

In-Home PLC Coexistence with Wi-Fi and Ethernet access Networks

E. Hamiti, T. Berisha and F. Peci

Abstract—BPL or PLC is relatively a new technology that is considered an attractive system to deliver broadband communications over power lines. The main objective of paper is to understand the impact of in-home PLC devices in case of integrated environment with other technologies. Initially, FTW Simulator for channel transfer function analysis of an in-home PLC network topology is used. Furthermore, through measurements conducted in laboratory environment different scenarios are built for different test scenarios and the coexistence of in-home PLC, Ethernet and Wi-Fi Networks is investigated. Toward the end of the paper, throughout different scenarios the impact on video quality of in-home PLC, will be closely monitored and evaluated.

Index Terms—BPL, channel transfer function, FTW simulator, in-home PLC.

I. INTRODUCTION

THE PLC (Power-line Communications) in general is a promising solution for first mile and last mile broadband access. It appears that broadband access is a broader concept related to the growth of science, economy aspects and also tourism and culture. In-home PLC, Home-plug AV and indoor BPL (Broadband over Power-lines) are dedicated standards providing a broadband access solution to in-home users. Nowadays there are a lot of PLC devices with different characteristics of transmission speeds and capabilities. Moreover Home-plug and BPL devices include products that have flown from different standards.

In this section the simulations derived from FTW are described and a simulator is used for modeling channel transfer function for in-home PLC [1,2] (FTW is PLC Simulator based on Matlab source code which is used to characterize PLC channels). Through this simulator are conducted a considerable number of simulations for different kind of topologies and characteristics. In power-line communication network the signals propagate

from transmitter to receiver facing a harsh and noisy transmission medium. Using the FTW simulator is possible to derive the best possible frequency band where the voice and data can be transmitted.

The simulations are performed in the frequency band from 100 KHz up to 30 MHz matched to the modeled characteristics of the simulator.

There are a number of basic conducted measurements performed in various scenarios as well. Measurements include different topologies and each of them designed for various purposes. By using various scenarios the importance of PLC is investigated as a redundant link during intermittent drops of one healthy link while video-streaming. In the rest of scenarios the focus is on load-sharing of packets where the topology includes two links for transmitting the signals from transmitter to receiver. The topology is composed of different technologies like Wi-Fi and Ethernet along with in-home PLC devices.

The motivation for building these kind of topologies is derived from the possibilities of using the in-home PLC not only for home use where the inside users can have access to broadband, but also in the environments like mining industry and other kind of industries where the broadband access is necessary even for monitoring purposes. The efficient bandwidth utilization is another target analyzed in measurements conducted on this paper.

The paper is organized as follows: Section II elaborates the channel transfer function (H) for a predefined in-home PLC topology, Section III analyses the laboratory measurements and Section IV gives a conclusion.

II. CHANNEL TRANSFER FUNCTION ANALYSIS THROUGH SIMULATIONS

The proposed simulations in this paper include the in-home PLC network topology that matches as close as possible to a realistic indoor power-line networks in our country (Kosovo, South Eastern Europe). On the other hand the channel transfer function is defined from the theory of two-port network model as a ratio between load voltage V_L and source voltage V_S by:

$$H = \frac{V_L}{V_S} \quad (1)$$

The above can be rewritten as a function of A, B, C, D, ZL, and ZS as follows:

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$$H = 20 \times \log_{10} \left| \frac{Z_L}{A \times Z_L + B + Z_S \times (C \times Z_L + D)} \right| \quad (2)$$

where A, B, C, D are the 2x2 matrix elements according to the ABCD Line Modeling, whereas Z_S and Z_L are the source impedance and load impedance respectively [3-6].

In this paper the in-home PLC network topology that is matched to our country environments will be presented. Referring to the topology as depicted below (Figure 1), there are a service panel (SP) positioned in the center of topology and outlets (OL) connected to the distribution boxes (DB) etc. The DBs are considered boxes positioned per each room for in-home environments. The SP connects the energy provider side to in-home electrical side.

