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Measurement of Powerline Performance in Residential Context

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***Abstract* – In recent years, Power Line Communication (PLC) has had a wide use in various contexts. PLC systems are non-invasive, low cost and combine electrical installation with network connectivity. By reducing installation time and costs, the PLC is a valid alternative to wireless technology. The electrical system is designed to meet the requirements in terms of installed power, connected loads, line length and cable section. Therefore, in a real context, the PLC performance can be influenced by the impedance of the communication channel, but also by the injection of harmonics into the electrical system, which reduce the signal-to-noise ratio. The purpose of this paper is to measure the performance of a PLC system in terms of the main parameters, such as bit rate, transmission time, retransmission packet, and others. The performance tests were carried out in a system that reproduces a domestic plant by means of concentrated impedances, to guarantee the repeatability of the tests and to allow easy modification of the power supply system. The loads are integrated in this system, to reproduce the real problems.**

I. INTRODUCTION

Connectivity is changing the way people live and work [1]. This aspect is increasingly important for the diffusion of new transmission technologies: wireless, wired networks or PowerLine Communications (PLC) [2]. In lighting contexts, these technologies bring companies closer to the Industry 4.0 paradigm, connecting every element of the network, for example to optimize the use of lighting and allow a reduction in costs, through intelligent maintenance. In extended lighting systems located in remote areas, for these reasons, companies have developed single chip powerline modems, to make installation and diffusion of this technology more efficient.

The main advantage of PLCs is to be able to transmit data on existing lines, which are also used for electricity distribution. Initially, this technology was used for remote reading of energy meters. Subsequently, it established itself in the industrial and residential context with "smart" electronic products that communicate, such as air conditioners, heating systems, smart locks or smart bulbs.

The first PLC applications were point-to-point communications on MT and AT networks (1920), for the remote monitoring and control (1950). Since the 1970s, the distribution network has been automated using the PLC on dedicated frequencies [3]. In Italy, the ENEL distribution company began developing the first projects in the 1980s.

Initially this transmission used low frequencies, with different modulation techniques. In the 2000s, the Home plug 1.0 standard was defined, evolved into the AV Home plug standard with speeds up to 200 Mbit/s. In 2010, the IEEE Std 1901-2010 standard for communications on home electricity networks was officially published [4]. The European standard CENELEC EN 50065-1: 1991 defines the operating frequencies and electromagnetic disturbances, for equipment that transmits information on the low voltage network. The standard is still used, updated to version 2012 [5].

Powerline can be an important alternative in environment where the wireless signal is not allowed (quite radio zone) and to reduce installation cost [6].

Powerline systems are able to transmit data even in noisy environments, using proprietary optimization methods, dynamic modulation techniques and non-standard bands.

Therefore, each device has different performances and behaviors, depending on the installation [7]. These systems may have reduced performance due to interference in electrical systems. Installing these devices on multiple sockets can also cause problems. Other transmission problems arise in systems protected by differential switches, due to the presence of the coil.

The PLC is very sensitive to impulsive disturbances, such as the signals provided by microwave ovens, autoclaves, motors, switching power supplies and neon lamps. In effect, impulsive disturbances have a diffusion spectrum which is superimposed on the band used by PLC devices and therefore degrades the signal-to-noise ratio. The main problems on the distribution lines are due to electromagnetic interference also due to arcs or opening and closing maneuvers [8].

The reliability of communication and the speed of data transfer are critical parameters when it is necessary to guarantee a stable and efficient connection. The purpose of the paper is to measure the performance of powerline systems in the domestic context.

