Towards the Powerline Alternative in Automotive Applications

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Abstract

The Power Line technology has received an increasing attention in the last decades due to its inherent benefits, mainly related to the reduction of cabling and associated costs. Power Line Communication (PLC) was first employed in power utilities and since the 80s in home automation, too. However, its use in the automotive field received relatively little attention. This paper revisits the related work in using PLC technology for communication within the automotive domain and outlines its possible benefits. Then, it focuses on the issues that need to be addressed when introducing the PLC in the automotive domain. The final goal of this work is to carry out a practical assessment of the PLC technology in the referred domain that may open the way for future use in industrial scale.

1 Introduction

Power Line Communication (PLC) aims at exploiting the power supply line to send/receive information without using separate dedicated wires.

The PLC is nowadays adopted in many application domains, like power utilities to interconnect and control faraway units, automatic remote meter reading, and home and building automation [12]. The latter is, perhaps, the most promising field for PLC due to the large number of potential customers. Indeed it seems a natural way to connect intelligent home devices like lights, doors and household appliances, to a home control unit. In this field a number of widely adopted communication protocols have been developed, starting from the low speed low cost X10 technology up to recent implementations like HomePlug [4], which is also targeted to high speed communication, in order to support High Definition TV and VoIP.

The PLC technology can be classified with respect to the transmission frequency, which determines, in turn, the transmission bitrate. Low frequency transmission is well regulated in Europe, with a band range from 3 up to 148,5 kHz, and a maximum bitrate of 1 Mbps. Regulation for larger transmission range is ongoing (CENELEC SC205A WG10), allowing for operation up to 30 MHz, and higher bitrate (up to 200 Mbps); a number of devices and technologies are already available on the market.

A common feature of these applications is that the power carrier is AC 50/60 Hz at medium (power utilities) or low voltage (110 and 220 V for home). Conversely, in specific cases, such as the automotive domain, the power line operates at lower DC voltage complying with batteries and electronic devices (e.g. 3.3, 5, 9, 12 and 42 V), which implies a different coupling technology.

Two key aspects drive the research on PLC: (i) physical transmission of the modulated signal and (ii) the data link and upper layers to allow the correct communication among devices. The former issue is related to the study of the noise and compatibility on the PLC line, which is prone to interference due to non-linear loads that can, for example, show impulsive behaviors (i.e., when a motor is switched on). The latter issue determines the flexibility and re-configurability available during the application design, set up and management. It also addresses the communication determinism in terms of guaranteeing the communication timing constraints, i.e., periodic transmission, end-to-end message deadlines, etc.

When looking at a potential automotive application there are a number of issues that PLC technology should address [1]. In fact, the automotive communication technologies used today are likely to impose requirements on the PLC technology proposed for automotive usage. There are two scenarios to explore: (1) providing a different communication system with respect to the current technologies used in existing automotive systems. In this case, it is important to provide adequate bandwidth, responsiveness, tolerance to EMI etc. (2) providing a physical replacement of existing fieldbuses that is transparent at the application level. In this case, the PLC should provide a similar, or the same, temporal behaviour as the original bus.

Within the automotive domain, excluding the infotainment subsystem, there are currently three common buses, namely LIN [7], CAN [5] and FlexRay [3]. LIN provides time triggered communication at speeds of 20 kbps for messages containing up to 8 bytes of payload data. It is meant for inexpensive communication without reliability or timeliness requirements. CAN provides event triggered communication at speeds of up to 1 Mbps for messages containing up to 8 data bytes. It is a very versatile bus providing good levels of reliability and timeliness. FlexRay provides time-triggered communication at speeds up to (2x) 10 Mbps for messages containing up to 254 data bytes. It is meant for safety-critical systems and as a backbone to interconnect different segments.

When considering the use of PLC, it is important to define the kind of target subsystems in order to define the associated requirements. In our work, given the versatility and widespread use of CAN, we will analyse PLC to provide similar features. Initially we will consider PLC a physical replacement for CAN but then also as a fully featured communication system. In this paper we discuss the benefits of using PLC in the automotive domain and we analyse the main benefits and challenges, and propose a set of guidelines, for realizing and evaluating a PLC infrastructure for automotive applications.

The paper is organised as follows: while Section 2 introduces the benefits of using PLC in the automotive domain, Section 3 presents the issues that need special attention. Section 4 presents a set of tests that will support a quantitative characterization of the PLC solution. Section 5 discusses some related work and, finally, Section 6 concludes the paper.