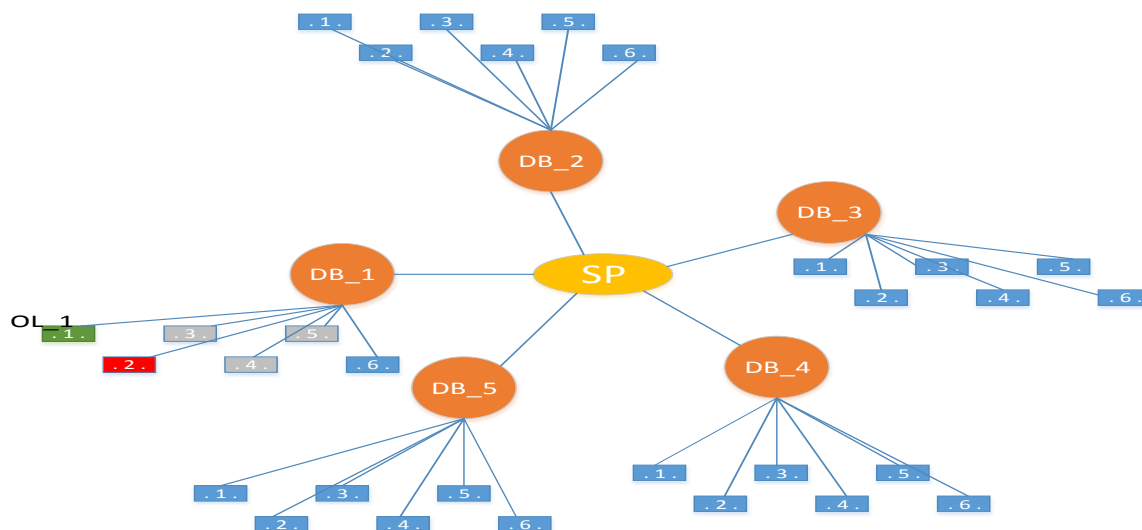


Fig.1. The topology of in-home PLC network for channel transfer function analysis

From the above topology we can see the connections between topology elements. The distance between SP and DBs is 6 m and is the same for five connections, whereas the distance between each DB and OLs connected to it are 5.2, 5.4, 5.6, 5.8, 6.0 and 7 m respectively. Cable types used in topology are of sections 2.5 mm. Transmitter (equivalent as Z_S and colored as green) and receiver (equivalent as Z_L and colored as red) have a common value of 100 Ω . Star connection type is used for connection between OLs and respective DBs.

It is important to see what happens to the channel transfer function for the topology as above on situation where position of receiver changes from OL_2 to OL_3 and so on. Below are depicted the graphic results which will be analyzed on the following.

Figure 2 shows an example from which may be observed that differences between channel transfer functions are slightly change from each other.

The analysis as it can be seen from the legend is performed for the cases where receiver changes the position from one outlet to another within distribution

box (DB_1 in this case) in which is connected to. If the range from transmitter (T) to receiver (R) is increased there is a longer path linking T and R. It is expected to be corrupted the channel performance caused by this increasing. The simulations are conducted from 100 KHz up to 30 MHz as it can be seen from Fig. 2. Also the bandwidth from 7-15 MHz is not suitable for transmission because of high level of attenuation. Apart from transmitter and receiver the topology presented consists of RLC circuits as well. These circuits are considered as appliance circuits when are connected to outlets in randomly way. In the topologies where there is no RLC circuit connected to outlets, the bandwidth up to 5 MHz shows an improvement of attenuation, whereas the bandwidth from 7-15 MHz remains problematic. The receivers from different vendors have their specifications related to the receiving capabilities. The power noise level is not desirable to be lower than around -90 dB for getting the better performance for receiver devices. The careful should be taken mainly in the bandwidths mentioned above although nowadays devices use bandwidth up to 62.5 MHz for networking, HD video-streaming, online gaming and more services.

