abstract: **In this paper a comparison is made between different architectures but also between test bed and commercial installation regarding performance. This paper also addresses an issue appearing on network architectures that mainly consist of BPL nodes or series of nodes regarding throughput reduction and remedy thereof.**

Keywords: ***BPL, PLC, Throughput, Bit Rate, Hybrid.***

I. Introduction

The goal of this paper is to present different BPL (Broadband over Power Lines) based architectures and investigate with regard to the parameters that most affect throughput performance. Measurements and respective graphs from actual networks are included in the analysis and provide a guide in order to better assess the situation and possible degradation causing factors. An installation on an actual commercial power distribution network, other than introducing scientifically real conditions, also introduces uncontrolled variables such as relatively random noise surges and similar condition to the same effect, i.e. slight throughput reduction. However, measurements have been taken at times when the network appeared clear of unwanted effects. The issue of throughput reduction on networks consisting of segments with different communication technologies is also addressed as is the effect on networks that include long lines of consecutive BPL links.

A. Analysis Outline

The structure of this paper will cover these issues in roughly the following sections.

B. BPL-based Architectures and Related Parameters:

There are tree general frames of design for a BPL-based network [1]. After an elementary introduction of the BPL technology, these frames are briefly presented and their pros and cons are outlined. These architectures are: The star topology, where one central BPL node serves a number of separate nodes one hop away, the straight run of consecutive modems and the mesh topology of BPL segments of few modems connected by a link of a different sort such as Wifi [10].

C. Results and Architecture Evaluation:

Similar tests have been performed on all of the previously mentioned architectures and the results are concisely presented in tables and graphs. These results enable us to assess and evaluate each design's advantages and disadvantages and from there on to be able to make an informed decision according to project specification.

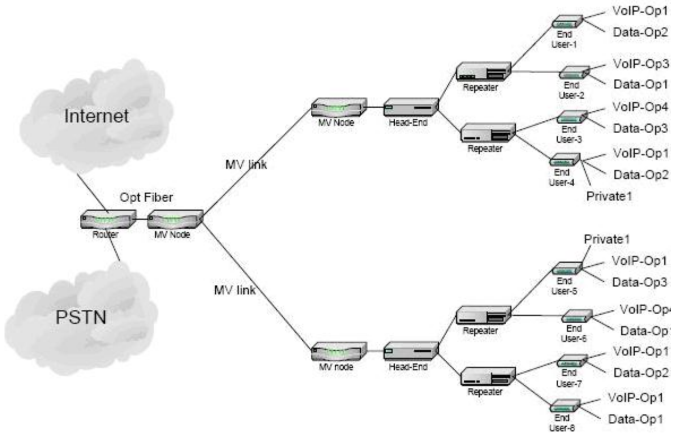

Figure 1. Core Network PLC featuring Head-End, Repeaters and Customer Premise Equipment [1]

II. BPL-based Networks and Architectures

A. BPL Basics

There are three kinds of BPL nodes. The Head End (HE) also called a Master, the Repeater (Rep), which can either be a Time Division Repeater (TDR) or an Frequency Division Repeater (FDR) and the Customer Premise Equipment (CPE) also called a slave [2],[3]. The HE is responsible for allocating resources to all nodes that belong to its BPL cell or group, among other things distributing the token amongst the nodes in the cell. It also ensures that QoS profiles and conditions are met within the cell. The Rep is a node used to increase the distance and hence the coverage of the BPL cell in cases where the end node is too far away from the HE. Repeaters are either connected directly the HE or previous Rep that acts as their master. It in turn acts as a master for the nodes that follow it on the BPL line. CPEs form the end of the BPL lines. A CPE undergoes a process that establishes its validity before gaining access to the BPL network. Once the CPE is

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deemed valid to enter the network it will either receive an auto-configuration file as part of the auto-configuration process or it may alternatively use a configuration provided before the unit is mounted on the power grid pole and physically connected to the network medium. The CPE connects to the HE or a Rep and is always a slave.

