Exploring Powerline Networking for the Smart Building

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The Smart Building: How and Why?

- Better understanding of “resource” utilization and quality
  - Resources: Space, power, lighting, etc...
- Instrument a building with sensors
  - Occupancy
  - Lighting
  - AC Load Monitoring
  - ...

Example: UofM Music School

- Needs to understand and optimize use of practice rooms
  - Occupancy
  - Temperature
  - Humidity
- Deployment
  - Epic + sensors + BLIP + **Battery**
  - Adds sensor lifetime: 6 months+?
- Wireless #1 power draw: Idle listening

Why not network growing cadre of plug load meters over power lines?

- Lots of AC meters: UCB, Stanford, Arch Rock, JHU, Colorado School of Mines, etc.
- All use one interface for sensing, another for power, but…could
  - Use PLC to network
  - Remove meters from crowded spectrum
  - Lets usage follow

Powerline Communications (PLC) is better suited than wireless

- Power is ubiquitous in buildings
- PLC is informative technology
  - Learns building topology
- (Functionally) PLC is
  - Single hop
  - Fully connected

PLC History

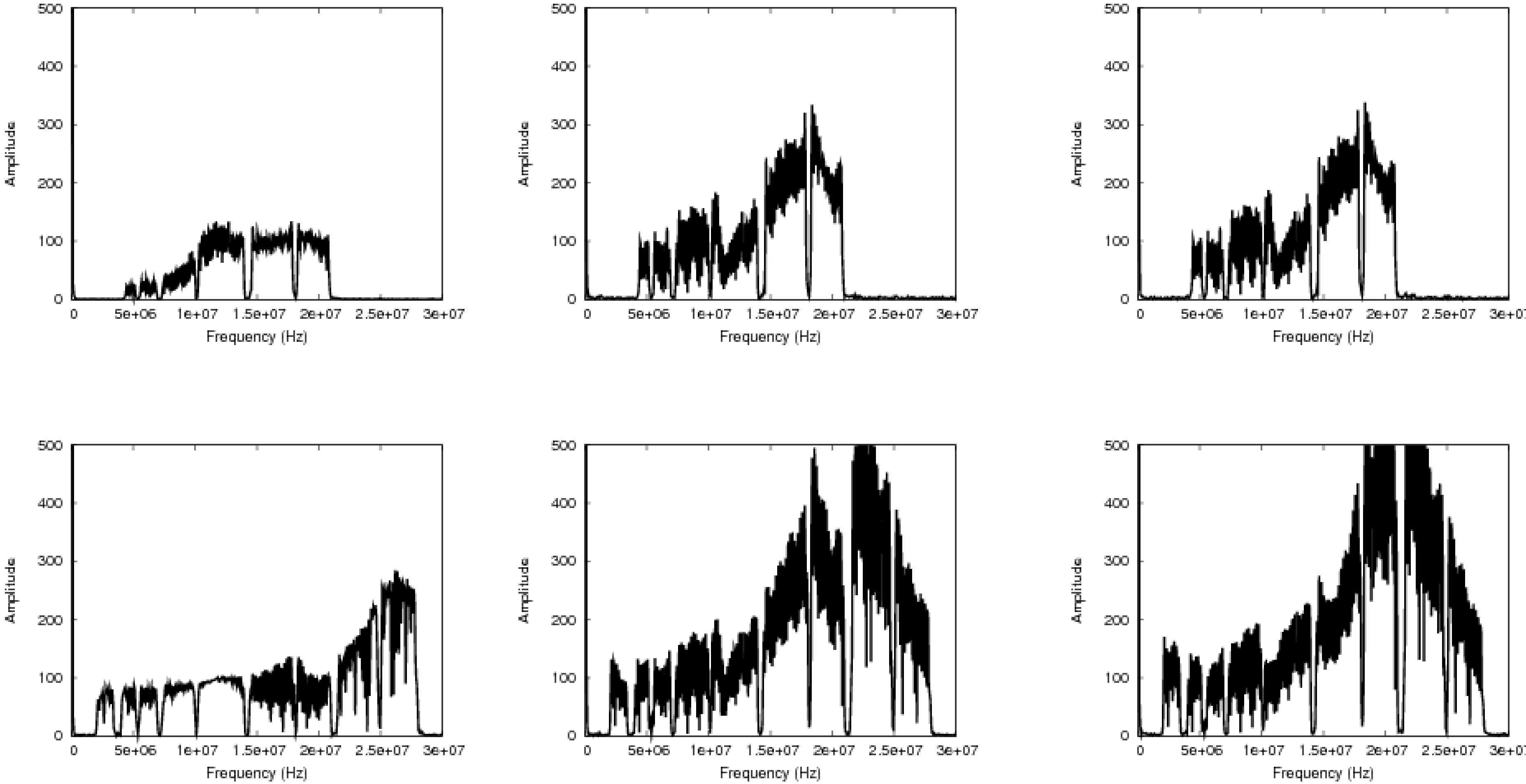
Technology	PHY Speed	Modulation	Application Space
X10	20 bps	ASK	Home Automation
Insteon	2,880 bps	BPSK	Home Automation
Ariane	30 kpbs	FSK	Building Automation
HomePlug 1.0	14 Mbps	OFDM	IPoP
HomePlug AV	200 Mbps	OFDM	IPoP