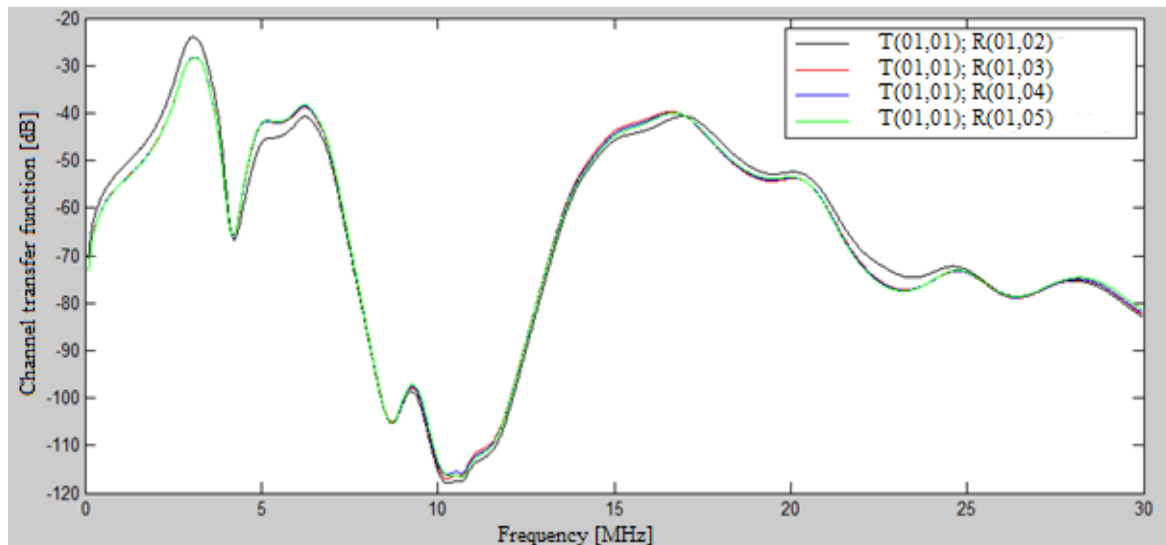


Fig.2. Channel transfer function (H) realizations of 4 different receiver positions

III. LABORATORY TESTBED AND IN-HOME PLC MEASUREMENTS

Using PLC adapters for different environments when there is no need for building infrastructure is optimal solution and even cost-effective. The general purpose of measurements is to investigate the coexistence between technologies like in-home PLC, Wi-Fi and Ethernet. The jitter and latency for video-streaming and similar services like monitoring are to be analyzed whereby the results are shown on the following.

3.1 Laboratory Test-bed

The proposed test-bed in this paper consists of:

- 2 PLC adapters compliant with IEEE1901 and compatible with Homeplug AV [4],
- 2 PCs equipped with 100 and 1000 Mbps NIC (Network Interface Cards),
- 2 Cisco routers
- 1 Cisco Ethernet switch (not presented on the following topologies).

Within this paper three measurement scenarios were conducted:

- Scenario 1: Bottleneck analysis near 100 Mbps and importance of different transmission mediums.
- Scenario 2: High Redundancy analysis in case where the primary link is down (Ethernet link) and video-streaming

quality between PC_1 (transmitter) and PC_2 (receiver).

- Scenario 3: Load-sharing per packet (utilizing two links, PLC in combination with Wi-Fi and Ethernet) analysis and video-streaming quality.

The scenarios are shown on subsequent figures. Scenario 1 (Figure 3) is composed of PLC adapters (HD Power-line Adapter with data rate 500 Mbps) and 2 PCs connected on each side.

