Communications for the Smart Grid

Sumit Roy
roy@ee.washington.edu

www.ee.washington.edu/research/funlab
“Edison’s Grid” Today

- Simple concept
  - Robust; Effective

- Complex in execution
  - Thousands of power plants
  - Web of regional transmission lines
  - More complex web of local distribution lines

- Increasing demand
- High Aggregate Losses
- Ageing assets…transformers, feeders etc.,
- Grid to carry more power
  → Need for Greater Reliability and Security
- Energy mix: Integrate Renewables to reduce carbon footprint
Smart Grid: A New Digital, Information-Age Grid

Basic structure

- **Smart Components**
  - New Digital Power Electronics with integrated processors, transceivers and sensors

- **Smart Infrastructure (the Network)**
  - Protocol Stack that provides more *timely* and *reliable* data

- **Smart Computational Intelligence (Decision/Estimation/Control)**
  - Fusion of information to extract patterns and information from data, to direct network operations
Smart Grid Components

- **From One-Way → Two-way communication**
  - Smart Meters (Advanced Metering Infrastructure)
  - Smart relays
- **Sensors** at relays, circuit-breakers, transformers, substations
An Integrated Energy System

- Incorporates entire energy pathway, from generation to customer
- Demand Response
- Load Control
- Distributed generation
- Energy storage
Integrating Two Infrastructures

Power Infrastructure

Central Generating Station
Step-Up Transformer
Distribution Substation
Receiving Station
Distribution Substation

Information Infrastructure

Control Center
Micro-turbine
Residential Data Concentrator
Photo voltaics
Batteries
Residential

Gas Turbine
Distribution Substation
Recip Engine
Cogeneration
Industrial
Commercial

Data network Users
Recip Engine
Commercial
Flywheel
The Smart Home

- Added green power sources
- Plug-in hybrid electric cars
- Real-time and green pricing signals
- Smart thermostats, appliances and in-home control devices
- High-speed, networked connections
- Customer interaction with utility
AMI (Advanced Metering Infrastructure)

- Automated meter reading, load control, in-home displays, distribution monitoring and control etc.
Smart Meters

Modern Solid-state meter (left); Traditional Electro-mechanical (right)

Grid Friendly Appliance Controller
Smart Grid Web Portal

- Allows customer to monitor and manage their energy use
- Online tools provide more options, choice and personal control
Energy Management Systems (EMS) for Home

Residential EMS

- Thermostat
- In-Home Display
- Web Portal
- V2G Storage
- Hot Water
- Other Appliances
- EV Charging
- Distributed Generation

![Image of car and thermostat]
Smart Grid Commn. Standards

- Too many niche standards!
- Inter-Operability!
# Wireless Technologies

<table>
<thead>
<tr>
<th>Technology</th>
<th>Range</th>
<th>Advantage</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bluetooth</td>
<td>1-100 meters</td>
<td>Widely used, low cost</td>
<td>Security, limited range</td>
</tr>
<tr>
<td>Wi-Fi</td>
<td>100 meters</td>
<td>Widely used, low cost, strong security</td>
<td>Limited range, performance degrades quickly based on range, spectrum assignment not consistent worldwide</td>
</tr>
<tr>
<td>WiMAX</td>
<td>30 miles</td>
<td>Long range, large bandwidth, low cost</td>
<td>Bit error rate increases with range, available bandwidth shared with users, not widely deployed</td>
</tr>
<tr>
<td>Zigbee</td>
<td>10-75 meters</td>
<td>Low cost and power, long battery life</td>
<td>Limited range, low data rate</td>
</tr>
</tbody>
</table>
System Architecture
Home Area Networks
ZigBee basics

- Short range radio based on IEEE 802.15.4
- 2.4 GHz Mesh radio
- Limited to 10 mW/MHz in Europe by EN 300 328
- 10k-115.2kbps data throughput
- 10-75m coverage range
- Up to 65k slave nodes per network
- Up to 100 co-located networks
- Up to 2 years of battery life on standard Alkaline batteries

<table>
<thead>
<tr>
<th>BAND</th>
<th>COVERAGE</th>
<th>DATA RATE</th>
<th>CHANNEL(S)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.4 GHz</td>
<td>ISM Worldwide</td>
<td>250 kbps</td>
<td>11-26</td>
</tr>
<tr>
<td>868 MHz</td>
<td>Europe</td>
<td>20 kbps</td>
<td>0</td>
</tr>
<tr>
<td>915 MHz</td>
<td>ISM Americas</td>
<td>40 kbps</td>
<td>1-10</td>
</tr>
</tbody>
</table>
Topology Models

- Star
- Mesh
- Cluster Tree

- Coordinator
- Full Function Device
- Reduced Function Device
Original Applications

ZigBee
LOW DATA-RATE
RADIO DEVICES

INDUSTRIAL & COMMERCIAL
monitors
sensors
automation
control

CONSUMER ELECTRONICS
TV
VCR
DVD/CD
remote

PERSONAL HEALTH CARE
monitors
diagnostics
sensors

PC & PERIPHERALS
mouse
keyboard
joystick

TOYS & GAMES
consoles
portables
educational

HOME AUTOMATION
security
HVAC
lighting
closures
Smart Energy 2.0 and Zigbee

- **US National Institute of Standards and Technology (NIST)**
  - Direction on standards selection
- **UCA International OpenSG**
  - OpenHAN System Requirements Specification (SRS)
  - Market Requirements Document (MRD) and Use Cases for Smart Energy 2.0
- **ZigBee**
  - Developing IETF based IP stack for IEEE 802.15.4 based platforms based on OpenHAN SRS and Smart Energy 2.0 MRD
- **HomePlug**
  - Developing IEEE P1901 compliant powerline carrier solutions: HomePlug AV and HomePlug SE
- **Recognized Standards Development Organizations (SDOs)**
  - IETF, IEC, IEEE, W3C
Broadband over power lines (BPL)

- FCC approved power utilities to carry data on electrical wires to provide broadband services

- Appropriate for underserved (small towns and rural) areas and developing world!

