Diamond: Nesting the Data Center Network with Wireless Rings in 3D Space

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Data center networking

• Existing DCNs
  – Hierarchical layers
  – Oversubscription
  – Static & symmetrical topology

• Challenges
  – Large-scale: complex cabling & maintenance
  – Dynamic traffic (e.g., random hotspots):

  One static & symmetrical topology does not fit All the traffic patterns

Dynamic topology?

Fat-tree, Mohammad Al-Fares et al. Sigcomm08

Figure source: Daniel Halperin et al. Sigcomm 2011
Dynamic data center networking

- **Wireless** hybrid networking: *Flyway, 3D-Beamforming, Firefly...*
  - Deploy *directional wireless* radios (60GHz or Free-Space-Optic (FSO)) at ToR
  - Direct *rack-to-rack* wireless links: *built on demand* to remove dynamic hotspots

Flyway [Halperin et al, Sigcomm 2011]
3D-Beamforming [Zhou et al, Sigcomm 2012]
Firefly [Hamedazimi et al, Sigcomm 2014]
Hybrid data center networking

• Existing wireless hybrid DCNs
  – Wireless radios on top of rack
  – Wireless network on top of existing wired network
  – Rack-level reconfigurable topology to fit dynamic traffic

• Challenges
  – Limited wireless links: small rack size & dense interference
  – Easy blocking: ceiling mirror is unavailable in modern data centers
  – Difficult cooperation: the wired part is kept unchanged, hence hard to cooperate with newly added wireless part

Not hybrid enough!
Challenge—**Limited** wireless radios & links!

- **Wireless on Top of Rack?**
  - The top of each rack can hold *at most 8* wireless radios
  - Small rack size: more radios on top of rack lead to denser interference

- **Ceiling mirror?**
  - Unavailable mirror: requires a restricted-height (3 meters) clear space above rack
  - Modern data centers: complex steel structures & air conditioner plan above racks
Solution 1—Multi-reflection Ring

• Motivating example

Wireless Ring: any two racks (e.g., A & B) on the ring can communicate with multi-reflections
Solution 1—Multi-reflection Ring

• Scaling: add more *wireless rings*!
• But *circular reflector* board? *Hard&costly* to produce in industry...

![Diagram showing multi-reflection effect with circular reflector and A, B, C points]
Solution 1—Multi-reflection Ring

- Using *equal-length flat reflection board* instead: easy & cheap for production
  - *Racks* are placed at the *vertex points* of regular polygon
  - *Reflection boards* are placed at the *edges* of regular polygon

![Diagram showing multi-reflection ring]

*Ring width: stable!*
Solution 1—Multi-reflection Ring

- 3D Reflection in ring space: offering much higher flexibility

Deploy wireless radios on servers:
Enable a large number of direct *server-to-server* wireless links
Challenge—Interference

- Directional wireless link (60GHz) is not “ideal thin line”: it has certain *beam width* and small *side-lobes* to create interference.

*Figure source: Ji-Yong Shin, et al. ANCS’12*
Solution 2—Precise reflection

• Filling the reflection board with **absorbing paper**, while only leaving special **small holes** for intended reflection points

Any 60Ghz wireless signal will be completely absorbed if it hits the “absorbing paper”
Solution 3—Cooperation with wires (Diamond)

• Function of wireless part: handling in-ring transmissions
• Function of wired part: handling cross-ring transmissions

Overview of our Diamond architecture

A real diamond...
Solution 3—Cooperation with wires (Diamond)

- Function of wireless part: handling in-ring transmissions
- Function of wired part: handling cross-ring transmissions
Solution 3—Cooperation with wires (Diamond)

• Design of virtual switch: De-Bruijn graph
  – Without additional switches
  – Well-defined recursive routing structures
  – Logarithmic network diameter

• Design of routing
  – Hotspot traffic: designated centralized routing
    (centralized scheduled by controller)
  – Non-hotspot traffic: real-time hybrid routing
    (distributed scheduled by server)
Testbed

• Single & Double reflection tests
Experiment result

• Misalignment
  – Potential beam width is about 20°: a certain degree of fault tolerance on antenna misalignment

• Reflection hole
  – Proper hole size (diameter): 10cm
  – Hole reusing: above 50% reflection holes can be reused for different wireless links (symmetrical structure)

• Multi-reflection
  – Little energy loss when using flat metal board
  – Little energy loss when using 10cm reflection holes on the flat metal board filling with absorbing paper
Simulation result

• Cover range
  – Cover 90% of ring within 3 reflections when ring number <10
  – Roughly, 1000 servers have potential 0.1 million wireless links within 2 reflections

• Different traffic patterns
  – Average 5 times higher throughout than others
  – Average 70% less flow completion time than others

• Scheduling delay
  – Greedy runs each schedule within 100ms, while Optimal runs with exponential time of the problem scale

• Architecture cost
  – Diamond’s cost is highest (comparable to Firefly), while it trades off a larger number of wireless links than others
Conclusion

• Diamond can bring significant performance benefits for topology-reconfigurable DCNs
  – No need of the restricted-height clear ceiling space/ceiling mirror
  – Enable a large number of highly-flexible server-level wireless links
  – Better cooperation between wireless and wired transmission components

• Future vision: running FSO (Free-Space-Optics) in Diamond
  – Potential Tbps bandwidth
  – Nearly zero beam width: little interference

• Try it out for fun:
  @ http://www.4over6.edu.cn/cuiyong/app/diamond.apk
Thank You!