3D Beamforming for Wireless Data Centers

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Challenges in Data Centers

- Measurements show that many applications generate short-lived traffic bursts across racks → Sporadic congestion

Possible Solutions
- Add wired links/switches for capacity
  - Extremely high cost
- Change data center architecture
  - High complexity in wiring + labor cost
Wireless Data Centers

• Augmenting data center with wireless links
• 60 GHz wireless technology
  – 7 GHz unlicensed band → multi-Gbps data rate
  – Fast signal attenuation → short transmission range
• Key benefit: Flexible link configurations
60GHz Beamforming

• Extend transmission range by concentrating energy in desired direction

Omni antenna

Directional antenna

• Achievable using horn antenna or antenna array

• But there are limitations
Limitation #1: Link Blockage

• Transmissions easily blocked by small obstacles
  – Wave length of 60 GHz signal is only \(5\text{mm}\)
  – Any obstacle larger than \(2.5\text{mm}\) can block the signal!

• Must use multi-hop forwarding
  – Particularly harmful due to antenna rotation overhead
Limitation #2: Radio Interference

- Beam interferes with racks in its direction
  - Exacerbated by dense rack layouts
  - Signal leakage makes it worse
  - Result: very few links can be active at the same time

How do we address these limitations?
3D Beamforming

Reuse existing hardware, low maintenance cost!

A
B
C

Reflector
Absorber

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3D Beamforming

- Reuse existing hardware, low maintenance cost!

Benefits over 2D Beamforming
- Extended connectivity
- Reduced interference
A Closer Look at Reduced Interference

Horn antenna

Antenna array

2D

3D
Impact on Data Centers

• Case study
  – Rack-based layout (160 racks, SIGCOMM’11)
  – Bi-directional link w/ data rate $\geq 5.53$ Gbps

• Observations

  Connect any two racks via a **single hop**

  75% of them can be on **concurrently**!

  94% of links can be on concurrently when using $\leq 2$ hops

  More than half w/ data rate $> 10$ Gbps! (0.5 Tbps to the network)

*Similar observations hold for container-based layout*
Impact on Data Centers

• Case study
  – Rack-based layout (160 racks, SIGCOMM’11)
  – Bi-directional links w/ data rate $\geq 5.53$ Gbps

• Observations

  Connect any two racks via a single hop

  Create a highly flexible network with data rates closed to wired networks

  More than half w/ $10+$ Gbps data rate! ($0.5$ Tbps to the network)

*Similar observations hold for container-based layouts*
Long-Term Implications

• Flexible traffic scheduling
  – Point-to-point link, eliminating cable constraints

• Easy rack movement/replacement
  – Quick calibration of beam direction

→ Moving towards full wireless data centers
Deployment Challenges

• Placing racks/reflectors
  – Raised floor
  – Use existing metal surface
  – Use cable trays to cover wiring

• Rotating antenna to meet traffic dynamics
  – Horn antenna: a few seconds
  – Antenna array: 50ns

• Connection management
  – Coordinating TX and RX
  – Scheduling concurrent links
  – Diagnosing network faults
Conclusion

• 3D beamforming as a new wireless primitive for wireless in data centers
  – Extends the reach of wireless links and reduces interference
  – Solves key limitations of today’s 60GHz links

• Still, challenges ahead towards fully-wireless data centers
  – Physical and network management
  – Experimental testbed
Thank you!