Low Frequency, Narrowband PLC Standards for Smart Grid –
*The PLC Standards Gap!*

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December 3, 2009
Outline

• Need for Narrowband PLC Standard
  – LF/NB PLC Requirements for Smart Grid
    – What are the gaps?
• Some Application Scenarios
• Strawman Narrowband PLC Requirements
The PLC Standards Gap

• **International Standards for PLC:**
  – Broadband @ >100 Mbps: IEEE P1901, ITU-T G.hn
  – Command & Control: IEC-61334 SFSK, LonWorks, HomePlug C&C
  – HomePlug Green PHY: 3.8Mbps (not an international standard)

• **Do we need an international narrowband PLC standard as follows:**
  – Scalable bitrates from 1bps to ~10Kbps up to ~500Kbps
  – Supporting rural and urban power grid PLC communications
  – DC and AC power lines

• **Existing standards do not exactly address smart grid requirements**
  – Overkill or not enough throughput, too complex, not scalable
  – Should we accelerate focused NB PLC standardization?

• **Low frequency, narrowband PLC**
  – LF/NB OFDM PLC trials in progress: PRIME / Iberdrola, G3 / ERDF (Cenelec A band)
  – Focus on grid-to-meter, EV-to-charging station, home appliances
Low Frequency, Narrowband PLC Bands Plus Very Low Frequencies

• PLC Frequency bands in Europe
  - Defined by the CENELEC:
  - CENELEC-A (3 kHz – 95 kHz) are exclusively for energy providers.
  - CENELEC-B, C, D bands are open for end user applications
  - Bands A, B and D protocol layer is defined by standards or proprietarily defined
  - Band C is regulated – CSMA access

• PLC Frequency bands in USA
  - Single wide band – from 150 to 450 kHz
  - FCC band 10kHz – 490kHz
  - Access protocol defined by standard
  - HomePlug Broadband: 2-30MHz

• PLC Frequency bands in Japan
  - ARIB band 10kHz – 450kHz

• PLC Frequency bands in China
  - 3-90KHz preferred by EPRI
  - 3-500KHz single band not regulated
### PLC PHY Standards Overview

<table>
<thead>
<tr>
<th>Standard</th>
<th>Technology</th>
<th>Band Occupied</th>
<th>Data Rate range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iberdrola PRIME</td>
<td>OFDM</td>
<td>42-90 kHz</td>
<td>21-128 kbps</td>
</tr>
<tr>
<td>ERDF G3</td>
<td>OFDM</td>
<td>35-90 kHz</td>
<td>2.4-34 kbps</td>
</tr>
<tr>
<td>P1901 / G.9960</td>
<td>OFDM</td>
<td>2-30 MHz</td>
<td>&gt;100 Mbps</td>
</tr>
<tr>
<td>Homeplug Green PHY</td>
<td>OFDM</td>
<td>2-30 MHz 120-400 KHz</td>
<td>250Kbps – 3.8Mbps</td>
</tr>
<tr>
<td>IEC 61334</td>
<td>SFSK</td>
<td>60-76 KHz</td>
<td>1.2-2.4kbps</td>
</tr>
</tbody>
</table>

- PRIME designed for low voltage lines with low noise → targets higher data rates
- G3 designed for medium voltage lines → lower data rates, 802.15.4 MAC
- Homeplug Green PHY specification in progress nearing completion
- SFSK implementations available in Celenec A or B bands
- Also HomePlug C&C and LonWorks
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Low Voltage to Medium Voltage to Substation Communications

- Cenelec A, FCC, or ARIB
- >100 Kbps
Low Voltage to Medium Voltage to Substation Communications

- Low frequencies <1KHz, Cenelec A, FCC, or ARIB
- 1 bps to 10Kbps

Substation to Meter
-- 1-2 Km
-- 100 Km
## PowerLine Intelligent Metering Evolution (PRIME)
### MV/LV Transformer-to-Meter
#### PHY Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>DBPSK</th>
<th>DQPSK</th>
<th>D8PSK</th>
</tr>
</thead>
<tbody>
<tr>
<td>Convolutional Code (1/2)</td>
<td>On</td>
<td>Off</td>
<td>On</td>
</tr>
<tr>
<td>Information bits per subcarrier $N_{BPSC}$</td>
<td>0.5</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Information bits per OFDM symbol $N_{BPS}$</td>
<td>48</td>
<td>96</td>
<td>96</td>
</tr>
<tr>
<td>Raw data rate (kbps approx)</td>
<td>21.4</td>
<td>42.9</td>
<td>42.9</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base Band clock (Hz)</td>
<td>250000</td>
</tr>
<tr>
<td>Subcarrier spacing (Hz)</td>
<td>488.28125</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of data subcarriers</td>
<td>84 (header)</td>
</tr>
<tr>
<td>Number of pilot subcarriers</td>
<td>13 (header)</td>
</tr>
<tr>
<td>FFT interval (samples)</td>
<td>512</td>
</tr>
<tr>
<td>FFT interval (μs)</td>
<td>2048</td>
</tr>
<tr>
<td>Cyclic Prefix (samples)</td>
<td>48</td>
</tr>
<tr>
<td>Cyclic Prefix (μs)</td>
<td>192</td>
</tr>
<tr>
<td>Symbol interval (samples)</td>
<td>560</td>
</tr>
<tr>
<td>Symbol interval (μs)</td>
<td>2240</td>
</tr>
<tr>
<td>Preamble period (μs)</td>
<td>2048</td>
</tr>
</tbody>
</table>
PRIME / Narrowband OFDM Modem Test Kit