B. Architectures

The number of innovations in network design when the case is one with as flexible a solution as BPL nodes is only limited by the designers imagination and the project's general goals and frame [5]. Especially when one is inclined or required to introduce different technologies, such as wireless links of all sorts [4], in order to formulate mesh network architecture, the possibilities are virtually endless.

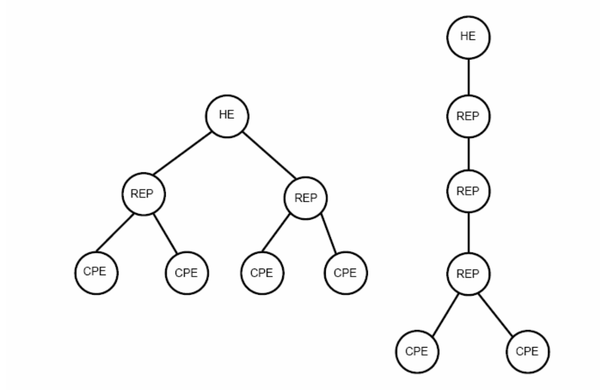


Figure 2. Typical Access Scenario for PLC featuring Head-End, Repeaters and Customer Premise Equipment [1]

Fig.2 shows two types of basic architectures [1]. The first instance is the simplest form of what is referred to as the star topology. Usually with more repeaters connected directly to the HE and therefore more BPL segments, the star topology is considered the optimum architecture in most ways of bandwidth usage and throughput. It allows the cell to expand in all directions but not very far. The second instance on Fig. 2 is the straight line of nodes which can even be as long as ten nodes and perhaps more, if the design specification is met in terms of throughput. Each repeater node introduces a reduction in throughput to the end of the line, the CPE. The longer the line, the smaller the throughput. This caused by the fact that each repeater, whether TDR of FDR, will either reduce the time for which the full bandwidth is used or the bandwidth available to a given node for transmission [2]. There are other parameters to consider when investigating throughput reduction but increasing number of nodes will always bring decrease in throughput [6]. The obvious benefit of this architecture is that distant nodes can be connected to each other as far as 7km or 10km, assuming that successive nodes are about 700m to 1km apart. The third architecture discussed in this paper is the case of small BPL segments interconnected via a Wifi WDS link [9]. This architecture has in effect exchanged a BPL link for a Wifi link. The immediate result as we will demonstrate is not the increase of end to end throughput but an overall increase in network capacity and efficiency owing to the fact that each segment now passes a token that takes far less time - a fraction approximately equal to one over the number of segments in the network – to return to a given node. These are the architectures on which basic parameters of BPL network design will be tweaked and their effects recorded and evaluated.

C. Parameters and Approach Variations

In the process of achieving the best result according to each project's specification the party charged with network architecture and then perhaps implementation and optimization can pursue these goals in many different ways, use various techniques and adopt a number of approaches. These include changing the injection point of the network, i.e. the point where the network connects with its backhaul router, tampering with the nodes' inherent noise thresholds if the infrastructure justifies such decisions, changing the MTU on parts of the network to match whatever is more convenient [11], [12] (in cases of different network interfaces), splitting the network into different segments and interconnecting them with non-BPL links or altering the general tree structure of the network moving nodes from branch to branch if it would fit the need. Consequently, both architecture variations and network/technology parameters are at one's disposal to best meet the requirements set. However, in this paper will only investigate a few methods of structuring and optimizing a network, in order to better illustrate the behavior of a BPL-based network, or potentially a hybrid network as we might call it, when non-BPL links are included. The comparison between the commercial BPL network's performance and that of its "lab" counterpart clearly demonstrates the impact that a power grid has on a BPL network [8] and also hints to the difficulties that an engineer charges with setting up such a network, will have to overcome [7].