Current PLC deployments are in the home, not buildings

Understanding PLC

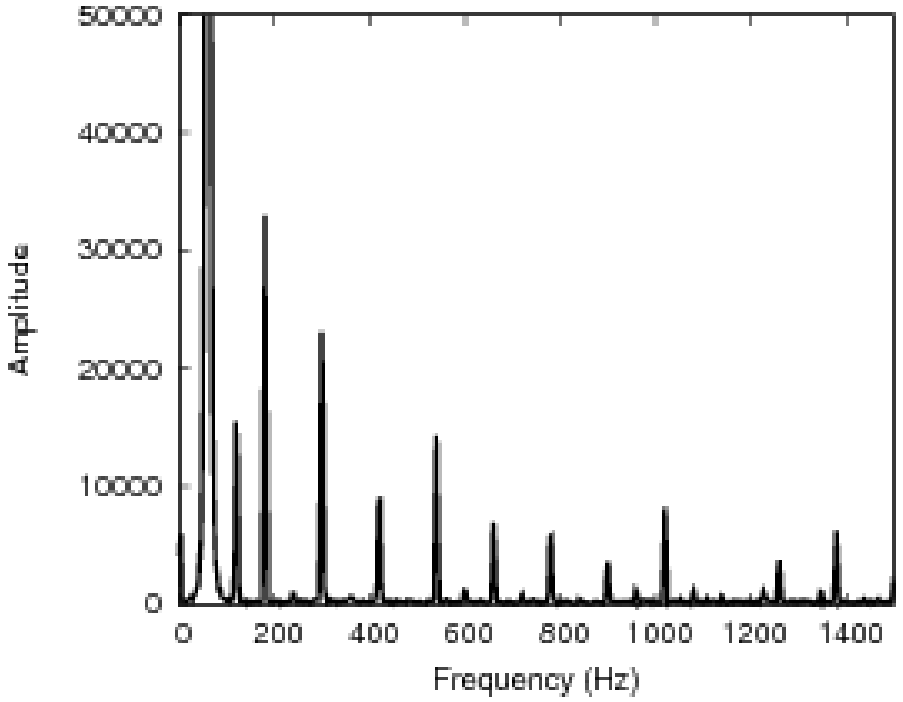
HomePlug 1.0

HomePlug AV

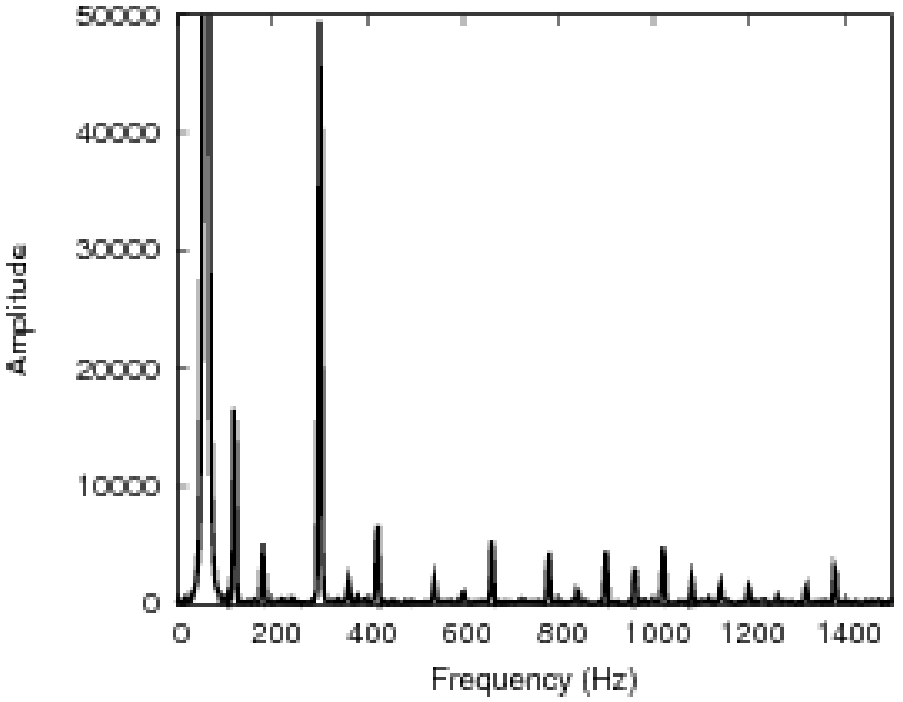


Powerstrip | “Strong” | “Weak”

