On the Feasibility of Completely Wireless Datacenters

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Conventional Datacenter

Core Switch

Aggregate Switch

Top of Rack Switch
Conventional Datacenter
Going Completely Wireless

• Opportunities
  – Low maintenance: no wires
  – Low power: no large switches
  – Low cost: all of the above

  – Fault tolerant: multiple network paths
  – High performance: multiple network paths

Which wireless technology?
60GHz Wireless Technology

- Short range
  - Attenuated by oxygen molecules
- Directional
  - Narrow beam
- High bandwidth
  - Several to over 10Gbps
- License free
  - Has been available for many years

Why now?

- CMOS Integration
  - Size < dime
  - Manufacturing cost < $1

[Pinel ‘09]
60 GHz Antenna Model

- One directional
  - Signal angle between $25^\circ$ and $45^\circ$
  - Maximum range < 10 m
  - No beam steering

- Bandwidth < 15Gbps
  - TDMA (TDD)
  - FDMA (FDD)

- Power at 0.1 – 0.3W

How to integrate to datacenters?
Designing Wireless Datacenters

• Challenges
  – How should transceivers and racks be oriented?
  – How should the network be architected?
  – Interference of densely populated transceivers?
Completely Wireless Datacenters

- Motivation

- *Cayley* Wireless Datacenters
  - Transceiver placement and topology
    - Server and rack designs
  - Network architecture
    - MAC protocols and routing

- Evaluation
  - Physical Validation: Interference measurements
  - Performance and power

- Future

- Conclusion
Transceiver Placement: Server and Rack Design

• Rack

3D View

• Server

3-way switch (ASIC design)

Inter-rack space

Intra-rack space

2D View

How do racks communicate with each other?
Cayley Network Architecture: Topology
Masked Node Problem and MAC

• Most nodes are hidden terminals to others
  – Multiple (>5) directional antennae
    => Masked node problem
  – Collisions can occur

• Dual busy tone multiple access [Hass’02]
  – Out of band tone to preserve channels
  – Use of FDD/TDD channels as the tone
Cayley Network Architecture: Routing

- Geographical Routing
- Inter rack
  - Diagonal XYZ routing
- Turn within rack
  - Shortest path turning
- Within dst rack to dst server
  - Up down to dst story
  - Shortest path to dst server
Completely Wireless Datacenters

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  – Performance and power

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Hardware Setup for Physical Validation

• Use of a conservative platform
• Real-size datacenter floor plan setup
• Validation of all possible interferences

Intra-rack communications  Inter-rack communications
Physical Validation: Interference Evaluation
(Signal angle $\theta = 15^\circ$)
Physical Validation: Interference Evaluation
(Signal angle $\theta = 15^\circ$)

Orthogonal Inter-Rack Space (Tx on Rack D)

Diagonal Inter-Rack Space (Tx on Server 2 of Rack D)

Non-Adjacent Inter-Rack Space (Tx on Rack D)

Edge of signal: can be eliminated

Potential Interference: can be blocked using conductor curtains
Evaluation

- **Performance**: How well does a Cayley datacenter perform and scale?
  - Bandwidth and latency
- **Failure tolerance**: How well can a Cayley datacenter handle failures?
  - Server, story, and rack failure
- **Power**: How much power does a Cayley datacenter consume compared to wired datacenters
• Simulate 10K server datacenter
  – Packet level: routing, MAC protocol, switching delay, bandwidth

• Conventional datacenter (CDC)
  – 3 Layers of oversubscribed switches (ToR, AS, CS)
    • (1, 5, 1), (1, 7, 1) and (2, 5, 1)
    • Latency: 3-6us switching delay
    • Bandwidth: 1Gbps server

• FAT-tree: Equivalent to CDC (1,1,1)

• Cayley wireless datacenter
  – 10Gbps bandwidth
  – 1 Transceiver covers 7 to 8 others
  – Signal spreading angle of 25°
  – Low latency Y-switch (<< 1us)
Evaluation Setup

• Uniform random
  – Src and dst randomly selected in entire datacenter

• MapReduce
  – Src sends msg to servers in same row of rack
  – Receiver sends msg to servers in same column of rack
  – Receivers send msg to servers inside same pod with 50% probability
Bandwidth

- Burst of 500 x 1KB packets per server sent

Maximum Aggregate Bandwidth Normalized to Fat-tree

- Cayley datacenters have the most bandwidth
Latency

• Uniform random benchmark

- **Uniform Random (4KB Packet)**
  - fat-tree
  - CDC 251
  - CDC 171
  - CDC 151
  - Cayley

- **Uniform Random (16KB Packet)**

• MapReduce benchmark

- **MapReduce (4KB Packet)**

- **MapReduce (16KB Packet)**

Cayley datacenters typically performs the best
Cayley datacenters are extremely fault tolerant
Power Consumption to Connect 10K Servers

• Conventional datacenter (CDC) *
  - Depending on the oversubscription rate **58KW to 72KW**

<table>
<thead>
<tr>
<th>Switch Type</th>
<th>Typical Power</th>
</tr>
</thead>
<tbody>
<tr>
<td>Top of rack switch (ToR)</td>
<td>176W</td>
</tr>
<tr>
<td>Aggregation switch (AS)</td>
<td>350W</td>
</tr>
<tr>
<td>Core switch (CS)</td>
<td>611W</td>
</tr>
</tbody>
</table>

• Cayley datacenter
  - Transceivers consume < 0.3W
  - Maximum power consumption: 6KW

• Less than 1/10 of CDC power consumption

* Cost and spec of Cisco 4000, 5000, 7000 series switches
Discussion and Future Work

• Only scratched the surface
  – How far can wireless datacenters go with no wires?

• Need larger experiment/testbed
  – Interference and performance of densely connected datacenter?

• Scaling to large datacenters (>100K servers)?
• Scaling to higher bandwidth (> 10Gbps)?
Conclusion

• Completely wireless datacenters *can be* feasible
• Cayley wireless datacenters exhibit
  – Low maintenance
  – High performance
  – Fault tolerant
  – Low power
  – Low cost
References

