PowerMan: An Out-of-Band Management Network for Data Centers Using Power Line Communication

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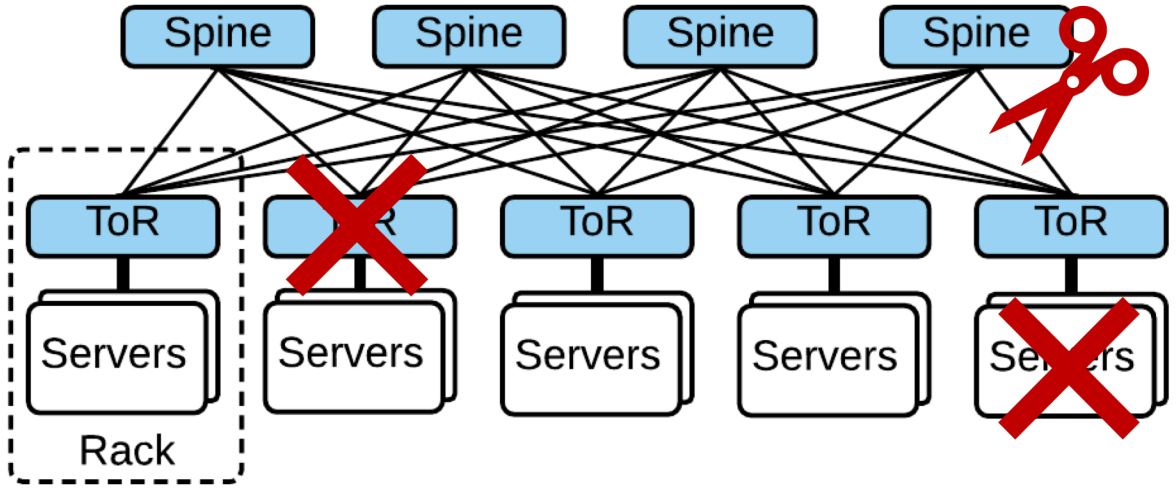
Managing Large Data Centers

- Data centers can contain tens of thousands of devices.
- Operations and management tasks:
  - device installation, bring-up/restart, configuration, diagnostics…

Data Center Management Requirements

- Survive failures
- Scalable
- Can be easily deployed



Fate-sharing

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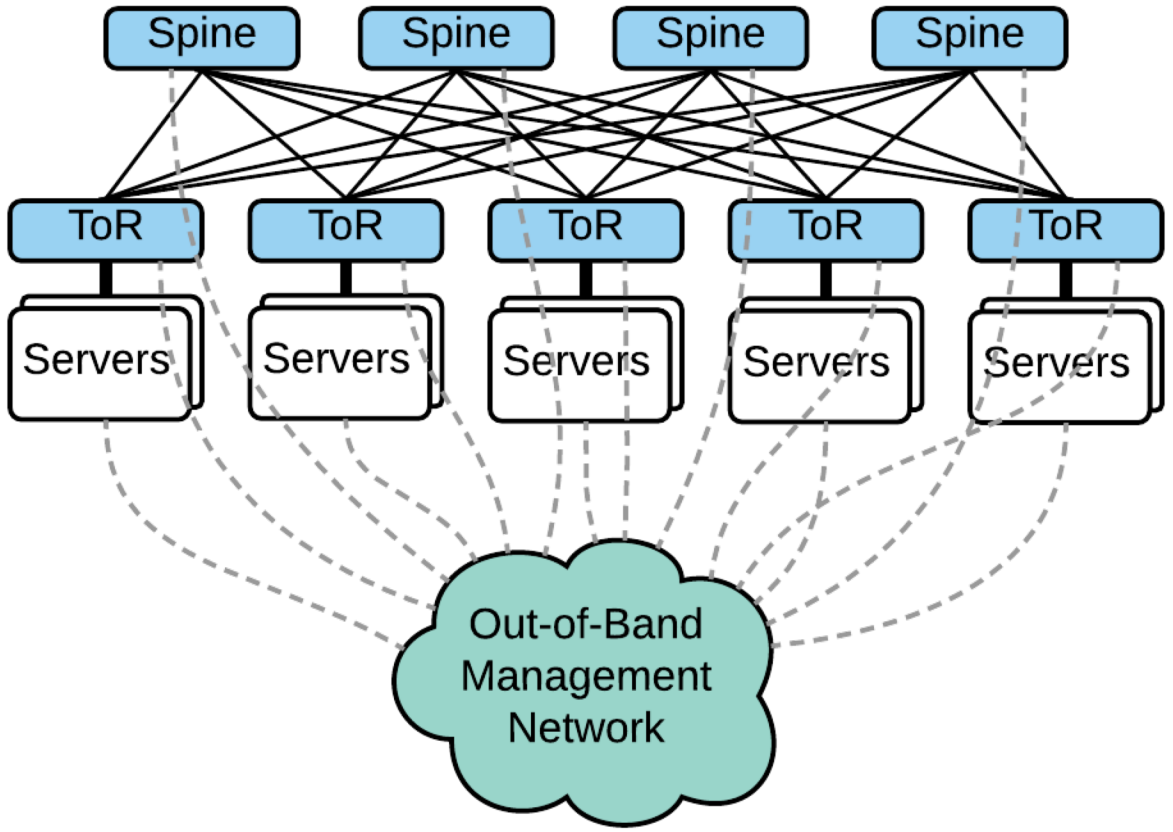

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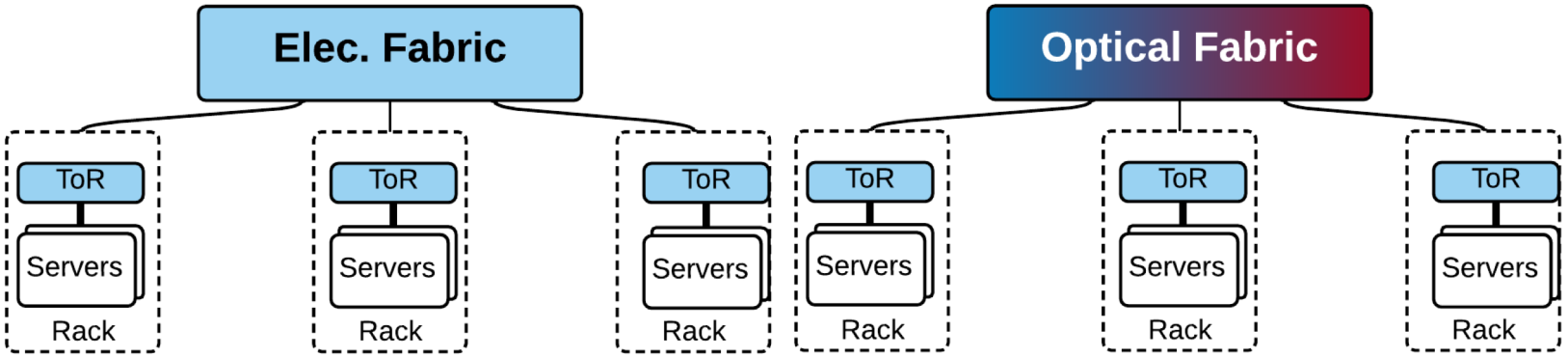

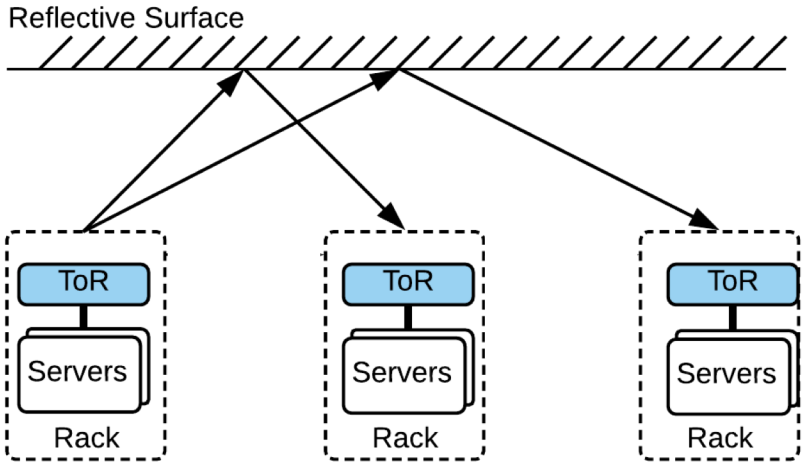

3D-Beamforming [Sigcomm'12]
Firefly [Sigcomm'14]
ProjecToR [Sigcomm'16]
Diamond [NSDI'16]

Flyway [Sigcomm'11]
Angora [Mobicomm'14]

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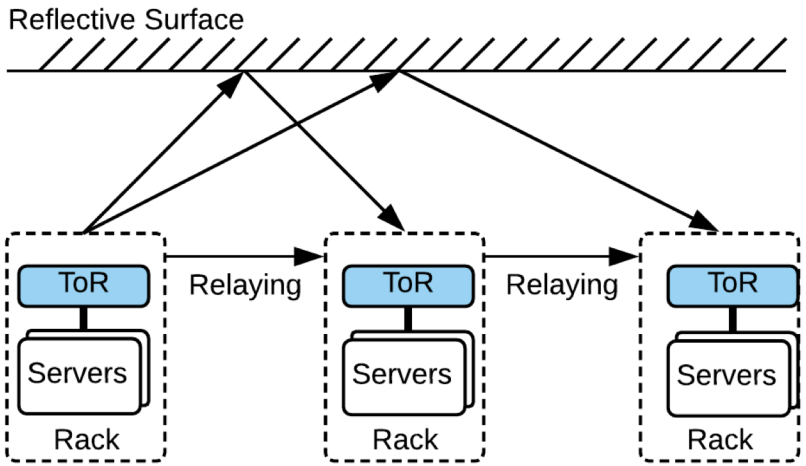

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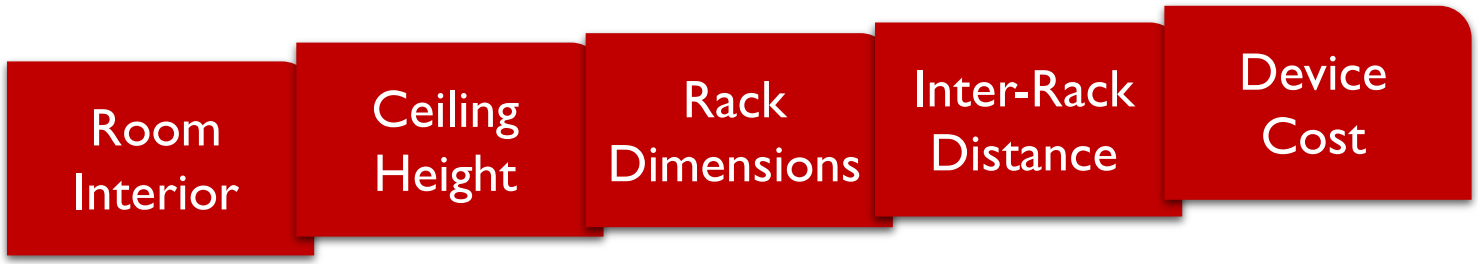