II. POWERLINE TECHNOLOGIES

The different standards for PLCs focus on different parameters and different applications or operating environments [9]. Very popular is the technology based on the LonWorks protocol, also ISO 14908-1-2-3-4 [10] [11] [12] [13]. The PLC can be divided into three classes:

- Ultra Narrow Band (UNB): very low data rate (about 100 bps) in a range of frequencies of 30 Hz-3 kHz. Very long distances, even exceeding 150 km, can be reached. The UNB-PLC transmissions are already "mature", and implemented by at least two decades, but unfortunately they adopt proprietary technologies.
- Narrowband (NB): a standard that operate in the frequency bands VLF/LF/MF (3-500 kHz). The NB can be divided into Low Data Rate (LDR), with speeds up to a few kbps and High Data Rate (HDR), up to 500 kbps. The NB bands are: 3 to 148.5 kHz (CENELEC Europe); 10 to 490 kHz (FCC America); 10 to 450 kHz (ARIB Japan); 3 to 500 kHz (China).
- Broadband (BB): this technology operates at frequencies of HF/VHF (1.8-250 MHz) with a data rate range from a few Mbps to several hundred Mbps [14].

The European CENELEC standard EN 50065-1 [3] relating to the transmission of signals in low voltage electrical systems in the NB. As shown in Fig.1, four bands are defined: i) Band A (3- 95 kHz), assigned to the electricity distribution companies; ii) Band B (95-125 kHz), for common use, no access protocol; iii) Band C (125-140 kHz), for home use with CSMA / CA (Carrier Sense Multiple Access / Collit Avoidance) access protocol; iv) D band (140-148.5 kHz), for security and alarm systems, no access protocol [15].

The best modulation technique for PLC is OFDM, which dynamically allocates the transmission bandwidth according to the type of network connection. The level of interference essentially depends on the line impedance. Another problem occurs when two long power lines are placed side by side, due to mutual coupling, which causes interference.

Fig. 1. Main classes of powerline technologies classified according to the operating frequency.

III. THE MEASUREMENT SETUP

As previously introduced, the purpose of this work is to analyze the performance of powerline modules connected to a home network. In other paper [16] the performances of powerline have been tested using 120 m^2 area apartment fed by a single-phase power installation in a seven-apartment building with a three-phase residential power distribution installation. In order to allow tests to be carried out in traceable and flexible conditions, the electrical network of a typical apartment was built, using concentrated impedances to emulate the behavior of the power cables.

Fig. 2. Measurement setup

The adopted test platform (Fig. 2), consists of:

1) the TL-PA4020P KIT PLC modules under analysis;
2) a PLC management computer;
3) the electrical system with concentrated parameters that simulates a home power system;
4) the electrical loads connected to the system:
5) a measuring rack with the main instruments;
6) a computer for the instrumentation management;
7) a Tektronix TDS 5054 Digital Oscilloscope, for displaying voltage and current of input power supply;
8) a FTP-Client system, for downloading the test file.

The instruments labelled (5) in Fig.2 include:

a) National Instruments PXI-1010, for the voltage and current acquisition of input power supply.
b) EMC-Partner Transient 2000, to supply the electrical system with an undistorted sinusoidal voltage. It is characterized by zero impedance, to eliminate the error due to this parameter, and guarantee traceability and repeatability of the tests.
c) Harmonics-1000 of the EMC-Partner, connected to the Transient 2000 output, to both inject and measure the harmonic content.

The computer (2) is used: a) to manage the powerline network with the tpPLC Utility software; b) as FTP-Server for storing the test file; c) for the analysis of network traffic with the Wireshark software. A schematic representation of the measurement setup is reported in Fig. 3.

A. Electrical system with lumped parameters

As reported in [17], the equivalent electrical system was developed with concentrated impedances, equivalent to the impedances of the real lines, for a 74 m^2 house. The system was developed on the basis of the Italian standard

(CEI 64-8 [18]), and powered at 230 V - 50 Hz. In Fig. 4 the position of the sockets in the electrical system have been reported.

