Impact of household electrical appliances on transmission speed in PLC networks

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***Abstract*—The paper deals with the impact of switching power supplies, surge protection and current protector on the throughput in PLC (Power Line Communication) networks created with PLC adapters TL-PA8010v2 and TL-WPA8630v2. TCP (Transmission Control Protocol) and UDP (User Datagram Protocol) protocols were used for data transmission and the PLC network itself was implemented on aluminum and copper lines. Measurements of transmission speeds made it possible to analyze the various effects of interference on data transmission on both lines and compare them. This paper is a supplement to the testing of PLC networks with the mentioned adapters, which is the subject of another paper at the conference.**

***Index Terms*—Smart Home, PLC, Noise, Appliances disruption**

I. Introduction

The Smart Home is an already well-known concept historically here from the 2001s project called "Orange at Home" [1], [2]. As the years past, the concept got clearer shape created by several requirements via services, which are being fulfilled by a wide range of technologies or solutions, including trending Internet of Things (IoT) [3], [4]. Nowadays, the essential parameters for smart homes are comfortable living, life safety, cyber-security and general system efficiency [5]–[9]. These are met by a multi-technological approach and hybrid heterogeneous networks, which works together in smart home infrastructure [10].

PLC technology enables data transmission via power lines [11], [12] and it is suitable for many different infrastructural communication applications including smart grid, smart city, smart factory, smart hospital, and especially smart home [13]–[22]. It can be used for communication without the need to build a new communication line [23] and also allows the replacement of Ethernet solutions in home networks and small business networks [24], [25]. With the help of PLC adapters, it is possible to replace Ethernet network cables, provided that the ends of the network are installed on the same phase of the electrical distribution [26].

Recently, new PLC adapters have appeared on the market, which enables data transmission at high transmission speeds and thus provide space for the provision of broadband services - IPTV, video telephony, etc. [27]. The tests of the PLC network, which we performed, were created on aluminum and copper lines in apartment buildings to monitor the impact of various electrical appliances (connected to the electrical network as jammers) on data transmission by measuring the transmission speed [28]. In this paper, we monitored the effect of switching power supplies, surge protection and RCD on throughput. We chose Tp-link AV1300 TL-WPA8630v2 KIT PLC adapters for testing. Using PLC adapters was also dealt with by other authors in the works [29]–[31].

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II. Experimental setup

The TP-Link AV1300 and TL-WPA8630v2 KIT adapter set consists of one TL-PA8010v2 transmitter and one TL-WPA8630v2 1350 Wi-Fi receiver. The transmission speed that this set allows to be reached is close to 1300 Mbps, which can satisfy even users who require more bandwidth. The first TL-PA8010v2 adapter contains one Ethernet port with a transmission speed of 1 Gbit/s, which connects to the router and then to the Internet. This Ethernet port is reserved for this purpose. The transmission speed of 1300 Mbps is considered as the theoretical maximum data transfer rate; real measured transmission speed depends on the quality and performance of the adapter's Ethernet port and the conditions on the used network, such as noise caused by the transmission channel, the condition and material of the wiring (Al or Cu), but also on interference from other electrical devices connected to the network. To test the operation of the PLC network, we used various of switching power supplies - charger for mobile phones Samsung (5 V/1.55 A) and Huawei (5 V/1 A), surge protection EATON series Protection Box 1 FR 16A and single-phase current protector Merlin Gerin Multi 9 (Fig. 1.

Fig. 1. Surge protection EATON Protection Box 1 FR and circuit breaker Merlin Gerin Multi 9

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Protective features such as surge protection and a circuit breaker are often used to protect electrical equipment in the power grid. When testing the PLC network, we used the EATON Protection Protection 1 FR 16A series and the Merlin Gerin Multi 9 jet protector. When measuring transmission, we used the Java software tool JPerf version 2.0.2, which also allows the generation of a data stream, which is then sent to the network (PC and Laptop end nodes). We tested the influence of switching power supplies and over-voltage protection on the transmission speed on aluminum and copper lines 230 V/50 Hz, the impact of single-phase current protector only on the copper lines of adapters PLC adapters TP-Link TL-PA8010v2 and TL-WPA8630v2 (marked as PLC) were connected according to the diagram, which is shown in Fig. 2 (as previously said and as might be seen in the figure, there are three types of physical media: (i) Wireless IEEE 802.11, (ii) Wired Ethernet IEEE 802.3 with 1 Gbps throughput, Wired Electrical cable of (iii.a) aluminium - Al and (iii.b) Copper). The two adapters (power node plug) were 20 m apart, between them, there was one socket, which was used to connect the already mentioned electrical appliances as sources of interference (noise injector).