III. PERFORMANCE MEASUREMENT AND EVALUATION

In order to obtain the measurements required the "lab" network was set up using a total of nine nodes in three different arrangements to match the architecture in question. The nodes were not put on the power grid and physical connection between nodes was achieved by a regular copper cable through couplers that provided attenuation reaching 10db. Except in the fourth set of measurements, where we used a real BPL network with a near linear architecture in order for us to obtain measurements, in all the lab setup scenarios two laptops where used in order for the measurements to be acquired. These laptops would act as a server and a client and the IPERF [13] software suite was used. The laptop running the server was always connected in modem number 1 as depicted in the different scenarios herein. The client laptop was moved and was connected in each and every other modem consecutively for the according measurements to be acquired. In the first two scenarios, we used a common medium for all nodes and repeaters were set at TDR mode so there would only be a single node transmitting on the wire at any given time. Provisions were needed to be made in the case of the third architecture scenario, the hybrid of three BPL segments, i.e.

interconnected by Wifi links, so that the three segments did not interfere with each other.

In the following few pages of this paper we present the results obtained from the different scenarios with comprehensive graphs but also a comparative set of measurements from a BPL network set on a commercial power grid with the permission of PPC (Public Power Corporation). It helps to illustrate the differences between ideal and actual conditions which as one can easily notice are noteworthy to say the least.

A. *Linear Architecture*

In the linear architecture the modems are connected in a straight line creating a TDR token network where modem number one is the master and the other modems until nine re TD-Repeaters. Modem number nine is a slave and will not retransmit packets.

As we can seen from the measurements in the tables and figures in this layout as we get further away from the master (modem 1) the available bandwidth is decreased as the ping time is increased when the physical speeds saty more or less the same hop by hop.

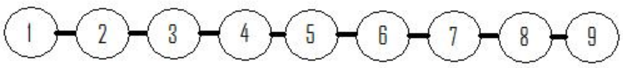


Figure 3. Linear Architecture Layout

TABLE I: IP SPEEDS AND LATENCY FOR LINEAR LAYOUT

From 1 to Unit	Speed	Ping
2	28.3	17
3	17.4	17.4
4	13.5	18
5	12.2	18.6
6	10.1	19.3
7	9.31	19.5
8	7.02	31
9	7.79	35
Avg	13.2025	21.975

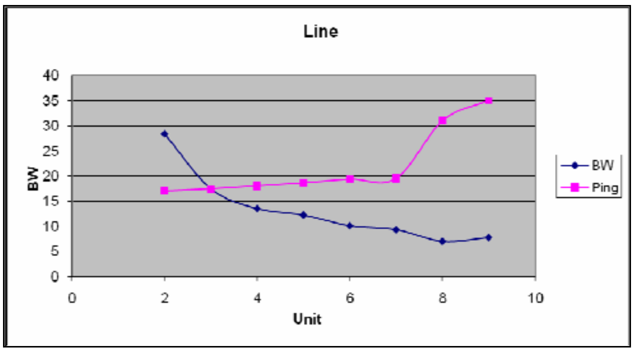
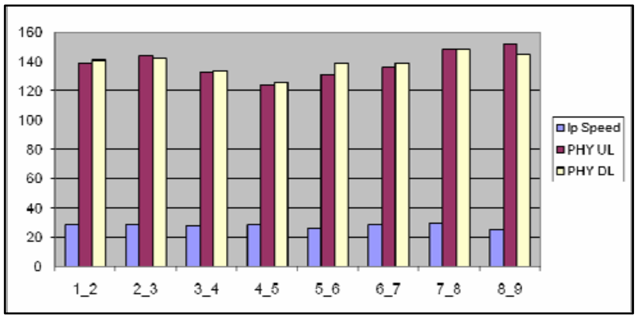


Figure 4. Table I Data Chart

TABLE II: PHYSICAL LINK SPEEDS FOR LINEAR LAYOUT

Unit1-Unit2	Ip -speed	PHY speed UL	PHY speed DL
1_2	28.3	139	141
2_3	28.9	144	142
3_4	27.8	133	134
4_5	28.2	124	126
5_6	26.5	131	139
6_7	28.2	136	139
7_8	29.6	148	148
8_9	25.7	152	145
Avg	27.9	138.375	139.25



B. *Star Architecture*

In the star architecture the units are dispersed in four directions creating a sparse TDR token network with the master placed in the center of the star and the edges being slaves. The units in between are TDR repeaters.