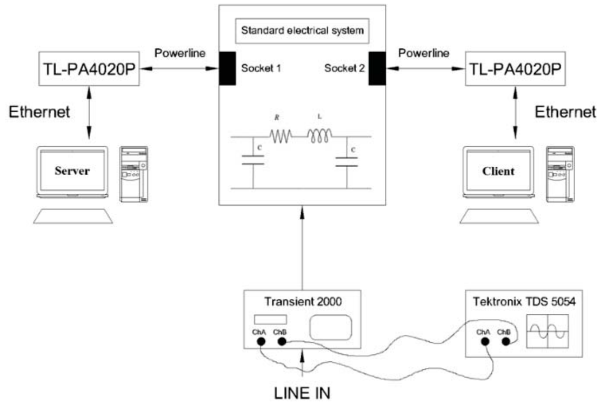

Fig. 3. Schema of the measurement setup

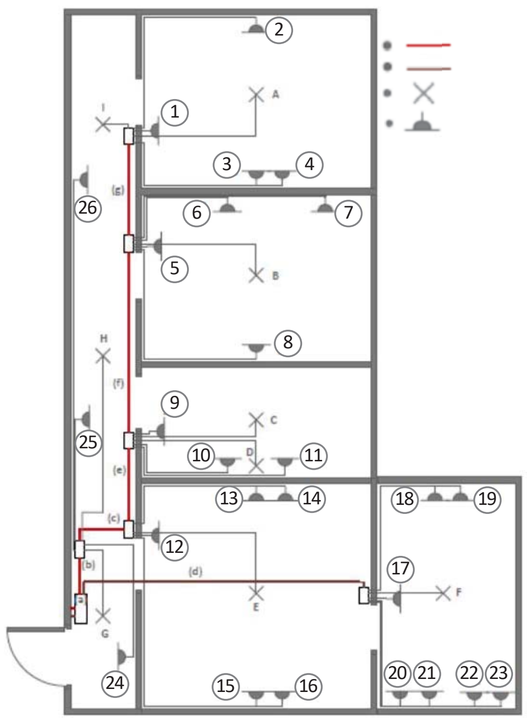

Fig. 4. Position of sockets in electrical system

B. Powerline modules

The adopted TP-Link TL-PA4020P modules, are designed to extend an existing data network through the electrical network. Main features are: i) OFDM modulation; ii) maximum load: 13 A; iii) power consumption: 2.91 W; iv) supported standards and protocols: HomePlug AV, IEEE 1901, IEEE802.3, IEEE 802.3u; v) Encryption: 128-bit AES.

Home Plug AV is the main standard used by most powerline products. It provides a speed of 200 Mb/s and operates in the range between 2 and 28 MHz. The TL – PA4020P has a speed of 600 Mbps as complies with the HomePlug AV 2.

C. Loads connected to the electrical system

Some loads have been connected to the electrical system, to emulate real behavior in residential contexts. In particular, the main loads used are: i) 500 W electric heater; ii) 189 W single-phase induction motor with 19 W cooling fan; iii) 24W fluorescent lamp.

IV. TEST PROCEDURE AND RESULTS

A. Test procedure

The tests were conducted by powering the measurement platform with the Transient 2000, and connecting the powerline modules in two different sockets. Subsequently, the acquisition of TCP/IP packets was started, with the network analysis software. For each test, the transfer of FTP files between the PC client and the PC server was performed, and the acquired packages were processed.

The following configurations have been analyzed:

- PLC 2-4 sockets: both modules installed inside the study room, respectively in sockets 2 and 4. This configuration has been considered to examine the case in which the two powerline modules are electrically close together;
- PLC sockets 2-23: one module installed in socket 2 of the study room and the second in socket 23 of the kitchen. This configuration has been considered because the kitchen line is a dedicated line separated from the rest of the apartment;
- PLC sockets 2-26: one module installed in socket 2 of the study and the other module in socket 26 of the corridor. This configuration has been considered because the two devices are positioned at the ends of the system.

Table 1. Sockets used to connect the loads

Test N°	Lamp	Heater	Motor
1	3	/	4
2	3	/	11
3	3	/	23
4	3	/	26
5	3	4	/
6	3	11	/
7	3	23	/
8	3	26	/
9	3	8	11
10	3	23	11
11	3	26	11
12	3	4	23
13	3	11	23
14	3	25	23
15	3	10	26

16	3	21	26
17	3	15	26
18	10	7	23
19	22	19	11
20	26	23	7
21	/	/	/

Several electrical loads have been connected to the electrical system according to the configurations shown in the Table 1. The first column shows the number of the test performed, while the other columns show the number of the power outlet used to connect the load to the system. The symbol "/" indicates no connected load.