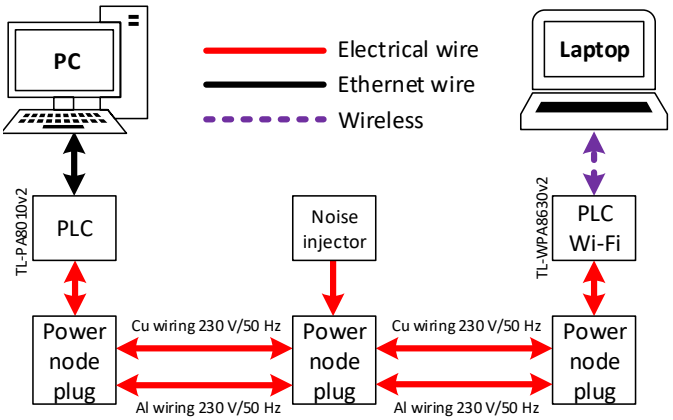

Fig. 2. Scheme of measuring workplace

III. Experimental Measurements

A. Power supplies as sources of interference

To test PLC transmission, switching power supplies were also used - mobile phone chargers, namely the Huawei charger (1.00 A) and the Samsung charger (1.55 A), which was actively charging devices during the connection. The measurements took place separately, so in one measure, the impact of the Huawei charger was monitored and, in the other measurement, the impact of the Samsung charger. A switching power supply is an electronic device that can convert an input voltage to high-frequency pulses. The pulses are later transformed into an electrical voltage, rectified to obtain the desired output voltage. These sources can be found in televisions, mobile phone chargers, computer sources, and other power supplies. The following transfer speed on the aluminum network with TCP (Fig. 3) and UDP (Fig. 4) transmissions show the effect of the connected Samsung and Huawei chargers on the transmission speed.

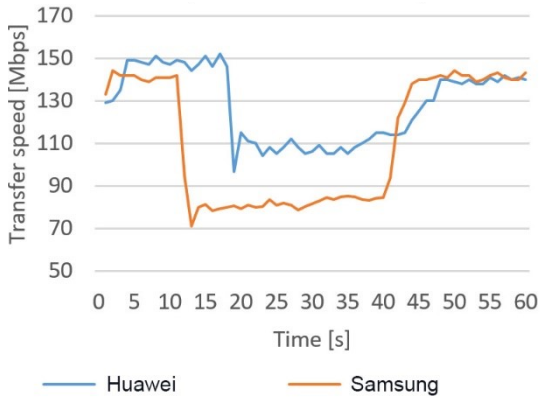

Fig. 3. Measured transmission speeds on Al network with TCP transmission using the Huawei and Samsung chargers

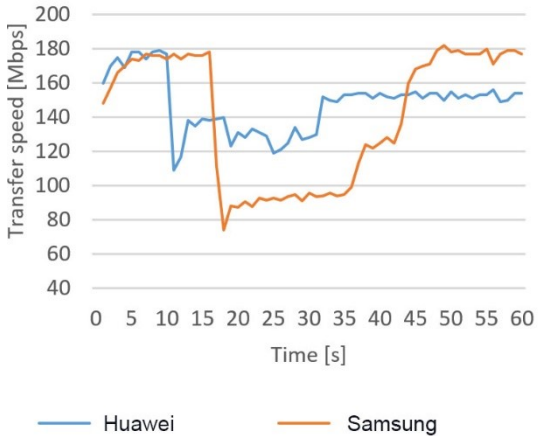

Fig. 4. Measured transmission speeds on Al network with UDP transmission using the Huawei and Samsung chargers