2 PLC and automotive

A modern car represents a complex merging of mechanical and electronic technologies. There are several Electronic Control Units (ECUs) to control all the crucial on-board subsystems, like ignition and braking systems [11]. ECUs are directly connected to sensors and actuators, and are interconnected through dedicated data lines. The interaction among ECUs allows to maintain an updated global view of the system under control (the car), and to improve the quality of control, reliability, safety and comfort. Moreover, being electronic devices, the ECUs share the power line for power supply.

There are several reasons motivating our research for a PLC solution for the automotive domain, essentially related to the reduction of cabling. The cabling burden implies

- a more difficult design to account for hand made required assembly,
- electric bundle increase and related problems when passing through dashboard and instrumentation panels,
- more complex diagnostics and maintenance,
- reduced benefit cost ratio, for any new device requiring an extra wiring,
- car weight increase and reduced efficiency, and
- increased problems related to ECM (both immunity and emission).

To reduce the number of wires has thus a direct impact on weight, costs, and space filling. Moreover, cabling represents a critical issue in terms of on-board deployment. The design of a car must take into account the path of wires to facilitate the task of installing and deploying the wires within the car. In certain application niches such as motorsport, connector cables and the connectors themselves are very expensive since they must carry tens or hundreds of wires per cable. Reducing this bundle will have a strong impact on the complexity, costs and reliability of connectors. Modern ECUs may take up to 20% of their size for contacts and physical connections, as it can be roughly derived from the schematics of ECUs available at [9]. Therefore, reducing the number of wires also affects size and costs of each single ECU.

PLC presents some issues and potential drawbacks that must be carefully accounted when a choice among available technologies has to be done. The main issue is represented by the current less performance of PLC with respect to the most powerful alternatives, i.e., FlexRay [3]. It is worth to observe that this situation is currently limited to the automotive domain, since in other applications, like home and building automation, PLC already outperforms automotive fieldbuses in terms of maximum bandwidth. On the other hand, the actual maximum bandwidth of PLC is comparable with the one offered by LIN and CAN.

A potential technological drawback is the need of special solutions to partition the network into physically disjoint sub-networks, since PLC relies on one-to-all broadcasts, while typical fieldbuses have dedicated communication channels.

A detailed description of the most important issues is given in Section 3.

3 Issues to be addressed in a PLC solution

The main purpose of the solution based on PLC for automotive communication is the cost reduction. Thus, to correctly evaluate the benefits in this direction, a key issue is the cost balance between the saving from cabling reduction and the potential higher cost of the network interfaces. In fact, neither the modems required to interface with the physical layer (PHY) implemented by the

DC power bus, nor the digital devices required to implement the medium access control (MAC), are yet available in a scale large enough to significantly reduce the costs. Nonetheless no actual technological obstacle can be foreseen; so that a strong commitment of companies would certainly overcome the problem by the adoption of this technology on a large scale basis.

Furthermore, the cost reduction must be balanced with a minimum performance requirement. In order to match CAN and provide adequate communication service to the systems that typically connect to that network, a bandwidth of at least 500 kbps is required.

Another design issue to be addressed is that of network segmentation, which is considered fundamental to provide adequate insulation and integration among subsystems that have very different requirements, e.g., the body and the powertrain networks in a car. With typical buses, this insulation / integration is achieved via gateways, i.e., special ECUs connected to more than one segment that filter the traffic passing through. However, all systems typically share the same power supply line. On a car there is usually only one battery, which powers all the components. Considering PLC, this single power supply line is equivalent to a single shared bus used by all on-board devices. This scenario could be undesired for several reasons. On one hand, the whole ensemble of connected devices in the system might exceed the maximum number of nodes supported by the bus. On the other hand, such single segment configuration may generate additional mutual interference between systems that should be insulated. Therefore, even when dealing with PLC, a way must be found to support the typical segmentation. We believe this can be easily achieved with filters that allow the power supply to pass through while blocking the communication which must be routed through a gateway. Another less practical solution would be to use different batteries but this would increase the costs and create space problems.

When using PLC as a physical replacement of another bus, e.g., CAN, problems might occur if the MAC is not enforced in a similar fashion so that the timing and order of the transmissions are observed. Even if the response-times to transmission requests are complied with, if the order is not, an application may behave differently with PLC than with the original bus, which is of course, undesired. On the other hand, if PLC is used as a different communication system, it may represent a redundant communication channel that can, for example, be used for fault-tolerance [10].

4 Assessment of PLC

In order to assess the use of PLC in the automotive domain, we propose a set of tests that cover three main domains, the physical layer, the data link layer, and performance aspects.

