Evolution and Limit of Performance of OFDM-based Narrowband PLC

Alfredo Sanz
Director of Operations & Technology of Power Line Communication Products in Atmel
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Evolution and Limit of Performance of OFDM-based Narrowband PLC

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PLC trends for the Smart Grid

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Latest trends in PLC for Smart Metering
PLC technologies and pioneer countries – 2015

“Access Domain” PLC technologies:

Standardization bodies working on Narrowband PLC:
Atmel’s worldwide PLC connectivity
Atmel is part of all narrowband-PLC technology trends

- @Sep 2015: 6.8 Mio meters deployed
- **PRIME** evolution, V1.4: extended frequency range and more robust communications
- Interoperability process defined, field trials started
- Increasing the number of G3-PLC Alliance members
- Narrowband PLC (<500kHz)
- Smart Metering, Electric Vehicles, Lighting, Solar Panel monitoring...
PRIME Alliance: Atmel is a founding member
Proven Smart Metering technology currently being deployed
G3 PLC Alliance: Atmel is a member
PLC trends for AMR/AMI: Deployments and status

Evolution and Limit of Performance of OFDM-based Narrowband PLC

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OFDM-based PLC standards – status overview

Approximately 5 years are required to reach maturity
PRIME Alliance: Atmel is a founding member
Proven Smart Metering technology currently being deployed

6'838'031

Meters Deployed Worldwide

Australia
Brazil
Lebanon
Poland
Portugal
Romania
Spain
Switzerland
United Kingdom
PRIME
More than 6 Mio Smart Meters deployed

PRIME Milestones:

2009 – PRIME Alliance established – 8 founding companies
2010 – first interoperable system installed
2011 – Iberdrola first controlled Spanish deployment: 100k meters
2011 – Gas Natural Fenosa rolling out PRIME and building a PRIME research + test laboratory in Madrid
2012 – PRIME Alliance registered as a Belgian non-profit association
2012 – EDP Portugal first installation: 90k meters in 6 different locations (InovGrid Project)
2012 – first installation outside Europe (Energex, Australia)
2013 – Energa-Operator, Poland 310K rollout, first significant implementation outside of Spain
2014 – Utility Projects in Argentina, Brazil, Lebanon and Romania
2014 – 5’000’000 Deployed PRIME Smart Meters
2015 – Specification Version 1.4 released
PRIME

World wide acceptance and application

• **Provide a cost effective system architecture**
  PRIME-PLC provide the best performance and cost efficiency for medium and low voltage power grid, by communicating over the very lines that it measure and control. PLC technology minimizes infrastructure and maintenance cost

• **Is standard based to assure interoperability**
  PRIME-PLC Support frequency bands worldwide (10 kHz to 490 KHz). Coexist with IEE P1901 and ITU G.hn

• **Minimize infrastructure cost**
  PRIME-PLC provide long range communications and can effectively cross MV-LV transformers reducing the number of concentrator needed

• **Can support new distribution switches, sensors**
  PRIME-PLC incorporates 6LowPAN adaptation layer to transmit IPv6 packets over power line channels.

• **Includes security mechanisms to protect grid assets**
  PRIME-PLC support MAC-level security using and AES 128 cryptographic engine

• **Can function in hash, noisy environments**
  The “robust” mode of PRIME-PLC improve communication under noisy channel condition, operate at -12 dB SNR
## PRIME V1.4

<table>
<thead>
<tr>
<th>Feature</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Expanded Frequency</td>
<td>Expanded Frequency PRIME bands span from CENELEC A band (&lt;95kHz) to FCC and ARIB spectrums (&lt;500 kHz) with a data rate of 980kbps</td>
</tr>
<tr>
<td>Backwards Compatibility</td>
<td>Fully backwards compatible with the +6 million installed meters, corresponding Data Concentrators and Gateways with PRIME Specifications 1.3.6.</td>
</tr>
<tr>
<td>Increased Robustness</td>
<td>New PHY PDU defined, adding increased robustness without additional complexity or cost implication</td>
</tr>
<tr>
<td>IPv6 Support</td>
<td>IPv4, IEC 62056-4-32 support and IPv6 support as a convergence layer over PRIME MAC and PHY layers.</td>
</tr>
</tbody>
</table>

**PRIME v1.4:** robustness improvement, throughput increase, band extension, backwards capability + ALL the benefits of PRIME v1.3.6
PRIME v1.4 - Reality beyond Metering

Version 1.4 now:

• makes PRIME **fit any grid or environment worldwide**:
  – FCC and ARIB bands (0 – 500 kHz)

• makes PRIME **fit any application worldwide**:
  – Medium voltage transmission, automotive comms, ...

