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

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December 3, 2009

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Outline

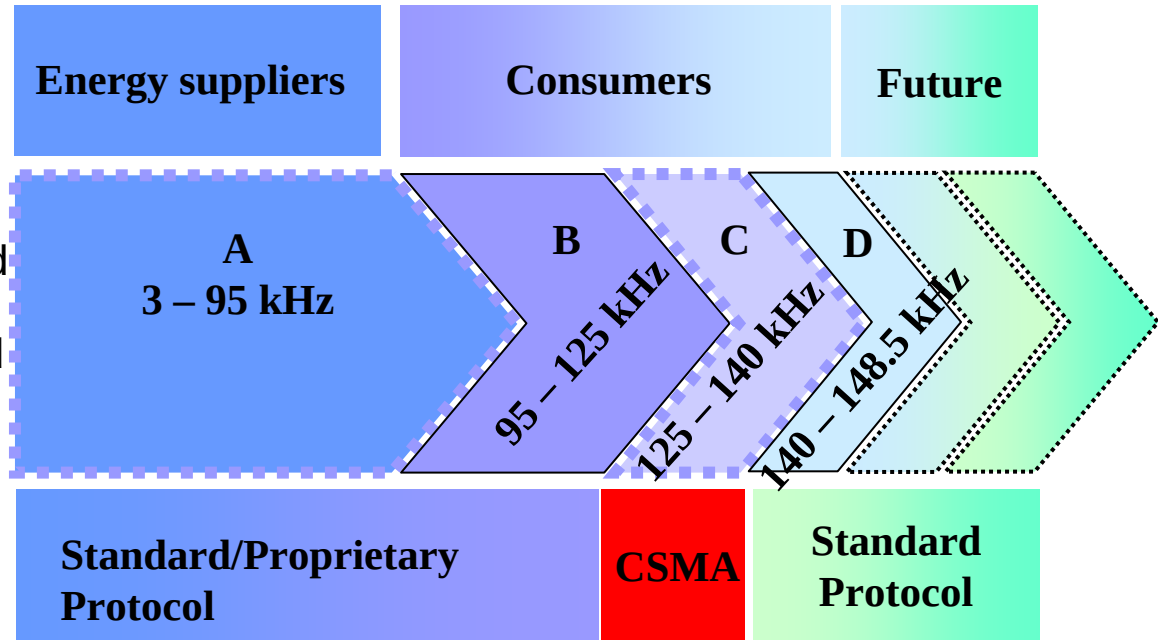
- **Need for Narrowband PLC Standard**
  - **LF/NB PLC Requirements for Smart Grid**
  - **What are the gaps?**
- **Some Application Scenarios**
- **Strawman Narrowband PLC Requirements**

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

Standard	Tech-nology	Band Occupied	Data Rate range
Iberdrola PRIME	OFDM	42-90 kHz	21-128 kbps
ERDF G3	OFDM	35-90 kHz	2.4-34 kbps
P1901 / G.9960	OFDM	2-30 MHz	>100 Mbps
Homeplug Green PHY	OFDM	2-30MHz 120-400 KHz	250Kbps – 3.8Mbps
IEC 61334	SFSK	60-76 KHz	1.2-2.4kbps