- PRIME / Narrowband OFDM PHY
  - Field and lab tested for robustness in harsh operating environment
- PRIME MAC (Support Lower MAC - datapath)
- PRIME Convergence Layer (Support IPv4 CL)
PRIME PHY Field Trials (LV to Meter)

- 64 Kbps with no packet errors seen in 8 out of 12 houses
- One home required a repeater
- 42 Kbps reception achieved at 263m
PRIME Field Trials with MAC / PHY (LV)

- 24 meters in 8 houses, single phase and 3-phase injection at the distribution transformer
- One “switch node” in each house connects other phases to distribution transformer
- Automatic network configuration, node promotion, application-level data transfer tested
NB PLC for MV / LV Grid-to-Home

<table>
<thead>
<tr>
<th>Technology Cenelec Band</th>
<th>MV Master ➔ LV Slave</th>
<th>LV Slave ➔ MV Master</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Data Rate (bps)</td>
<td>FER (Frame Error Rate)</td>
</tr>
<tr>
<td>S-FSK</td>
<td>763 bps</td>
<td>12%</td>
</tr>
<tr>
<td>OFDM 97 Carriers</td>
<td>1400 bps</td>
<td>38%</td>
</tr>
<tr>
<td>OFDM 36 Carriers</td>
<td>4175 bps</td>
<td>1%</td>
</tr>
</tbody>
</table>

MV / LV transformer crossing OK with the 3 technologies (ERDF Data Results)
Rural Meter Reading via NB PLC

• PLC—medium speed
  – Requires one concentrator per transformer
  – U.S. grid topology not amenable (e.g., 1-3 homes per transformer)

• PLC—low speed
  – Requires one concentrator per substation
  – Low speed still allows interval data reads daily
  – 1 bps, 100Km with no repeaters
Electric Vehicle Charging Scenario

- Point-to-point

- High charging power dictates demand response and load leveling

- Authentication / security to ensure billing is correct

- Assume 8 kWh to charge EV
  - Level 1 Charging: 120V, 12A AC, 7-8 hours to charge
  - Level 2 Charging: 240V AC - 3 hours to charge – limited by onboard charger
  - Level 3 Charging: DC / external inverter
    - Using 40A breaker in home – 1.25 hours to charge
    - Charging station – 0.5 hours – limit is EVSE
NB PLC 100A DC Charger Scenario (** from Maxim)

- Switching frequency harmonics @ 140KHz, 210KHz, 280KHz…
- It will be better to use high frequency band between 250KHz-450KHz to get better performance.
- ARIB Data rate = 21Kbps in ROBO mode and 85Kbps in Normal Mode
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Strawman NB PHY/MAC PLC Requirements

• Power Grid to Meter, Electric Vehicle to Charging Station (EVSE), HAN
• Scalable standard to support multiple bands (regions), applications
• Frequency bands: Cenelec A/B/C/D, FCC, ARIB
• Data Rates: 1bps to 10Kbps up to 500Kbps, low frequencies
• Medium / Low Voltage Powerline Communications for Rural and Urban
  – Up to ~100Kbps over LV lines to/from meter up to 300 meters
  – Up to ~10Kbps MV/LV to/from meter, ~ 1Km
  – 10’s of Km’s at lower bitrates for rural areas
• PHY: Consider OFDM for coexistence, robustness, scalability
  – Coexistence with PRIME, G3, SFSK, LON, others TBD
• MAC:
  – Network automatic detection and formation for tree/star or mesh
  – Support contention-based and contention-free for thousands of nodes
  – High-level of security
  – Packet Aggregation/ARQ for additional robustness
• IPV6/IPv4 Dual Stack
Alliances & Standardization Bodies

• IEEE2030 Smart Grid Interoperability
• IEEE P1901 (Broadband PLC)
• IEEE 802
• HomePlug Alliance (HPAV, HPGP, HPCC)
• NIST Smart Grid Interoperability Study Group
• ITU-T G.9960/G.hn (Broadband PLC)
• CEN/CENELEC/ETSI Mandate 441 Interoperability Standards
• PRIME (PoweRline Intelligent Metering Evolution) (NB PLC)
• ERDF G3 (NB PLC)
• Society of Automotive Engineers (SAE)
  – J2993 – Hybrid Electric Vehicle Use Cases / PLC
  – J1772™ PEV Cordset
• UCA International User Group (UCAIug – OpenSG/OpenAMI)
• Others