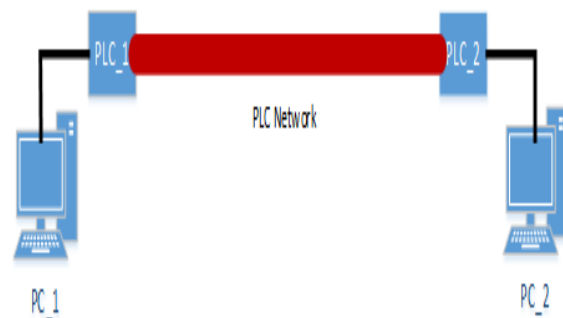


Fig.3. Scenario 1

Scenario 2 is composed from two links whereas scenario 3 is composed from a mixed network. The latest scenario is the most complicated compared to others. The size of video-streaming file is 700 MB which is transmitted through the mixed network and Ethernet network, alternatively, with target to measure the quality of video in transient moments of different scenarios.

PLC adapters are used throughout all the scenarios, capable to transmit in data rates up to 500 Mbps and range distance up to 300 m for in-home environments.

3.1 Bandwidth, Jitter, Latency Measurements and Quality of Video-streaming

Scenario 1 illustrates an example where PLC_1 (transmitter) transmits a video-streaming to PC_2 (receiver) through the Ethernet and PLC Network. The primary objective of this scenario is to measure the video quality at PC_2 for the data rates 10, 100 and 1000 Mbps. PLC adapters have capability of 500 Mbps data rates, but both of PLCs are equipped with 100 Mbps NICs whereas 1000 Mbps NICs are not used. It is obvious that in case of 10 Mbps data rate the video quality transmitted via UDP on port 1234

(User Datagram Protocol) has not changed. In the second test the data rate is increased to 100 Mbps, the incoming rates with value 96.5 Mbps at PC_2 were recorded using **Iptraf** tool [7]. In this case quality of video is qualitatively degraded as it is shown on Figure 4. From this scenario it is understood that even when PLC adapters have a data rate of 500 Mbps, using cat5e Ethernet cables, it is not able to utilize the capacity of PLCs because of auto-negotiation mechanism. This mechanism offers the data rates limited on 10/100/1000 Mbps as Ethernet standard does not support other data rates. The scenario 1 shows such a problematic solution in these situations.



Fig.4. The degradation of video quality for 100 Mbps data rate.

Scenario 2 as depicted on Figure 5 illustrates a different case where the PLC Network is used as a redundant link. On the interfaces of routers is activated the OSPF (Open Shortest Path First) protocol. In this test is forced an Ethernet link dropping down in order to measure the video quality at receiver PC as well as transient period. In case of Ethernet link goes down, it is observed a delay of up to 4 s for the video to turn into acceptable quality.

Figure 6 shows the video quality at receiver side, whereas on right hand side of this one is shown the original image. This is done for comparison reasons where original image is used as a reference of comparison.

From the above figure we are also able to observe the time when the link is on switching phase from Ethernet to PLC link.

The load-sharing is such a mechanism that provides packet balancing which results in utilizing two links (Ethernet and PLC in our case). This is another test where on the router from left hand side the load-sharing per packet is enabled. On both sides (transmitter and receiver) are running the **Jperf** through which it has been able to measure jitter.