NB PLC

BB PLC

- 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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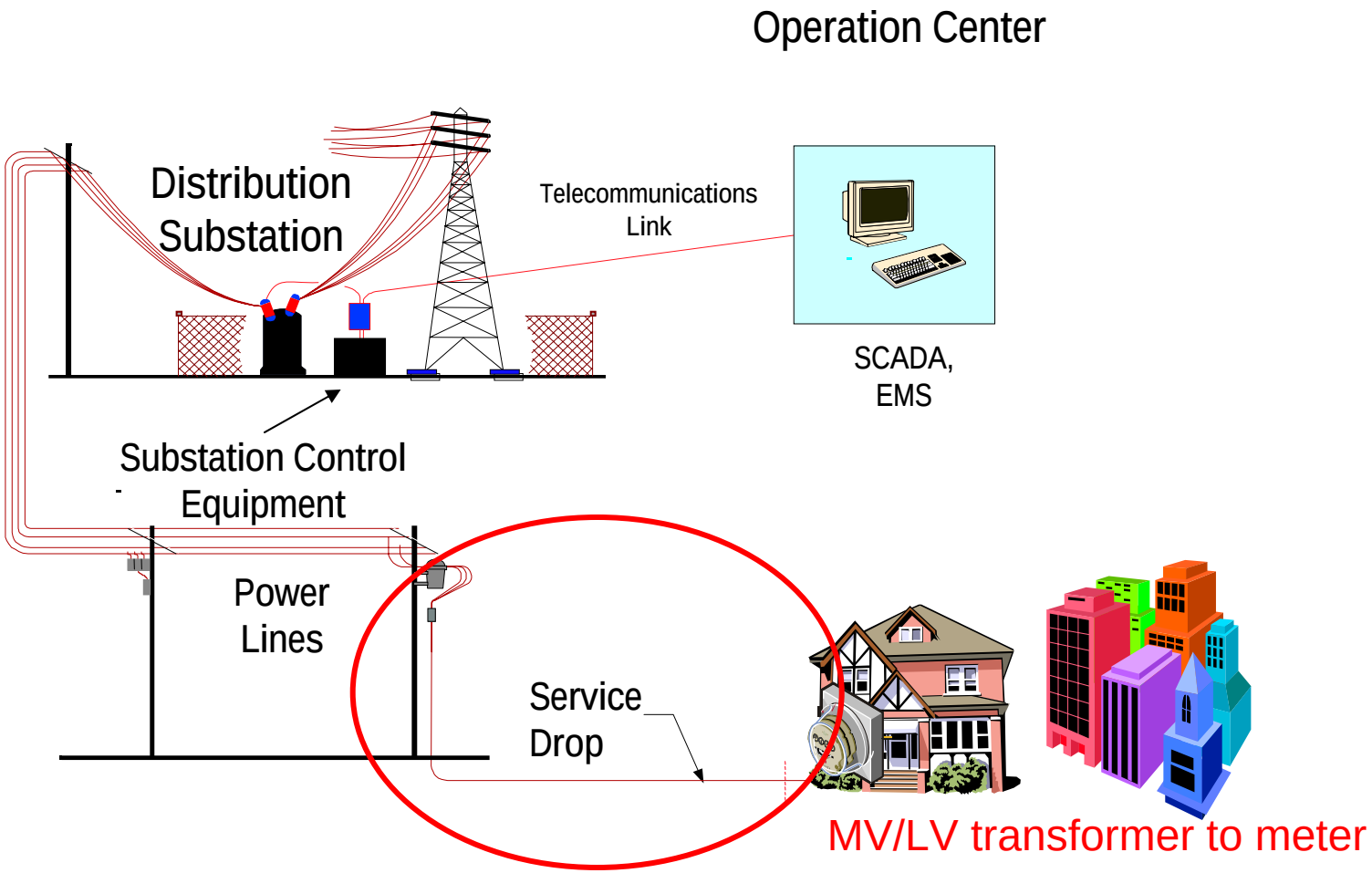
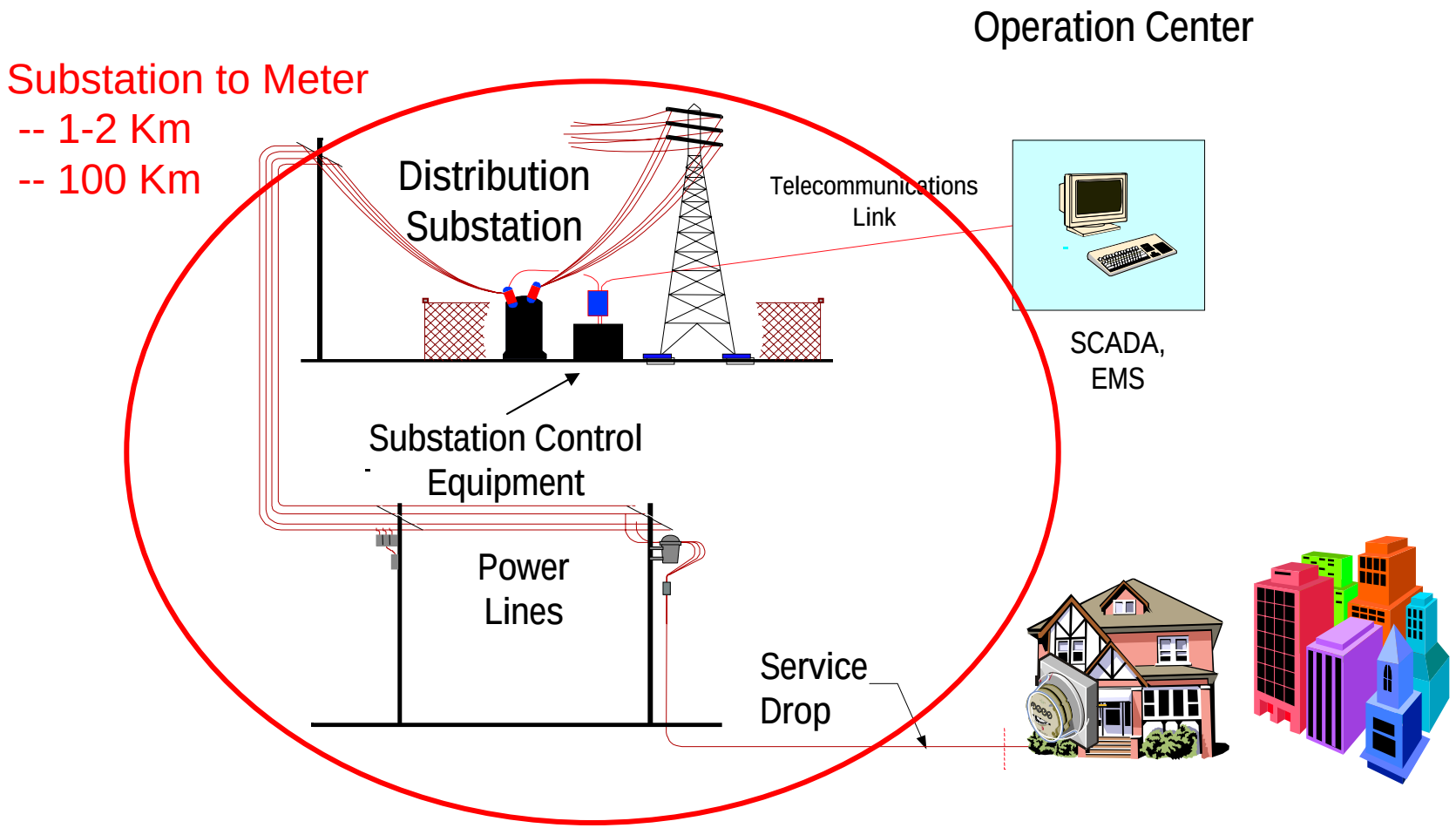
Low Voltage to Medium Voltage to Substation Communications



