Testing home PLC network in multi-storey house

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***Abstract*—The technology based on the principle of data transmission over electrical networks called PLC (Power Line Communication) PLC modulate high-frequency signal in the order of tens of MHz to low-frequency electric signal 50 Hz. This technology is suitable for data transmission, whether in the form of narrowband or broadband services. This paper deals with the measurement of transfer rates in a real home network built on a PLC technology platform, which allows the construction of a less expensive functional home network without the need for new structured cabling. The results of measurements of transmission rates in individual parts of the apartment house will serve for a more optimal distribution of terminal equipment in the home network.**

***Index Terms*—PLC, Smart Home, Attenuation, Broadband Power Line, Throughput, Smart metering**

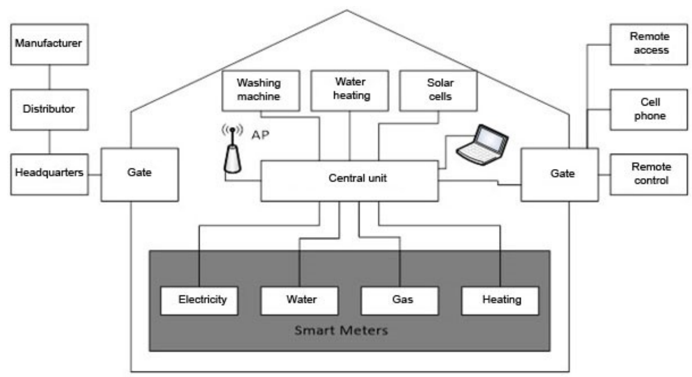

Fig. 1: PLC in SMARD grid Home.

I. Introduction

Nowadays, the phenomenas of Smart City, Smart Home and general intelligent technology is taking over the world [1]–[3]. Many issues are considered as a crucial in this area such as privacy, general security, reliability, sustainability, performance, and many others [4]–[10]. However, to selecting the right technology for specific use-cases and applications is the first step.

Power Line Communication (PLC) technology is currently considered to be a high-speed transmission medium that allows data transmission over electrical wiring [11]–[16]. Electrical networks, in apartments, single-family houses or various buildings, mostly provide 230V connection in Slovakia. However, they also provide the possibility to use PLC technology. The possibilities of using PLC communication are different [17]. PLCs are used for data transmission in simple data services that do not need high transfer rates (hundreds of kbps) [18]–[20]. Another example is the so-called "Smart Grids" (Fig. 1), which require high data rates (tens to hundreds of Mbps) [21], [22]. BPL (Broadband over Powerline) networks have thus become an alternative to other types of broadband network systems xDSL.

The PLC/BPL network environment is very demanding in terms of data transmission. The various types of interference and other undesirable effects that occur on electrical wiring are involved in the degradation of the transmitted data (detailed description in [11], [15]). According to [11], the most important undesirable influences can be considered: (i) divarication of the signal in multiple ways, (ii) time-varying network topology and the resulting frequency and time-varying line attenuation, (iii) intense background colour noise, (iv) various forms of impulse noise and (v) interference.

In this work, we focused on measuring transmission rates in a real home network created using PLC technology, which took place in the living space of a multi-story residential house. The measurement conditions were not changed for other household appliances that were permanently connected in the apartment itself and the surrounding apartments. The PLC adapters that were used for testing were TP-LINK TL-WPA8630P AV1200. The aim of measuring the baud rates was to verify the parameters given by the supplier and then use the measured baud rates to optimise the distribution of terminal equipment in the home network.

The rest of the paper is divided into the following sections. Section II contains information and technical details about used equipment and devices. Section III brings closer the experimental settings and configuration followed by Section IV including first results obtained via PLC-wireless medium (WiFi, 802.11) tested with printer and television use scenarios. Section V includes measurements and results obtained via PLC-Ethernet connection with same scenarios and conditions as in case of previous wireless part. Finally, Section VI summarized our obtained results and the contribution of the authors.