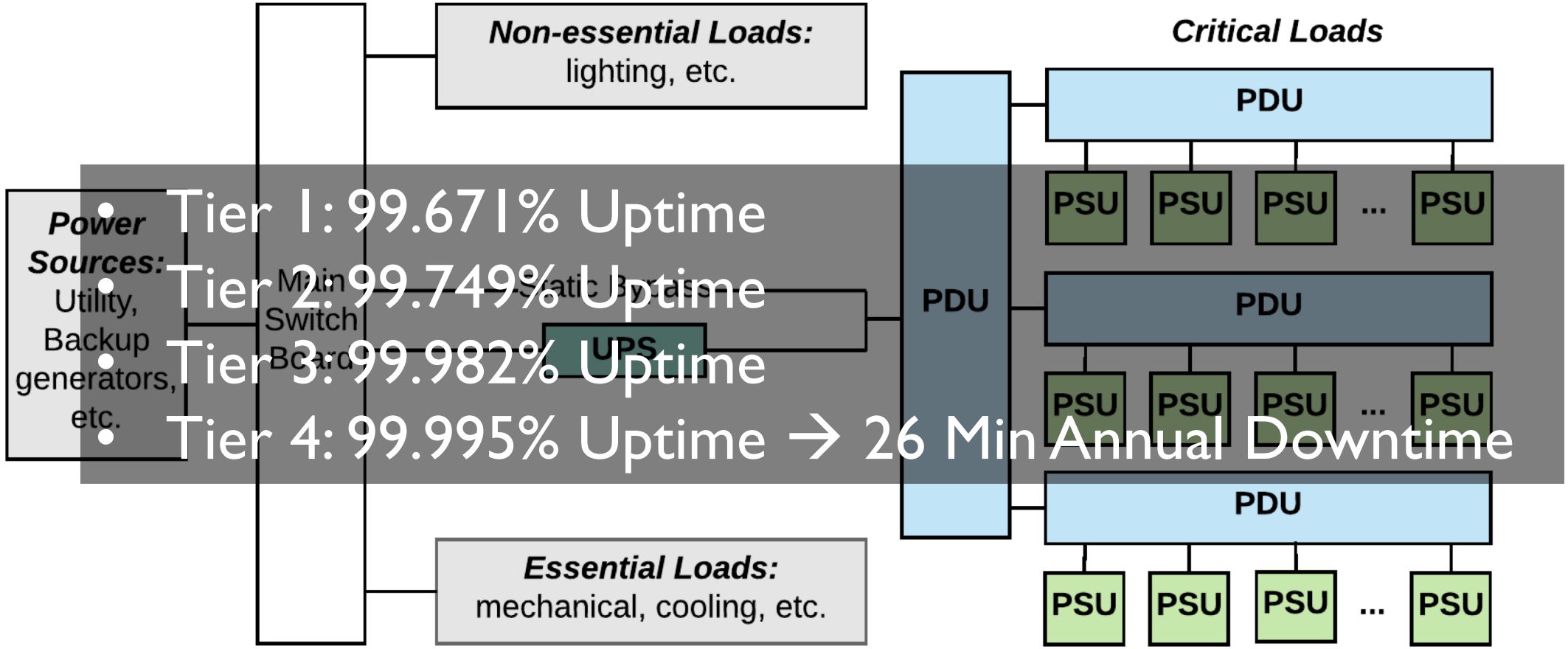
How to Build a Robust & Scalable System?

- How hard is it?
  - Short answer: It's hard.
  - ✓Redundancy
  - ✓Graceful degradation
  - ✓Failure isolation/localization
  - ✓Ease of repair/replacement
  - ✓…
- Whenever we build a new distributed system, we have to check all the above boxes again.
- Do we have to?

Key Insight: ***Borrowing*** robustness and scalability from closely-coupled systems.

Data Center Power Systems (DCPS)

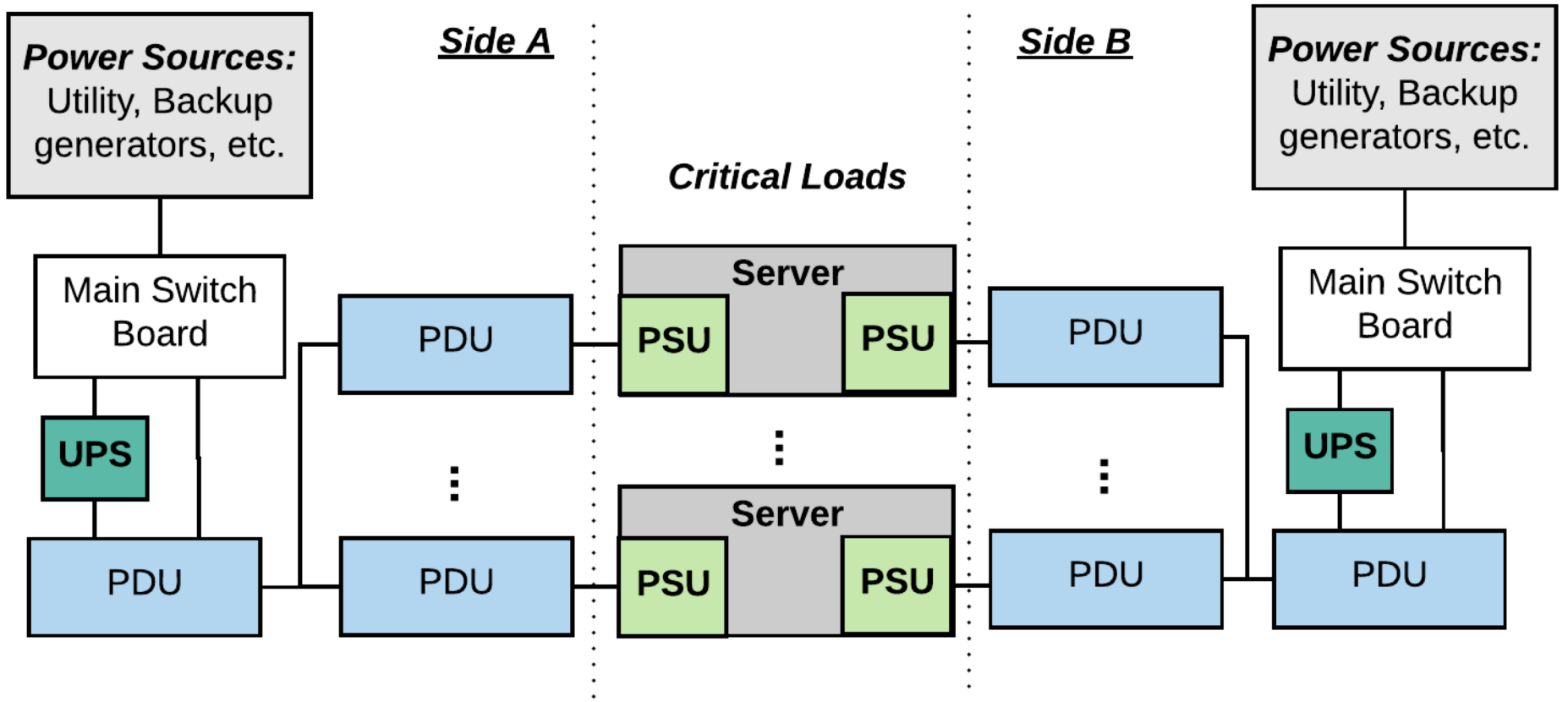
Power System: The Most Robust System in Data Centers



- Tier 1: 99.671% Uptime
- Tier 2: 99.749% Uptime
- Tier 3: 99.982% Uptime
- Tier 4: 99.995% Uptime → 26 Min Annual Downtime

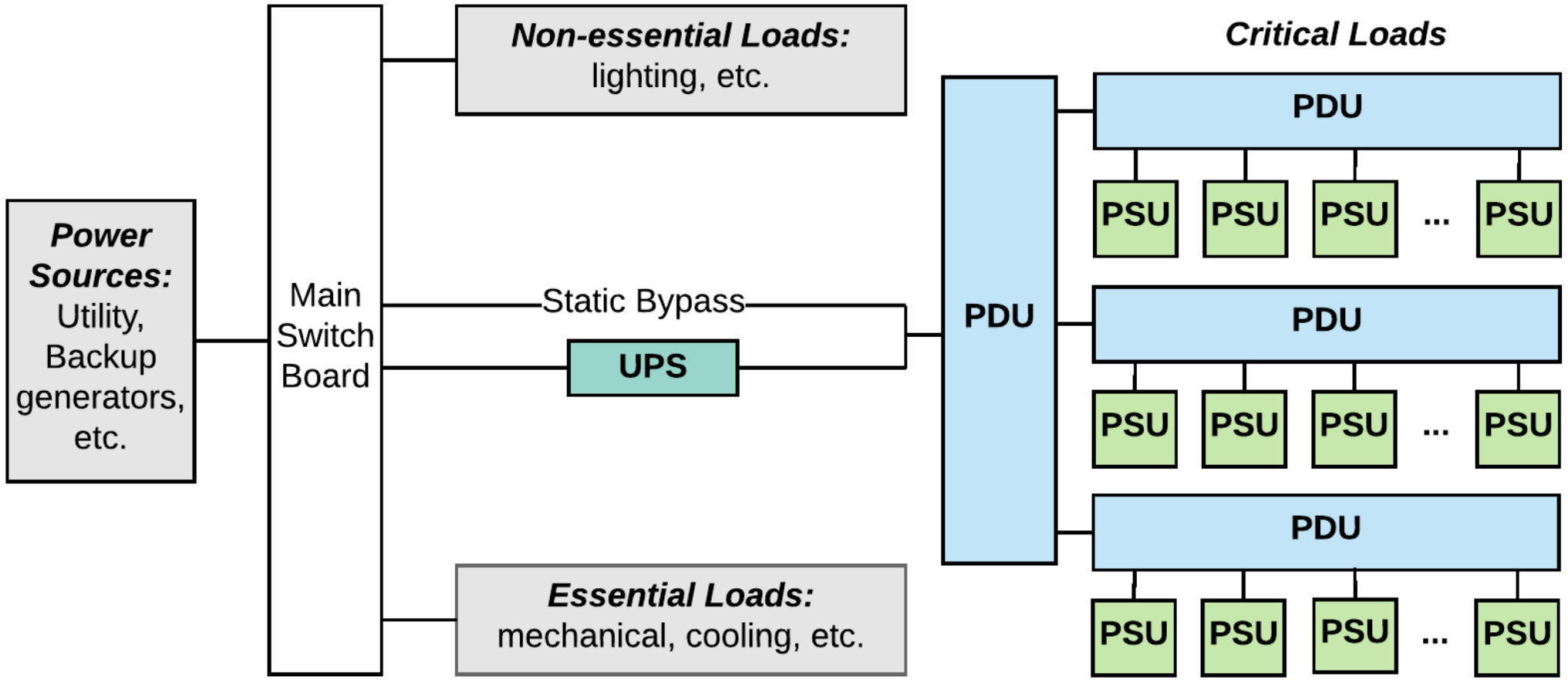
Data Center Power Systems (DCPS)

Redundant Power Distribution Paths



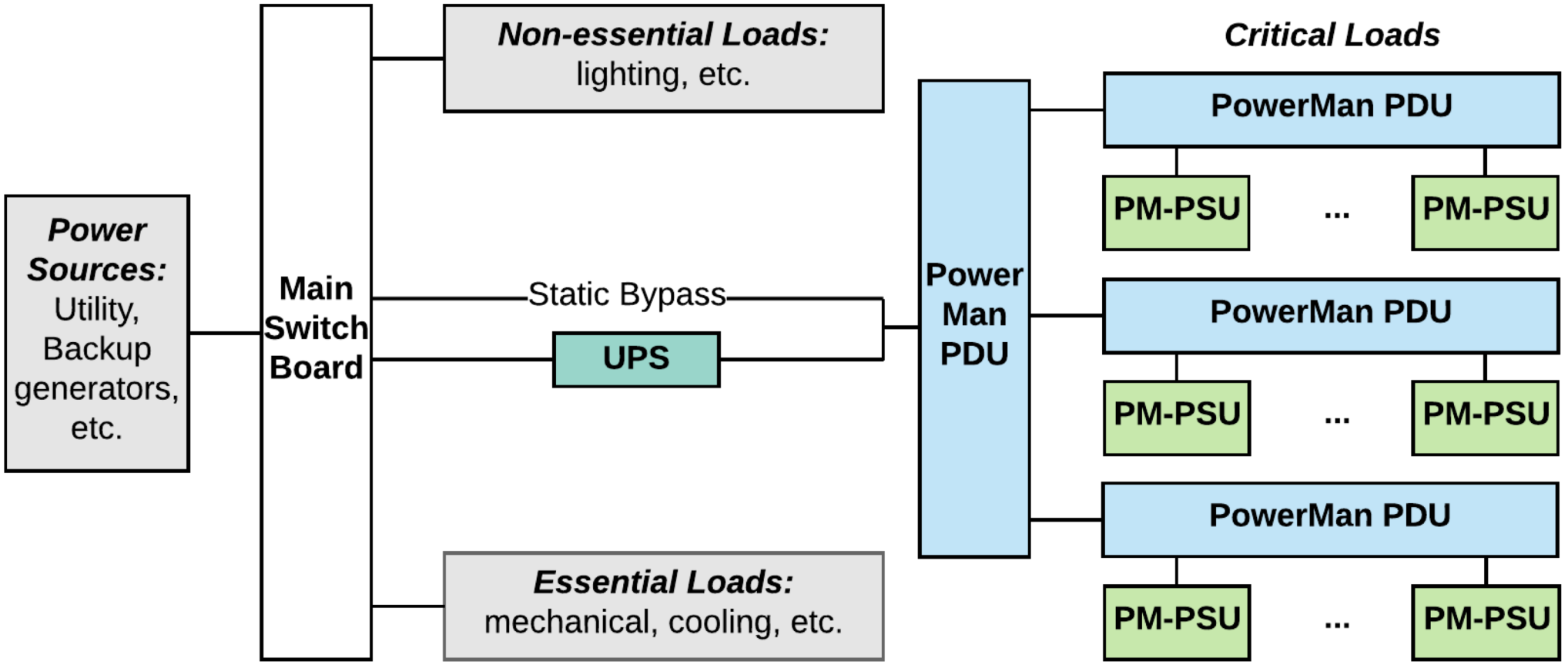
Data Center Power Systems (DCPS)