Tests on the physical layer. This set of tests is addressed at the characterization of the physical channel, mostly with respect to the immunity from ElectroMagnetic Interference (EMI) and noise [2, 6]. The interference can be originated from other circuits which are sufficiently close to the considered cable. We will consider two cases, the cell phone and the ignition system with its sparks with a current of 3-4 A and a voltage of 20-30 KV (Figure 1). On the other hand, the modulated signal on the power line may cause problems to the connected electronic circuits due to the potential fluctuation on the power signal (Figure 2). This will also be tested and the quality of the power supply in the end nodes will be measured.

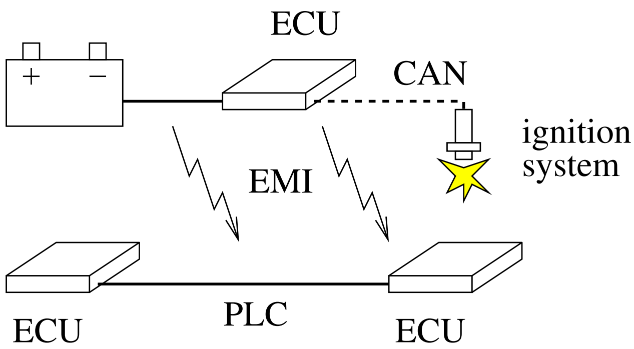

Figure 1. EMI from neighbour systems.

PLC Data link test. In this case, two sets of tests are being considered, one for the case when PLC is used as a physical replacement of a bus and the other for the case when PLC is used as a different communication system. In the former case, the tests will verify the conformance of the MAC mechanisms to those of the original protocol, verify the order of transmissions and check the behaviour in case of bit errors. In the latter case, similar measurements will be carried out only in order to characterize the PLC channel.

Performance test. This type of tests is meant for the evaluation of the communication protocol behaviour in terms of throughput, response time, end-to-end latency,

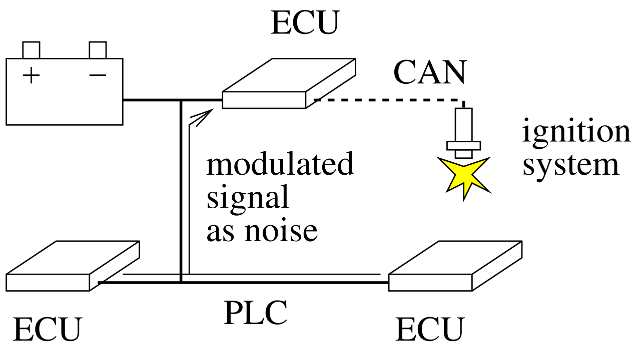

Figure 2. The modulated signal is seen as noise from regular ECUs.

etc. Realistic scenarios will be considered, including the presence of noise and interference from multiple nodes. Performance tests, in terms of timing analysis, are already available for most of the buses, even newer ones like FlexRay [13].

5 Related work

In [2, 6], a characterization of noise and interference over a PLC channel in the automotive environment has been carried out. This represents a fundamental starting point for engineering a complete PLC solution that would achieve the interoperability with solutions already in use. In fact, in [10], a PLC solution is proposed for adding redundancy to the CAN bus and thus to provide a higher overall reliability.

In [14], the authors investigate an architecture to seamlessly integrate PLC and CAN. The board is based on the DSP/FPGA technology and is suitable for automotive applications. However, it allows a network speed of up to 50 kbps. Such a speed is comparable with LIN, but cannot compete with CAN.

Commercial solutions are also available for building an automotive communication infrastructure. For example, devices from Yamar [8] provide a speed up to 500 kbps and are compatible with LIN and CAN. Those solutions, however, are essentially gateways that can interface a PLC channel to LIN/CAN channels: the boards accept I/O from regular CAN/LIN, and translate the signal onto a PLC channel.

6 Conclusions

The use of PLC in utilities, home and building automation is already common place. However, we believe that PLC can also be very beneficial in the automotive domain, as a substantial mean to reduce cabling. Today, the communication in the automotive domain is dominated by widely available and robust solutions like LIN, CAN, and FlexRay. Therefore, an approach based on PLC must be comparable with those solutions in key aspects like reliability, bandwidth and latency.

This paper addressed the main issues related with the use of a PLC-based communication infrastructure in automotive applications. We depicted the main benefits and the most relevant problems to solve so that PLC may become a viable alternative and/or a solution to be used in conjunction to existing communication infrastructures. We defined a set of tests to be carried out (on-going work) that will allow to establish a quantitative characterisation of the PLC solution.

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