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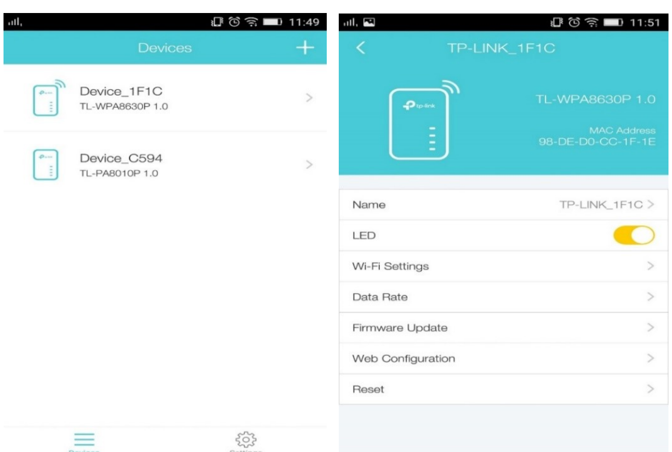
II. PLC Adapters

A set of two PLC TL-WPA8630PKIT adapters from TP LINK was used for measurement. The first TL-WPA8630P adapter (Fig. 2) worked in the ”Master” mode and the second TL-PA8010P adapter (Fig. 2 left) worked in the ”Slave” mode with Wi-Fi access. The slave adapter has three Ethernet outputs with a RJ45 connector, which allow the connection of three other devices (notebook, IPTV, or other terminal devices). The TP-Link TL-WPA8630PKIT adapter kit allows creating a home wireless Wi-Fi network operating in two bands (2.4 GHz, 5 GHz) with a total transfer rate of up to 1200Mbps. For correct communication, the PLCs were configured via a smartphone. The PLC configuration procedure is described in the following section.

Fig. 2: PLC adapters TL-WPA8630PKIT

III. PLC configuration

Nowadays, smartphones and devices provide some features that allow to set and configure many devices in so-called Smart Houses remotely. The manufacturer of tested TP-Link PLC Adapters provides the tpPLC application (Fig. 3), which (freely available on the Internet) simplifies the configuration of PLC adapters.



(a) tpPLC main menu. (b) PLC adapter functions.

Fig. 3: tpPLC application.

By using the tpPLC application and implemented 2x2 MIMO system, the user can easily create more connections and then used high network speed. The first point in the configuration is the selection of the PLC adapter. The clone ”Wi-Fi” button automatically copies the router’s SSID and password. Using the ”Pair” button, settings such as SSID, password, Wi-Fi schedule, and LED schedule for all devices in the network are automatically synchronized [23]. After the synchronization process is finished, the WiFi network is created and it is possible to connect. Within this network, it is possible to see two devices that we can distinguish according to the identification numbers from the manufacturer. Figure 3a shows that when open tpPLC application, there are two options ”settings” and ”devices”. Within this network, two devices have been synchronized - TL-WPA8630P and TL-PA801P.

Both devices contain functions that the user can set as shows Fig. 3b. The application allow set functions such as the name of the selected device (Name), the setting of LEDs (LED) indicating the triggering of a certain PLC adapter function that can be controlled remotely (e.g. blinking user sleep). Wi-Fi Settings shows in which frequency band the user wants to work (2.4 GHz or 5 GHz band). Wi-Fi Schedules - allows to set the time when we want to activate and deactivate the Wi-Fi connection, which saves energy and protects the user from unnecessary microwave radiation. The app also allows to set SSID, protection, and password. The Data rate function allows the user to see the actual value of the transfer rate between devices in Mbit/s units, whether by the PLC or Master adapter. Firmware Update provides information about the current firmware version. Web Configuration is configured via a web browser, and Reset is used to restore the entire application due to a possible application error.

IV. Measurement via wireless

Figure 4 shows a plan view of the apartment in which the transmission rate measurements were made. Internal walls and partitions are paneled. Electrical wiring is copper and distributed throughout the household. The electrical circuit is distributed at end devices such as a dishwasher, washing machine, and refrigerator. The measurements were performed within one electrical circuit for the PLC device pairing. In the hallway, out of the apartment, there is a distribution cabinet, which distributes electrical wiring to the entire apartment. Also on the ground floor, there is an optical cabinet, which distributes optics to the whole apartment complex.

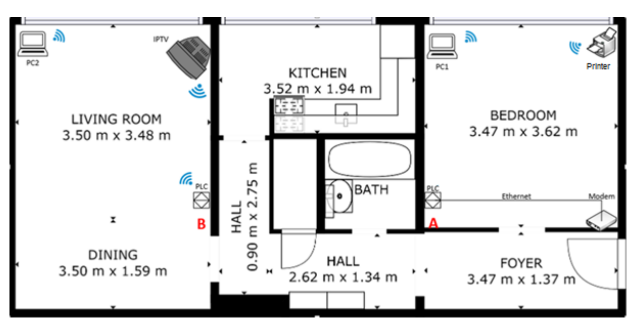


Fig. 4: Floor plan of residential space for Ethernet connection.