Primary Power Path



PowerMan: Embedded in DCPS

Enabling Technology: Power Line Communication (PLC)



Outline

1. Overview of Power Line Communication (PLC)

2. Problems of Current PLC Technology & PowerMan Design
   - Wiring → PowerMan Power Supply Unit
   - Scalability → PowerMan Power Distribution Unit

3. Prototype Implementation & Evaluations

Power Line Communication (PLC)

What is PLC?

- Power lines deliver electricity to devices.
  - AC Operating frequency: 50~60Hz.
- PLC uses existing power distribution wires to transmit high frequency data signals.
- Very challenging communication environment.
  - High attenuation.
  - Multipath fading.
  - Noise.
  - …

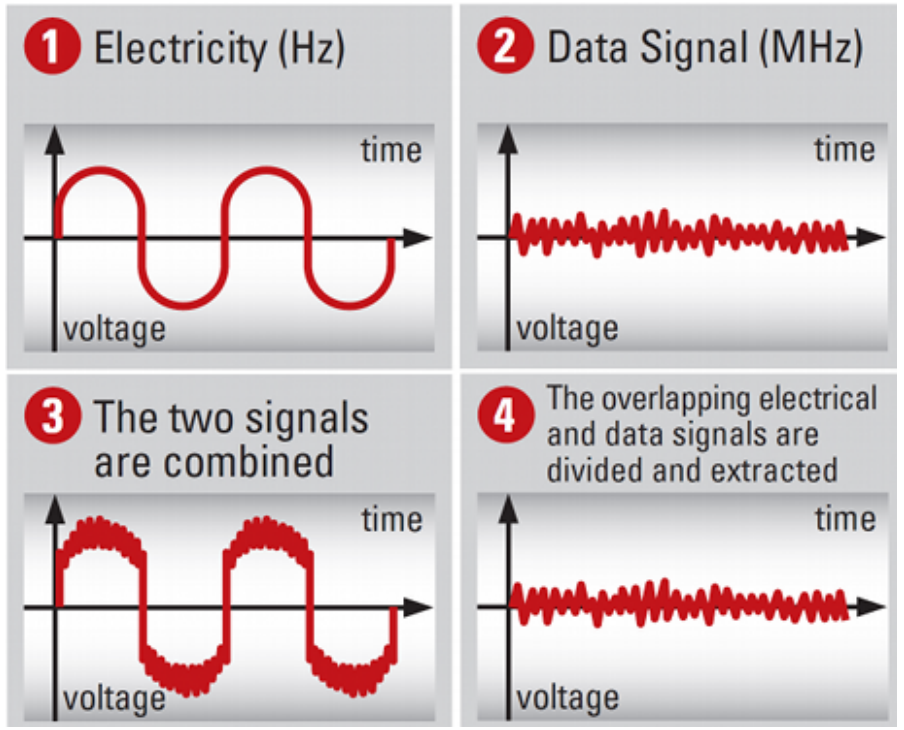
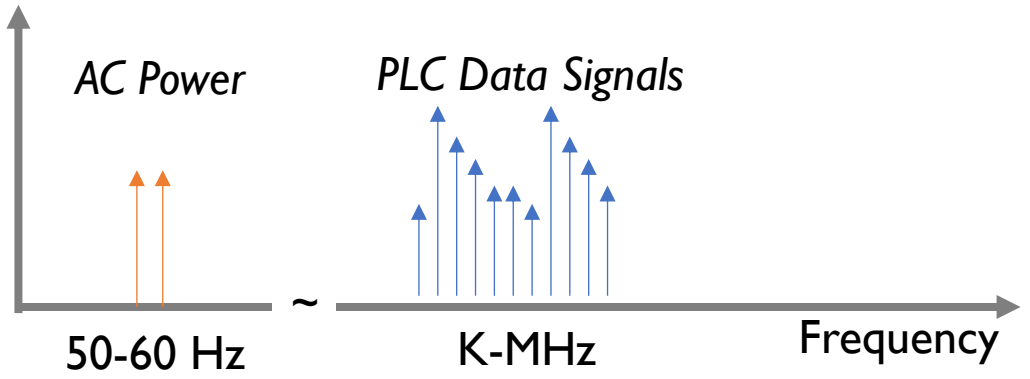


Image by powerethernet.com



PLC Applications

- PLC uses existing power distribution wires.
- PLC has been in use for many decades.
  - Industrial control.
  - Energy management.
  - Remote metering (telemetering).
  - Power line maintenance.
  - …
- Data rate: A few Kbps.

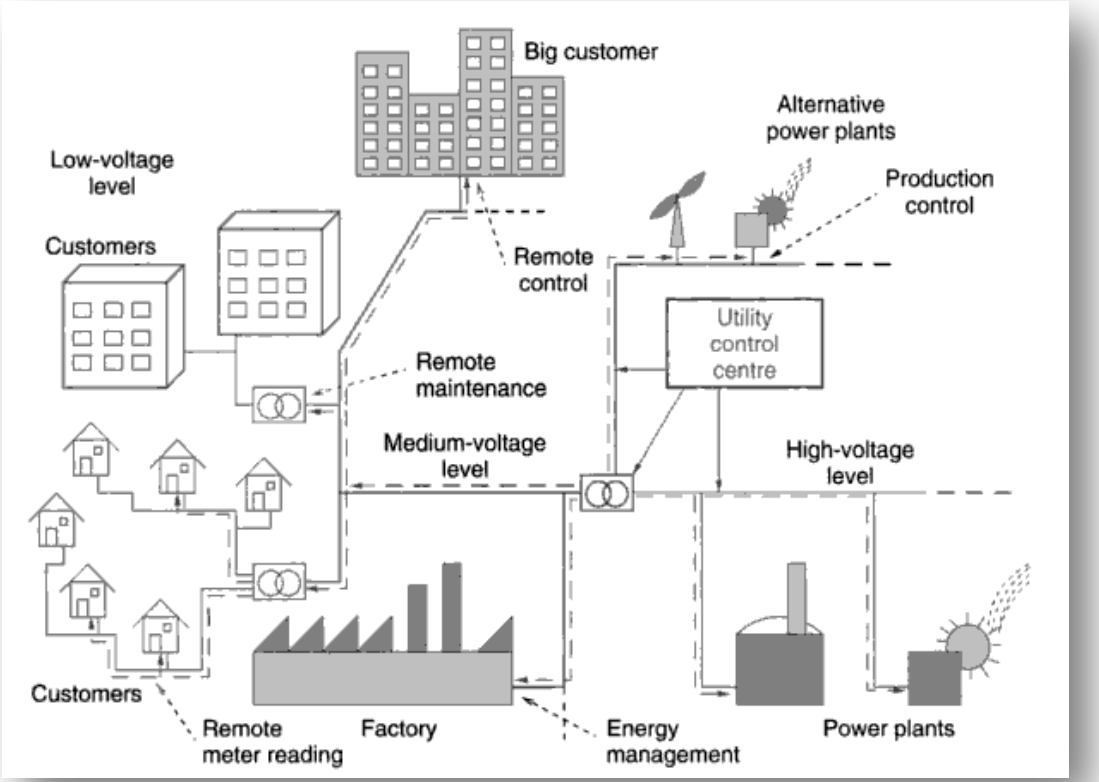


Image from: Pavlidou, Niovi, et al. "Power line communications: state of the art and future trends." IEEE Communications magazine 41.4 (2003): 34-40.

Recent Advances: PLC for Home Networking

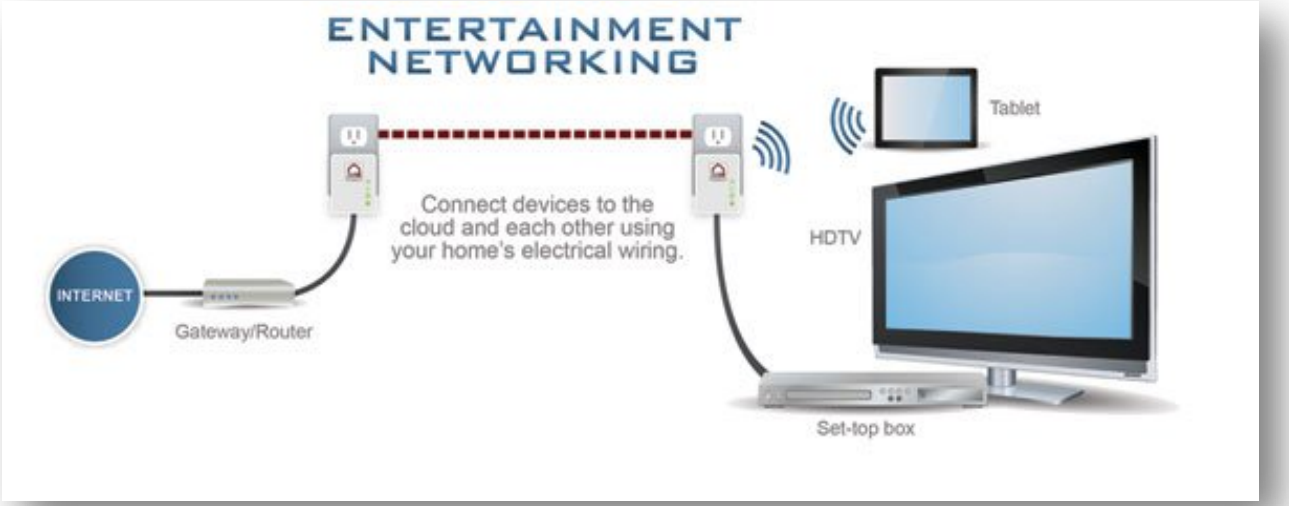
Standards

- IEEE 1901, Broadband Power Line Standards.
- ITU-T G.9960 Standards.
- CENELAC Standards.
- ETSI Standards.

Protocols

- HomePlug
- CEBUS
- LonWorks
- UPA
- SiConnect
- G.gn

PHY	MAC
ASK	Token-based
FSK	TDMA
BPSK	FDMA
OFDM	**CSMA/CA**



HomePlug Protocols provides Ethernet networking for house-hold scenarios, with up to 1200 Mbps data rate.