PLC in a Home vs a Building: The Good



Student's Apartment



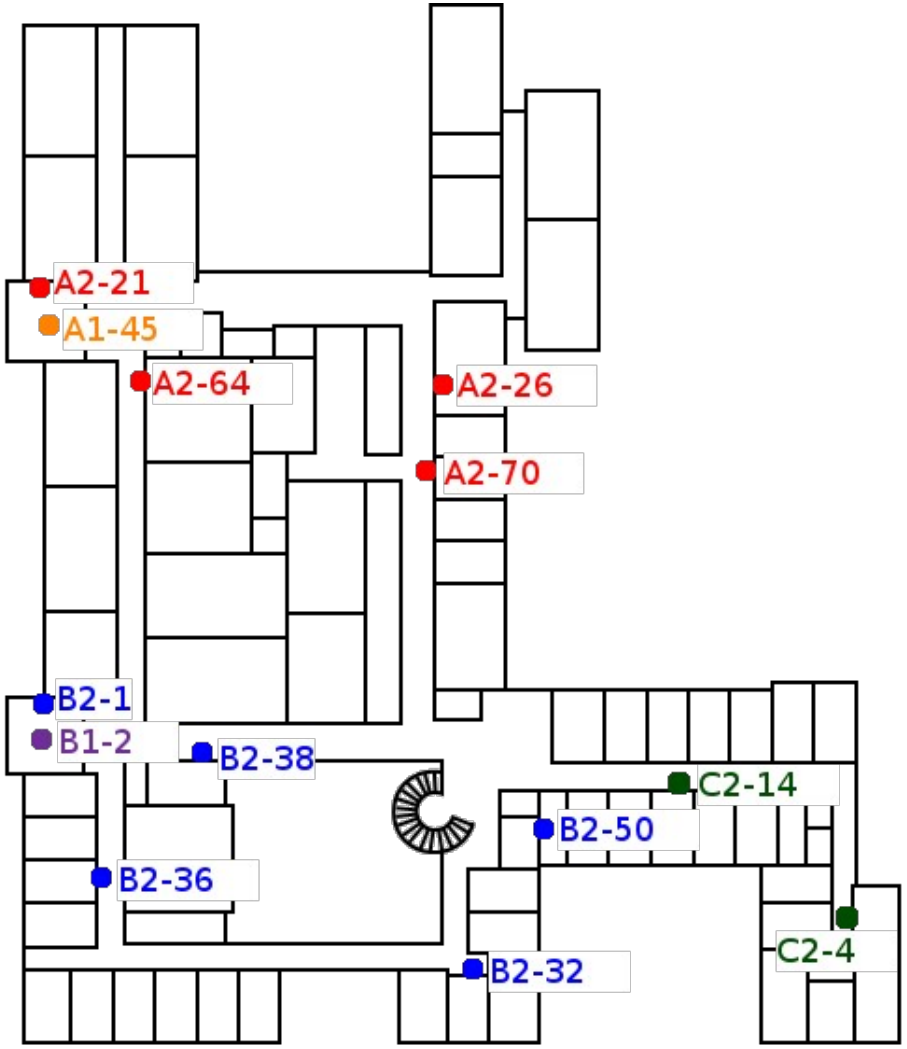
CSE Building

PLC in a Home vs a Building: The Bad

- Homes: simple
  - One “power domain”
  - Supply:
    - 120V
    - 1 phase + neutral
  - Outlet:
    - 120V
    - 1 phase + neutral
- All outlets can “see” each other

