Towards Power Line Communication in vehicle

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Abstract

This paper is a review of studies dealing with Power Line Communication (PLC) in vehicle. The electronic control units (ECUs) that replace mechanical or hydraulic systems require specific buses in order to exchange information between sensors and actuators. Different networks as LIN, CAN, Flexray have been proposed, from low up to high data rate. Considering these networks, we can observe that each solution uses its specific wires and communication system. The growth of the complexity leads to the necessity to commit to a limited set of networks which answers to these multiple applications. An attractive solution to reduce the wires is the power line communication (PLC) using the power lines (12/42V) to transmit both the power and the messages without functional barriers domain. The channel characterizations of the PLC lines, the impact of the noise, and the resulting system parameters are presented. Taking into account the PLC channels, optimizations of the system parameters are carried out especially the CP length and the bandwidth, Numerical results show obtained significant improvements.

1. Introduction

In order to connect the huge number of sensors and actuators, protocols in the automotive fields have been proposed, namely LIN, CAN, FLEXRAY \([1]\). Each network uses its own bus and communication protocol. Gateways are then necessary to switch from one system to another one. One attractive solution to avoid the growth of wires would be to use the PLC technology that is currently developed for indoor AC networks to transmit information over the 12V power distribution \([2]\). The possible applications of automotive PLC are very wide, extending from low data rate for activating actuators to high-speed multimedia and plug and play applications. Previous and current studies are first addressed in Section 2. These studies demonstrate that the PLC channel is frequency selective. To face with this selectivity, multi-carrier modulation, namely Orthogonal Frequency Division Multiplex (OFDM) has been proposed as for indoor-PLC \([3]\ \[4]\). This technique has been evaluated in vehicle over the DC line using PLC standards Homeplug V1.0 and Homeplug AV (HPAV). First results demonstrate the feasibility of OFDM for PLC in vehicle. However, to optimize the communication system, characteristics of PLC channels must be carefully studied. Section 3 provides a description of the experimentations we have conducted. Results for different cars configurations are presented. Taking into account the results, performance analysis of the proposed system is assessed in Section 4. Finally, conclusions and perspectives are presented in the last section.

2. In-vehicle PLC: background and current studies

Indoor PLC is nowadays widely used. Different standards, like HomePLUG AV, HDPLC \([5]\ \[6]\) have been proposed and are still subject to improvement. However, it is not possible to apply them directly to vehicles because the geometrical characteristics and wires topologies are totally different, namely the length of the wires, size of harnesses, loads. Furthermore the indoor power spectral density mask is not compliant with EMC vehicle specifications.

In \([7]\) the authors focus on the issues that need to be addressed when introducing PLC in vehicle. Three main domains need to be covered: the physical (PHY) layer, the data link layer and the performances. In order to answer to them, the properties of the automotive in board PLC supply networks have been investigated in \([3,4,8,9]\). The results, obtained for different vehicles, show the insertion losses are about -15 dB and -36 dB in the frequency range \([0.500-30]\) MHz. The noise measurements show an increasing background noise in the frequency ranges \([0-50]\) MHz, especially at frequencies less than 10 MHz, the peaks of the noise could be in the range \([-90 \text{ dBm/Hz}; -40 \text{ dBm/Hz}]\).

More recently, the authors in \([9]\) have studied the impact of the engine speed over the PLC channel, in term of frequency responses and noise measurements. Results are similar to those obtained in \([4]\). According to the engine state, results show differences about 2 dB for short paths connected to the same fuse (direct path according to \([4]\)) and up to
15 dB for paths on ECUS using different fuses (indirect paths according to [4]). The noise has been recorded for the same paths and engine states. The noise level remains the same in the three engine states. However, the authors do not give any information concerning the vehicle (A Fiat car has been used).

Different channel measurements in electric cars have been carried out in [10]. Similar cases to previous studies are considered (front to/from rear part) with different vehicle’s configuration (position key, battery,…). As for fuel vehicle, the channels are very frequency selective in the [0-30] MHz. However, additional measurements must be carried out in order to conclude about the influence of the motorisation on PLC applications (heat or electric engines). These results illustrate the wide diversity of studies.

As for indoor, varying space between cabling and car body results in changing behavior of the whole system. Thus, new wiring harness structure has been proposed based on a star structure using active star couplers [11]. However this solution needs to re-organize all the harness, which is actually different from one vehicle to another one. The car manufacturers used their own harnesses without any standardization, except for the embedded networks as LIN, CAN or FLEXRAY.

To prove the feasibility of PLC communication, experimentations using indoor OFDM PLC modems have been carried out and presented in detail in previous studied [11]. With HPAV V1.0 PLC modems, an 8 Mbps is achieved with a transmitted power of -50 dBm. With a higher level (-37 dBm), we achieve about 12 Mbps. For multimedia applications, this rate can be sufficient, but decreases rapidly according to the ECU loads. More recent measurements have been carried out with HPAV PLC modems. Different paths and engine states have been considered. Measured throughputs are higher than 35 Mbps (engine off) and are higher than 15 Mbps for all the paths in motion and can reach about 40 Mbps for short paths [3].

In order to design a future PLC modem it is necessary to obtain statistical results. Three parameters are particularly studied: the transfer function, the attenuation and the noise. To do so, additional transfer functions are measured on five different vehicles. The vehicles are classified according to: the number and type of ECUs, the length of wires and the combustion engine. Next section deals with the measurement setup and results.