Problems of Current PLC Technology & PowerMan Design

Wiring Complexity	Limited Scalability
• PowerMan PSU	• PowerMan PDU

Problems of Current PLC Technology

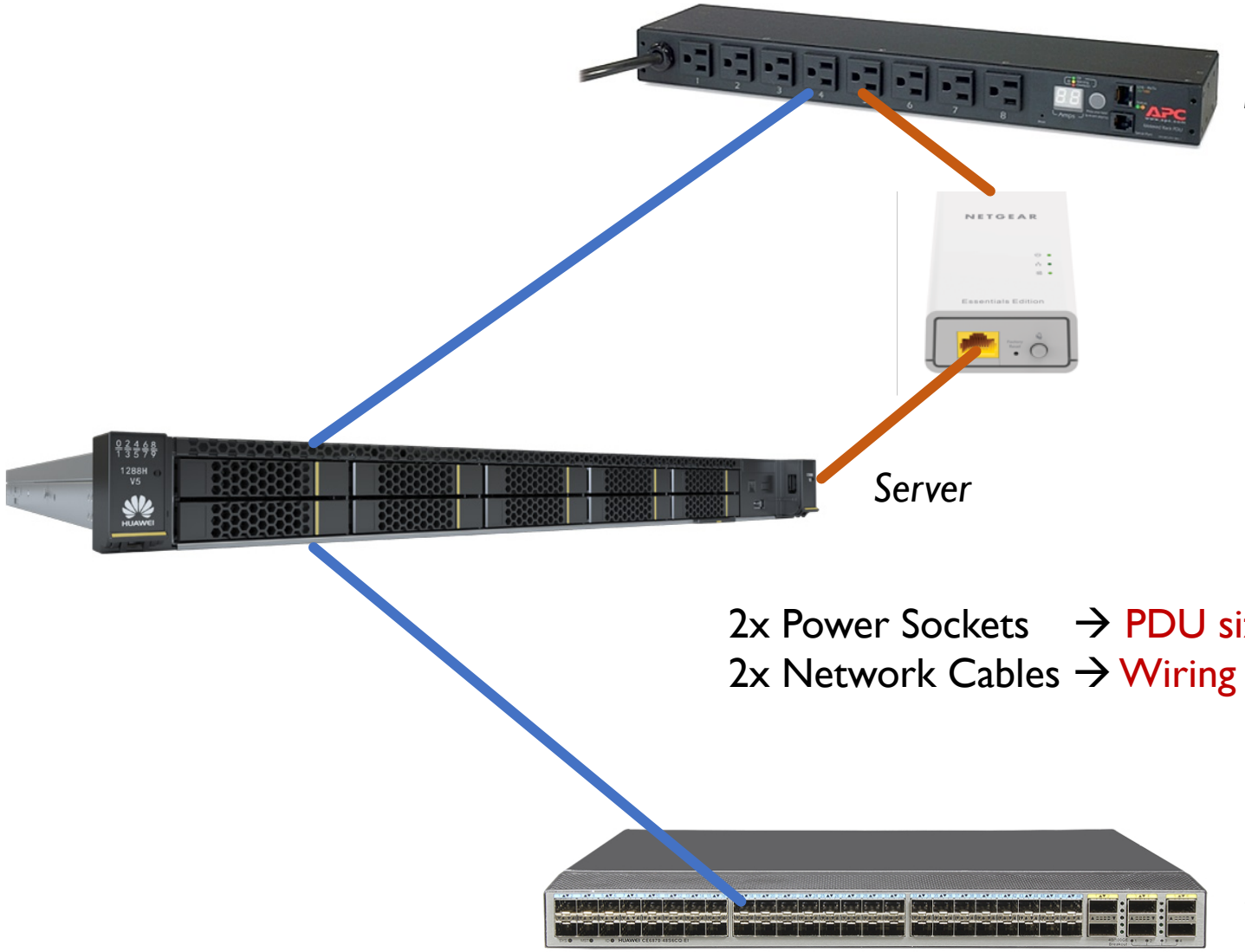
- Wiring
- Scalability

Netgear Powerline 1000 (PL1000) PLC modem

- 1000Mbps PHY data rate
- US$ 30.3 per piece (via local home appliance vendors)
- 1x built-in power plug
- 1x RJ-45 port for Ethernet connection.
- Max power consumption: 3.73 Watts
- HomePlug AV protocols
- OFDM carrier frequency range: 2 MHz to 86 MHz

Problems of Current PLC Technology

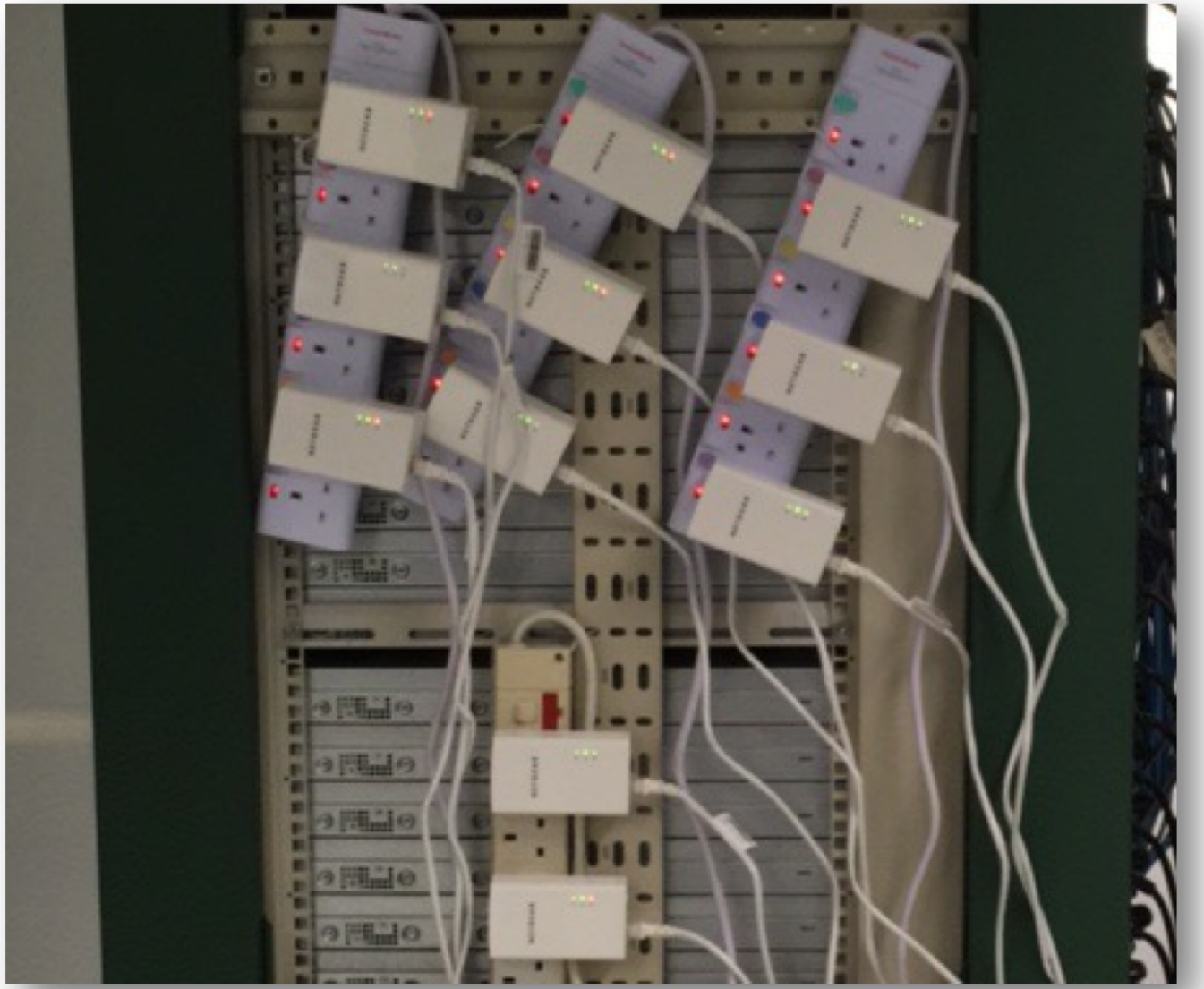
- Wiring
- Scalability



2x Power Sockets → PDU size
2x Network Cables → Wiring space in rack

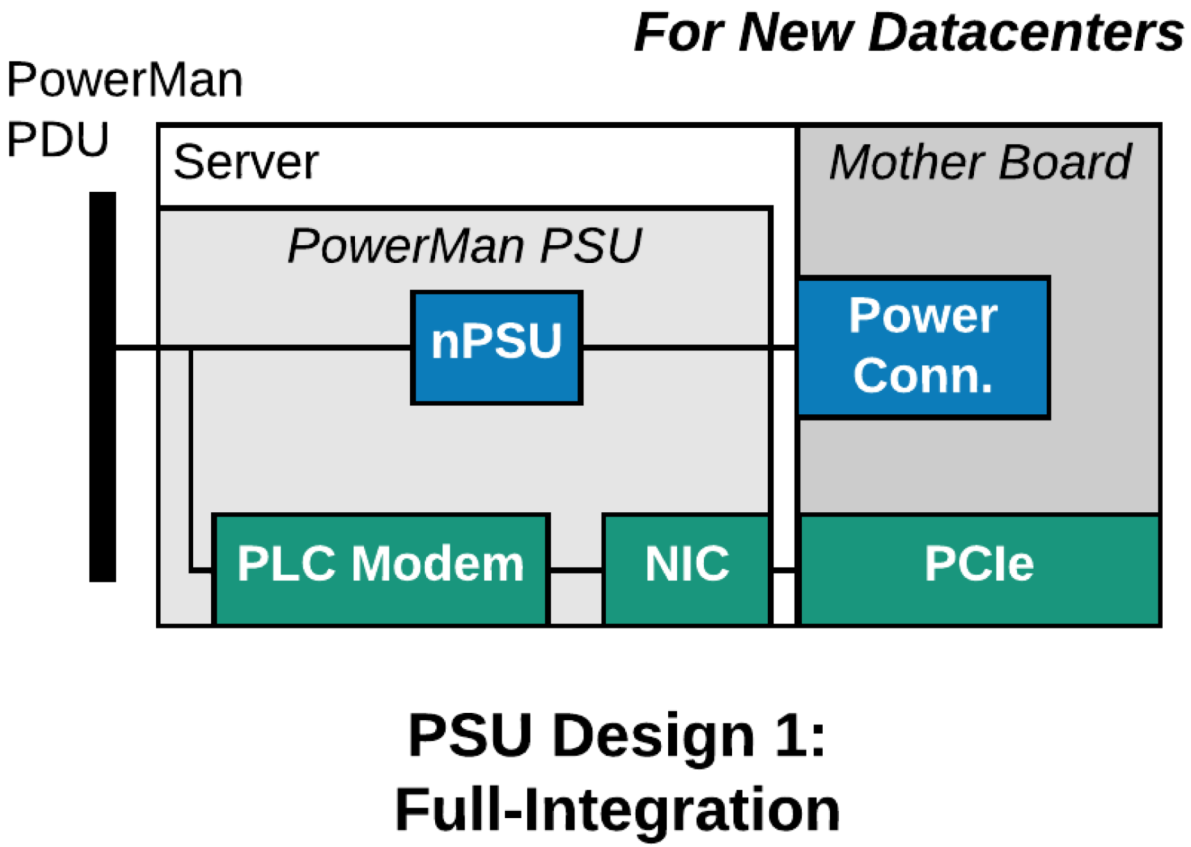
Problems of Current PLC Technology

- Wiring
- Scalability

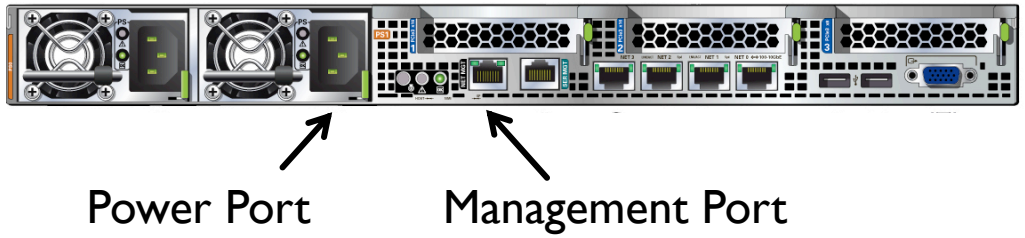


Wiring: PowerMan PSU

- Reduce wiring by combining PLC modem with existing device PSU.