The measurements acquired indicate that this is a symmetric architecture with the bandwidth and that ping times being equal regardless the direction.

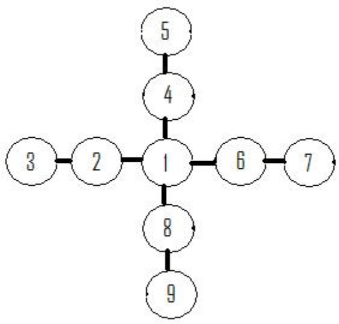


Figure 6. Star Architecture Layout

TABLE III: IP SPEEDS AND LATENCY FOR STAR LAYOUT

From 1 to Unit	Speed	Ping
2	38.8	7.95
3	23.2	13.2
4	39.3	7.76
5	22.8	12.4
6	38.4	6.9
7	21.4	17
8	37	7.3
9	20	17.6
Avg	30.1125	11.26375

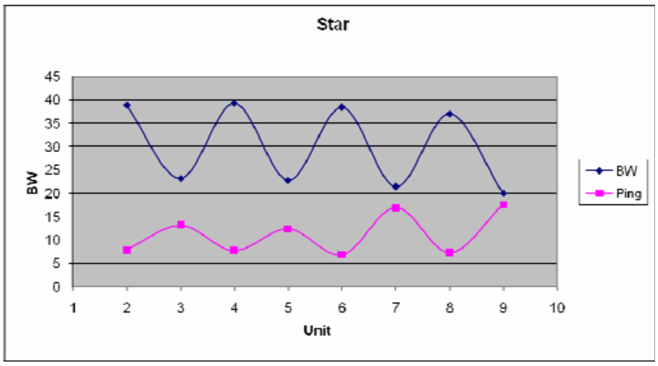


Figure 7. Table III Data Chart

TABLE IV: PHYSICAL LINK SPEEDS FOR STAR LAYOUT

Unit1-Unit2	Ip -speed	PHY speed UL	PHY speed DL
1_2	_	_	_
2_3	36.1	133	142
3_4	_	_	_
4_5	38.4	144	144
5_6	_	_	_
6_7	30.5	102	106
7_8	_	_	_
8_9	38.6	152	145
Avg	35.9	132.75	134.25

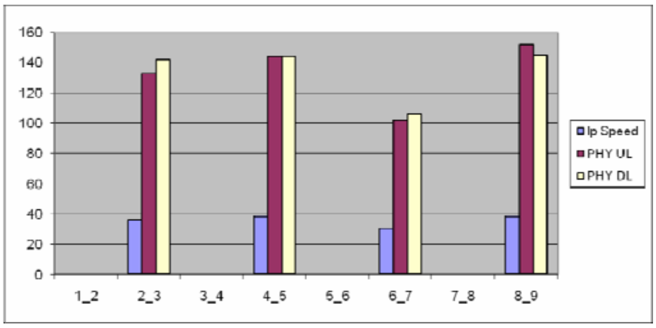


Figure 8. Table IV Data Chart

C. *Hybrid BPL/WiFi Architecture*

In the Hybrid BPL/WiFi architecture the units are separated in smaller TDR token networks interconnected via WiFi. This was done in order for us to test the effect of different physical layers in the overall IP speed.

The measurements acquired indicate that there is no significant change in speed (bandwidth) and quality (ping time).

Figure 9. Hybrid BPL/WiFi Architecture, black lines are BPL links and the red lines are WiFi links.