3. In-vehicle measurements setup

The five vehicles we have considered are two 407 SW (recent car, diesel and gasoline), a Renault Laguna II Estate (gasoline), a Renault Espace (diesel) and a Citroën C3 (gasoline). In order to analyze the channel transfer function, the S-parameters are recorded using a full 4 ports Vector Network Analyzer (VNA) with 50 Ω reference impedance and a PC interfaced to remote the device. We record the S-parameters during about 10 minutes while the car is moving. The S-parameters are recorded about every 10 seconds for 3 different paths: GF, GH and HD. These paths have been chosen in order to analyze the differences between front to front and rear to front.

Regarding the noise, two different noise studies have been carried out on the same paths. The first consists of the measurement of the power spectrum at each point during 10 minutes every 10 seconds with the vehicle moving. The second is a measurement in the time domain. To do so, a digital storage oscilloscope (DSO) has been used to record at each point the signal over the DC line. With this testbed we are able to record two signals at two different points simultaneously. Figure 1 illustrates the testbed for all these vehicles. Four points are considered. A path is referenced as (source/destination). Additional details are given in [12]. In the next part, the results are studied.

Figure 1: Vehicle Testbed
4. Main results

Figure 2 and Figure 3 illustrate respectively the channel transfer function and the recorded noise obtained on the vehicles. We can observe the selectivity of the channel, the noise level in the lower band. These results can be used to compute the coherence bandwidth, the delay spread and the attenuation. In Figure 3, we observe the band under 5 MHz is disturbed, thus the PLC transmission will avoid this band.

The first parameter we compute is the channel capacity $C$ according to the Shannon capacity formula:

$$C = \Delta f \sum_{i=0}^{N-1} \log_2 (1 + \text{SNR}_i)$$

with $\Delta f$ the sub-carrier bandwidth, $\text{SNR}_i = (|S21|_i^2 \cdot \text{Pe}/P_n)$ the signal to noise ratio per subcarrier $i$, $\text{Pe}$ is the PSD of the emitted signal and $P_n$ is the PSD of the AWGN noise. The system parameters are the HPAV parameters (FFT size = 3072, $\Delta f = 24.414$ KHz). We have considered an AWGN noise with a $P_n$ value of -120 dBm/Hz. We observe as presented in [12] the theoretical capacity for the studied paths are between 180 Mbps and 320 Mbps.

The second parameter is the coherence bandwidth (BC). In Table I, we summarize the BC values obtained for four vehicles. We can observe a great disparity in the values. However, the results are closed to one's obtained in [4] and [10]. If we consider the mean value, the BC varies from about 412 KHz up to 4 MHz. If we focus on the two 407SW, we can observe the results differ in a ratio of 2. In comparison with indoor, the BC is about 32 KHz. If OFDM modulation is applied, these first analyses will allow us to increase the OFDM sub-channel $\Delta f$, which involves a reduction of the FFT size. This work is currently in progress.

The third parameter to analyze is the cyclic prefix (CP) which is linked with the delay spread. In Table I, the delay spreads are given for the same vehicles. The delay spread is linked to the DC lines topology and loads. In [13], the authors have proposed two algorithms that perform both bit-loading and optimal CP length computation for indoor PLC. If we consider the HPAV CP duration of 5.57 $\mu$s, it is twenty times longer than the maximum delay spread we observed in vehicles. Generally as in [4], the CP is equal to four times the delay spread. Considering Table I, by reducing the CP to about 1$\mu$s, the capacity for OFDM modulation can be increased, while keeping no interference between sub-channels and symbols. The CP can be optimized to be less than the maximum delay spread while allowing no interferences between OFDM symbols and sub-carriers [13]. Furthermore, this optimum CP will increase the data rate.

5. Conclusion

This paper presents current studies on PLC in-vehicle. The channel and noise measurements allow us to have knowledge of the lines. The analyses lead us to optimize the bandwidth, the sub-channel spacing and the CP duration of the OFDM proposed technique.
Table I: Coherence bandwidth and delay spread (mean values)

<table>
<thead>
<tr>
<th>Path</th>
<th>Vehicle</th>
<th>Coherence bandwidth $BC_{0.4}$ (KHz)</th>
<th>Delay spread $\tau_{rms}$ (ns)</th>
</tr>
</thead>
<tbody>
<tr>
<td>GF</td>
<td>407SW gasoline</td>
<td>412.9</td>
<td>288.6</td>
</tr>
<tr>
<td></td>
<td>407SW diesel</td>
<td>615.6</td>
<td>186.9</td>
</tr>
<tr>
<td></td>
<td>Laguna</td>
<td>4102.7</td>
<td>27.4</td>
</tr>
<tr>
<td></td>
<td>C3</td>
<td>1685</td>
<td>68.2</td>
</tr>
<tr>
<td>GH</td>
<td>407SW gasoline</td>
<td>1214</td>
<td>108</td>
</tr>
<tr>
<td></td>
<td>407SW diesel</td>
<td>728</td>
<td>210.9</td>
</tr>
<tr>
<td></td>
<td>Laguna</td>
<td>1031</td>
<td>116.8</td>
</tr>
<tr>
<td></td>
<td>C3</td>
<td>978</td>
<td>133.5</td>
</tr>
<tr>
<td>HD</td>
<td>407SW gasoline</td>
<td>2038</td>
<td>50</td>
</tr>
<tr>
<td></td>
<td>407SW diesel</td>
<td>666</td>
<td>168.8</td>
</tr>
<tr>
<td></td>
<td>Laguna</td>
<td>726</td>
<td>170.7</td>
</tr>
<tr>
<td></td>
<td>C3</td>
<td>935</td>
<td>97.9</td>
</tr>
</tbody>
</table>

6. Acknowledgments

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7. References