• projects PLC for **Smart Metering into Smart Grid**:
  – LV grid remote control applications.
  – LV infrastructure control and knowledge: transformer, feeder and phase identification.
G3-PLC

World wide acceptance and application

- **Provide a cost effective system architecture**
  G3-PLC provide the best performance and cost efficiency for medium and low voltage power grid, by communicating over the very lines that it measure and control. PLC technology minimizes infrastructure and maintenance cost

- **Is standard based to assure interoperability**
  G3-PLC Support frequency bands worldwide (10 kHz to 490 KHz). Coexist with IEC 61334, IEE P1901 and ITU G.hn

- **Minimize infrastructure cost**
  G3-PLC provide long range communications

- **Can support new distribution switches, sensors and home area network applications**
  G3-PLC incorporates 6LowPAN adaptation layer to transmit IPv6 packets over power line channels. The 802.15.4 based MAC layer enable interoperability.

- **Includes security mechanisms to protect grid assets**
  G3-PLC support MAC-level security using and AES 128 cryptographic engine

- **Can function in hash, noisy environments**
  The “robust” mode of G3-PLC improve communication under noisy channel condition, operate at -1 dB SNR

- **Coexists with older technologies such as S-FSK**
  G3-PLC coexists with S-FSK and BPL
PRIME massive roll-out

Current version PRIME 1.3.6 – PHY Layer

- Power line Carrier Communications Technology within CENELEC Band A (3 – 95 kHz)
  - Ensures universal regulatory conformance
  - It uses a bandwidth of 47 kHz (from 42 to 89 kHz)
PRIME version 1.3.6: massive roll-out

PRIME 1.3.6 - MAC Layer

Switch transmits its own Beacon (BPDU): BC₁

Base Node transmits Beacons (BPDU): BC₀

Switch Node
S=(1,0)
T=(0,3)

terminal Node
T=(0,1)

Switch Node
S=(2,0)
T=(0,4)

Switch Node
S=(0,0)

Terminal Node
T=(0,2)

Terminal Node
T=(2,1)

Terminal Node
T=(1,1)

Terminal Node
T=(1,2)

BC₄ transmitted by S(2,0)
PRIME version 1.3.6: massive roll-out

PRIME 1.3.6 - PHY Layer Overview

- CRC
- Convolutional Encoder (optional)
- Scrambler
- Interleaver (optional)

- PLC: frequency fading -> error bursts
- Separate adjacent bits using interleaving
- Adjacent coded bits are mapped onto non-adjacent data subcarriers

- OFDM symbol + cyclic prefix
- Cyclic prefix
- OFDM freq allocation
- IFFT
- Sub-carrier modulator

- [0010..010]
- [000110010..010110101]

- 2.648 ms
- 4.48 ms / 2 OFDM symbols
- 2.24 * M ms / M OFDM symbols

- PREAMBLE
- HEADER
- PAYLOAD

- PLC

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04/08/2013
Histogram of the bit-rate in each scenario
PRIME evolution - PRIME 1.4!

PRIME 1.4 extended features – Robust modes (I)

+ (A) Addition of two ROBUST modes:
  - Robust DQPSK, Robust DBPSK
  - Robust PREAMBLE and HEADER have been defined as well

New “TYPE B” PHY frames

<table>
<thead>
<tr>
<th>PREAMBLE</th>
<th>HEADER</th>
<th>PAYLOAD</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.048ms</td>
<td>4.48ms</td>
<td>Mx2.24ms</td>
</tr>
<tr>
<td>2 symbols</td>
<td></td>
<td>M symbols</td>
</tr>
</tbody>
</table>

PRIME v1.4: “TYPE A” PHY frames

<table>
<thead>
<tr>
<th>PREAMBLE B</th>
<th>HEADER B</th>
<th>PAYLOAD</th>
</tr>
</thead>
<tbody>
<tr>
<td>8.192ms</td>
<td>8.96ms</td>
<td>Mx2.24ms</td>
</tr>
<tr>
<td>4 symbols</td>
<td></td>
<td>M symbols</td>
</tr>
</tbody>
</table>

PRIME v1.4: “TYPE B” PHY frames
PRIME evolution - PRIME 1.4!