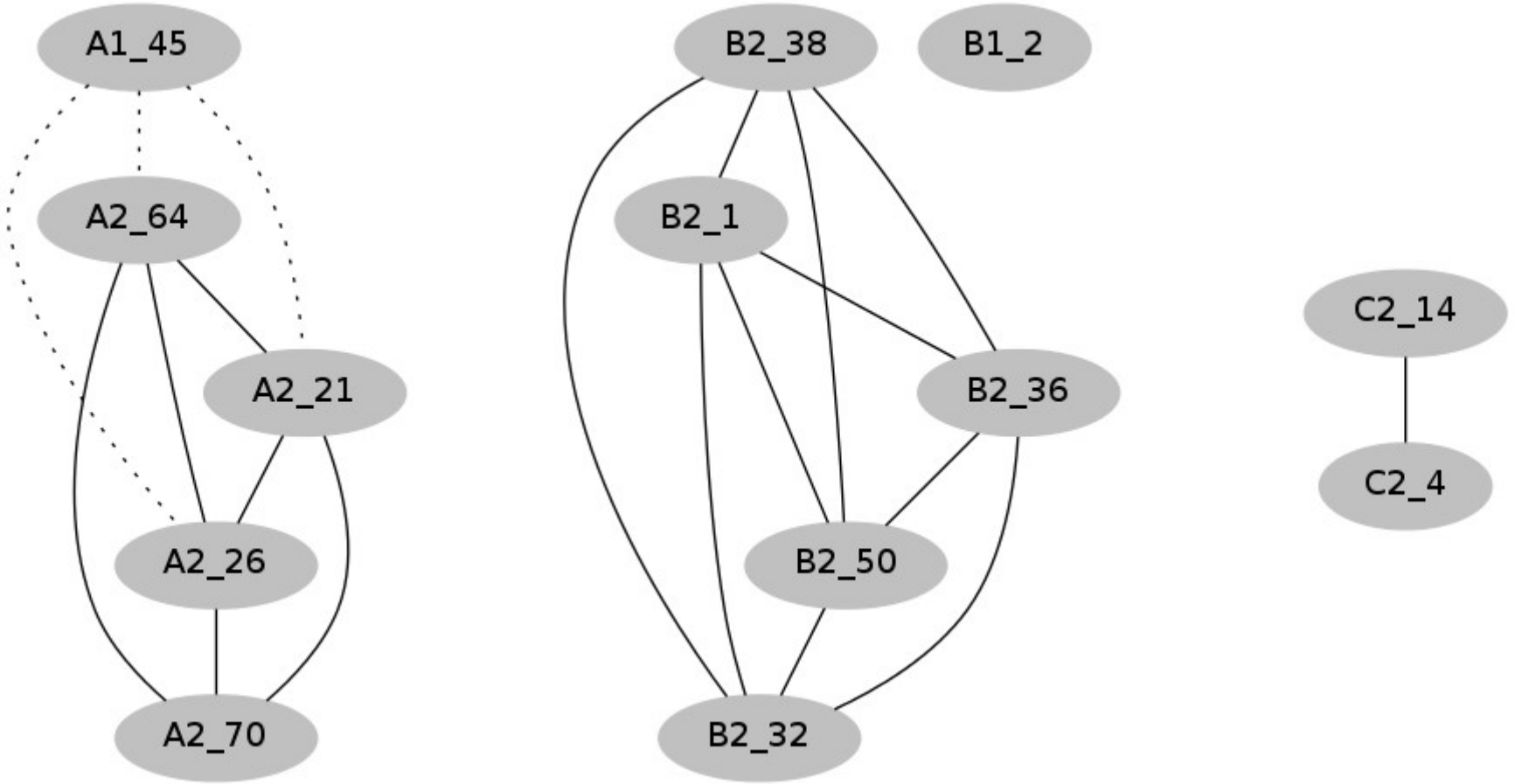
- Buildings: complex
  - Multiple “power domains”
  - Supply:
    - 480V
    - 3 phase, no neutral
  - Outlet:
    - 120V
    - 1 phase + neutral
- Outlets in the same room cannot “see” each other!

