**Communication in Smart Homes with Emphasis wn Power Line Communication**

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*Abstract:* **Power Line Communication (PLC) is a technology that allows consumers to use the already existing wiring infrastructure to exchange information. This paper overviews narrowband PLC in home automation, starting from the basics of power line communication and its advantages compared to wired and Wi-Fi automation systems, data modulation techniques, noise problems, frequency bands, all the way to regulations affecting PLC. The paper is finished off with an overview of three System on Chip (SoC) power line modems from a few different generations, Yitran’s IT800D from 2005, ON Semiconductor’s NCN49597 from 2012, and STMicroelectronics’s ST8500 from 2017.**

*Keywords:* ***Power Line Communication, narrowband PLC, PLC modem, System on Chip***

1. **Introduction**

Although home automation concept has been around for a quite some time, actual smart homes have only existed for a short time. This concept started with the invention of home appliances in the early 20th century, and has since developed with applications ranging from aiding senior and disabled, over energy efficiency solutions, all the way to simply making everyday life more relaxed and easier. Current trends in home automation include automated thermostats and lights, remote control, scheduling appliances, text notifications, and remote video surveillance [1].

Automation systems in new dwellings are nowadays planned ahead and require dedicated infrastructure, which gives motivation for the development of a system that operates on an already existing one, so that the owners of already existing homes wanting or needing home automation can obtain it. In this case, one of the solutions can be home automation through power line communication. Power Line Communication (PLC) provides both broadband and narrowband data communication on already existing wires used for electric power transmission using a modular signal. This is commonly done in electric power systems, mostly for the Automatic Meter Reading (AMR) purposes, but it can also be used for home or building automation systems [2]. The main advantage of the power line automation systems is that they provide so called “no new wires” automation, meaning that there is no need for expensive remodeling, installation of new wires, digging into walls, etc. but instead, already existing power line installation inside the object is used for automation [3] [4]. Another advantage PLC based home automation systems introduce is the solution for the problem emerging with Wi-Fi communication for appliances that are located in the basements with thick walls and on tops of buildings, i.e. heating systems and air conditioning devices respectfully.

The monitoring of these types of devices can present in a problem for Wi-Fi based home automation systems, whereas the PLC based systems can provide a solution for monitoring each device that has an access to electricity.

First use of power line communication has been in 1838, when an Englishman Davy proposed a solution for remote measurements system between London and Liverpool. In 1897, first patent was submitted by him for the remote measurement of electrical network meters communicating over electrical wiring [5]. Since then, PLC communication has found its place in several different categories, concerning the type of service it provides: communication over high voltage grid (i.e. AMR, theft recognition, fault locating), access to internet provider (broadband PLC or BPL), in-home networking with high data rate (internet, music distribution – BPL), and in-home networking with low data rate (narrowband PLC or NBPL used for sending small amounts of data sufficient to give a signal to a relay in order to perform a task) [3].

This paper reviews narrowband power line communication for affordable and easy-to-make home automation systems, and it also reviews three System on Chip PLC modem solutions from different generations in terms of their characteristics such as modulation techniques, data rates and field of application. SoC PLC modems compared are Yitran’s IT800D from 2005, ON Semiconductor’s NCN49597 from 2012, and STMicroelectronics’s ST8500 from 2017.

Along with the comparison between these SoC PLC modems, the paper overviews Wi-Fi and wired based home automation solutions, and the advantages and disadvantages of these types of systems, in comparison to PLC based home automation.

1. **Motivation**

This paper was in search for a cheap and easy to implement solution for home automation systems, and was also lead by the idea that power line communication can be used for more than simply carrying electricity. However, in order to see if PLC based home automation can work, it was necessary to examine what was missing from the other home automation techniques, especially wired and wireless systems.

