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
Data Center Management Requirements

- Survive failures
- Scalable
- Can be easily deployed
Data Center Management Requirements

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- Scalable
- Can be easily deployed

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

3D-Beamforming [Sigcomm’12]
Firefly [Sigcomm’14]
ProjecToR [Sigcomm’16]
Diamond [NSDI’16]
Data Center Management Requirements

- Survive failures
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- 3D-Beamforming [Sigcomm’12]
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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**

**Power Sources:**
- Utility, Backup generators, etc.

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**Side A**

- Main Switch Board
- UPS
- PDU
- PDU
- PDU
- PSU
- PSU
- Server

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**Critical Loads**

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**Side B**

- Main Switch Board
- UPS
- PDU
- PDU
- PDU
- PSU
- PSU
- Server

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**Power Sources:**
- Utility, Backup generators, etc.
Data Center Power Systems (DCPS)

Primary Power Path

Power Sources: Utility, Backup generators, etc.

Main Switch Board

Non-essential Loads: lighting, etc.

Static Bypass

UPS

Essential Loads: mechanical, cooling, etc.

Critical Loads

PDU

PSU

PSU

PSU

PSU

... PSU

PDU

PSU

PSU

PSU

PSU

... PSU

PDU

PSU

PSU

PSU

PSU

... PSU
PowerMan: Embedded in DCPS

Enabling Technology: Power Line Communication (PLC)

Power Sources: Utility, Backup generators, etc.

Main Switch Board

Non-essential Loads: lighting, etc.

Static Bypass

UPS

Essential Loads: mechanical, cooling, etc.

Power Man PDU

Critical Loads

PowerMan PDU

PM-PSU

PM-PSU

PM-PSU

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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 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.

### 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**
- ASK
- FSK
- BPSK
- **OFDM**

**MAC**
- Token-based
- TDMA
- FDMA
- **CSMA/CA**

HomePlug Protocols provides Ethernet networking for household scenarios, with up to 1200 Mbps data rate.
Problems of Current PLC Technology & PowerMan Design

- Wiring Complexity
  - PowerMan PSU

- Limited Scalability
  - 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.

For New Datacenters

PSU Design 1:
Full-Integration
Wiring: PowerMan PSU

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

For New Datacenters

For Existing Datacenters

PSU Design 1: Full-Integration

PSU Design 2: Bump-in-the-wire
Wiring: PowerMan PSU

…with PowerMan PSU

Power

PLC Signals

Server

PDU

ToR Switch
Problems of Current PLC Technology

- Wiring
- Scalability

Scalability of PLC networking for household 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.
• With reduced interference between PDU circuits, we can connect the PDUs using the same topology as the data center power system.

$k = 64$, $h = 3 \rightarrow 250K$ PSUs

$k$: # of PLC modems in the same circuit.
$h$: Tree height.
PowerMan leverages the redundancy in existing DCPS to achieve high robustness.
Prototype Implementation & Performance
Two-Layer PowerMan Prototype

- 5 servers in each Layer-0 rack.
- 2 gateway servers in Layer-1
• Two-Layer PowerMan Prototype

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

Throughput (Mbps)

- 1-to-1:
  - 0 PDUs: 28.75 Mbps
  - 1 PDUs: 26.62 Mbps
  - 2 PDUs: 25.28 Mbps

- 1-to-5:
  - 0 PDUs: 21.98 Mbps
  - 1 PDUs: 19.42 Mbps
  - 2 PDUs: 17.42 Mbps

- 5-to-1:
  - 0 PDUs: 14.57 Mbps
  - 1 PDUs: 14.00 Mbps
  - 2 PDUs: 12.00 Mbps

Round Trip Time (ms)

- 1-to-1:
  - 0 PDUs: 7.7 ms
  - 1 PDUs: 10.2 ms
  - 2 PDUs: 12.1 ms

- 1-to-5:
  - 0 PDUs: 4.7 ms
  - 1 PDUs: 6.52 ms
  - 2 PDUs: 8.92 ms

- 5-to-1:
  - 0 PDUs: 2.2 ms
  - 1 PDUs: 4.7 ms
  - 2 PDUs: 7.7 ms

# PDUs between src and dest
Completion Times of Management Tasks

<table>
<thead>
<tr>
<th>LAMP Server Setup</th>
<th>PowerMan (Layer-0)</th>
<th>PowerMan</th>
<th>Elec. Network</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>LAMP Server Setup</strong></td>
<td>5 min 14.7 sec</td>
<td>5 min 50.39 sec</td>
<td>4 min 33.45 sec</td>
</tr>
<tr>
<td><strong>Config Firewall</strong></td>
<td>20.97 sec</td>
<td>23.03 sec</td>
<td>17.91 sec</td>
</tr>
<tr>
<td><strong>Reinstall Nginx</strong></td>
<td>16.76 sec</td>
<td>17.65 sec</td>
<td>14.77 sec</td>
</tr>
<tr>
<td><strong>Collect Egress Rate</strong></td>
<td>0.04 sec</td>
<td>0.045 sec</td>
<td>0.032 sec</td>
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</tbody>
</table>
OoB Network Cost Comparisons (at 16000 Servers)

Deployment Difficulty

- Embedded in DCPS
- Reusing existing wiring
- No room/rack mods
- 60 GHz wireless
- Reflective rings/walls
- Rack dimension mods
- Free-space Optics
- Mirror on ceiling
- Room height mods

Component Cost (k$)

<table>
<thead>
<tr>
<th>Component</th>
<th>Cost (k$)</th>
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</thead>
<tbody>
<tr>
<td>PowerMan</td>
<td>1218</td>
</tr>
<tr>
<td>Diamond [NSDI'16]</td>
<td>3024</td>
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<tr>
<td>Firefly [Sigcomm'14]</td>
<td>2896</td>
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<tr>
<td>3D-Beamforming [Sigcomm'12]</td>
<td>2432</td>
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<tr>
<td>FatTree [Sigcomm'08]</td>
<td>2240</td>
</tr>
</tbody>
</table>

Operating Power (kW)

<table>
<thead>
<tr>
<th>Component</th>
<th>Power (kW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PowerMan</td>
<td>284</td>
</tr>
<tr>
<td>Diamond [NSDI'16]</td>
<td>3428</td>
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<tr>
<td>Firefly [Sigcomm'14]</td>
<td>4281</td>
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<tr>
<td>3D-Beamforming [Sigcomm'12]</td>
<td>3486</td>
</tr>
<tr>
<td>FatTree [Sigcomm'08]</td>
<td>3486</td>
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</tbody>
</table>

60 GHz wireless
Mirror on ceiling
Room height mods
• 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.