Power line Communication for transportation systems

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1. PLC context  
   From indoor environment to transportation systems
2. PLC on vehicular network
3. PLC on avionic network
4. Conclusion
5. On going and future works
1. PLC context and scientific approach

Broadband (BB) PLC for high-speed home networking
2 standards: IEEE P1901 and ITU G.hn in the 2-100 MHz (> 500 Mbits/s) in-home or access (for the last mile) network

NEW CHALLENGES?

Narrow band (NB) or BB PLC for smart grid

BB PLC for transportation systems?

- Need of communication (embedded system for safety and entertainment)

Interest: does not require a new communication bus
- complexity
- cable weight
- vehicle weight
- fuel

2. PLC on vehicular network

Context: need of high-speed communication without adding wires and nodes, and existing 12V supply lines in all cars

Objectives:
Deduce, from intensive measurements, an accurate and stochastic model of vehicular PLC channel to validate the feasibility of in-vehicle Power Line Communication

Main difficulties:
• EMC aspect: Impact of PLC systems on other services 
  ⇒ radiated and conducted emission limits
  ⇒ limited transmission power for PLC systems;
• PLC channel
  ⇒ Noise: stationary and impulsive
  ⇒ Transfer function: Multipath environment and time varying

Framework & project: PREDIT contract, in cooperation between VALEO, PSA-Peugeot-Citroën, IETR-INSa and IEMN-TELICE, the “Pole Sciences et Technologies pour la Sécurité dans les Transports” (Science and Technology for Safety in Transportation -ST2).
2. PLC on vehicular network

Architecture of the harness decided with car manufacturers
Modeling and characterization of the propagation channel

Deterministic propagation Model

CRIPTE : Succession of interconnected tubes. Each junction is characterized by its [S] matrix

\[
\text{total length} = 260 \text{ m} ; \ 116 \text{ terminal loads}
\]
2. PLC on vehicular network

Modeling and characterization of the propagation channel

Comparison between experiments and deterministic modeling

- Good agreement between theory and experiment
- Average insertion loss:
  - 20dB for direct path scenario
  - 35 dB for indirect path scenario
2. PLC on vehicular network

Highlights:
• Development of impulsive noise measurement system (4 *200 MHz)
• Characterization of amplitude, duration, frequency, IAT of the pulses => influence of the driving condition (cruising, braking ...)
• Elaboration of impulsive noise model
• Optimum modem impedance 50 Ω ~ 100 Ω
• Identification of two scenarios (Direct path and Indirect path)
• CISPR25 : PSD <-80 dBm/Hz
• Theoretical result : 14 Mbit/s available in direct path scenario

References:
Context: The More (or even the All) Electric Aircraft
- Replacement of hydraulic and pneumatic energy sources by electrical ones:
  - Higher electrical power
  - Changes in the voltage levels
  - Increase in the wires mass
- Increase data communication exchanges on A/C which leads to:
  - Increase in the number of wires
  - Increase system complexity

Framework & project:
- TAUPE Project with European Community's Seventh Framework Programme (FP7/2007-2012) under Grant agreement number 213645;
- DPCA contract “ISS Power and Control” in collaboration with Airbus and Safran Engineering Services;
- PhD. Thesis FIAC in collaboration with Sagem Défense, Safran Engineering Services and IETR from INSA – Rennes
- International Campus on Safety and Intermodality in transportation systems (CISIT).
3. PLC on avionic network

- 3 possible applications in a commercial aircraft
- DO160 EMC constraints => CM current limit $I_{CM}$

- A complex tree-shaped architecture of the harness
- Signal crosstalk between adjacent systems in bundles

Landing gear

- Between a motor and an PWM inverter on a 3 phase AC Power cable
- PWM impulsive noise

Flight control system (Spoiler, aileron)

- PP and Point-to-Multipoint topology
- HVDC network

Cabin Lighting System
A. PLC on Cabin Lighting System (CLS)

Typical architecture of a CLS: representative of tree-shaped of many aircraft harness configurations

**Power:** Secondary Power Distribution Box (SPDB) \(\Rightarrow\) Illumination Ballast Units (IBUs). Typically, 1 power line feeds 8 to 24 IBUs - Each power line runs within a cable bundle

**Data (control command):** Remote control (cabin crew) through the Cabin Interconnection Data System (CIDS) \(\Rightarrow\) Decoder Encoder Unit (DEU) \(\Rightarrow\) IBU

Idea: Dedicated transmission line can be removed by using PLC
STEP 1: Laboratory Test bench Simulation

- **Architecture**
  - Statistical channel properties for the various links based on the theoretical modeling of the propagation on the harness
  - Modeling the PLC link → expected throughput or BER

**SPDB : Distribution Box**
**IBU : Illumination Unit**

- Tree network architecture
- Maximum length SPDB-IBU: 43 m
- VT : multiplying connector
- PLC lines inside a cable bundle
- Number of wires in the bundle: 2 to 30
- Total length of the wires: 706 m
STEP 1: Laboratory Test bench Simulation

- Architecture
- **Statistical channel properties**
- Modeling the PLC link → expected throughput or BER