The layout of the terminal equipment of the home PLC network (computer, printer, television, PLC equipment) was realized to cover the most significant possible space in the apartment. In the design shown in Figure X, two PLC devices, indicated by the letters A and B, are shown. The PLC device A (master) is connected to a modem in the bedroom that provides an Internet network. At the same time, the PLC marked B (slave) is connected to the dining room in the living room. The two PLC devices are synchronized within one electrical circuit and communicate with each other. Since the PLC device B also has an Ethernet cable, it is possible to connect to the terminal devices via the Ethernet interface. The measurements were performed and tested on wireless Wi-Fi, but also separately on the Ethernet connection and the combined connection - wireless Wi-Fi connection and Ethernet connection.

A. Measurement via wireless Wi-Fi with VoIP traffic, IPTV and IP printer

The following Figure 5 shows the construction of a PLC network with Wi-Fi. The PLC network was realized by two transmission computers, where a call was made via Skype service. Then an IP printer and IPTV, which enables the use of the video on demand (VoD) service called Netflix. Before the measurement, we verified the individual connection of the given devices via the mobile application tpPLC. Also using the command ping in the command line, whether the computers are communicating with each other. Subsequently, the data rates were measured using the iperf3 software tool.

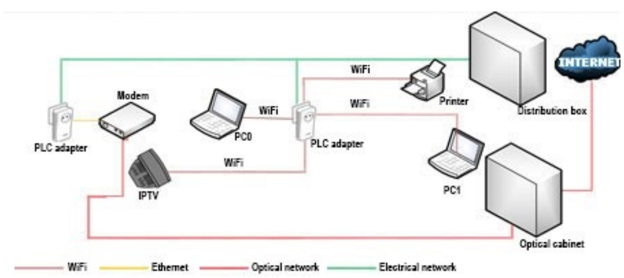


Fig. 5: PLC network in residential space with wireless WiFi connection.

Very low data rates were recorded when measuring via Wi-Fi connection. The measurement was realized using Youtube service on both computers, IPTV with Netflix was launched, and IP printer was also used. Bit rate measurement over WiFi with VoIP traffic and IPTV is shown in Table I.

Fig. 6 shows the transfer rate without load, and with load,During this measurement an IP call was made, IPTV was started, and an IP printer also worked. As can be seen in the figure, the load has significantly influenced the reduction of the transfer rate.

TABLE I: Bit rate measurement over WiFi with VoIP traffic and IPTV.

Number of intervals [s]	No-load meassurement [Mbps]	Load Measurement [Mbps]
0	0	0
1	99,6	29,1
2	99,6	27,4
3	98,5	27,4
4	97,6	28,3
5	101	29,4
6	99,7	21
7	94,3	29,3
8	103	30,4
9	99,5	32,5
10	97,6	31,5

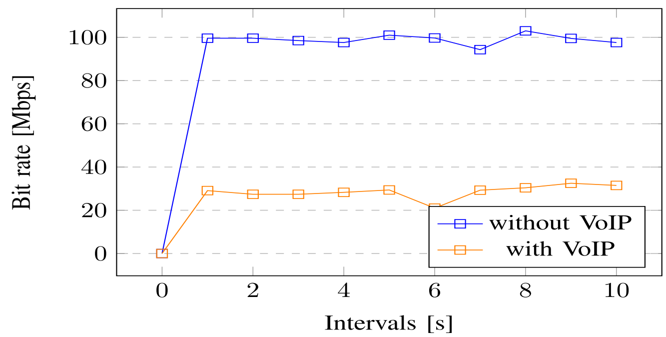


Fig. 6: Measuring WiFi connection without and with running VoIP traffic, IPTV and IP printer.

V. Measurement via Ethernet

As in the previous section, a design for an Ethernet connection was made. The measurement was carried out in the same residential space. Two portable computers and IPTV were used in this measurement. The printer was omitted due to an Ethernet connection that was not available on the printer (Fig. 7).

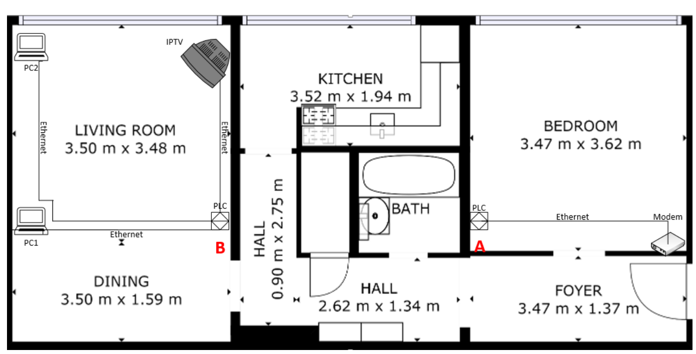


Fig. 7: Floor plan of residential space for Ethernet connection.