In wired Smart Home solutions, all of the gadgest connected to the automation system are connected to a 220 W power line, and acts as an independent node. The major advantage of these kinds of systems is reliability. While the wireless connection may be hacked, in wired systems the functions can be executed even if the central controller is broken down. However, even though the high performance is a plus, one of the disadvantages of wired home automation systems is the complex wiring which results in expensive house remodelling in order to install the system. The remodelling alone would be expensive, but what makes it even worse is the price of these kinds of systems where a decent wired home automation system is priced at around 50 000 USD and more sophisticated ones are priced at around 300 000 USD! Last, but certainly not the least of the problems is the scalability. In order to connect a new device to the system, the owner would have to contact the home automation installation company and have them design extra gateways and hubs [23].

However, this does not mean that wireless solutions are the way to go, as many (especially) Wi-Fi home automation systems’ advantages can easily be tuned to disadvantages. The first problem of wireless systems is the reliability, as Wi-Fi can often be down and is susceptible to hacking (hacker is one click away from making the user a prisoner of his own home). What is interesting is that this disadvantage is often sold as a strength, with statements saying that the Wi-Fi will notify the user when it is down. Unlike wired home automation systems, wireless based ones do seamingly offer lower hardware costs. However, if it is taken into account that Wi-Fi smart home systems require upgraded routers to maintain a strong signal, the cost can be significantly increased [24]. What is also important to note here is the problem emerging with Wi-Fi communication for appliances that are located in the basements with thick walls and on tops of buildings, i.e. heating systems and air conditioning devices respectfully, as the communication would imply setting a router on the roof of the building simply for the means of monitoring.

What PLC has to offer is the wired solution technology that does not need additional wires, therefore, it is cost effective and retrofit. It is two-way and has broadcast and repeating capabilities which most other technologies do not have. However, given that PLC is not designed for home automation systems it does encounter some problems, but it is a cheap and easy to implement solution.

1. **Power Line Communication Basics**

Power Line Communication is a technology which uses power lines as a physical media for data transmission; alternating current (AC) power wires serve as a transmission medium by which information is relayed from a transmitter or a control station to one or more receivers [7].

As it can be seen from the basic block diagram for PLC based home automation systems in **Fig.1** below, human machine interface is the first contact of user and the automation system, and it can be as simple as a keyboard, or in a more complicated case a Wi-Fi enabled device (in this case Wi-Fi needs to be enabled on the used microcontroller too, using a Wi-Fi shield or an Ethernet Card). When a user presses a particular button, a message is sent to a microcontroller which decodes it, and converts it to a simple control signal (i.e. switch ON/OFF device). This message is sent to the device via power line modem (transmitter), which modulated the message and sends it to the receiver side composed of a PLC modem (receiver) – microcontroller combination that listens to the command, checks if the message is intended to the corresponding device, and sends a signal to a corresponding relay [7] [8].

Like every other technology, power line communication has some advantages and disadvantages, and is not an exception to the rule. As already mentioned, the biggest advantage of these types of systems is that they use an already existing infrastructure, meaning that the cost of installation of this type of system is relatively low. However, this type of data transmission offers minimum security levels, data attenuation (due to the presence of numerous elements on a power line network), and noise problem (due to appliances such as vacuum cleaners, dimmers, drills, etc.) [9].



**Fig. 1** Basic Block Diagram of PLC based Home Automation System [7]

1. **Noise**

Power line channel has not been designed to carry information other than electric energy, so it does not have good characteristics in terms of noise robustness and attenuation of higher frequency signals. This makes power lines a particularly difficult communication environment [10] [3]. Studies have indicated that the noise in PLC systems can be classified in the following categories presented in the **Fig. 2** below.



**Fig. 2** Noise Contributions over a Power Line Network [3]

*Colored noise* has low power specter density that increases towards lower frequencies, and is usually a product of appliances such as dimmers, hair dryers, computers, etc.

*Narrowband background noise* happens because of amplitude modulated sinusoidal signals, and is typically generated by switching power supplies, fluorescent lamps, television sets, etc.

*Synchronous impulsive noise* is characterized by short voltage peaks, which are mainly caused by on/off switching actions and which appear at frequencies that are multiples of the main frequency (50 Hz in Europe, and 60 Hz in the USA).

*Asynchronous impulsive noise* is said to be the worst kind of noise that affects the power lines. Other than its variability in time, it is also characterized by three other random variables: amplitude, pulse width and interarrival time. This type of noise is usually caused by switching transients generated by switching power supplies [3] [11].