TABLE V: IP SPEEDS AND LATENCY FOR HYBRID LAYOUT

From 1 to Unit	Speed	Ping
2	53.3	4.3
3	27	8.7
4	12.4	23
5	12.4	15.7
6	11.5	30
7	9.4	31.8
8	8.6	26.7
9	8.31	39
Avg	17.8638	22.4

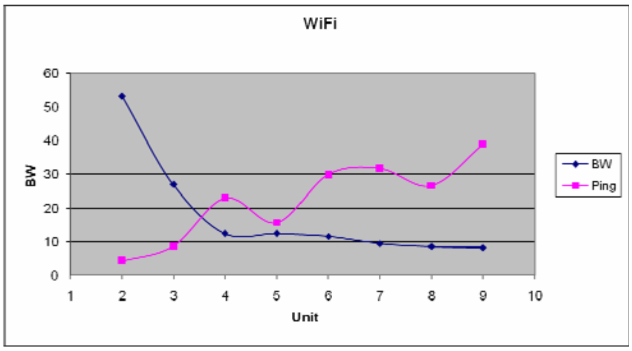


Figure 10. Table V Data Chart

TABLE VI: PHYSICAL LINK SPEEDS FOR HYBRID LAYOUT

Unit1-Unit2	Ip -speed	PHY speed UL	PHY speed DL
1_2	53.3	122	102
2_3	45	105	100
3_4	_	_	_
4_5	42	100	105
5_6	41.7	130	120
6_7	_	_	_
7_8	44.1	104	128
8_9	42.9	120	123
Avg	44.8333	113.5	113

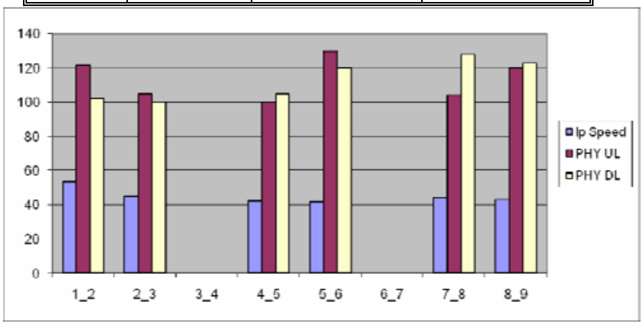


Figure 11. Table VI Data Chart

D. Near-Linear Architecture on Power Grid

In the near linear architecture we acquire measurements from a real commercial installation of BPL in Larissa-Greece. The network layout is as shown in figure 12 and it resembles a linear architecture, thus the results can be directly compared with the results acquired in case A.

As is shown in the tables and figures presented herein is that the results are very close to the ones from scenario A. Even though the speeds are smaller and the ping times are larger (since that is a real installation) the speed decreases as we move away from the beginning of the network while the ping times become larger.

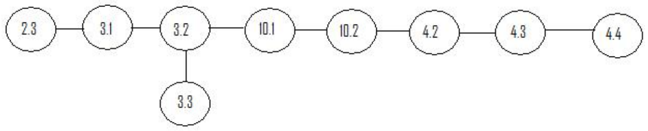


Figure 12. Near Linear Architecture on Power Grid

TABLE VII: IP SPEEDS AND LATENCY FOR LINKS ON POWER GRID

From 2.3 to Unit	Speed	Ping
3_1	16.9	16
3_2	13	20
3_3	10.4	25
10_1	10.4	32
10_2	6.5	37
4_2	3.9	45
4_3	3.9	52
4_4	3.2	57
Avg	8.525	35.5

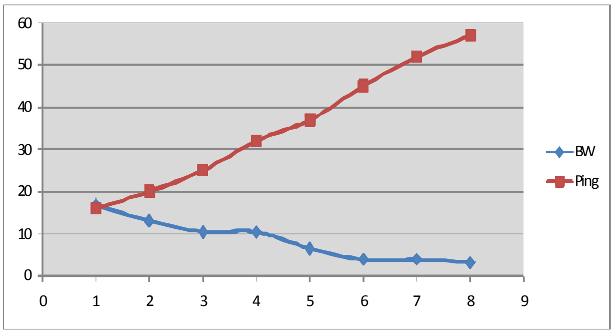


Figure 13.Table VII Data Chart

TABLE VIII: PHYSICAL LINK SPEEDS ON POWER GRID

Unit1-Unit2	Ip -speed	PHY speed UL	PHY speed DL
2_3->3_1	22.1	85	77
3_1->3_2	15.99	107	110
3_2->3_3	11.34	99	93
3_2->10_1	10.92	91	104
10_1->10_2	10.66	119	131
10_2->4_2	5.72	52	62
4_2->4_3	4.2	44	83
4_3->4_4	4.1	42	78
Avg	10.62875	79.875	92.25