- 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

PoweRline Intelligent Metering Evolution (PRIME)
MV/LV Transformer-to-Meter
PHY Parameters

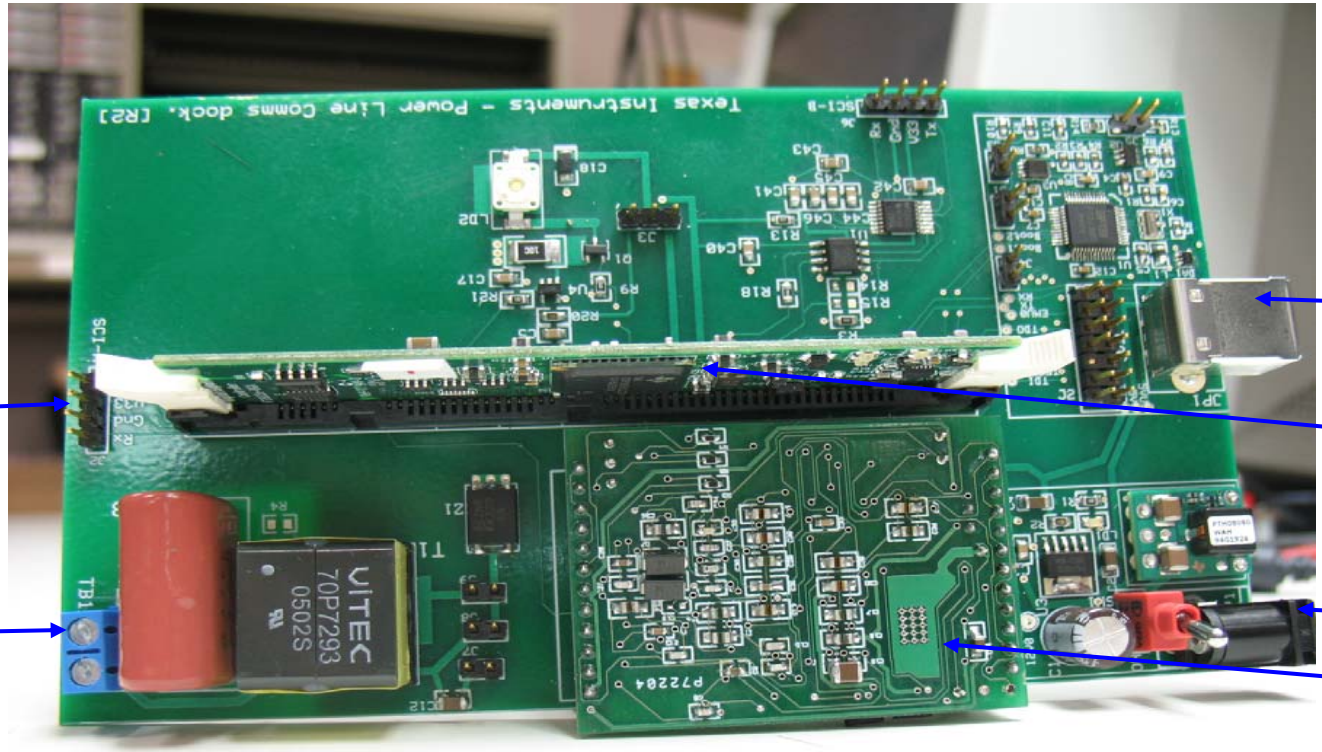
	DBPSK		DQPSK		D8PSK	
Convolutional Code (1/2)	On	Off	On	Off	On	Off
Information bits per subcarrier N_{BPSC}	0.5	1	1	2	1.5	3
Information bits per OFDM symbol N_{BPS}	48	96	96	192	144	288
Raw data rate (kbps approx)	21.4	42.9	42.9	85.7	64.3	128.6

Base Band clock (Hz)	250000
Subcarrier spacing (Hz)	488.28125

Number of data subcarriers	84 (header)	96 (payload)
Number of pilot subcarriers	13 (header)	1 (payload)
FFT interval (samples)	512	
FFT interval (µs)	2048	
Cyclic Prefix (samples)	48	
Cyclic Prefix (µs)	192	
Symbol interval (samples)	560	
Symbol interval (µs)	2240	