1. **Modulation Techniques**

Since power lines are primarily meant for conducting electricity they present a very harsh environment for data transmission, given that the equipment connected to them can induce unpredictable behavior. This means that PLC communication is based in signal modulation, which is superimposing the information contents of a modulating signal on a carrier signal (which is of high frequency) by varying the characteristic of carrier signal according to the modulating signal. Modulation is done through a modem and results in a new signal called modulated, with different characteristics more suitable to the behavior of the transmitting channel (in this case the power line) [3] [13].

There are several modulation techniques, starting with basic analog modulation schemes such as AM (amplitude modulation), FM (frequency modulation) and PM (phase modulation), going towards single carrier digital modulation techniques more appropriate for PLC uses such as ASK (amplitude shift keying), FSK (frequency shift keying), PSK (phase shift keying), spread spectrum modulation techniques (SST) such as DSSS (direct-sequence spread spectrum) and DCSK (differential chaos shift keying), all the way to multicarrier modulations such as OFDM (orthogonal frequency-division multiplexing). The choice of modulation technique lays in the designated bit rate, where methods using a digital single carrier modulation are suitable for low transmitting rates, and OFDM and SST are used for higher transfer rates and in order to avoid interference, attenuation and ISI (intersymbol interference) problems [3] [4]. The use of different types of modulation, as well as their field of application can be seen in Table 1 below.

Table 1 The Use of Different Types of Modulation Techniques and Their Field of Application [6]

|  |  |  |
| --- | --- | --- |
|  | **Narrowband PLC** | **Broadband PLC** |
| **Data rate** | Up to 200 kbps | Over 1 Mbps |
| **Frequency** | Up to 500 kHz | Over 2 MHz |
| **Modulation** | FSK, S-FSK, BPSK, SS, OFDM | OFDM |
| **Applications** | Building Automation, Renewable Energy,Advanced Metering,Street Lighting,Electric Vehicle, Smart Grid | Internet,HDTV,Audio, Gaming |

* 1. **Single carrier, Multicarrier and Spread Specter Modulation Techniques**

The single carrier transmission means one frequency carrier is used to carry the information, hence information in the form of bits is carried by one single carrier. In single carrier PLC technologies, an analog carrier signal is modulated by a discrete signal, and digital data is represented by a finite number of distinct signals [6] [14] [15].

OFDM, also known as multicarrier transmission or modulation, uses multiple carrier signals at different frequencies, sending some of the bits on each channel. This is similar to FDM (Frequency Division Multiplexing) however in the case of OFDM; all of the sub channels are dedicated to a single data source. In multicarrier PLC technologies, a large number of closely spaced orthogonal sub-carrier signals are used to carry data, and each sub-carrier is modulated with a conventional modulation scheme (such as BPSK, QPSK or QAM) [6] [14] [15].

Spread spectrum (SS) modulation techniques employ a transmission bandwidth which is several orders of magnitudes greater than the minimum required bandwidth of the signal carried information. Therefore the advantage of SS is that many subscribers can simultaneously use the same bandwidth without significant interference between them [16].

1. **OFDM Based PLC Transceiver Design**

This section provides information about OFDM based PLC transceiver. The design based in the processing chain specified in the IEEE 1901 FFT PHY layer model for payload transmission can be seen on the **Fig. 3** below [25].

The information at the transmitter side first undergoes scrambling by a pseudo-noise sequence in order to avoid long strings of repetitive bits. The data is next encoded and the redundant bits are introduced in order to provide error detection and correction. Next, the encoded data is interleaved by a block interleaver to minimize burst errors probability.