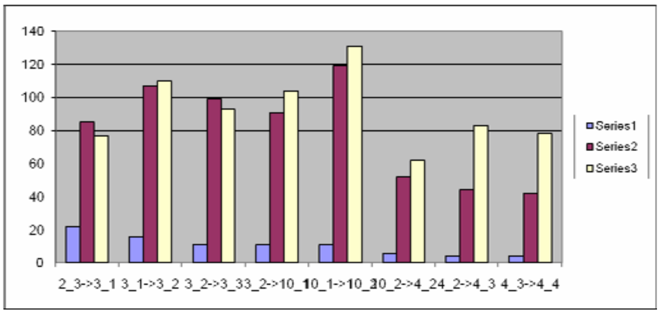


Figure 14. Table VIII Data Chart

E. Comparative Charts for Architecture Schemes

Collecting all relative data in one chart for each parameter, that is throughput and ping time, we create a visual representation of our measurements and clearly present their meaning, which in effect are the conclusions of this paper. We can clearly see that the star network while including the same number of nodes as a line network does not suffer the same degradation but cannot transmit as far as a linear topology. I can however cover a very wide area reliably if only radially developed from a center node. The importance of the BPL/WiFi architecture is as we can see not so much as a replacement of the linear architecture with a marginally better performance in throughput but the fact that it can provide the data network with a means of transcending a power network across different power lines from the same or different high voltage to medium voltage substations. It is best used for “hopping” from one power line to the next.

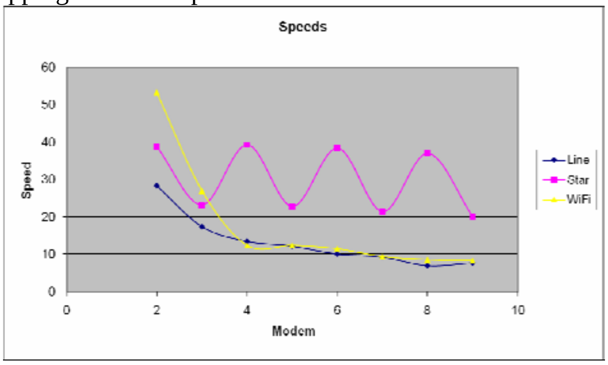


Figure 15. Throughput Comparative Chart

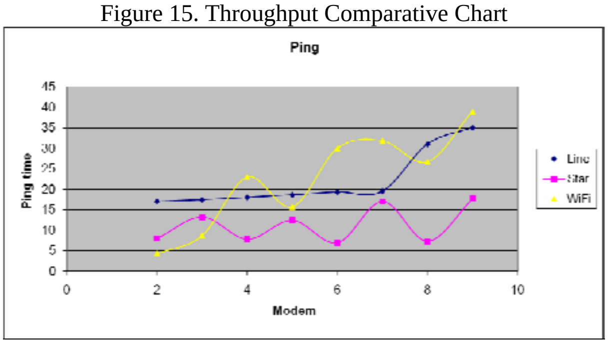


Figure 16. Ping Time Comparative Chart

IV. Conclusion

We have obtained quantative sets of results on three different architectures as well as a fourth set from a commercial application BPL network on PPC power grid and those sets have been both numerically and visually presented. Advantages and disadvantages of each architecture scheme are therefore easy to deduce comparatively. The substantial difference between a real network on a power grid and one designed and formed to operate as a test bed is also clearly shown. Techniques for improving and eliminating possible hindrances have been mentioned and explored yet their results were not always consistent nor clearly measurable to be presented in this paper, however their do provide some insight on how to deal with potential problems and difficulties in the field.

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