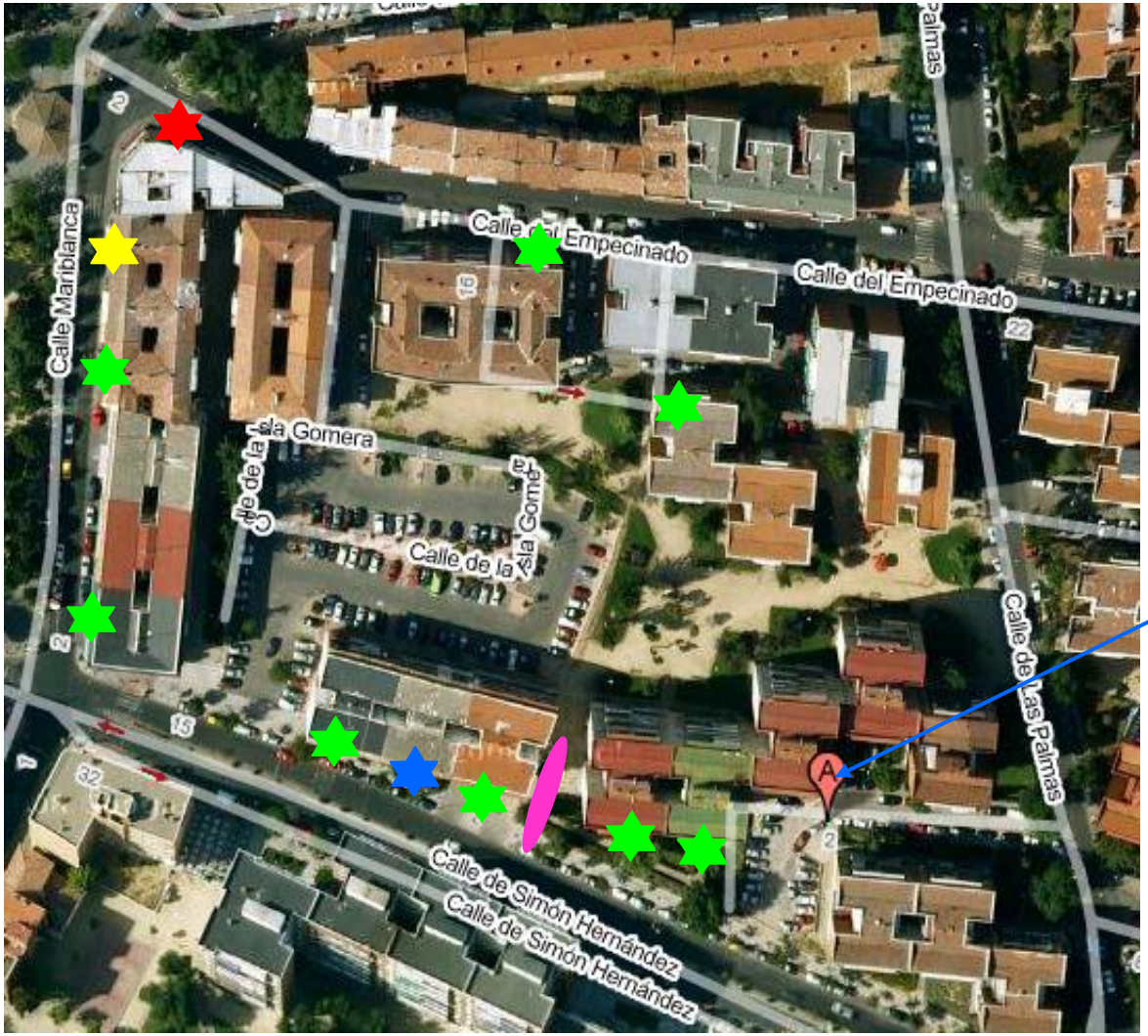
Preamble period (µs)	2048

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

42 kbps

21 kbps

Transmitter In MV→ LV transformer room

- 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)