Data is then put through Quadrature Phase Shift Keying (QPSK) constellation mapping, which leaves it mapped to QPSK symbols. The serial stream is converted to a parallel and modulated by an Inverse Fast Fourier Transform (IFFT), a core element of OFDM. One of the most crucial properties of this channel affecting communications is the presence of random time-varying impulsive noise. OFDM performs better than single-carrier modulation techniques in the presence of impulsive noise. After the data has been modulated, it is then converted back to a serial stream, and a cyclic prefix (CP) of 1252 samples is inserted at the beginning of the symbol. A good length CP should be around two or four times the root-mean-squared delay spread. The longer the symbol duration relative to the CP length, lesser is the loss, due to the CP. At the same time, this means a bigger number of subcarriers with less spacing given a specific bandwidth, adding extra implementation complexity and leading to problems related to frequency and phase offset. The long symbol period in OFDM gives the technique extra strength against intersymbol interference (ISI). Although the insertion of a cyclic prefix reduces the useful data rate of the system, it gets rid of any ISI that can result from multipath when designed to have a longer duration than the delay spread of the PLC channel. The last step at the transmitter side is the extended symbol being sent to an analog front end (AFE) module which couples the signal to the power line medium. The receiver performs the reverse process to that being carried out by the transmitter. Receiver side uses a Viterbi decoder block which generates one bit for each two bits of input. It employs the Viterbi algorithm to find the path in the Trellis diagram whose sequence of output symbols is the closest match to the received data sequence [25] [26].



**Fig. 3** PLC Transceiver Block Diagram [25]

1. **Regulations**

When it comes to regulations regarding the narrowband PLC in Europe, regulations are described in the CENELEC standard EN 50065-1:2011 “Signaling on low-voltage electrical installations in the frequency range 3 kHz to 148.5 kHz – Part 1: General requirements, frequency bands and electromagnetic disturbances”. As it can be seen in the Table 2 below, the standard states that sub-band 3-95 kHz is limited to energy providers and the sub-band 95-148.5 kHz is designated for user applications. In the C band the regulation states that every PLC device must use the frequency of 132.5 kHz to inform that it wants to start transmission in the band 125 kHz – 140 kHz, and CSMA (Carrier Sense Multiple Access) protocol is mandatory [12] [3].

Table 2. Frequency Bands Used in PLC According to CENELEC [4]

|  |  |  |
| --- | --- | --- |
| **Frequency Band** | **Frequency Range** | **Usage** |
|  | 3 kHz – 9 kHz | To electric distribution companies |
| A | 9 kHz – 95 kHz | To electric distribution companies and Power Licenses |
| B | 95 kHz – 125 kHz | To consumers with no restrictions |
| C | 125 kHz – 140 kHz | To consumers for media protocols only |
| D | 140 kHz – 148.5 kHz | To consumers with no restrictions |

1. **System On Chip Power Line Modems**

This paper was in search for a simple solution for adding narrow band power line capabilities to appliances, and therefore several system-on-chip solutions for PLC modems are presented in the next few subchapters.

* 1. **IT800D**

IT800D is a highly integrated System on Chip (SoC) power line communication modem first presented by Yitran in 2005, and because of it high performance Data Link Layer (DLL) and extremely reliable Physical (PHY) it provides an ideal solution for a variety of applications and supports the implementation of various protocols. Extremely robust communication with data rates of 7.5 kbps is achieved through advanced patented DCSK spread spectrum modulation technique, and in addition to inherent interference immunity provided by the DCSK modulation, the device utilizes special synchronization algorithms, as well as forward short block soft decoding error correction algorithm. It is ideal for Command and Control applications such as Energy Management, Smart Grid, AMR, Home/Building automation; lighting, security and HVAC control and more [17]. Yitran’s leadership in PLC started with IT800, and continued with IT700 and IT900 (which was first fully integrated PLC modem and application solution on a single chip to feature DCSK Turbo speed and robustness, as well as data rate of 500 kbps) [18]. The basic block diagram for the IT800D can be seen in the **Fig. 4** below.



**Fig. 4** IT800D Basic Block Diagram [17]

* 1. **NCN49597**

NCN49597 was released in 2012 by a company under the name of ON Semiconductor, and it is a powerful spread frequency shift keying (S-FSK) communication SoC designed for communication in hostile environment. It is based on 4800 baud S-FSK dual channel technology and it combines a low power ARM Cortex M0 processor with a high precision analogue front end. It is fully reprogrammable and its frequency range covers all CENELEC bands for use in applications such as AMR, home automation, street lighting, solar power control and monitoring as well as transmission of alerts [19]. This device was built on ON Semiconductor’s 10 years of experience in e-metering, and offers a versatile and robust solution in all sectors of smart grid market development [20]. **Fig. 5** below shows the basic block diagram of NCN49597.