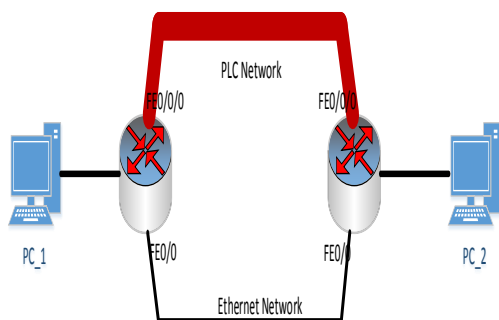


Fig.5. Scenario 2

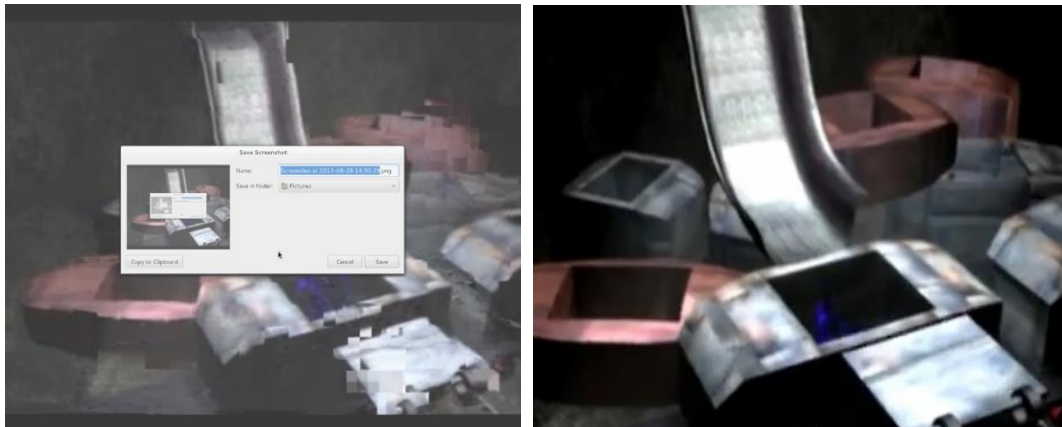


Fig.6. The degradation of video quality at the moments when link (Ethernet) goes down

Figure 7 shows the jitter results measured for the last 30 s (transmit interval is 60 s with 5 parallel streams). UDP is used with 10 MBps throughput, 41 kB buffer size and 32 kB packet size. Jitter results

show that for this period the maximum value of jitter is 1.25 ms. The real-time applications are sensitive to latency and jitter so a latency of more than 50 ms should be considered for different services.

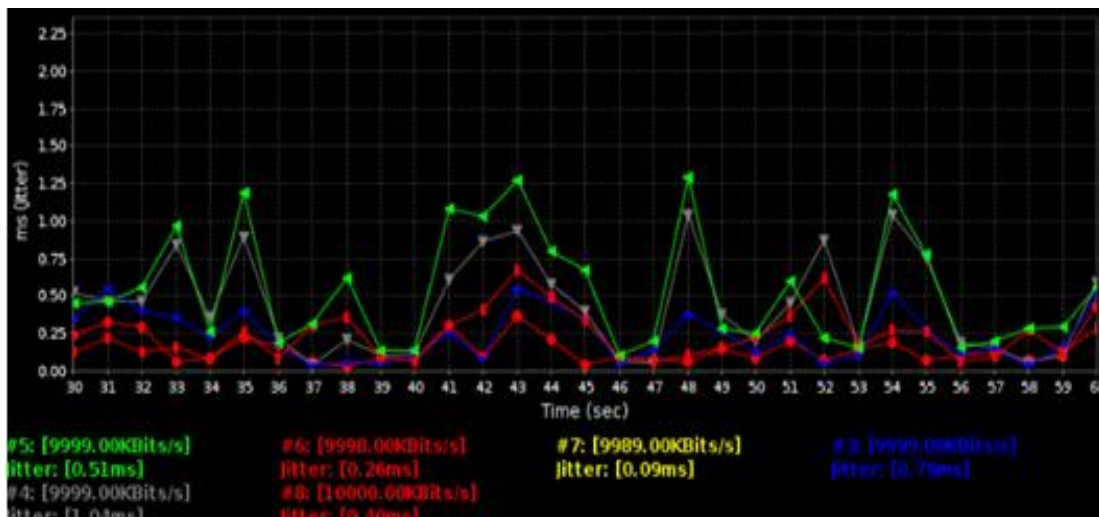


Fig.7. Jitter values for load-sharing per packet

Scenario 3 is more complicated in comparison to other scenarios because the network topology consists of two links (Figure 8) where the upper link is a combination of three technologies, Ethernet, Wi-Fi and PLC.

After configuring the load-sharing per packet on router the traffic is divided, such that one packet goes via upper link (PLC and Wi-Fi) and the next one goes via lower link (Ethernet only).