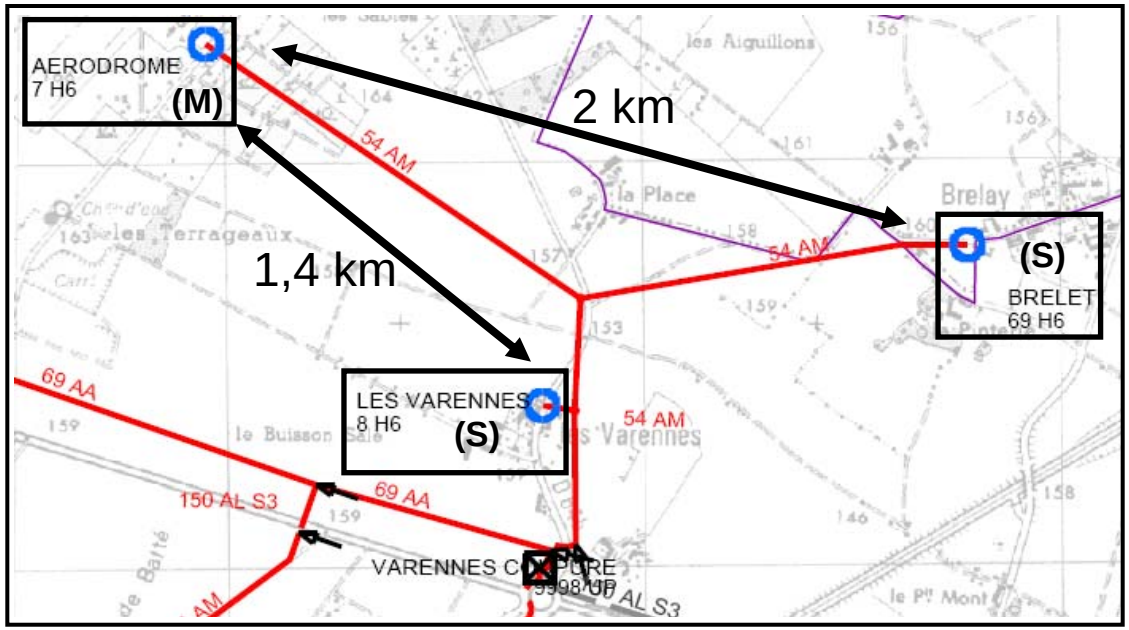
Transmitter In MV→ LV transformer room

- 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

Master Point (M)
Capacitive coupling on **MV** network

Slave Points (S)
on **LV** network



Technology Cenelec Band	MV Master ➔ LV Slave		LV Slave ➔ MV Master	
	Data Rate (bps)	FER (*Frame Error Rate*)	Data Rate (bps)	FER (*Frame Error Rate*)
S-FSK	**763 bps**	**12%**	**763 bps**	**12%**
OFDM 97 Carriers	**1400 bps**	**38%**	**2170 bps**	**17%**
OFDM 36 Carriers	**4175 bps**	**1%**	**2425 bps**	**12%**

➔ MV / LV transformer crossing OK with the 3 technologies (ERDF Data Results)

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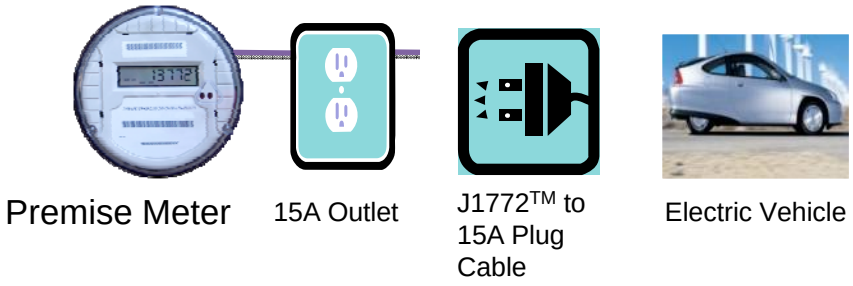
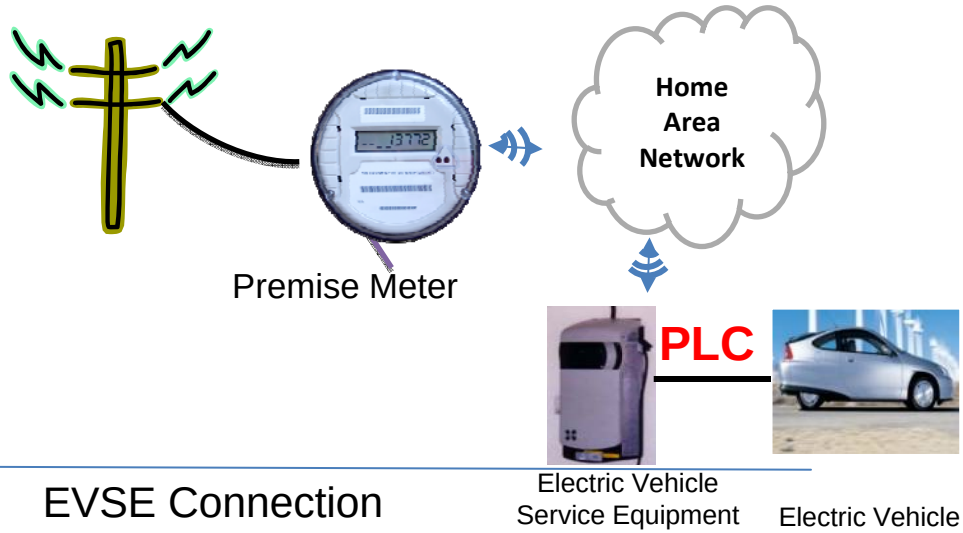
Rural Meter Reading via NB PLC

