Narrow Band PLC, Broad Band PLC and Next Generation PLC

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Some considerations on PLC for the Smart Grid

Acknowledgment

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Spin-off
Udine, Italy

Telecommunications
Signal Processing
Electronics

Smart grid
- Connectivity
- Monitoring
- Measurements
- Data analytics

Automotive
- Vehicular communications
- Localization
- Battery management systems
So many dilemmas...

- Does PLC work?
- Is it a valuable solution w.r.t. to other wireline and wireless technologies?
- Is it better narrow band or broad band PLC?
- What standard should I consider?
- ...
Let’s refocus!

Firstly,

- we have to specify what *applications and requirements*
- distinguish between
  - PLC spectrum
  - PLC technology
  - PLC standards

*The terminology NB PLC and BB PLC is not well defined*
Applications and network coverage

Applications
- Metering
- HEMS: home energy management systems
- Microgrid control, islanding,…
- Monitoring and protection, e.g., faults, power quality,…

Network coverage

- High Speed HAN
- Home Automation
- Metering & SG
- Grid Control
- Internet
- LV line
- MV line
- Microgrid

broad requirements rate, latency, reliability
One or more standards for everything...

**Home Automation**
ISO/IEC 14543-3
EIA 600

**High Speed HAN**
ITU-T G.9960
G9961
IEEE P1901

**Metering & SG**
ITU-T G9901
ITU-T G9960
IEEE P1901.2
IEC 61334-5-1

**Internet**

**ITU-T G9901**: NB-OFDM PSD specs
**ITU-T G9902**: NB-OFDM tranceivers
**ITU-T G9903**: NB-OFDM G3-PLC
**ITU-T G9904**: NB-OFDM PRIME
**ITU-T G9960**: BB PHY specs
**ITU-T G9961**: BB MAC specs
**IEEE P1901.2**: NB-OFDM PHY and MAC specs
**IEC 61334-5-1**: NB-SFSK PHY specs
**ISO/IEC 14543-3**: Konnex
**IEC 15118-3**: HomePlug Green PHY

**no standard**
Let’s make some distinction

We have to distinguish between:

- **NB Spectrum and BB Spectrum** (NB-S, BB-S)
- **NB Technology and BB Technology** (NB-T, BB-T)
- **NB Standard and BB Standard** (NB-ST, BB-ST)

The key thing is the medium
There are challenges, but there is nothing that prevents us to make it work!
The NB Spectrum and the BB Spectrum

Narrow band (NB-S)
- 3-148.5 kHz (CENELEC band) and 3-500 kHz (FCC/ARIB band)
- Maximum symbol rate: 0.497 Msymb/s

Broad band (BB-S)
- 2-86 MHz
- Maximum symbol rate: 84 Msymb/s

In principle, the BB-S offers
- 20 times higher rate, or 20 times lower latency with same target rate
- Higher flexibility to design the transmission technology
- Higher EMC constraints and complexity
The true capacity, coverage, latency depend on the application segment

- **Low voltage (LV) lines**
  - Topology with bus structure and short branches
    - EU: big cells (300 houses, ~1 km)
    - Asia & USA: small cells (<10 houses, 100 m)

- **Medium voltage (MV) lines**
  - Topology with tree structure with large length and few branches
Discontinuities

- Circuit breakers and transformers may act as discontinuity elements
- Is it positive or negative?
  - Cell partitioning allows to increase capacity
  - Higher deployment costs since you need concentrators/repeaters

Spectrum dependency

- **Signaling** in the BB-S has higher bypass ability
Medium characteristics

- The channel exhibits
  - Frequency selectivity (multipath propagation)
  - Time variations
  - Frequency selective line impedance

- The noise comprises
  - Stationary, cyclo-stationary and unstationary components
  - High interference from RF systems
  - Interference from other PLC nodes and DSL lines

- The characteristics are different in the NB-S and BB-S
Measurements and characterization

**In-home**

**ETSI STF 410 – MIMO**

**MV Grid**

**Industrial grids (Strathclyde Univ. 2009)**

**Cruise ship**

**Electrical car**

Medium properties

Path loss

- **Narrow band**
  - ↓ selectivity, ↓ attenuation

- **LV vs. MV**
  - Opposite behavior in NB and BB

![Graphs showing Path loss for Narrow Band and Broad Band](image_url)
Medium properties

Path loss

- **Narrow band**
  - ↓ selectivity, ↓ attenuation
- **LV vs. MV**
  - Opposite behavior in NB and BB

**Line impedance**

- **Narrow band**
  - Low values *(poor coupling)*
- **Broad band**
  - Selective behavior

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**Narrow Band**

- **Average Path Loss (dB)**
  - LV vs. MV graphs showing frequency vs. path loss.