The Experiment

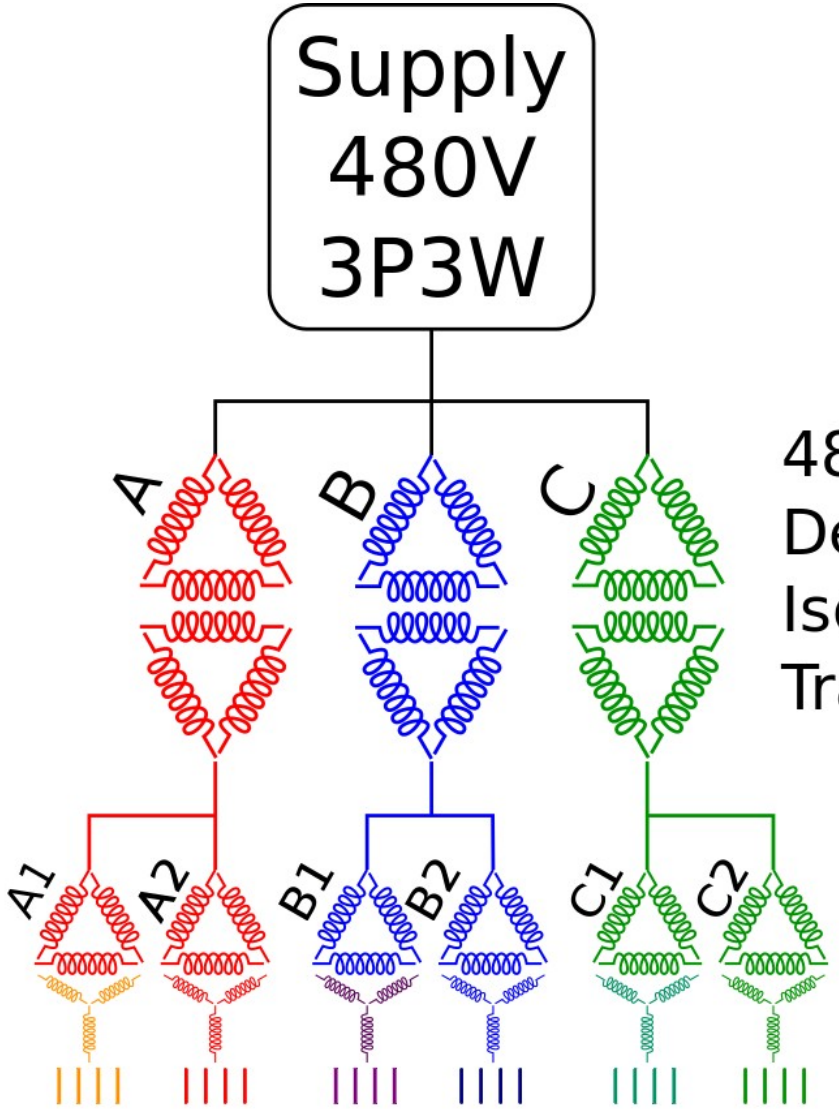


- Plug into outlets “round-robin” and see what's connected
- Node names match blueprints
  - *These will be important soon*

Observed Connectivity



CSE Power Distribution



480/277 3P3W
Delta-Delta
Isolation
Transformers

208/120 3P4W
Delta-Wye
Step-Down
Transformers

Each transformer outputs 3 120V taps (3 phases) and neutral
Each circuit uses all 3 phases, loaded equally