PSU Design 1:
Full-Integration



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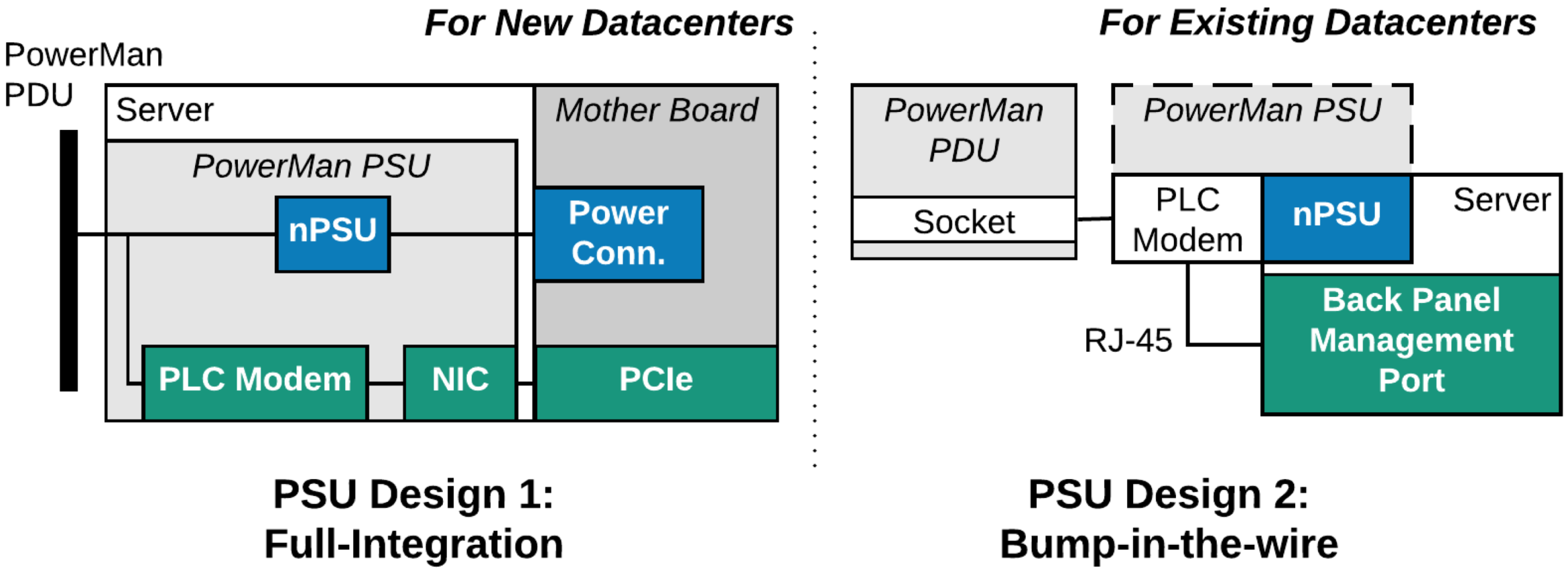


Wiring: PowerMan PSU

PDU

Power

PLC
Signals

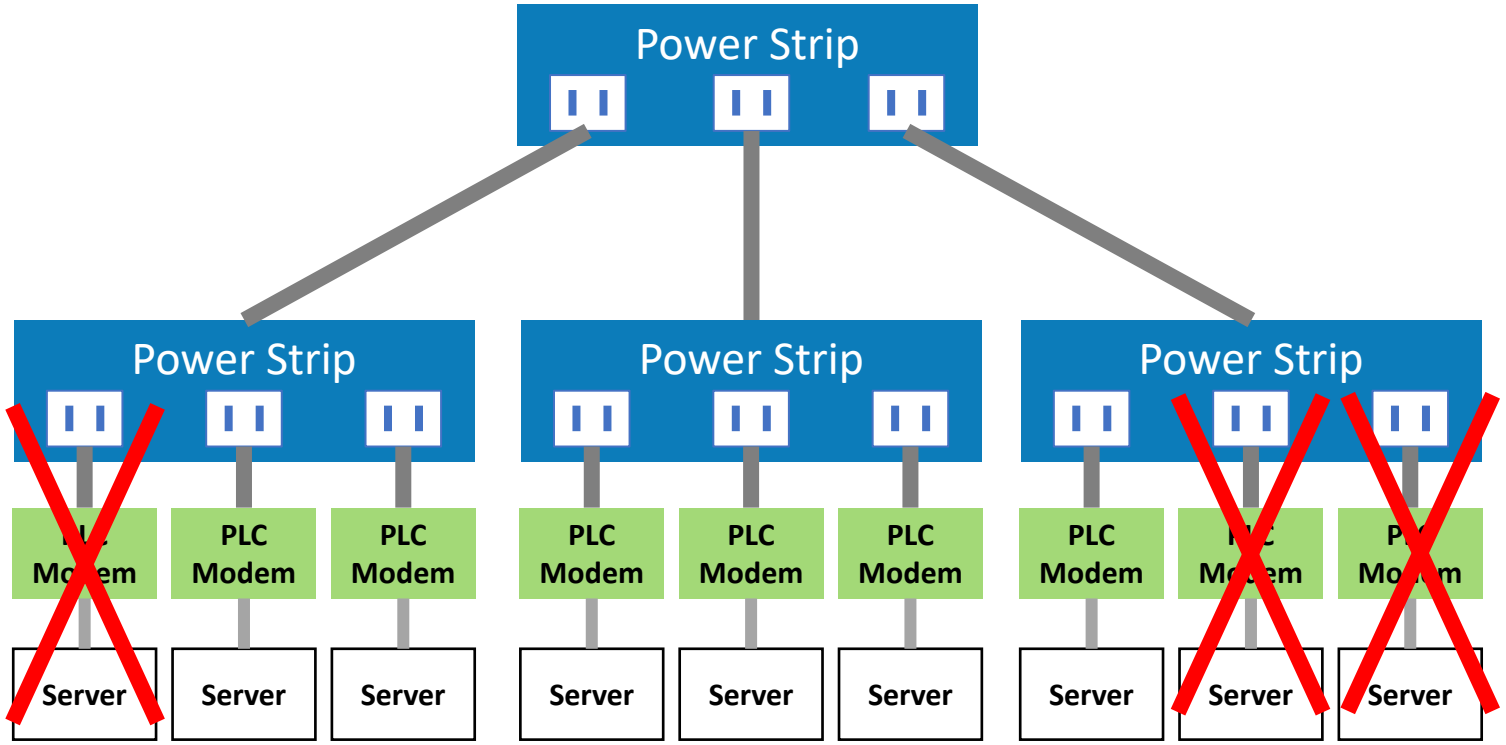
Server

…with PowerMan PSU

ToR Switch

Problems of Current PLC Technology

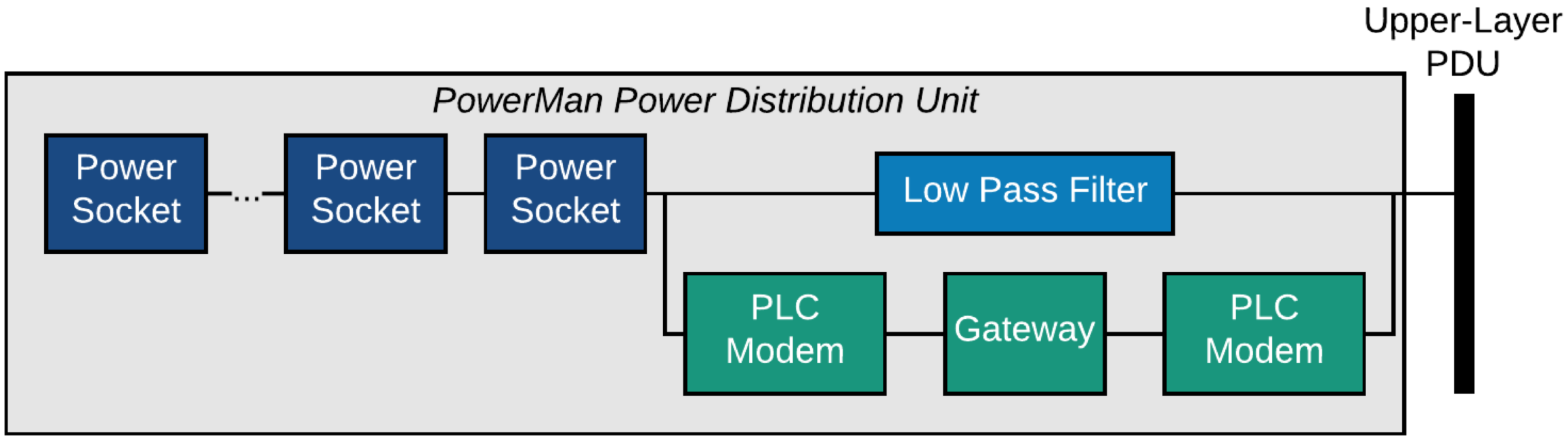
- Wiring
- Scalability



Scalability of PLC networking for house-hold use is limited.

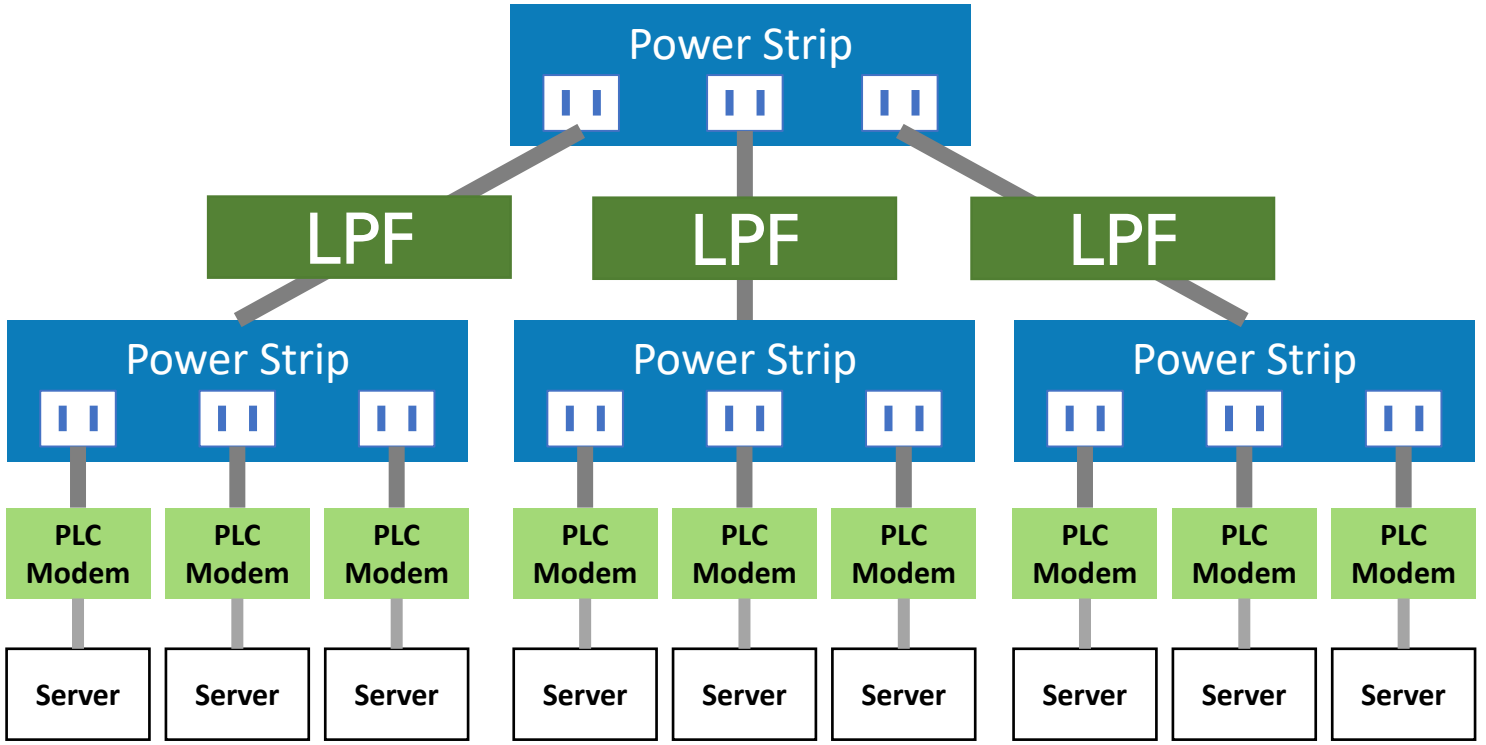
Scalability: PowerMan PDU

- How to scale with current PLC modems?
  - Form a big network with smaller ones.
  - Prevent cross-circuit interference with Low-Pass Filter.
  - Preserve cross-circuit network connectivity with a packet-forwarding gateway.