The acquired messages were processed by the Wireshark software, analyzing the following parametrs:

- *Total packets*: the number of TCP/IP packets exchanged during the file transfer;
- *TCP Flags*: TCP ACKed unseen segment, TCP Dup ACK, TCP Fast Retransmission, TCP Keep-Alive, TCP Keep-Alive ACK, TCP Out-Of-Order, TCP Port numbers reused, TCP Previous segment not captured, TCP Spurious Retransmission, TCP Retransmission, TCP Window Update, TCP ZeroWindow, TCP ZeroWindowProbe and TCP ZeroWindowProbeAck.
- *Retransmission*: Retransmissions occur when there is a return of damaged or lost packet.
- *Dup_Ack*: ACKs sent when gaps are found between the packets. Dup_Ask does not always imply that there are packet losses every time duplicate retransmissions and Acks occur.

B. Results

An example, the tests shown in Figs. 5 to 9 are related to test number 13, with the PLCs in sockets 2 and 4.

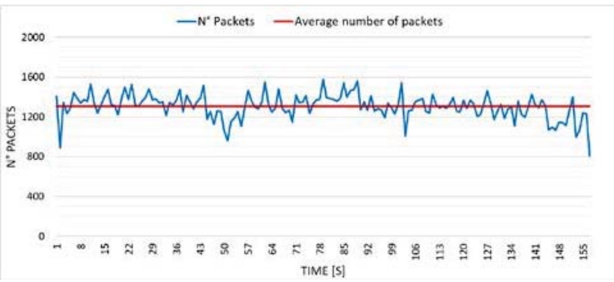

Fig. 5. Number of packets transmitted over time

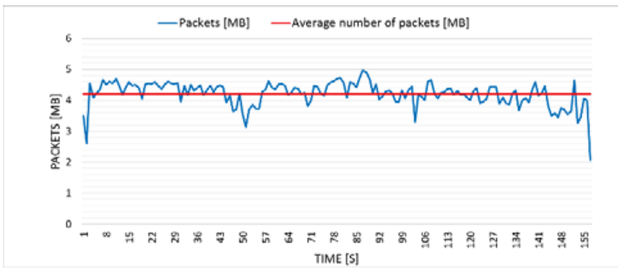

Fig. 6. Number of bytes transmitted over time

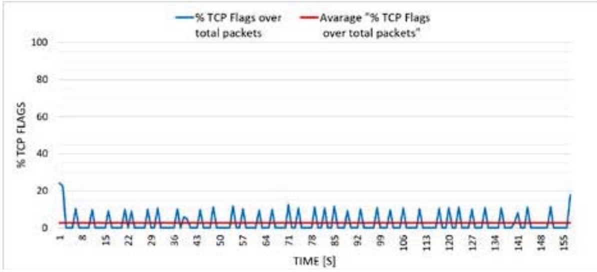

Fig. 7. Number of TCP Flags over time

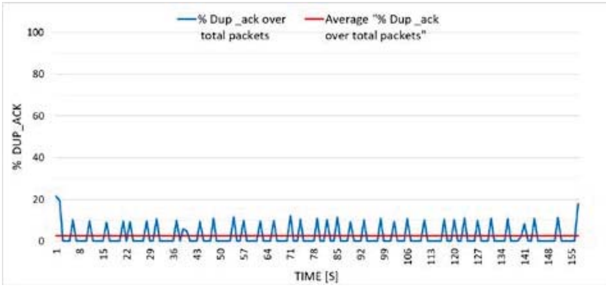

Fig. 8. Number of DUP_ack over time

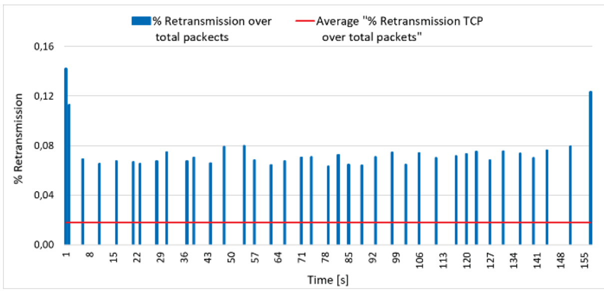

Fig. 9. Number of retransmissions over time

C. Comparison

In order to compare the results obtained from the 20 tests for the 3 different configurations, a system has been developed in which a score is assigned for each result. Scores range from 0 to 4 for a total of 5 possible scores. The scores are assigned as follows: 1) a configuration is selected; 2) for each test, the acquisitions obtained through the Wireshark software are processed in order to evaluate the following parameters: a) total transfer time; b) the average value of the packets transmitted in the unit of time; c) the average value of the *Dup_Ack* compared to the total packets; d) the average value of the bytes transmitted in the unit of time; e) the average value of the TCP retransmissions compared to the total packets; f) the average value of the *TCP Flags* with respect to the total packets; 3) once a parameter has been set, the maximum and minimum values are determined to evaluate the range; 4) the range obtained is divided into 5 equally spaced classes; 5) each parameter evaluated is associated to a class; 6) each class has a score from 0 to 4. The value associate to the class gives the quality of PLC communication. For example, considering the parameter of transfer time: a high value will be assumed if the time is shorter, while a low value is assumed if the time is large. On the contrary, considering the parameter of average value of the bytes transmitted in the unit of time, a high value will be assumed if many bytes are transmitted, on the other hand, a low value will be assumed if few bytes are transmitted. 6) For each test performed, the score obtained are added up and the result is expressed in percent. The results are shown in the Table 2.