The Samsung charger was connected from the 12th second to the 40th second of the measurement. To be able to compare the courses, the Huawei charger was connected between 19 and 43 seconds. In both cases, it is possible to see a more significant effect of both chargers, which reduce the transmission speed. In the case of TCP data transfer, the connection of the Huawei charger decreased 34% from the initial rate before the connection and it was up to 50% reduction for Samsung chargers. As in the previous measurement, in data transmission with UDP, there was a significant change in transmission speed immediately after connecting the chargers and during their connection to the electrical network. In this case, the transmission speed was significantly reduced by 37.4% (Huawei charger) and in the second case by up to 58.5% (Samsung charger). The lower transfer rate remained throughout the connection of the chargers to the network. After disconnecting the Huawei charger, the transmission speed increased, but the values did not reach the initial values. The cause was

probably due to the use of different modulation and transmission frequency in the adapters than at the beginning of the measurement. PLC adapters are configured to automatically find the most suitable modulation and frequency that is least disturbed. The manufacturer does not state how the system works. Similar to the measurements on the aluminum network, the same switching power supplies were used in the case of the copper network - mobile phone chargers of the Huawei brand (1 A) and the Samsung brand (1.55 A). Fig. 5 and Fig. 6 show the measured courses of the transmission speed after switching power supplies for TCP and UDP transmissions. The displayed courses of the measured transmission speed show that the chargers used significantly affect the transfer rate during their operation. After connecting the Huawei charger in the 16th second during TCP transmission, the transmission speed was reduced by 22.7%. After connecting the Samsung charger in the 20th second, the transmission speed was decreased by 33.95%. A decrease in the transmission speed can be observed during the entire connection time of both chargers, which means that the interference from these chargers limits the actual data transmission in the established PLC network.

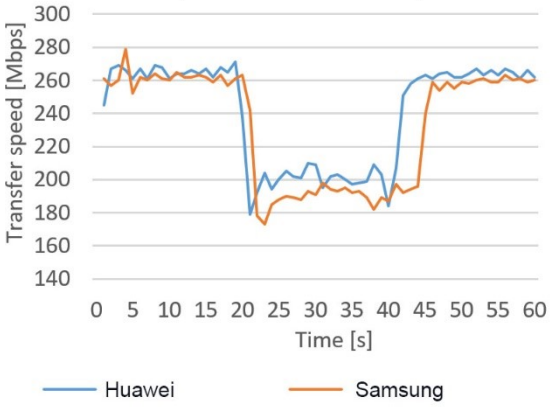

Fig. 5. Measured transmission speeds on Cu network with TCP transmission using the Huawei and Samsung chargers

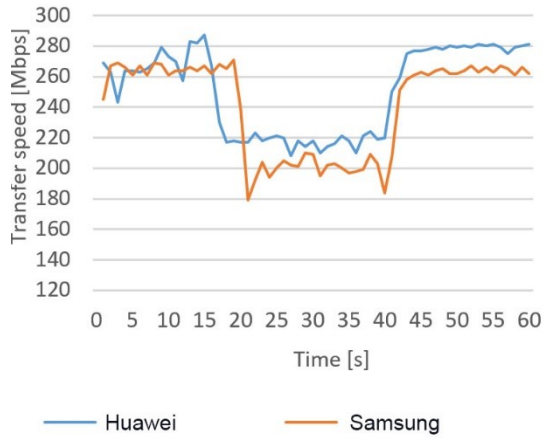

Fig. 6. Measured transmission speeds on Cu network with UDP transmission using the Huawei and Samsung chargers

B. Over-voltage protection scenario

In the case of the implementation of PLC networks, we often encounter how to deal with surge protectors. The purpose of surge protectors is to protect electrical networks and equipment from surges caused by atmospheric discharges or from various other electrical equipment in the network. When testing a PLC network created on both aluminum and copper networks, we monitored the effect of surge protection on the transmission speed. For this purpose, the EATON over-voltage protection of the Protection Box 1 FR 16A series. After connection via over-voltage protection, the values of the transfer rate did not reach the values without connection of the interference source, which can be attributed to limitations on the side of the adapter. There was not possible change in modulation and the most suitable transmission frequency was not found, which was reflected in the transmission speed of individual measurements. Values of transmission speeds ranged from 105 to 128 Mbps for TCP transmission (Fig. 7) and 144 to 160 Mbps for UDP transmission (Fig. 8).