- **Challenges**
  - EMI to other radio signals in vicinity
    - Restricts service in areas where it could affect public safety
  - Dynamic Load fluctuations!
  - PLC signals cannot readily pass through transformers (block high frequency signals) → repeaters are needed to bypass every transformer.
    - PLC signals do not propagate long distances
BPL solution for the distribution grid

1. CT Coupler™
2. CT Backhaul Point™
3. CT Bridge™
4. Third-party HomePlug® BPL Modem
5. CT-View Management System

HomePlug® is a registered trademark of the HomePlug Powerline Alliance, Inc.
HomePlug 1.0 Frequency Spectrum

- 84 carriers from 4.5-21 MHz – notches for amateur radio bands
  - Raw Throughout 14 Mbps $\rightarrow$ Effective throughput 6-7 Mbps
  - DES encryption

Marker 11.730000 MHz -18.86 dBm
Sec 15.209

1.705-30.0 MHz -- 30 $\mu$V/m at 30 meters, quasi-peak measured in 9 kHz

30-80 MHz -- 90 uV/m at 10 meters, quasi-peak measured in 120 kHz

On VHF, Class A limits apply to medium-voltage, primary distribution lines, even in residential neighborhoods

Class B limits apply to LV lines

Hybrid devices that operate on both MV and LV lines use Class A limits
Emission Mask: Work in Progress

Electric field limits proposed by different regulatory bodies for PLC emission.

- Norwegian Proposal (Pk)
- BBC Proposal (Pk)
- UK MPT1570 (Pk)
- German NB30 (Pk)
- EN55022 Class B (QPk) (Derived below 30 MHz, Pk above 1 GHz)
- PLC Proposal (QPk) (derived from FCC limits using 33 dB/dec)
Figure 4 – These are the signals that were present on the 14-14.35 MHz Amateur band on October 1, 2004 at 2220 UTC. The lower line shows the sensitivity that would result from the use of a typical communications receiver with a 12 dB noise figure.
Channel Responses

Frequency Domain

Scenario 1

Time Domain

Scenario 2
PLC Noise

- Noise Classification:
  - Colored background noise
  - Narrowband noise
  - Periodic impulsive noise, asynchronous to the main frequency
  - Periodic impulsive noise, noise, synchronous to the main frequency
  - Asynchronous impulsive noise

- Our concentration
  - Colored background noise
  - Asynchronous impulsive noise
Colored Background Noise

- Quasi-Static behavior
- Statistic information is extracted in table
- Can be modeled as:

\[ N(f) = 10^{s-b\cdot f^c} \ (W/Hz) \]
Random Impulsive Noise

- Caused by frequency bursts generated by electrical devices connected to the powerline.
- Statistical information is extracted

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>Standard deviation $\sigma$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amplitude ($mV$)</td>
<td>229</td>
<td>121</td>
</tr>
<tr>
<td>Duration ($\mu s$)</td>
<td>205</td>
<td>157</td>
</tr>
<tr>
<td>Interval time ($ms$)</td>
<td>0.667</td>
<td>0.445</td>
</tr>
</tbody>
</table>
Advanced PLC Modems: DMT Technology

- **Discrete Multi-tone Modulation (DMT)**
- **Advantages:**
  - Multicarrier technology – combat frequency selective fading
  - Dynamic bit loading based on SNR – efficient spectrum utilization
  - High channel capacity
### Smart Grid Applications: Network Requirements

<table>
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<tr>
<th>Applications</th>
<th>Properties</th>
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<tbody>
<tr>
<td></td>
<td>Bandwidth</td>
</tr>
<tr>
<td>Power Quality Monitoring</td>
<td>Low</td>
</tr>
<tr>
<td>Distribution Automation (Voltage/VAR control)</td>
<td>Low</td>
</tr>
<tr>
<td>Advanced Metering</td>
<td>Moderate</td>
</tr>
<tr>
<td>Protective Relaying</td>
<td>Low</td>
</tr>
<tr>
<td>Demand Response (Pricing, Load Control)</td>
<td>Low</td>
</tr>
<tr>
<td>Rural Broadband Access (*)</td>
<td>High</td>
</tr>
</tbody>
</table>
Smart Grid Requirements - II

- Some applications (Voltage Control) requires low latency: 6 cycles or 100 ms.

- Most applications do not need more than few Mbps link rates!

- Most radio technologies cannot meet the 100 ms constraint (WiMAX being only potential exception) → wired solution!

  e.g. Fibre optic cable is 5 microseconds per kilometer.
Examples of Smart Grid Deployment

**SmartGrid City (Xcel Energy) Boulder, Colorado**
SmartGrid City (Xcel Energy) Boulder, Colorado

- **Phase I** – automating the entire electric system, installation of a high-speed communications network, sensing equipment, and 15,000 Landis+Gyr smart meters for the first group of customers.

- **Phase II** – complete the installation of the distribution and communication network for the remaining areas in Boulder, two additional substations, 20 feeders, more smart meters, and the addition of 35,000 commercial and residential buildings.

- **Smart Substations** – include more intelligent systems to monitor loads and grid conditions for real-time decisions.

- **Smart Feeders** – consisting of reclosers, switches, and other devices that are capable of two-way communications with the utility; allows the utility to monitor power flows, outages, and the performance and operations of feeder equipment.

- **Smart Distribution System** – each transformer and smart meter in the distribution system will be outfitted with power analyzers which will provide real-time data about power consumption, outages, restorations, and fault locations.