Important local fading due to multipath + coupling to the other wires

Statistical aspects on:
- Path loss
- Coherence bandwidth (band in which \( H(f) \) does not vary “appreciably”)
STEP 1 : Laboratory Test bench Simulation
- Architecture
- **Statistical channel properties**
- Modeling the PLC link → expected throughput or BER

### 3. PLC on avionic network

#### A. PLC on Cabin Lighting System (CLS)

Comparison statistical behavior of the channel

Predicted results vs Measurements
=> Good agreement

Input for the simulation
of the data transmission
STEP 1: Laboratory Test bench Simulation

- Architecture
- Statistical channel properties
- Modeling the PLC link → expected throughput or BER

- HPAV specifications
  - 1155 subcarriers on [1.8-30] MHz (only 917 sc with spectrum mask)
  - ½ Turbo convolutional code and channel interleaving
  - compatible with the CLS channel characteristics

- What’s about injection and noise power?
STEP 1: Laboratory Test bench Simulation

A. PLC on Cabin Lighting System (CLS)

Amplitude of noise and signal current on the PLC line?

- Noise due to systems directly connected to the PLC line is assumed to be well filtered.
- Noise is due to the coupling of the disturbing currents flowing on the other wires.

Norme DO160 => $I_{CM} \leq 20$ dBµA/kHz

3. PLC on avionic network

Signal Amplitude?

$$I_{DM\text{ signal}} = I_{CM\text{ signal}} + CF_{DM-CM}$$

Noise Amplitude?

$$I_{DM\text{ noise}} = I_{CM\text{ dist}} + CF_{dist} I_{DM\text{ signal}}$$

$$CF = \frac{I_{CM\text{ signal}}}{I_{DM\text{ signal}}}$$

$$CT = \frac{I_{dm\text{ noise}}}{I_{cm\text{ dist}}}$$
A. PLC on Cabin Lighting System

• Characteristics of the “Univ. Lille” modems
  – Design and development of “versatile” modems (based on FPGAs) to be able to change:
    • Signal processing, modulation scheme, etc.
  – In the following HPAV standards

• Principle of the experiments (DM)

![Diagram](image)

1: Adjust the power of the modem \( I_{CM \text{ signal}} < 20 \, \text{dB} \mu \text{A} \) in the whole bandwidth

2: Adjust the power of the noise generator \( I_{CM \text{ noise}} < 20 \, \text{dB} \mu \text{A} \) in the whole bandwidth

3: Send 100 PHY Block (520 bytes) of OFDM frames, Store the Rx frames \( \rightarrow \) BER
STEP 2 : Lab. Test bench Experiments

### Throughput : Maximum bit rate to guarantee a BER <= 10^{-3}

maximum bit rate : 98.5 Mbits/s.

Throughput : Maximum bit rate to guarantee a BER <= 10^{-3}

Chosen values for CF and CT for a percentile to 80%

<table>
<thead>
<tr>
<th>Distance (m)</th>
<th>IBU 1</th>
<th>IBU 2–4</th>
<th>IBU 5–7</th>
<th>IBU 8–11</th>
<th>IBU 12–14</th>
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<tr>
<td>11.6</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Throughput Exp. (Mbits/s)</td>
<td>98.5</td>
<td>98.5</td>
<td>98.5</td>
<td>94.6</td>
<td>91.4</td>
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<tr>
<td>Throughput Th. (Mbits/s)</td>
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<td>98.5</td>
<td>98.4</td>
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</tbody>
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V. Degardin et al., "Investigation on power line communication in aircrafts", *IET Commun.*, vol. 8, no. 10, 1868-1874, 2014.
3. Performance on the avionic network

B. PLC on a 3 phase AC Power cable between a motor and a PWM inverter

Objectives:
- Feasibility of a PLC communication on a 3 phase AC power cable
- Decreasing the number of wires to be used and simplifying the architecture

Highlights:
- Measurements of PWM impulsive noise => influence of the cable length, motor speed, inverter voltage, and equipment.
- Measurement of insertion gain
- Optimize the PLC link with noise processing
- at 20 Mbit/s, a CSD > 56 dBμA/kHz is required to obtain BER < 10^{-4}
- Study and optimize the MIMO – PLC link (SFBC code) – bit rate of 5 Mbits/s: Gain of 7 to 10 dB

References:
• Analysis of the feasibility of the PLC communication in vehicular and avionic environments
• The scientific approach:
  • Characterizing and modeling the networks (Insertion gain and noise)
    ✓ Impulsive noise measurement system (4 inputs 200 MHz)
    ✓ Vehicular noise models
    ✓ Deterministic model of avionic and vehicular representative harnesses validated by measurements
  • Modeling and optimizing the PLC link to predict BER and throughputs
    ✓ PLC simulation tools based on OPERA and HPAV specifications
  • Validating the theoretical results with configurable modems
    ✓ Versatile modems
• Applicability of PLC to aircraft: Need to fulfill regulatory requirements for reliability, susceptibility and robustness
  – EMC susceptibility standards
  – After an interruption of the link, PLC communication must be reestablished t<1ms
  – Low latency
    => HPAV specifications not adequate. Simplify the transmission scheme while guaranteeing the prescribed maximum value of the BER. Optimize channel coding and modulation
• New application: default detection, cable monitoring, arc tracking avoidance
Thank You.