A Wireshark capture is run on both sides of network topology (PC_1 and PC_2) [8]. Packets sent from transmitter to receiver are different in order.

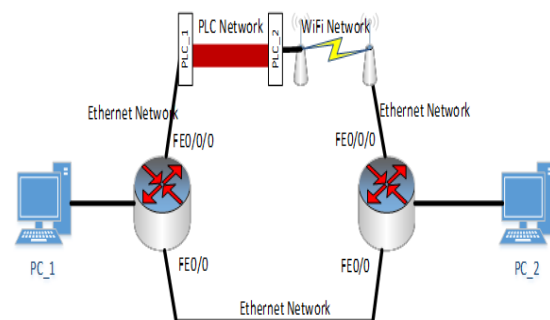


Fig. 8 Scenario 3

The load-sharing per packet affected MPEG packets (Figure 9) where is observed that a few packets to be lost. Therefore, in the situations of packet-sharing enabled the video quality may be degraded.



Fig.9. Video quality at receiver side (left image) in case of load-sharing per packet enabled

If the quality of the received video is compared to the original image captured at the transmitter side there are differences at the certain moments. However, this quality is acceptable because these degradations are appeared only in short intervals and non repeatable. Therefore, in these situations although is utilized the upper and lower capacity of links and also the packet-sharing is enabled this is not any more

excellent video quality guarantee. **Jperf** is run similarly to scenario 2, on PC_1 and PC_2. Figure 10 shows the jitter measurements for 5 parallel streams. The testing interval is 60 s. regarding to the jitter results observed, the value of jitter is significantly higher than the same results from scenario 2. The jitter and also latency are increased due to Wi-Fi and PLC networks.

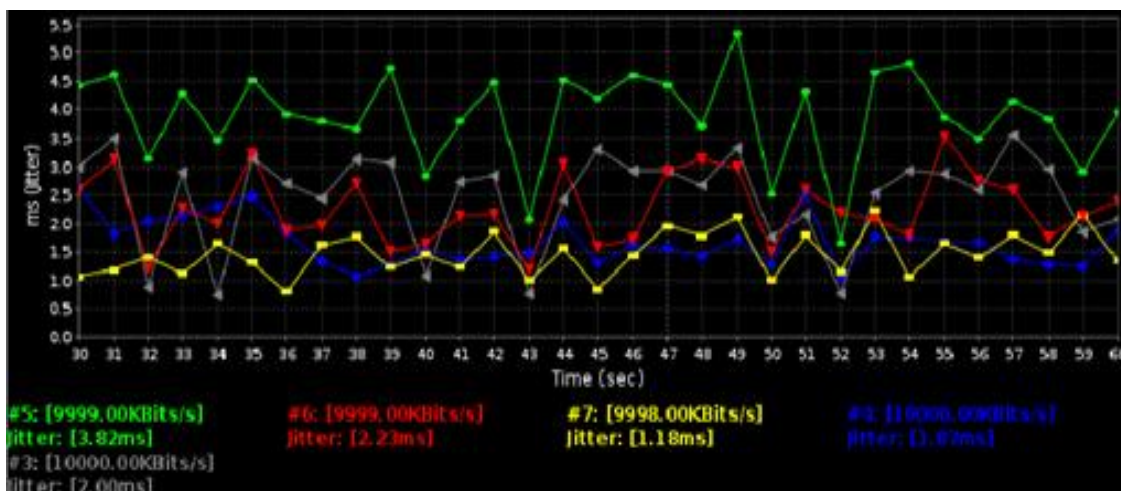


Fig.10. Jitter values for scenario 3 load-sharing per packet

Below are tabulated values for three cases related to the jitter and latency parameters about all mentioned technology combinations. It is interesting to observe the latency of packets for different cases. The mean values of latency are derived from 34 packets measured from ping test. Figure 11 illustrates the latency for every packet including cases of technology combinations.