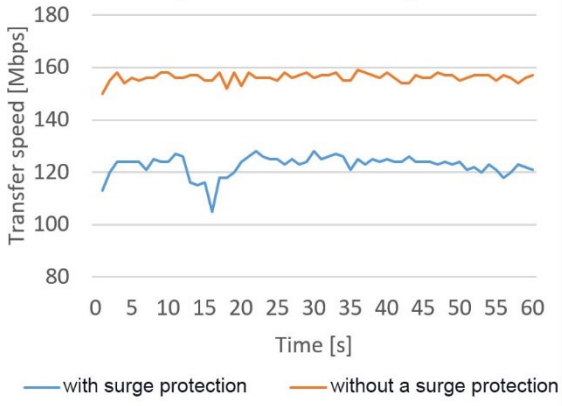

Fig. 7. Measured transmission speeds on Al network with TCP transmission when using surge protection

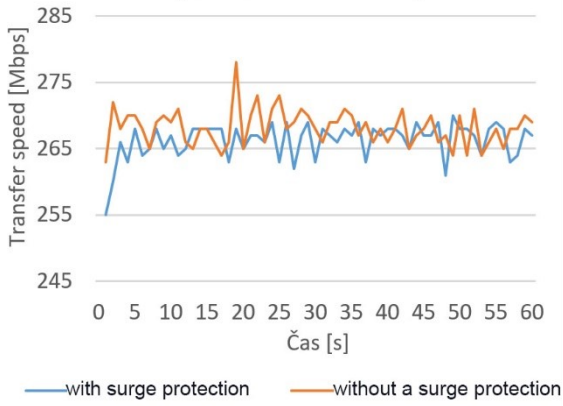

Fig. 8. Measured transmission speeds on Al network with UDP transmission when using surge protection

The manufacturer itself does not recommend that the PLC adapter be connected to networks with surge protection, as the transmission properties in such a network may deteriorate. This was reflected in the measured results. Interestingly, the use of surge protection in the electrical network with the copper network had a completely different course of measured transmission speeds than it was in the previous measurement in the aluminum wiring (Fig. 9 and Fig. 10). The automatic switching caused a larger decrease in the transmission speed in the 12th second in UDP transmission on another electrical appliance connected in the used electrical network; in our case, it was turning on the fridge compressor. The average throughput was 266.3 Mbps (TCP) and 278.6 Mbps (UDP).

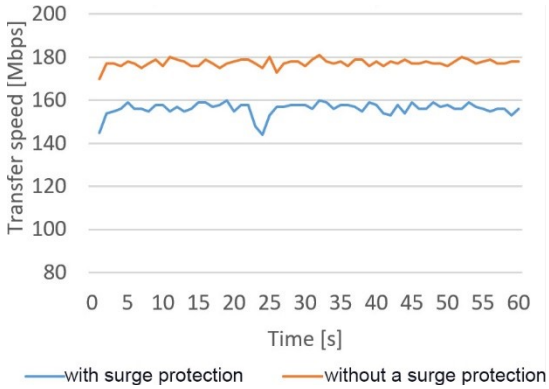

Fig. 9. Measured transmission speeds on Cu network with TCP transmission when using surge protection

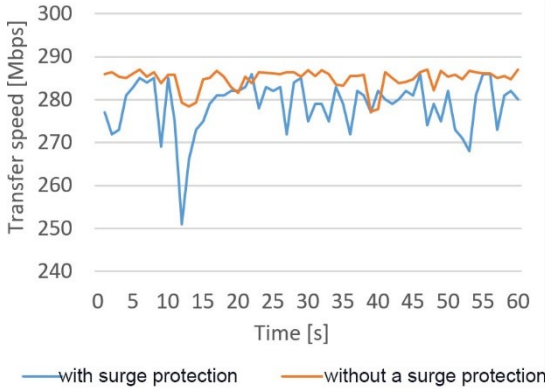

Fig. 10. Measured transmission speeds on Cu network with UDP transmission when using surge protection