Delta-Wye Transformer

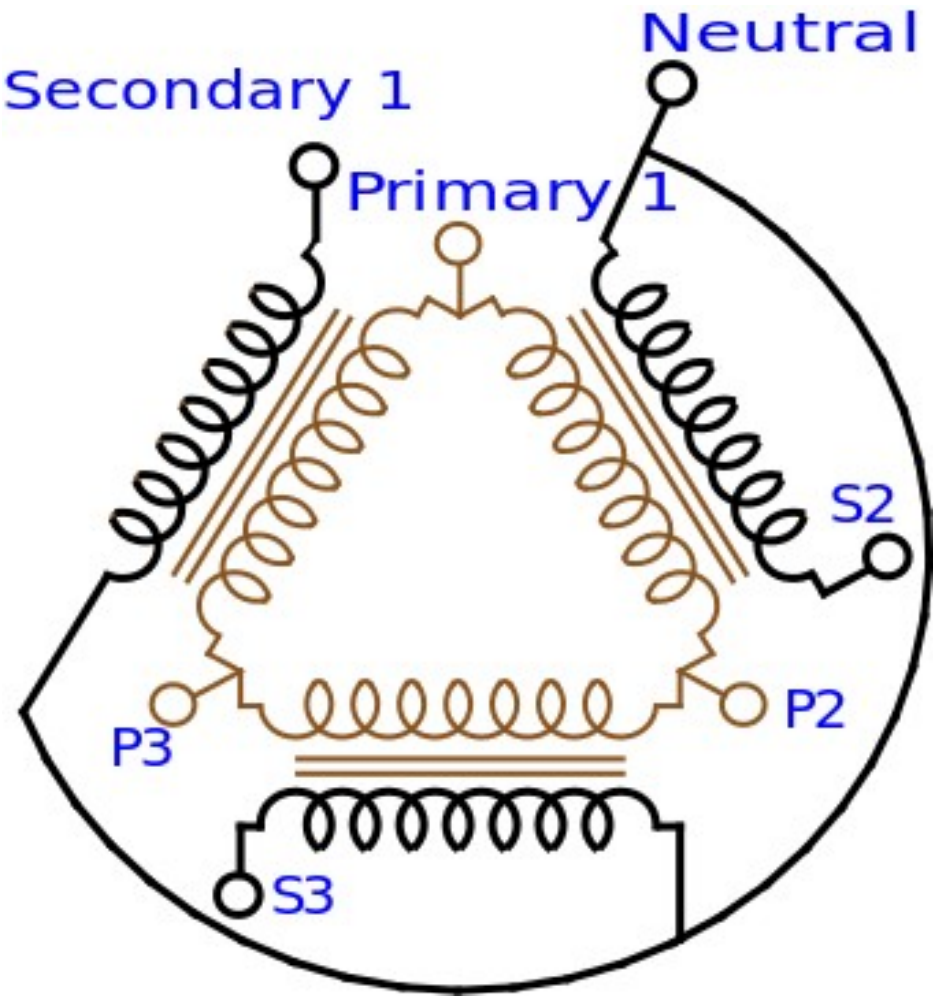