If we relate Figure 11 and results from Table I (mean value of latency), it is able to observe the whole interval of packets whereby the combination of Wi-Fi+Ethernet+PLC contains the largest values of latency.

TABLE I
JITTER AND LATENCY VALUES FOR DIFFERENT CASES.

Measured values	Load-sharing per packet enabled		
	Wi-Fi + Ethernet + PLC	WiFi+Ethernet	Ethernet + PLC
Max. value of jitter [ms]	5.5	3.5	1.25
Mean value of latency [ms]	5.3235	1.4412	3.0645

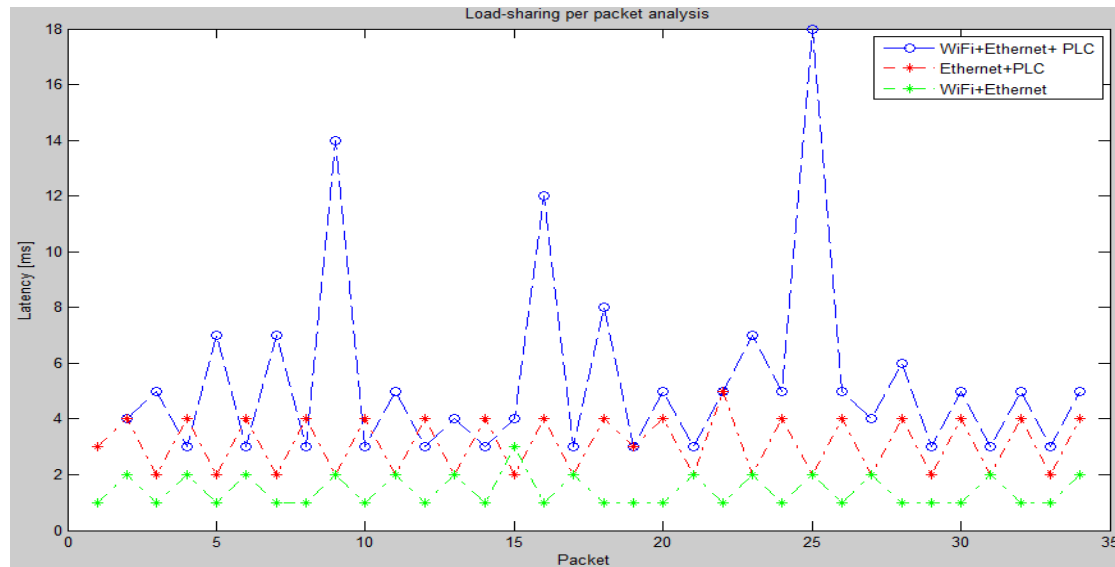


Fig.11. Latency values for 34 packets with various combination of technologies

IV. CONCLUSION

Apart from home use the PLC technology apparently due to its good bandwidth characteristics there may be more alternatives where this technology may penetrate. The environments such as: Mining industry for monitoring purposes or Urgent cases whenever there is an already existent electrical infrastructure.

The channel transfer function is very important, so the results presented in this paper show a problematic bandwidth from 7-15 MHz. The data transmitted should be under control in order to make sure that the power noise level is not being lower than -90 dB. Also differences in distance range between outlets from different distribution boxes may cause changes in channel transfer function more than outlets positioned within the same distribution box. In the situations where the network topology is complicated there are presented more oscillations on channel transfer function.

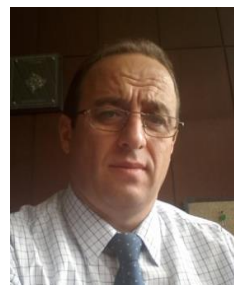
In case of using PLC as a redundant system, this operates very well regardless some seconds of video degradation. This video degradation occurs to be at the moments when secondary link gets recovered from primary link. In case of using the load-sharing per packet mechanism the situation may change somehow. Although the idea of using the both links is desirable, there is needed more attention when a few technologies are used in combination, as latency and jitter are fundamental parameters for real-time applications.

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BIOGRAPHIES



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