**Fig. 5** NCN49597 Basic Block Diagram [19]

* 1. **ST8500**

Released in the late 2017, ST8500 is STMicroelectronics’s latest addition to power line modem family. It is a high performance, fully programmable SoC modem, able to run any PLC protocol in the frequency band up to 500 kHz. The device has an architecture designed to target CENELEC EN50065 Standard, and it supports all major PLC protocol standards, protocol specifications and evolutions. Unlike the two previously mentioned SoC PLC modem solutions, the ST8500 has both analog and digital front end (AFE and DFE), as well as Real Time Engine (RTE – the digital core running the lower layers of the PLC protocol stack and implementing modulation, demodulation and advanced forward error corrections (FEC) algorithms).

Its core is a standard ARM 32-bit Cortex-M4F, with 3-stage pipeline Harvard architecture, making it ideal for demanding embedded applications. To facilitate the design of cost –sensitive devices, this processor implements tightly coupled system components that reduce the processor area while significantly improving interrupt handling and system debug capabilities. All of these characteristic classify it as a good solution for smart metering, smart grid and Internet of Things purposes [21]. ST8500’s basic block diagram is shown in the **Fig. 6** below.



**Fig. 6** ST8500 Basic Block Diagram [21]

1. **Power Line Communication Based Home Automation System Using A Wifi Enabled Device**

Power line communication is quite simple to establish, given that all that is needed to establish a communication is two PLC modems, and that it uses an already existing infrastructure. Yet despite the benefits, this technology is the least used one in Smart Home applications. The fact is that broadband PLC for Internet connection has some major issues [22], but NBPLC is often overlooked in comparison to IoT technologies (which has major interoperability standardization issues) where in reality, the Wi-Fi – PLC hybrid could make up a low cost home automation system.

As proposed in [7] by Shivaram et al., this solution requires that the microcontroller has an Ethernet card, that a WiFi network is set up using a wireless router, and that the device used for interface module is Wi-Fi enabled as well. When an instruction is sent from the interface, specific message is sent over the Wi-Fi network to the micro controller which then decodes the message, and converts these messages into simple control signals. These messages then follow the standard PLC protocol, and are sent by a PLC transmitter via electrical wiring to the PLC receiver, to the receiver end micro controller which instructs a relay to perform a proposed action [7].

1. **Conclusion**

Power Line Communication is not a new concept, but is certainly overlooked in the rise of new technologies. Even though PLC has issues reflected in noise and possible interferences, modern modulation methods make these systems affordable and reliable. Their main advantage is that it presents a ‘no new wires’ solution since they use the already existing infrastructure, and they are a base for a cheap and simple home automation system that can remotely open/close the doors, turn devices on/off, control lights, and all that without expensive remodeling. Important thing to note is that PLC provides a solution to the problem emerging with Wi-Fi communication for appliances that are located in the basements with thick walls and on tops of buildings, i.e. heating systems and air conditioning devices respectfully, as the Wi-Fi communication would imply setting a router on the roof of the building simply for the means of monitoring, and PLC offers a “no new wires” secure automation. This makes the world of PLC an interdisciplinary field that involves electronics, informatics and automation, which makes it an excellent education tool in the lives of engineering students.

Equipping a home environment with a smart power line domotic system, besides the possibilities of energy saving and comfort increasing is also one of the ways to try and give back a certain level of autonomy to people with special needs, as these systems can give them an independence in everyday activities different to that in a hospital like setting.

Wired technology is the best technology for Smart Home but it is cumbersome and costly. Next best is wireless but the inherent problems of interference and signal penetration has affected the use of Wi-Fi or wireless for Smart Homes. NB-PLC on the other hand is wired technology that does not need additional wires, therefore, it is cost effective and retrofit. It is two-way and has broadcast and repeating capabilities which most other technologies do not have, implying that it should be given more attention when discussing home automation systems.

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