When using an Ethernet connection, it can be seen as the practical advantage of a set of PLC devices. Despite the absence of longer Ethernet cables that would lead from the bedroom, the living room electrical outlet was connected to the dining room and used the same phase (verified by measurement). Both A (Master) and B (Slave) devices were synchronized, and terminal devices were connected to the Ethernet outputs of B (slave) devices.

A. Measurement via Ethernet connection with VoiP traffic and IPTV

Figure 8 shows the PLC network setup over an Ethernet connection. As mentioned above, two transmission computers and IPTV were used. The computers used the Youtube service to play videos, and a Skype call was also made. IPTV used Netflix, a video-on-demand (VoD) service. It was also verified that the PLC devices were synchronized via the tpPLC mobile application and then the ping tool was used to verify the functionality of the network. The data rates were measured by means of the aforementioned iperf3 software tool.

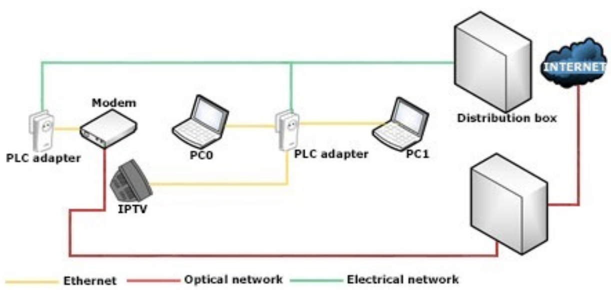


Fig. 8: Design of PLC network in residential space via Ethernet connection.

Thus, very high data rates were recorded for measurements over an Ethernet connection, as shown in Table II and Fig. 9. Tested TP-Link PLCs that operate in the "Ethernet" mode provide a transfer rate of up to 1 Gbps.

TABLE II: Bit rate measurement over Ethernet connection with VoIP and IPTV traffic.

Number of intervals [s]	No-load meassurement [Mbps]	Load Measurement [Mbps]
0	0	0
1	610	616
2	742	699
3	803	717
4	747	717
5	788	763
6	761	757
7	743	760
8	748	752
9	871	718
10	854	730

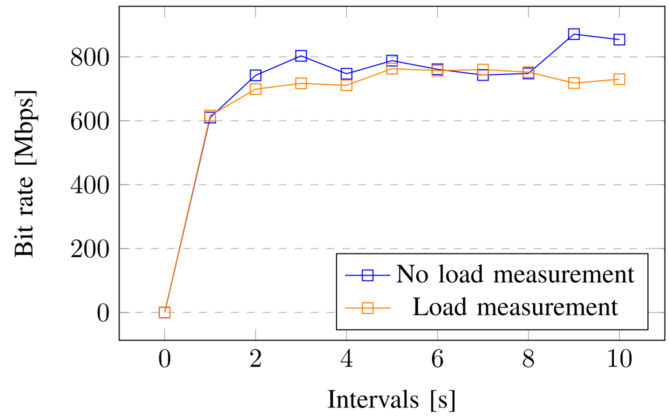


Fig. 9: Bit rate measurement over Ethernet connection with VoIP and IPTV traffic.

B. Measurement via Ethernet connection with VoiP traffic, IPTV and deployment of electrical appliances

Data transmission in PLC networks is strongly influenced by electrical appliances that have a high power consumption (cause voltage fluctuations and consequently adversely affect transmission speeds.). For this reason, measurements were also carried out with the connection of two electrical terminal devices with a power input of 800 W and 1000 W (Fig. 10). Both devices were connected via an extension cable to the tested home PLC network. In this measurement, both Youtube and Skype services were reused on both computers, as well as IPTV with Netflix. The devices were started along with the services listed.

