Nanogrids, Power Distribution, and Building Networks

Bruce Nordman
Lawrence Berkeley National Laboratory
February 24, 2011

BNordman@LBL.gov — eetd.LBL.gov/ea/nordman
Overview

- Nanogrids
- Power distribution generally
- Building Networks
  - relation to the ‘Smart Grid’
- Energy reporting
- Internet of Things

This is a work in progress
Nanogrid Overview

• What is a Nanogrid?
• Relation to other grids
• Examples
• Implementation
• The way forward

This an initial proposal, not a final design
Examples

No communications
• Vehicles – 12 V, 42 V, 400 V, …
• eMerge – 24 V, 380 V
• Downstream of UPS – 115 VAC

With communications
• Universal Serial Bus, USB – 5 V
• Power over Ethernet, PoE – 48 V
• Proprietary systems

Power adapter systems
• Universal Power Adapter for Mobile Devices, UPAMD – IEEE
• (Greenplug, Inc.)
• Wireless technologies
What is a Nanogrid?

“A (very) small electricity domain”

- Like a microgrid, only (much) smaller
- Has a single physical layer (voltage; usually DC)
- May have control
- Is a single administrative, reliability, and price domain
- Can interoperate with other (nano, micro) grids through gateways
Nanogrid details

- Must have at least one load*
- Must have a gateway*
  - Can be intermittently connected
  - Supply always via a gateway
- **Only implement power distribution**
  - Devices control themselves for functionality
- Can be highly dynamic in connected devices, power flow quantity (and direction), …
- Range in functionality of controls, gateways
- Loads usually < 100 W, sometimes < 1 W
Controller

- Can have ability to grant or revoke power to loads
- Negotiates with other grids through gateways
- Sets prices
- Manages storage
- Is the authority within the grid
- (Should) Provide minimal power to loads at all times to maintain communications ability
- Deals with loads that do not communicate
Gateways

- Can be one-way or two-way (for power)
- Most functional when communications exist
- Can be to a nanogrid, microgrid, or the megagrid
- Have a capacity limit
- Exchange voltage: ???
- Only information that passes across gateway is price, capacity, and availability

- Perhaps storage is just a (special) gateway?
Price

• Not required — but really useful
• Basic mechanism for devices to express preferences
• Can be unitary or a time series forecast
• Is local only to the nanogrid
• Used in deciding when to
  – exchange power across gateways
  – add to or withdraw from storage
• Exchange losses dictate differential ‘buying’ and ‘selling’ prices (gateway and storage)
• Gateways may track energy flows and prices
Relation to other grids

• Macrogrid (megagrid)
  – Large
  – No direct coordination between sources and loads
  – Oversizing and diversity enable this

• As grids get smaller
  – Potential for supply/demand imbalances increase
  – Need for coordination grows
  – Off-grid operation requires local generation or storage
  – Advances in communications technology enables coordination not before possible
Microgrids

• better integrate local (distributed) generation
• optimize multiple-output energy systems (e.g. combined heat and power, CHP)
• better integrate local storage
• provide a variety of voltages, including DC
• provide a variety of quality and reliability options.
• operate independently of the macrogrid (or connected)
• hide microgrid details from the macrogrid

Nanogrids implement only some of these
Microgrids vs. Nanogrids

- Few
- Building/campus scale
- Multiple voltage, reliability domains
- Includes generation
- Have to deal with implementation issues

- Many
- Few connected devices
- Single voltage, reliability domain
- No generation
- Already works!

- *Bottom-up approaches are more deployable, flexible, cost-effective, functional*
- *Nanogrids can enable a “better grid” faster and cheaper than the “smart grid” (though they can co-exist)*
Inspiration

- Existing technology
- Modeling network architecture on Internet
  - Randy Katz et al., UCB; “LoCal” – local.cs.berkeley.edu
  - Developing country needs; off-grid households
  - Eric Brewer, UCB; TIER – tier.cs.berkeley.edu

Technology and Infrastructure for Emerging Regions

Network of networks → Internet — Network of grids → Intergrid

photos: Colombia University
Photo: Matthew Kam, TIER
School near Lucknow, India
Examples

No communications
- Vehicles – 12 V, 42 V, 400 V, …
- eMerge – 24 V, 380 V
- Downstream of UPS – 115 VAC

With communications
- Universal Serial Bus, USB – 5 V
- Power over Ethernet, PoE – 48 V
- Proprietary systems

Power adapter systems
- Universal Power Adapter for Mobile Devices, UPAMD – IEEE
- *(Greenplug, Inc.)*
- Wireless technologies
Implementation