PRIME 1.4 extended features – Robust modes (II)

- Robust mode comprises:
  - **Repetition code** (4 repetitions) in addition to already existing PRIME 1.3.6 convolutional encoder.
  - Circular shift between the four repeated bit vectors, which introduces additional frequency domain diversity between the different replica of the bits.

- Robust mode **gain** compared to PRIME version 1.3.6:
  - **Best case tested:** + 14.5 dB
PRIME evolution - PRIME 1.4!
PRIME 1.4 extended features – Extended frequency range (I)
+(B) FCC/ARIB band extension
PRIME evolution - PRIME 1.4!

PRIME 1.4 extended features – Extended frequency range (II)

• **Mode 1: Single channel**
  • 1: CENELEC A
    • Robust mode “enabled” (Type B PHY frame)
    • Robust mode “disabled” (Type A PHY frame)
  • 2: FCC (single 47kHz channel in the FCC band)
    • Robust mode “enabled” (Type B PHY frame)
    • Robust mode “disabled” (Type A PHY frame)

• **Mode 2: Multiple channels**
  • Configurable “bands” comprised of combination of channels, for example:
    • ch3 + ch4 + ch5 + ch6
    • ch4 + ch5 + ch6 + ch7
    • ...any application specific “band” needs to be approved by the CERT TF in order to get PRIME Alliance’s certification.
PRIME 1.3 versus PRIME 1.4!
PRIME evolution - PRIME 1.4!

PRIME 1.4 extended features specific for American SG

• New features:
  • Robust mode “enabled” (Type B PHY frame)
  • FCC extension with Multiple channels
  • IP6 and 6LowPan supported
  • Back compatibility with PRIME 1.3.6 devices
  • At to **1024Kbps** using the 8 channel of 47kHz
  • **10-15Km in MV passing the transformers to LV**
  • A single DC in MV cover to 1k customer in LV
Pilot project in South America: Architecture

- Recommended architecture using PRIME 1.4:
  - LV devices only need to form network
  - Passes through the MV / LV transformers
  - Injection is not necessary in MV
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### Atmel PLC PC tools
- PHY Tester & Tx console (PRIME, G3)
- Multi-protocol sniffer (PRIME, G3)
- Network Manager
- Vendor Tool

### Atmel PLC software
- ASF_PLLC: SW drivers/libraries
- PHY IDE:
  - PHY Tester Tool Example
  - PHY Sniffer Tool Example
- “Node” projects (IAR & AS)
- PRIME Base Node tool (IAR & AS)
- SW for Cycles Test (DLMS cycling emulation)
ATMEL PLC internal Simulation Tool

Introduction

- PLC Virtual Simulation using real SW (MAC layer) and real traffic of data.
- High level of correspondence with real performance.
- Capable of simulating complex and high-density network.
- Total Flexibility in terms of defining distribution network characteristics.
- Improvement lines in order to get plenty coverage.
- Complementary field tool for an installation deployment in terms of:
  - Performance forecasting
  - New Release Test (before massive firmware upgrading)
  - Singularity analysis
  - Field communication issues
  - Manufacturer equipment performance
  - Interoperability test
ATMEL PLC internal Simulation Tool

Main Characteristics

**INPUTS**

- Network characteristic
  - Distribution (LV Map)
  - Meter Rooms
    - Location
    - Number of Meter per MR
  - Physical characteristics
    - Attenuation
    - Coupling
    - Noise Level

- Meter Physical Parameters
  - Power supply/Signal Level against different impedances
  - Sensitivity

**OUTPUTS**

- Real time simulating (depending on the number of nodes) of PRIME or G3 network registration process.
- Network Structure representation (XML format)
- Singularities identification according results shown.
- Improvement measures to possibles coverage issues.
- Multi-location Active Sniffer Logs
- Status and evolution graphic representation (text format) adaptable to end customer visualization.
- Network structure overlapping over Low Voltage & MV Schema
- Valid for hybrid PLC and RF systems
Conclusion

PLC is the reality & future-proven solution for Smart Grid communications in Medium, Low Voltage and In-Home Networks.