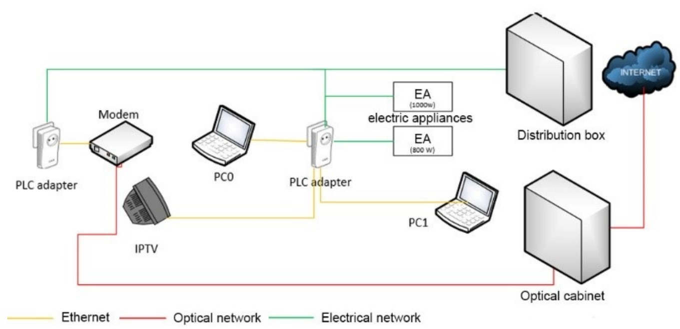


Fig. 10: Design of PLC network in residential space via Ethernet connection using high-end electrical appliances

From the measured values given in Tab. III and Fig. 11, it can be seen that the electrical devices had almost no effect on the transfer rates (the transfer rates were almost identical). It can be concluded that conventional household appliances such as a drill, vacuum cleaner, electric kettle and other electrical appliances in such a connected network practically do not adversely affect the transmission speed in the home PLC network. It can be assumed that electrical appliances with higher power consumption or several appliances could nevertheless affect the transmission quality and also the transmission rate although a refrigerator or electric oven is a higher-power appliance (which we have not used in our testing). These electric appliances should have their own electrical circuit for safety.

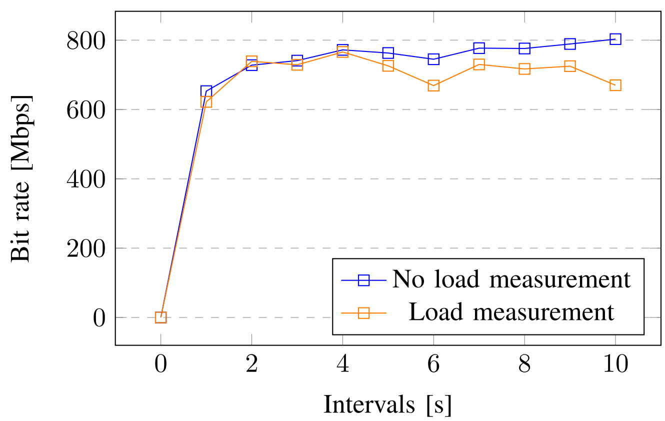


Fig. 11: Bit rate measurement over Ethernet connection with VoIP and IPTV traffic and and with connected electrical appliances.

TABLE III: Bit rate measurement over Ethernet connection with VoIP and IPTV traffic and with connected electrical appliances.

Number of intervals [s]	**No-load meassurement [Mbps]**	**Load Measurement [Mbps]**
0	0	0
1	653	622
2	728	739
3	741	729
4	772	766
5	763	726
6	745	669
7	777	730
8	776	717
9	789	725
10	803	670

VI. Summary

The values of measured transmission rates in the environment of real operation of an apartment building were in the order of tens of Mbit/s (up to 100Mbit/s), which was sufficient for the users of the above mentioned services. The advantage of this conceived PLC network was that all end devices in the PLC network were actually connected wirelessly. If home network PLC users would like to use broadband and high quality services, the TP-Link tested adapters include three Ethernet outputs that can also be used. In our testing we used all three outputs, one of which was connected to IPTV and the other two were connected to portable computers. For the sake of comparison, we measured the data rates first without any load (without using the above mentioned services) and then with the load with running services. The resulting data rates were up to 700 Mbit/s, which means that it is possible to use high-quality broadband services such as IPTV.

In order to sufficiently verify the functionality of the PLC adapters in real practice, we made another measurement, where we connected electrical devices (appliances) with high power. Our experience gained from testing various PLC adapters in the past has shown that electrical equipment, especially with higher power consumption, has adversely affected the PLC network in terms of interference and transmission speed. For this reason, measurements were made to determine whether this was the case with the tested adapters. Within one electrical phase, electrical equipment (a drill and a vacuum cleaner with a common power input of up to 1800 W) was connected and, in addition, the services mentioned above were started. When comparing the measured transmission rates, it appeared that the decrease in the transmission rate values was minimal, and even negligible, which did not adversely affect the quality of the broadband services used. Based on the measurements made, it can be stated that the use of TP-Link PLC adapters is a suitable solution for building home networks also in terms of operating broadband services. In addition, EMC radiation also has very good performance in terms of EMC radiation [24].

VII. Conclusion

The subject of this paper was the measurement of transfer rates in a real home PLC network with TP-Link TL-WPA8630PKIT adapters. The measurement was divided into testing of Wi-Fi network realized by the mentioned PLC adapters and Ethernet network where metallic connectors on PLC were used. Furthermore, the testing was divided into no-load and with-load (IPTV, VoIP and electrical appliances). According to the measurement results, it can be stated that the use of TP-Link PLC adapters is a suitable solution for building home networks also in terms of operating broadband services.

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