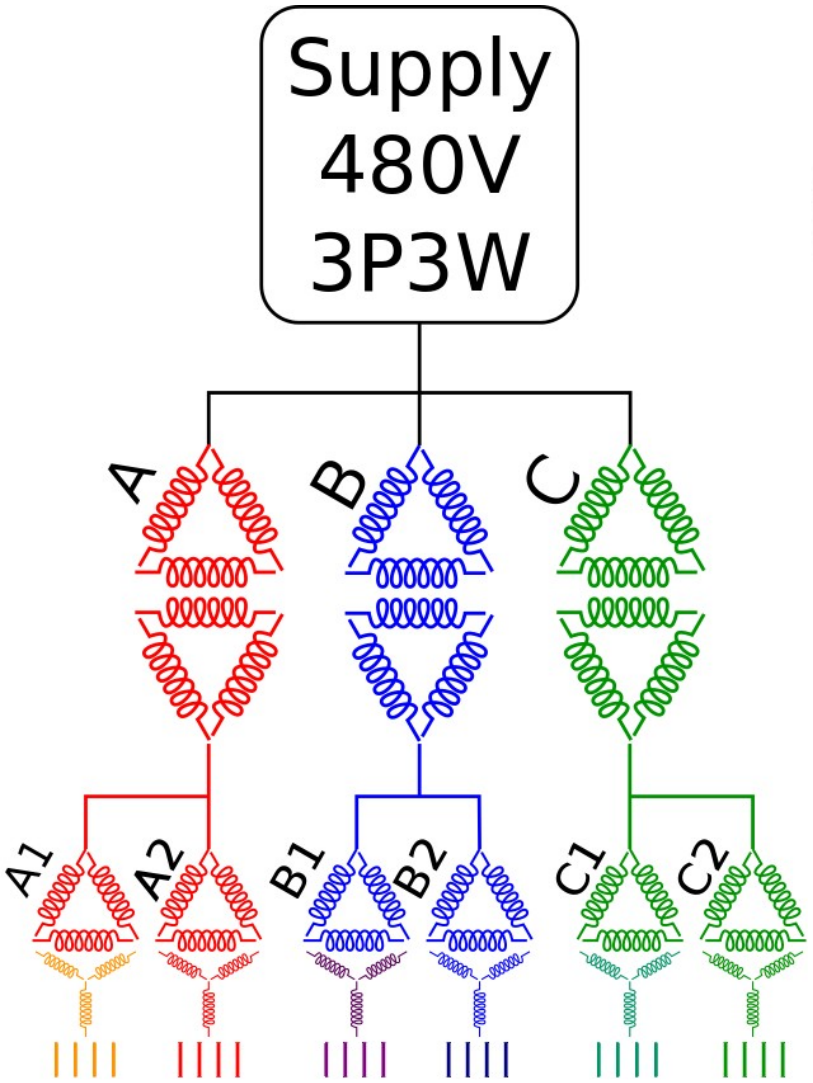
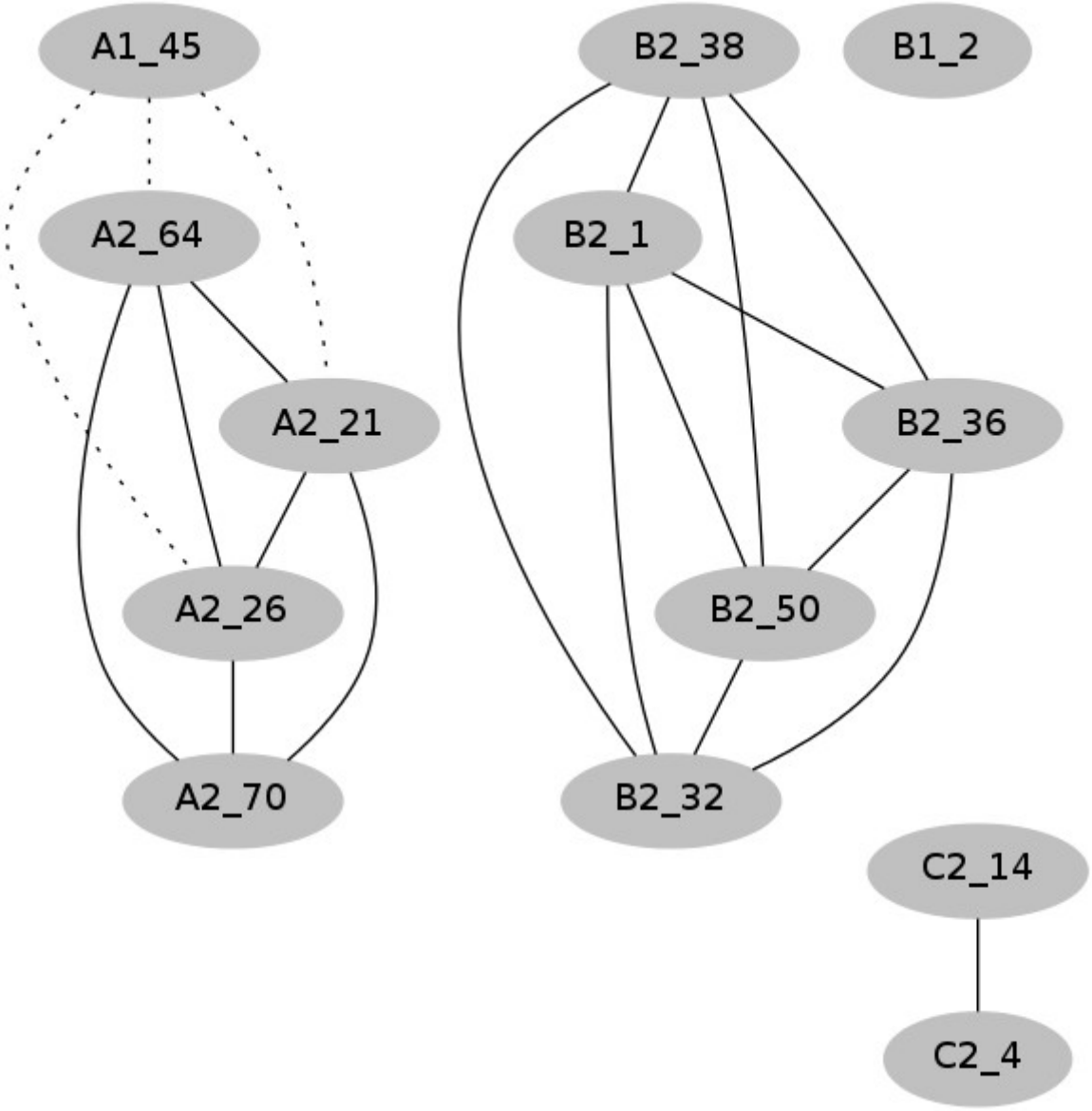