• Will be used because they are convenient
• Enable easy sharing of (surplus) local generation
• May (or may not) have efficiency advantages
• Most NG connected to the macrogrid (intermittently)
  – Even vehicles will be
• Price mechanism ensures that all power exchanges are mutually beneficial
• Gateways have “friction” — this enhances stability
• Using same technologies in many domains ensures that they are cheap and available for very poor
  – Example: proliferation of mobile phones
Village example

- Start with single house – car battery recharged every few days
  - Light, phone charger, TV, ???
  - Add local generation – PV, wind, …

- Neighbors do same
  - Interconnect two houses

- School gets PV
  - More variable demand

- Eventually all houses, businesses connected in a mesh
  - Can consider when topology should be changed

- Existence of generation, storage, households, connections all dynamic

- Can later add grid connection
Communication

- Ideally use functional communication path for power coordination, e.g. USB, PoE
- Otherwise need simple, robust, slow physical layers
- Single physical layer for power coordination within a NG
- At gateways need standard communication
  - G.hn? Internet Zero?
  - Need single gateway protocol / physical layer
- All communication only requires data links
  - not (complicated) network infrastructure
The way forward

- Better document **existing** nanogrids  
  - Capabilities, uses, …
- Define a “meta-architecture” for operation, gateways, prices
- Define specific gateways (voltage, communication)
- Define nanogrid implementation for existing technologies
- **Always** keep power distribution and functionality separate
- Identify promising applications
- Demonstrate, document, market
- Bring (more, better) nanogrids to the neediest
- Test price mechanism
Summary: Nanogrids …

... exist and are widespread

... have many advantages
- Likely better efficiency for native DC loads
- Easier (cheaper) renewables integration
- Ride on functional advantages for cost, motivation
- Benefits are immediate
- Are bottom-up and de-centralized
- Can (are) implemented only locally

... can help us quickly evolve our electricity system

... can interoperate with a smart(er) grid
Power distribution generally

- Traditionally fairly uniform physical layer — 110, 220 VAC
- Control – only circuit breakers, switched outlets
  - No communication – no reporting
- Over-invest in capacity
- Single quality / reliability domain (excepting breakers)
- No contribution to efficiency, renewables
- Doesn’t do storage well

- My house: only circuit breakers; 120 / 240 VAC, USB
- Building 90: Generator, UPS/batteries (several), PoE (access points), 120, 208, 277, 480 VAC
  - No devices directly report power info (VFDs indirectly)
Future B90?

● = electricity load

grid

PV

nanogrids
Building Networks

everything networked

communicate, cooperate
Universal Interoperability

Any device should work with all other objects in any space

- Across **building types**
  - Residential, commercial, vehicles, …
- Across **geography**
  - Countries, language, …
- Across **time**
  - Worthy of durability
- Across **end uses**
  - Coordination, cooperation
- Across **people**
  - Age, disability, culture, activity, context, …
“Apps for buildings”

... or “Apps for rooms” ...
Building Network — Definition

A communications network that:

• enables **arbitrary communication** between any two or more devices in a space / building
• provides for **location awareness** — devices understand their own location, and their relation to others
• logically contains **people as nodes on the network** (albeit with a different set of standard interfaces)
• provides a **common data model** — enables interoperability among devices and people
• embraces “**universal interoperability**” as a core goal

**A building can be a house, commercial building, car, …**
Building Networks — Deployment

- Building networks will evolve incrementally from our IT networks
- Energy just one of many reasons to network devices
- Will use many diverse physical media
- Will use almost entirely IP data transport
- Dynamic

- Meter is a “narrow waist” — Building Network ends there
  - Price, electrons down from grid
  - Current consumption back up
Building Networks — Device Operation

• Devices operate in a bottom-up fashion
  – First, self-manage in isolation
  – Then, discover and coordinate with objects in immediate vicinity (including people)
  – Then, coordinate with building-wide entities (and consider delegating authority)

• Key inputs to operations
  – Preferences
  – Prices (current, forecast)
## Building Networks vs. Smart Grid