C. Circuit breaker scenario

As with surge protection, in the case of using a circuit breaker in a PLC network, it is necessary to solve the problem of whether this electrical device can be used in the network or not. A circuit breaker is an electrical device that has the task of disconnecting a protected electrical circuit if part of the incoming current leaks out of the circuit, for example, in the event of damaged insulation of the device or human contact. It is connected so that all working conductors whose sum of currents usually is equal to zero, pass through the current transformer. The Merlin Gerin Multi 9 circuit breaker. It is a single-phase current protector designed for alternating (operating) voltage of 230 V, 25 A with a sensitivity of 30 mA. The first step of the measurement was to determine the current transmission speed in TCP and UDP transmissions when the circuit breaker was not connected. These data made it possible to compare the values of the transfer rate before and after the use of the circuit breaker, and thus to determine its effect on the data rate. The measurement of the course of transmission speeds was performed only on the copper network; the measured courses can be seen in Fig. 11 and Fig. 12. The measurements show that, regardless of the protocol used (TCP or UDP), the circuit breaker does not allow the use of higher transmission speeds above 70 Mbps. The average transfer rate for TCP transmission was 59.85 Mbps and 66.34 Mbps for UDP transmission. For comparison, the average transfer rate without a connected circuit breaker was 183.22 Mbps (TCP transmission), 202 Mbps (UDP transmission). This is a very significant reduction in transmission speed - up to 67.33% in the case of TCP transmission and by 67.16% in the case of UDP transmission. A positive moment is the finding that no electrical equipment in the PLC network was switched off or disconnected during the measurement. Despite the significant limitation of the transmission speed, it is possible to confirm that the data transmission is possible.

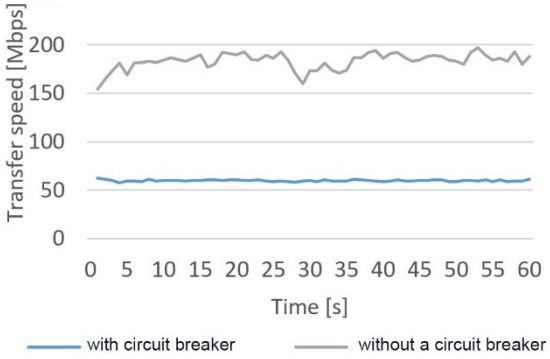

Fig. 11. Transmission speed comparison without and with surge protector for TCP transmission

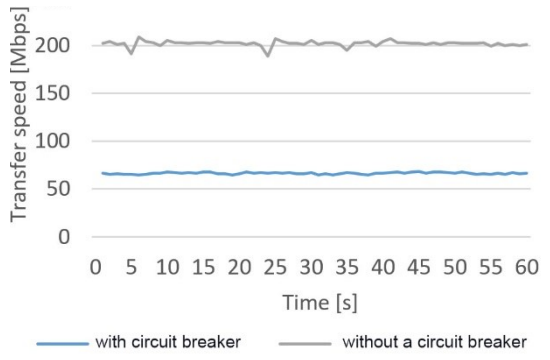

Fig. 12. Transmission speed comparison without and with surge protector for UDP transmission

IV. Conclusion

The measured results show that the copper line is providing higher and more stable throughput. Although lower transmission speeds characterize the aluminum line (which is still widespread), it is still usable for everyday needs. Switching power supplies - mobile phone chargers - significantly affected both TCP and UDP transmission. Compared to conventional electrical household appliances, when the transmission speed decreased significantly only when the appliance was switched on and off, the transmission speed decreased during the entire connection time of switching power supplies. When testing a PLC network with surge protection installed, the values of throughput did not reach the values of throughput without their connection. This may be due to a change in modulation and a search for a more suitable transmission frequency. The manufacturer of the tested PLC adapters does not recommend the use of surge protection. The use of surge protection in an electrical network with an aluminum line had a different effect on the measured transmission speed than in a copper line. The transmission speed was also measured in the PLC network, where a circuit breaker was connected. In this case, the transmission speed decreased by 67% in PLC networks with both aluminum and copper lines. However, the measurement proved that the actual transmission through the circuit breaker is possible, although with a larger limitation of the transmission speed, but the manufacturers of PLC adapters do not recommend the use of circuit breakers in the PLC.

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