Scalability: PowerMan PDU

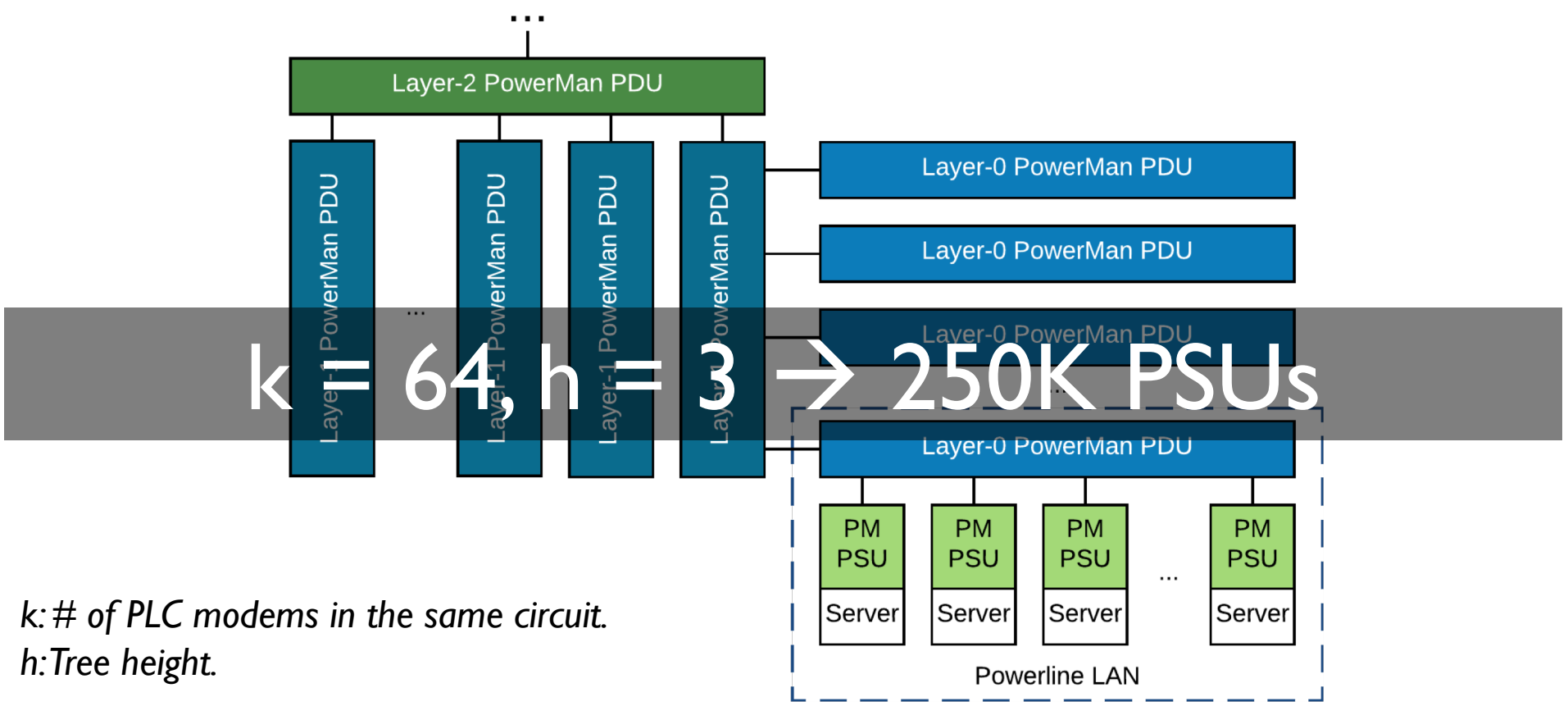
- Wiring
- Scalability



PowerMan PDU retains the same cable and socket count.

Interconnection & Scalability

- With reduced interference between PDU circuits, we can connect the PDUs using the same topology as the data center power system.

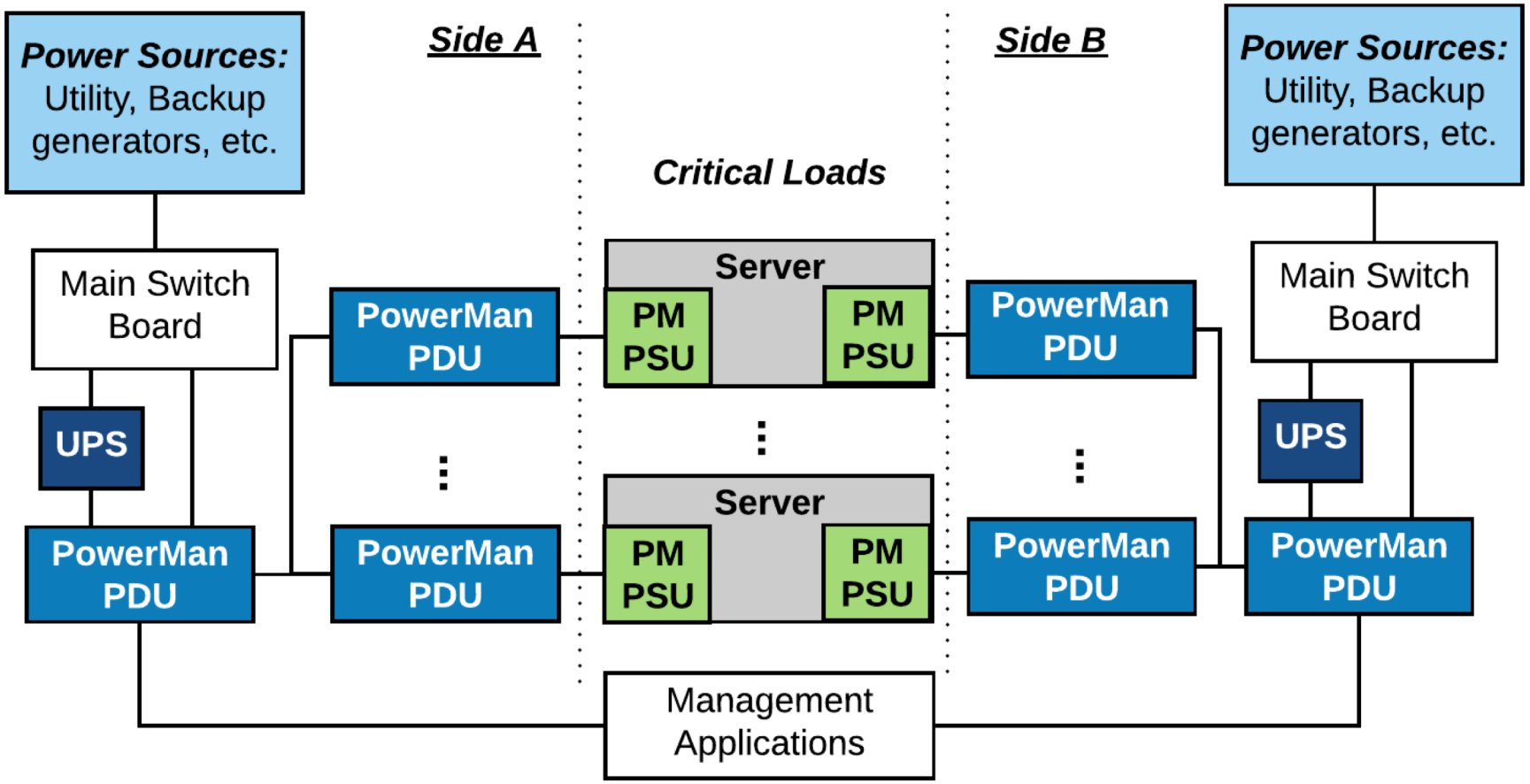


k = 64, h = 3 → 250K PSUs

k: # of PLC modems in the same circuit.
h: Tree height.

Borrowing Robustness from DCPS

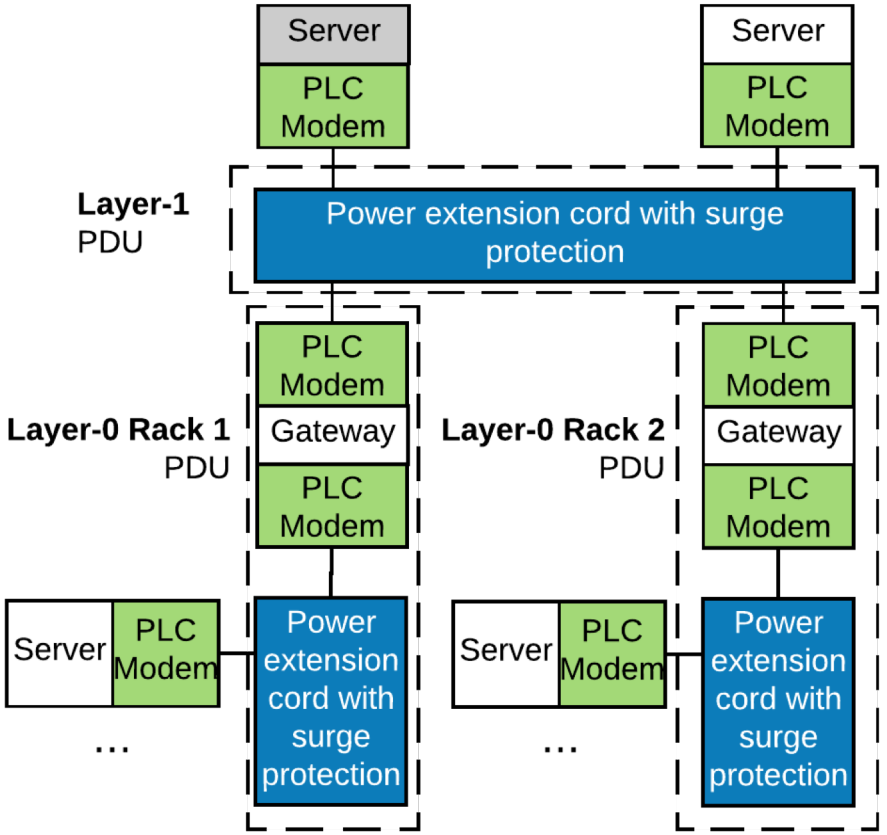
- PowerMan leverages the redundancy in existing DCPS to achieve high robustness.