<table>
<thead>
<tr>
<th></th>
<th>Building Network</th>
<th>Smart Grid</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Scope</strong></td>
<td>All devices in a building; only building side of meter</td>
<td>Power plant to end use devices (and everything in between)</td>
</tr>
<tr>
<td><strong>Focus</strong></td>
<td>Needs of people</td>
<td>Needs of electricity system</td>
</tr>
<tr>
<td><strong>Control Strategy</strong></td>
<td>Distributed, based on preferences, prices</td>
<td>Central, derived from existing control systems</td>
</tr>
<tr>
<td><strong>Paradigm</strong></td>
<td>Consumption</td>
<td>Production</td>
</tr>
<tr>
<td><strong>Interoperability goal</strong></td>
<td>Universal</td>
<td>Limited (<em>not</em> bldg types, countries, people, …)</td>
</tr>
<tr>
<td><strong>Utility role</strong></td>
<td>Source of (some) prices</td>
<td>Large; two-way communication</td>
</tr>
<tr>
<td><strong>Timeframe</strong></td>
<td>Existing &amp; medium/long term</td>
<td>Short term</td>
</tr>
</tbody>
</table>
Building networks and power distribution

For both:
- Multiple physical layers in each building
- Can be isolated if beneficial
- Can hide details from outside connected entities
  - Can separately evolve different networks
- Enables control, reporting
- Keep technology, architecture separate
Energy / power reporting

- Always helpful to know where energy is being used
  - B90 example
- Needs to be easy, universal → self-reporting
- Need ability to
  - Measure (or estimate) power
  - Accumulate
  - Communicate data
  - Report information
- Related to (but different from) control

Current / Future LBNL work
- Alan’s EPS project – measure, accumulate, communicate
- IETF/eman – IP reporting
Network Layers

Layers of connectivity:
- data link
- network
- application

(People as nodes on network)

OSI Model Layers
1-physical
2-data link
3-network
4-transport
5,6,7-application
8-user interface
Network Layers

Layers of connectivity:

- data link
- network
- application

Many

\{ \}

IP; TCP, UDP; etc.

Many

Only IP is Universal

IETF does these
IETF and energy reporting

- Internet Engineering Task Force (IETF, ietf.org) defines core protocols that enable Internet to operate

IF

- Energy reporting should be a basic device feature

And IF

- IP will dominate building networks (or even just be important)

Then IETF should define a basic protocol for energy reporting
IETF and Energy

• 2007 – Presentation to IETF ‘70
  – Not a priority at that time

• 2008 – Interest in energy began to grow (network eqt.)

• 2009 – Discussions in “opsawg”
  (Operations Area Working Group)

• 2010
  – Internet Drafts posted
  – September – “eman” created
    “Energy Management Working Group”
  – November – first eman meeting at IETF ‘79
eman Charter

• “The basic objective of energy management is operating communication networks and other equipments with a minimal amount of energy while still providing sufficient performance to meet service level objectives.”

• “… energy management, which includes the areas of power monitoring, energy monitoring, and power state control.”

• Goal: Finish key products by Sept. 2011

• MIB – Management Information Base
  – Standard way to represent useful data / variables

• SNMP – Simple Network Management Protocol
  – Method to exchange MIB data
Eman process

My roles

• Bring energy perspective to network community
• Bring technology results to energy community
• Help develop technology

• Once standard is defined, can require in voluntary and mandatory standards; purchasing requirements
• Can be applied to existing products
  – Via software, firmware upgrades
Eman reporting

- **Power source**
- **Power state**
- **Energy - cumulative**
- May be direct, proxied, or aggregated

- **Power Domain**

- **Identity**
  - **What**
    - Species: e.g. switch, server, notebook PC, display, …
    - Origin: e.g. brand X, model Y (URL)
  - **Who**
    - Name: <text string> ???
    - Unique ID: MAC address (1st) ???
“Internet of Things” — IoT

- Applying information technology to physical world
  - (smart grid does this to electricity system)
- Electricity-using devices are things
- Most effort on “infrastructure” for this (e.g. routing)
- Building Networks one application of IoT

- Concept much more popular elsewhere

- Upcoming IETF workshop on IoT, March 25
Conclusions

Power Distribution and Building Networks

- Important, in flux
- Need to actively engage both topics
- Need to help develop new technologies
- Need to demonstrate new technologies (testbeds)

- Power reporting a key near term opportunity
Thank you
Internet Engineering Task Force (IETF)

• “above the wire and below the application”
  – “IP, TCP, email, routing, IPsec, HTTP, FTP, ssh, LDAP, SIP, mobile IP, ppp, RADIUS, Kerberos, secure email, streaming video & audio, ...”

• Purpose: Develop protocols to enable the Internet to operate and provide useful services

• Structure: No members, no voting
  – does have working groups
  – “an organized activity of the Internet Society”

• The Internet enables us to do things not otherwise possible

• Core evolution of Internet occurs in IETF
Top Level View of IETF Organization

IAB

IASA

IAD

IESG

IRTF

RFC

IANA

area

area

area

“the IETF”

Source: IETF