Table 2. Comparison between the configurations

Test N°	Socket 2-4	Socket 2-23	Socket 2-26
1	41,67	70,83	58,33
2	41,67	41,67	70,83
3	41,67	29,17	83,33
4	37,50	29,17	29,17
5	41,67	20,83	66,67
6	41,67	50,00	66,67
7	25,00	62,50	75,00
8	25,00	66,67	62,50
9	29,17	12,50	70,83
10	12,50	29,17	66,67
11	12,50	41,67	50,00
12	16,67	37,50	70,83
13	29,17	50,00	58,33
14	45,83	58,33	62,50
15	16,67	33,33	20,83
16	16,67	79,17	45,83
17	12,50	33,33	62,50
18	33,33	0,00	50,00
19	50,00	70,83	54,17
20	41,67	54,17	79,17
21	100,00	100,00	100,00

In the first configuration, the parameters that give better results are the transfer speed and the transfer time. This is because the two powerline modules are electrically close. The worst cases are due to the presence of an ohmic-inductive load (the electric motor) which disturbs communication. On the contrary, the presence of the heater does not affect the quality of the transmission except in the case where the load is connected in the same socket of the powerline module. In this case, there is a localized disturbance.

The worst results for the transfer rate and transfer time parameters are obtained in the second configuration. In fact, in this configuration a transmission between two different power lines is tested: the kitchen and the general one. The communication passes through n.2 16 A automatic circuit breaker. The behavior of these devices is similar to a transformer. The low pass frequency response attenuates the high frequency harmonic components.

The third configuration represents an intermediate case with respect to the previous ones in terms of transfer rate and transfer time. In fact only n.1 automatic circuit breaker is installed between the two powerline modules. The worst cases occur in tests in which the electric motor is connected in the same socket as the powerline module.

Finally, the last configuration has been selected because the powerline modules are positioned at the extreme points of the electrical system used for the tests. Although the powerline signal decays at a distance, given the size of the test system, the distance did not affect the quality of the transmission.

V. CONCLUSIONS

In this paper the measurement of powerline performance in residential context has been presented. The measurement setup is based on a domestic installation based on lumped parameters to ensure repeatability of tests. A client-server system has been used in order to perform the same file transfer and to compare the data. The test procedure and some results have been reported. Further work will be oriented in the use of the proposed measurement setup to perform tests under disturbance introduced into the power system.

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