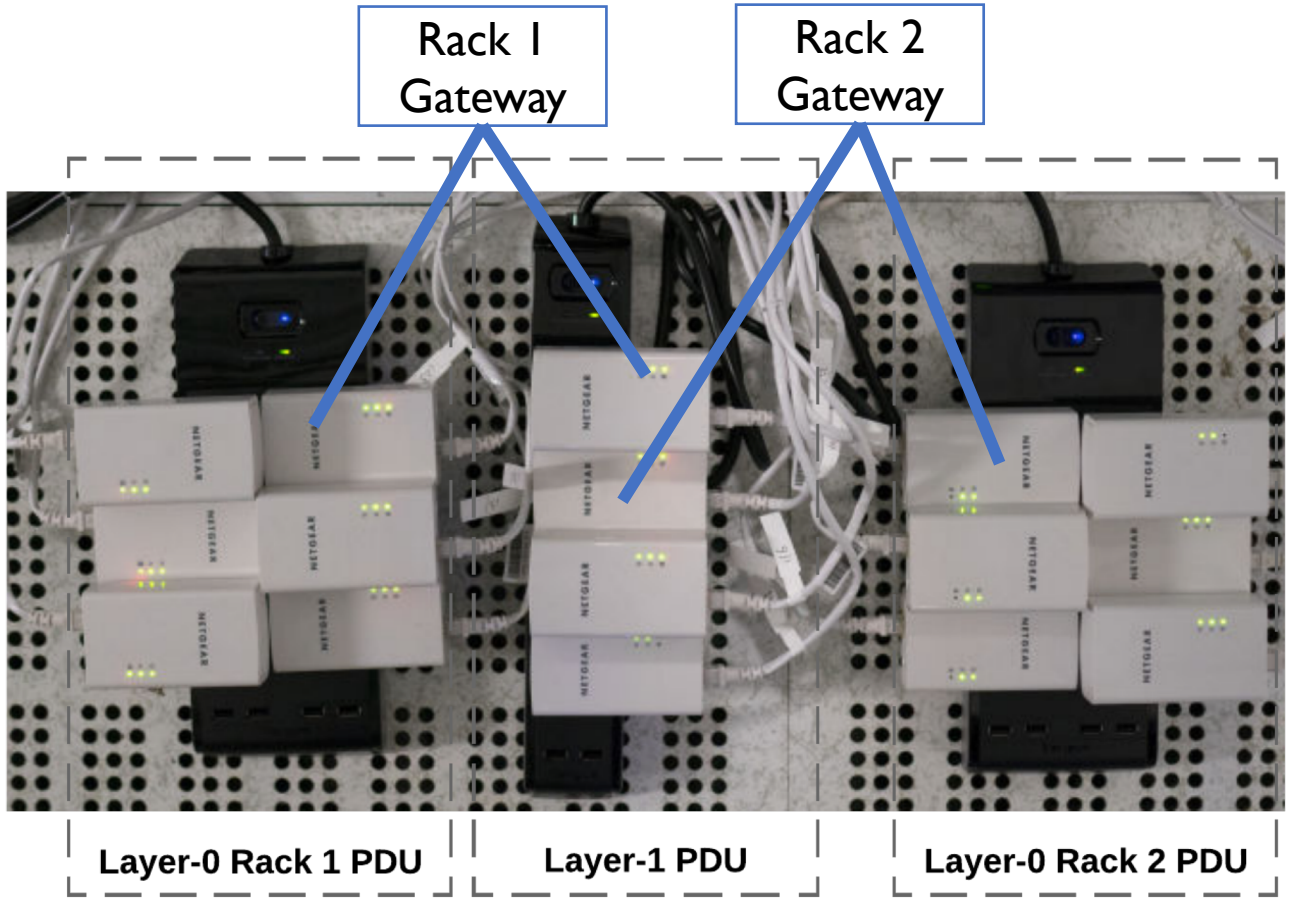


Prototype Implementation & Performance

PowerMan Prototype

- Two-Layer PowerMan Prototype

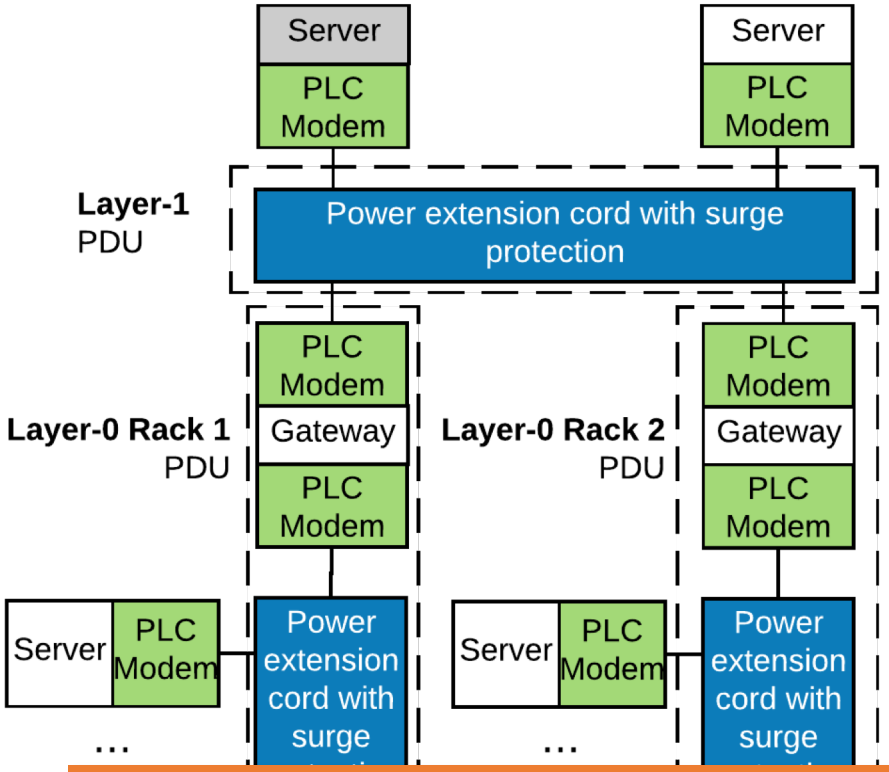


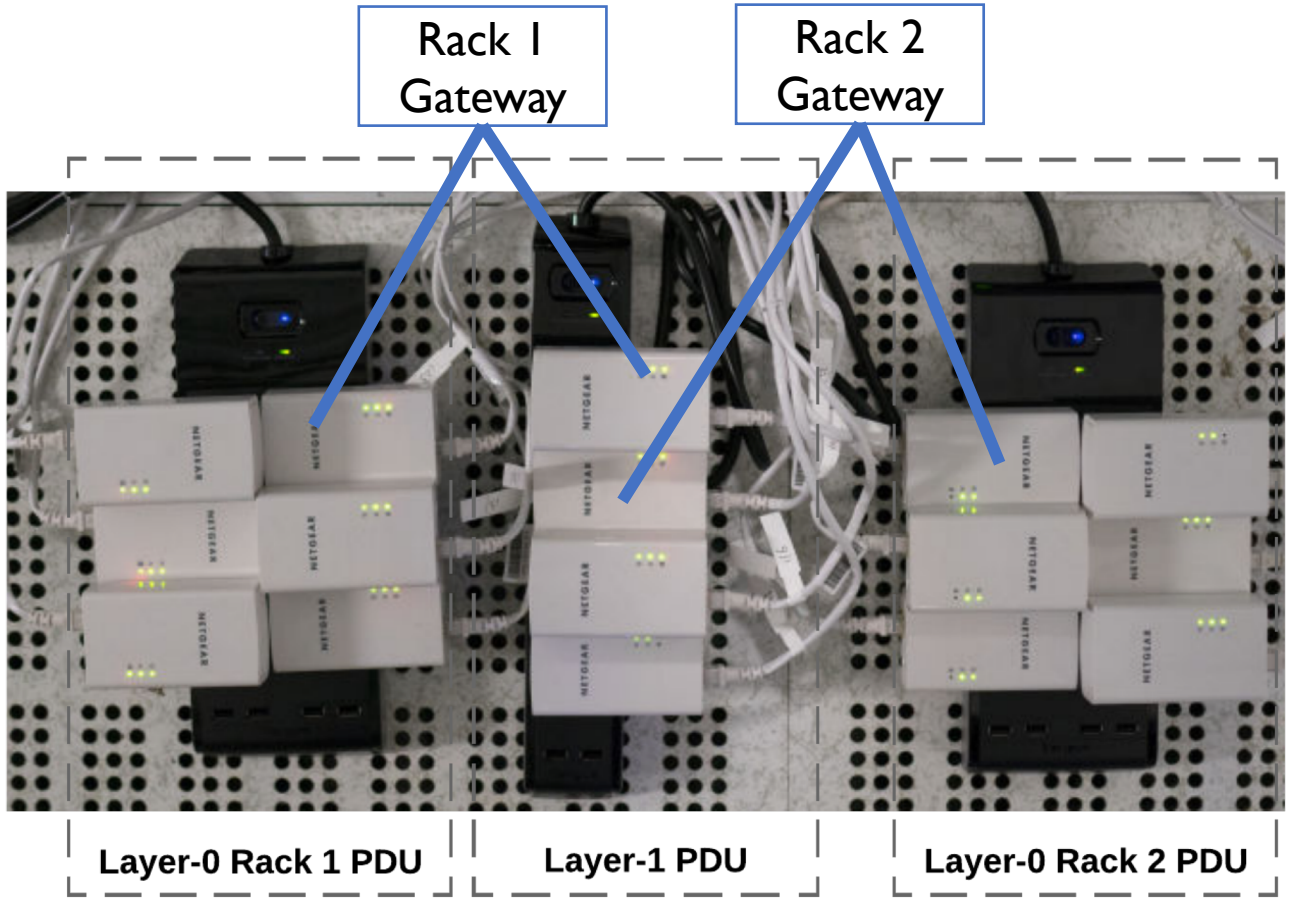


- 5 servers in each Layer-0 rack.
- 2 gateway servers in Layer-1

PowerMan Prototype

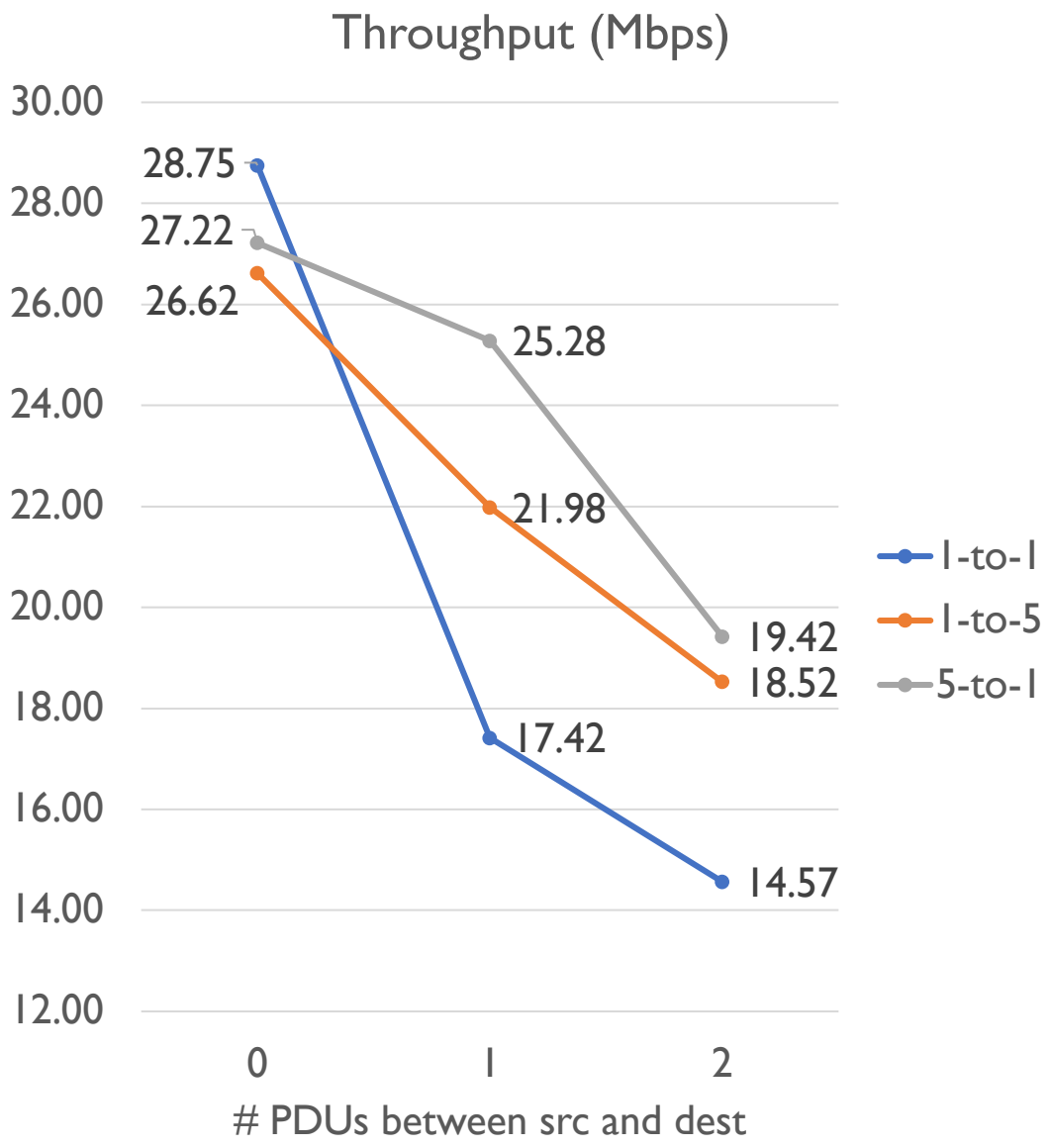
- Two-Layer PowerMan Prototype

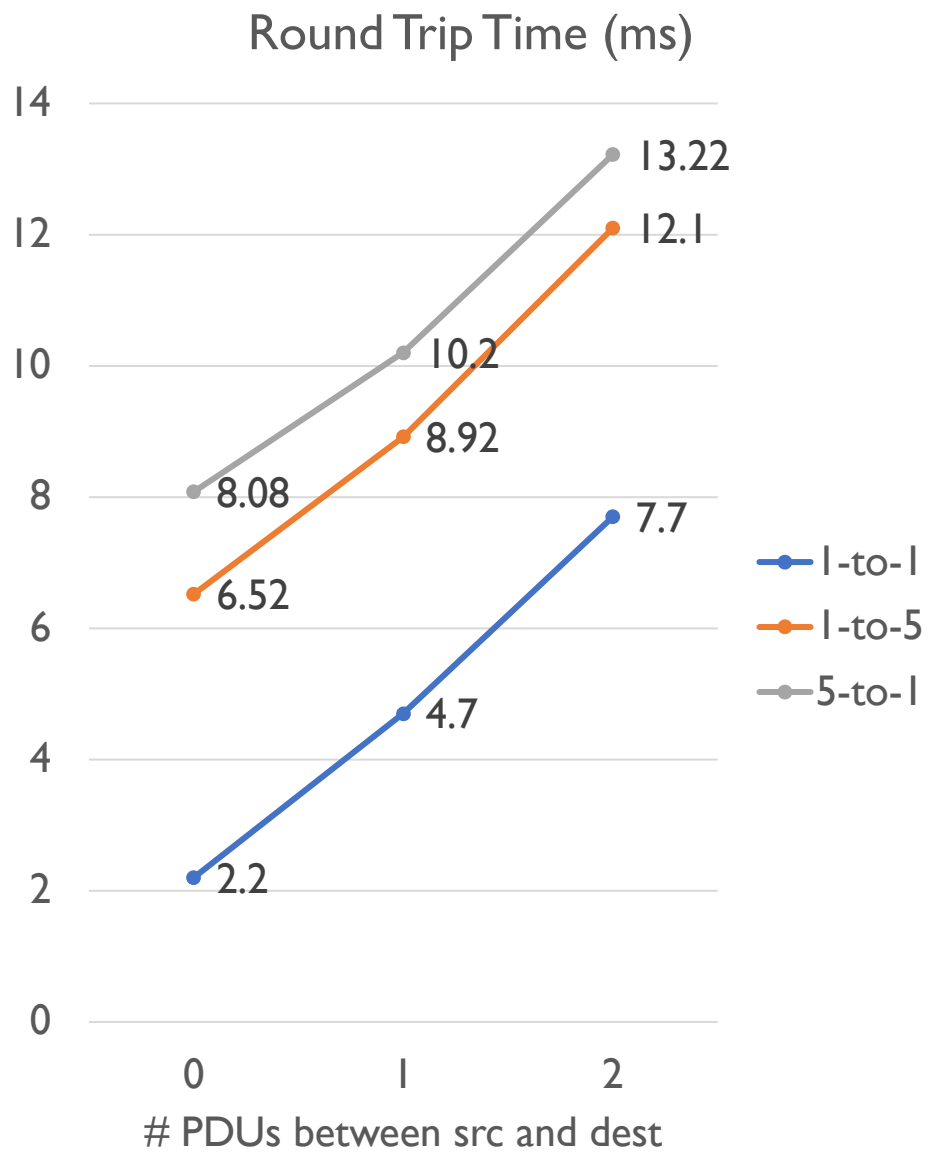




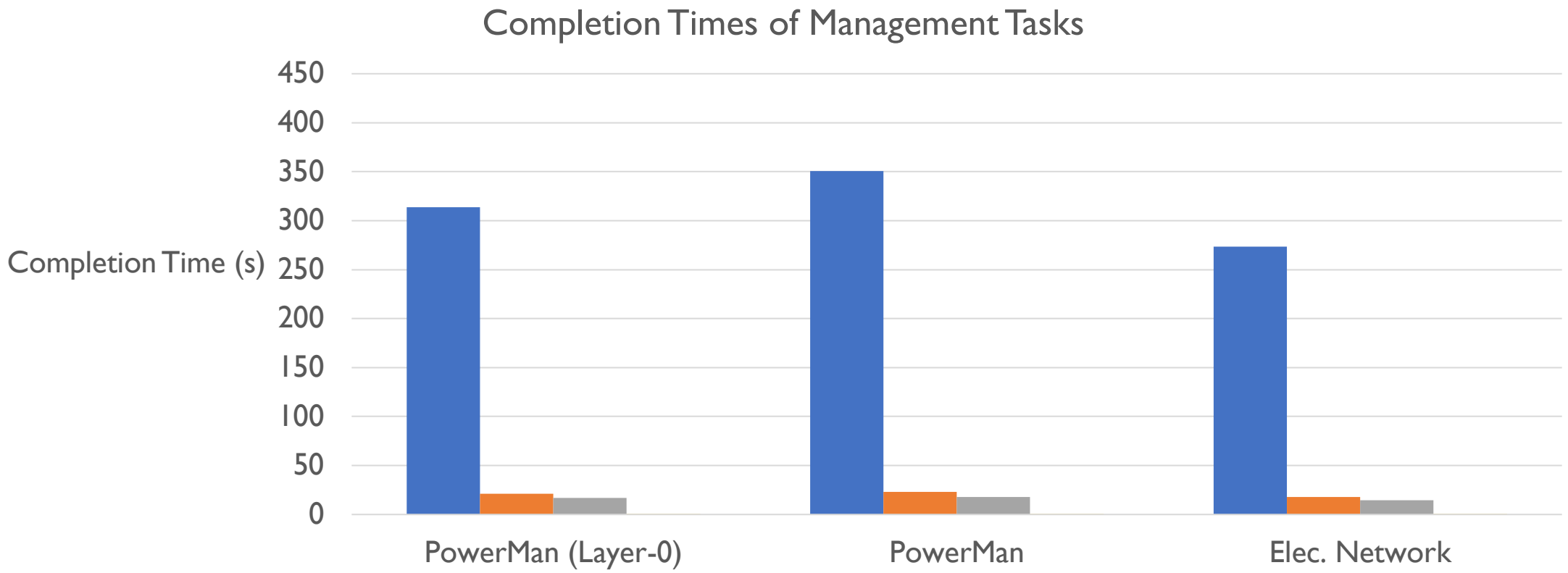
12 servers and 16 PLC modems in total:
Increases default PLC network size limit by 167%

Micro-Benchmarks



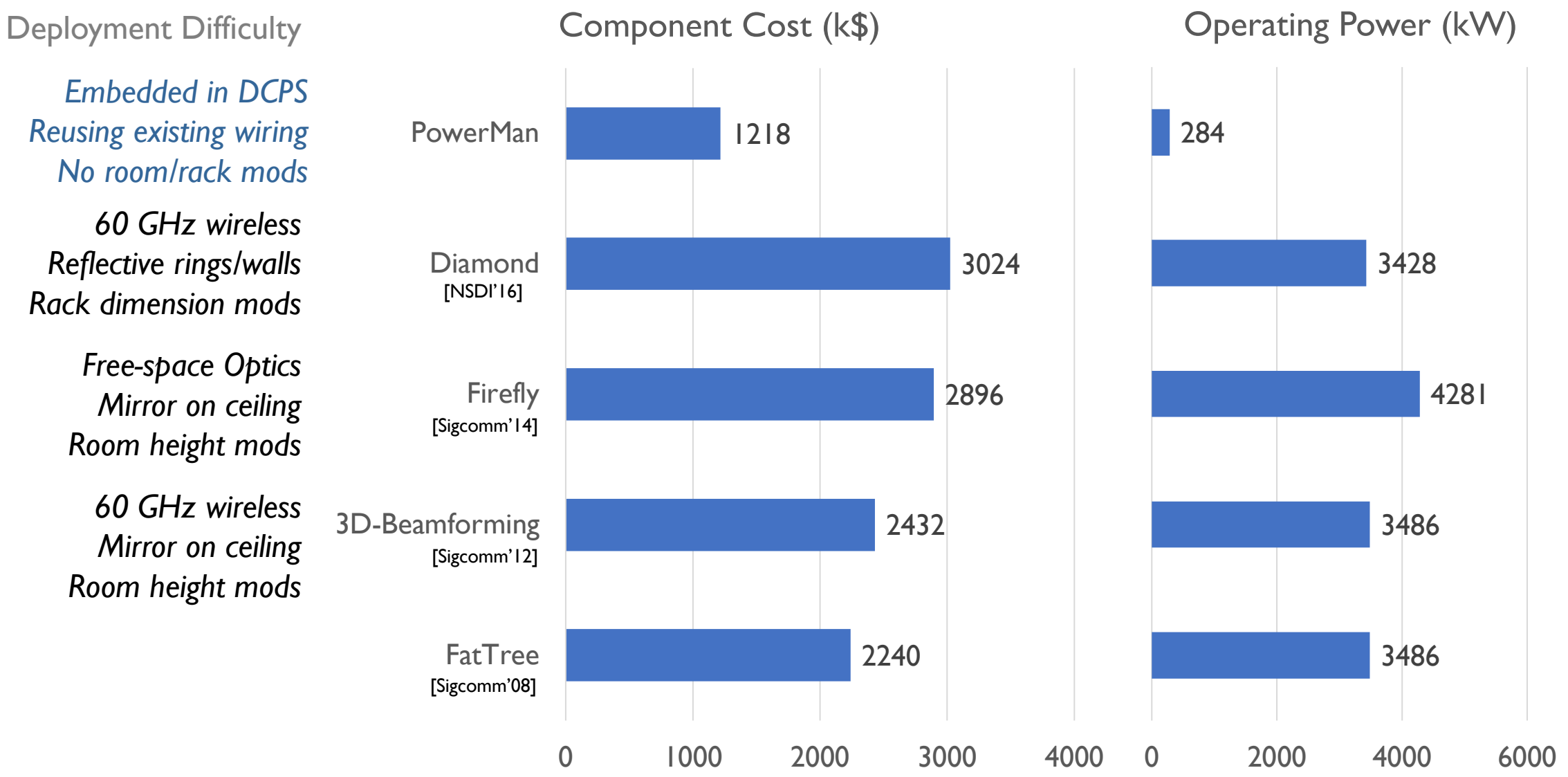


Management Application Performance



LAMP Server Setup	5 min 14.7 sec	5 min 50.39 sec	4 min 33.45 sec
Config Firewall	20.97 sec	23.03 sec	17.91 sec
Reinstall Nginx	16.76 sec	17.65 sec	14.77 sec
Collect Egress Rate	0.04 sec	0.045 sec	0.032 sec

OoB Network Cost Comparisons (at 16000 Servers)



Summary

- PowerMan is a robust, scalable, and easy-to-deploy management network for data centers.
  - Provides necessary bandwidth/latency for many management tasks.
  - Suitable as a **back-up/last-resort** network that can be constructed with ease and low cost.
- PowerMan employs PLC technology to ***borrow*** robustness and scalability from existing power systems.
- We redesign PSU and PDU to construct PowerMan with house-hold PLC devices.