**Broad Band**

- **Line impedance** graphs showing frequency vs. impedance magnitude and angle.
Background noise and SNR

Background noise

- Exponential decreasing profile
  - Higher in the NB-S
  - Higher in MV than in LV
Background noise and SNR

**Background noise**

- Exponential decreasing profile
  - Higher in the NB-S
  - Higher in MV than in LV

**Signal-to-noise-ratio**

- Concave behavior
  - ↑ attenuation + ↓ noise
  - Optimum windows exist!

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![Graph showing noise PSD and Average SNR](image-url)
NB-T and BB-T comparison

What performance can a transmission technology provide?

- Assumptions:
  - The same signal bandwidth of 500 kHz is used for NB and BB
  - Central carrier sweeps in the entire spectrum
  - A form of adaptive modulation

It can be noted as
- Optimal windows exist
- Poor rate in CENELEC
- ARIB and FCC are ok
- BB-T has huge potential
- BB-T is energy efficient
### NB-T and BB-T comparison

<table>
<thead>
<tr>
<th>Bandwidth</th>
<th>Capacity (Mbps)</th>
<th>Total power @1Mbps (dBW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3–500 kHz</td>
<td>6.87</td>
<td>-64.13</td>
</tr>
<tr>
<td>LV 7.385–7.885 MHz</td>
<td>7.34</td>
<td>-66.20</td>
</tr>
<tr>
<td>1.8–30 MHz</td>
<td>333.41</td>
<td>-68.13</td>
</tr>
<tr>
<td>3–500 kHz</td>
<td>1.32</td>
<td>-29.95</td>
</tr>
<tr>
<td>MV 24.35–24.85 MHz</td>
<td>9.69</td>
<td>-80.29</td>
</tr>
<tr>
<td>1.8–30 MHz</td>
<td>432.40</td>
<td>-82.11</td>
</tr>
</tbody>
</table>

Significant gains (channel dependent) in capacity and in energy efficiency!
At the heart of the existing technology, OFDM is used

The MAC and the Link layer can be better customized

Is there still space to improve the PHY layer?

- I believe so, with two approaches:
  - Filter bank modulation
  - Impulsive wide band PLC
Filter bank modulation

- **Filter bank modulation** is an advanced multicarrier modulation approach.
- It increases the notching ability, spectrum usage flexibility and noise margin.
- Applicable to both the NB and BB spectra.

**Example:**
In-building scenario
We may need less sub-channels.
Higher spectral efficiency with FBM than with OFDM.

Filter bank modulation

Higher throughput is achievable

**REF.** M. Giotto, A. Tonello, “Improved Spectrum Agility in Narrow-Band PLC with Cyclic Block FMT Modulation,” *IEEE GLOBECOM 2014*
Impulsive PLC

Another paradigm is to use I-PLC

- **Impulsive PLC**
  - Short duration adaptive waveforms
  - Extremely low PSD, at noise level
  - High coexistence with NB and BB without any coordination
  - Very simple implementation
  - Results show:
    - High rate
    - Coverage
    - Low latency

Two other areas

- **Multiple input multiple output (MIMO) PLC**
  - Good results in home networks
  - To be studied more in outdoor networks (multiple conductors not always available)

- **PLC and Radio Hybridization**
  - PHY layer diversity combining
  - Layer 3 convergence and hybrid routing via mixed radio and PLC links
  - Hybridization with 5G “may” take place
Conclusions

- **For metering:**
  - The usage of the NB-S appears reasonable

- **For all other SG applications:**
  - The BB-S offers more space
  - BB-T has much higher flexibility, scalability and better trade-off between data rate and energy efficiency

The **PLC technology evolution** must aim at providing
- Adaptivity, scalability, flexibility
- Smart use of resources