Image c/o Wikipedia

- Adds a neutral reference to 3-phase power
- **One Neutral** for all 3 phases
  - Likely why PLC works

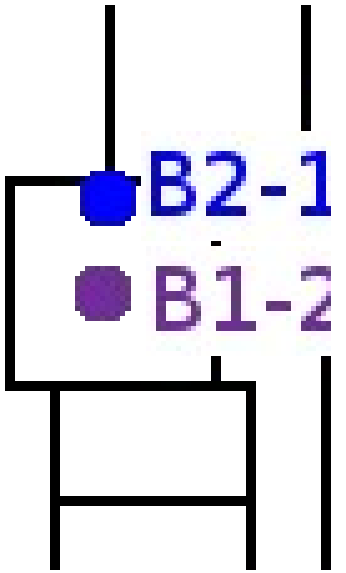
Observed Connectivity Explained



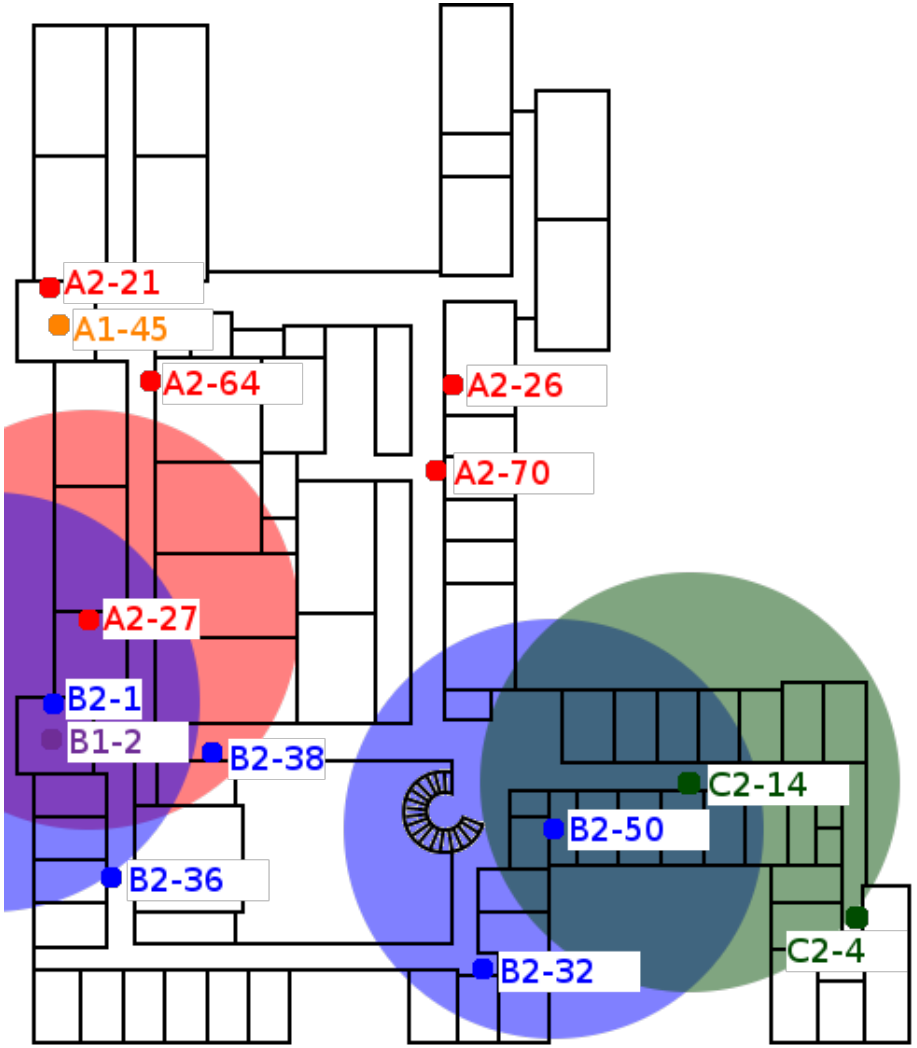


Result: Connectivity → Topology

- Power distribution can be counter-intuitive
  - Two outlets in the same room may be on different power networks
- PLC connectivity reveals power distribution topology
- But...
  - Now we have disjoint subnetworks



Using Wireless to Bridge the Gaps



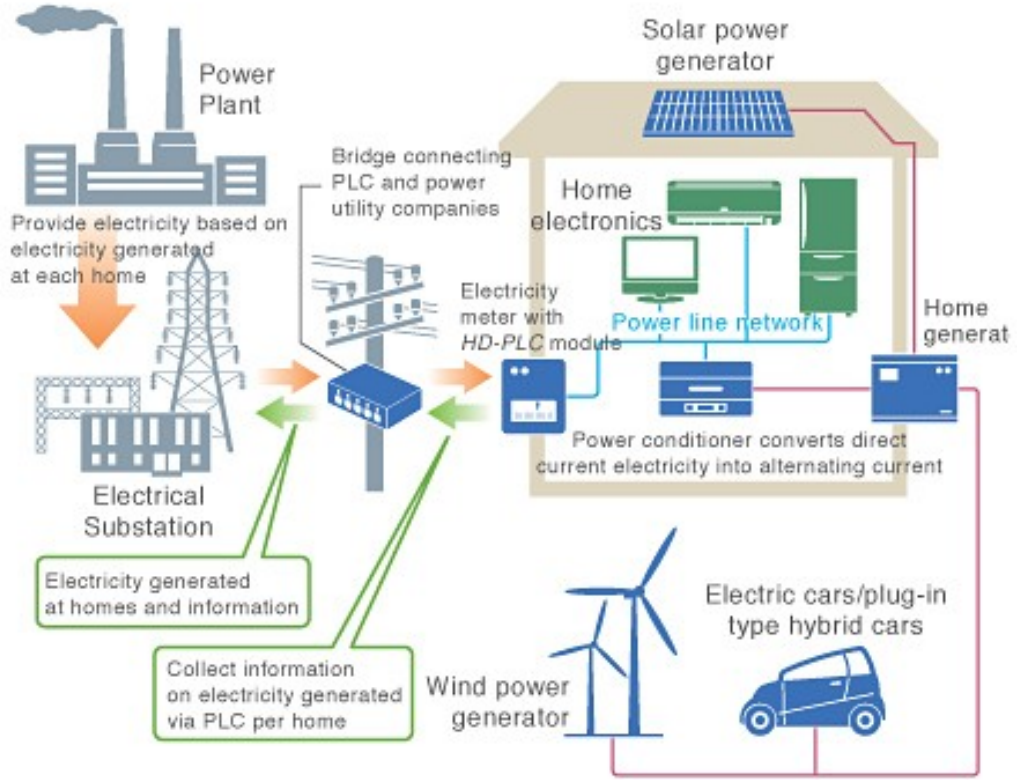
- PLC connectivity is orthogonal to geography
  - Two outlets that could not electrically “see” each other can physically “see” each other

Future Work: Taking it One Step Further

- Add wireless and PLC to **every** outlet
  - Removes idle listening requirement for other sensors
  - PLC network become wired and wireless sensor network backhaul
- Weird Topology
  - Mesh? Route? ...how?

Looking ahead: PLC for deep demand response of Smart Buildings

- Future Smart Grid
  - Bi-directional data exchange between bldg sources/sinks and utility systems
  - Dynamic response based on local grid conditions
- PLC networks
  - Enable “data follows wires”
  - Reduce virtual/physical gap, need to keep two in sync
  - Auto-discover loads and topology, even if they move
  - Simplify mapping of virtual load “names” to physical load “locations”



Conclusions

- PLC is feasible as a sensor network backhaul
  - *If* subnetworks can be connected
- Commercial buildings are more electrically complicated than homes
- PLC cannot cross transformers
  - But can cross phases
  - And sometimes connects wirelessly (!)

Questions?

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