- 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



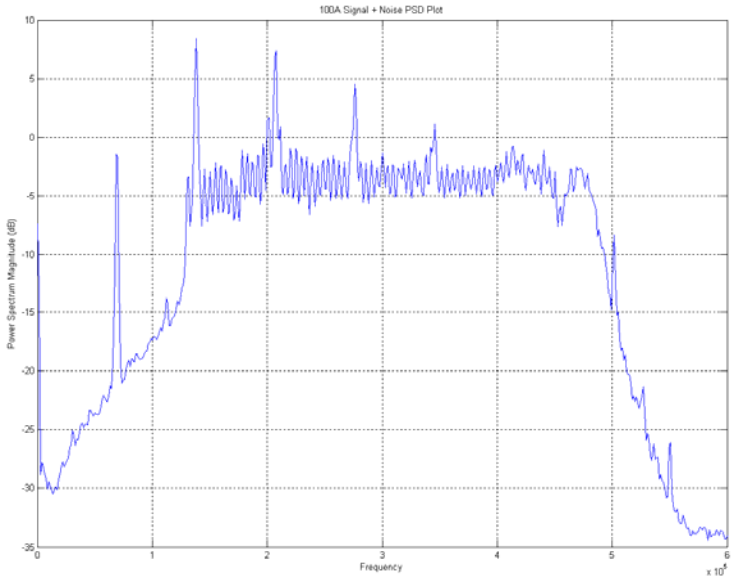
Direct Connection



EVSE Connection

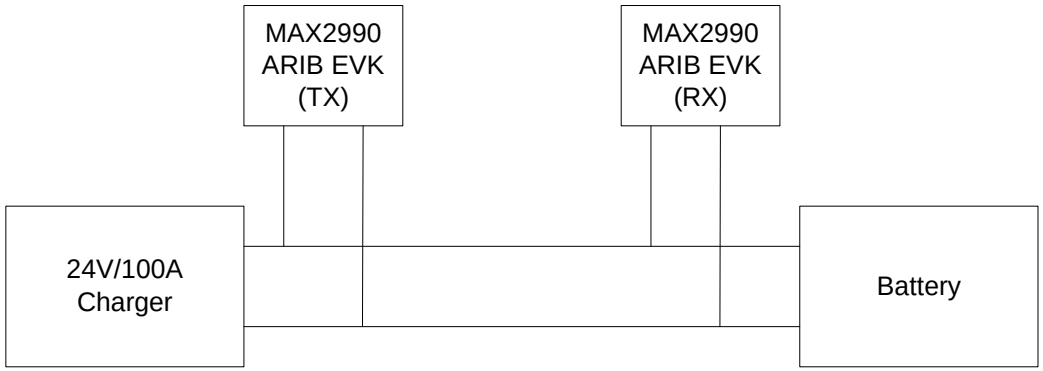
- Point-to-point
- High charging power dictates demand response and load leveling
- Authentication / security to ensure billing is correct
- Assume 8 kWh to charge EV
  - Level 1 Charging: 120V, 12A AC, 7-8 hours to charge
  - Level 2 Charging: 240V AC - 3 hours to charge – limited by onboard charger
  - 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)



Received Signal

eTec Test Setup



- **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**