SPARTA: Scalable Per-Address RouTing Architecture

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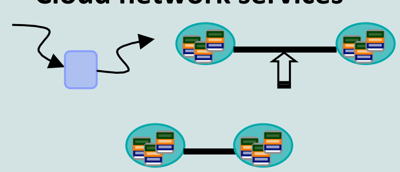
IBM Research activities related to SDN / OpenFlow

IBM Research started a strategic initiative in data center networking in 2010

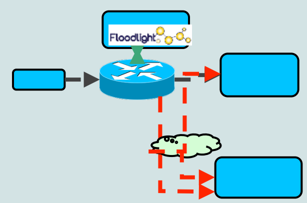
- Global participation from multiple labs, partnered with product teams
- SDN is one of the focus areas of the strategic initiative
- Heavily involved in ONF standards work (esp. FAWG → Table Typing Pattern)

SDN applications (examples)

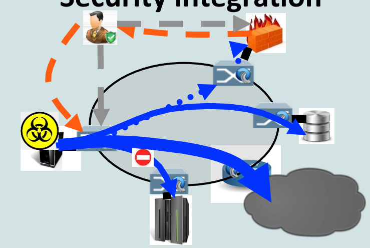
Cloud network services



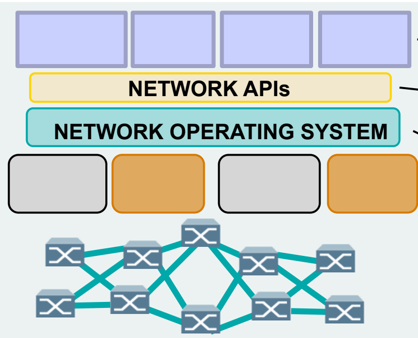
Flow replication / recovery



Security integration



SDN advanced controller capabilities

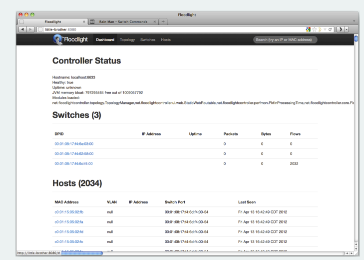


network control apps, IT-network integration

application APIs, network abstractions

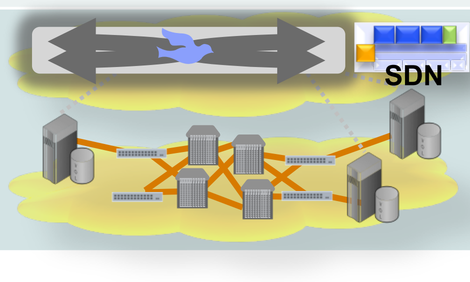
orchestration, workflows, network services

network device control and management (plugins / drivers)

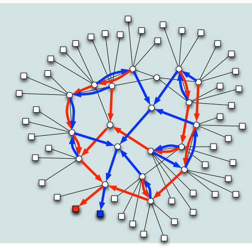


OpenFlow mgmt tools

Network fabric / virtualization



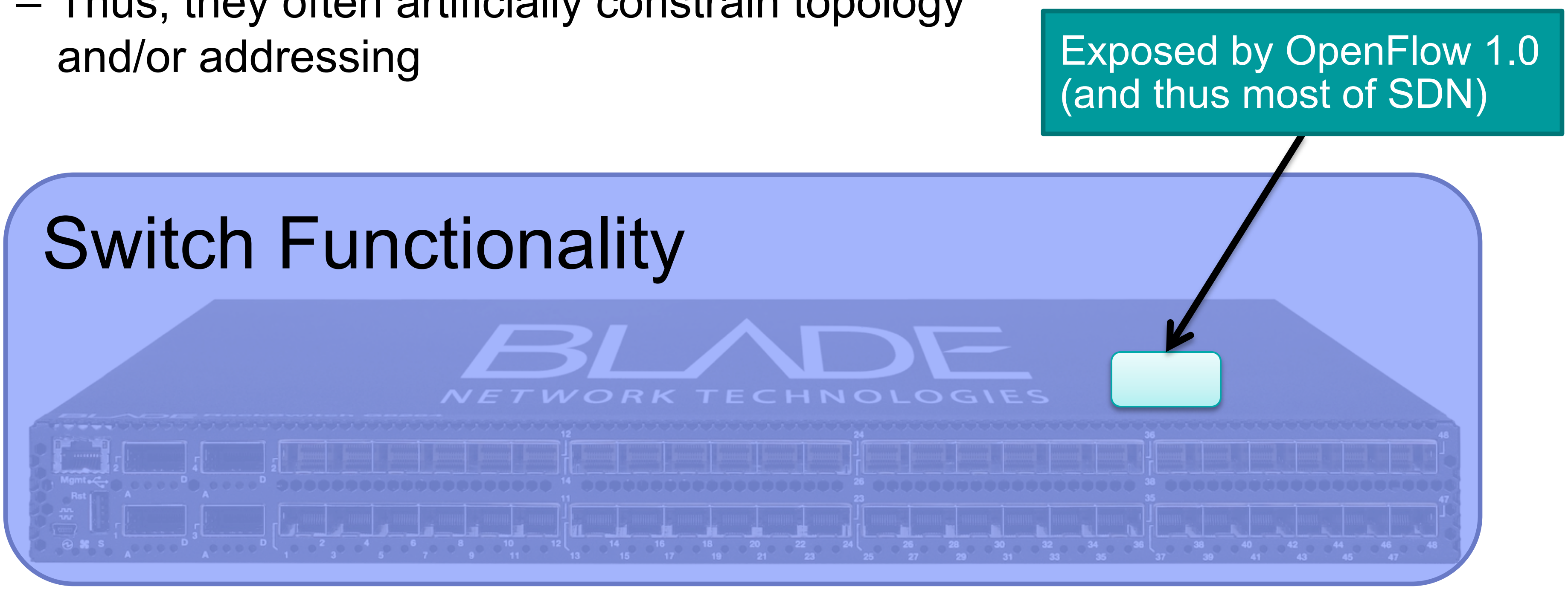
DOVE – distributed overlay virtual Ethernet



Scalable, flexible, converged data center fabric

Current SDN uses a tiny fraction of switch capabilities

- Previously proposed SDN routing architectures:
  - Largely based on OpenFlow 1.0
  - OpenFlow 1.0 only maps well on to (small) TCAM switch tables
    - Tiny fraction of switch functionality
  - Thus, they often artificially constrain topology and/or addressing



SPARTA: Scalable Per-Address RouTing Architecture

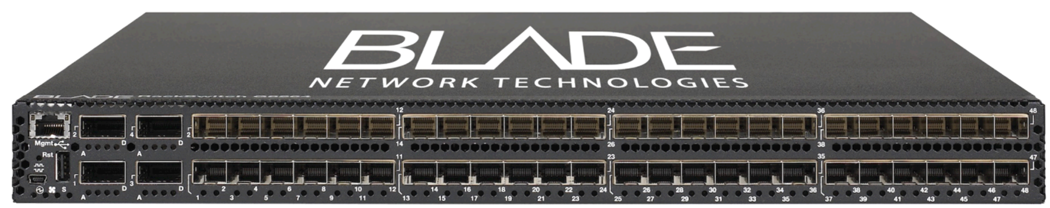
- SPARTA: Simple, HW-efficient, flexible routing mechanism
  - Build one spanning tree per destination host ([VLAN ID, DMAC])
  - Install one rule per tree per switch in (huge) L2 exact match table

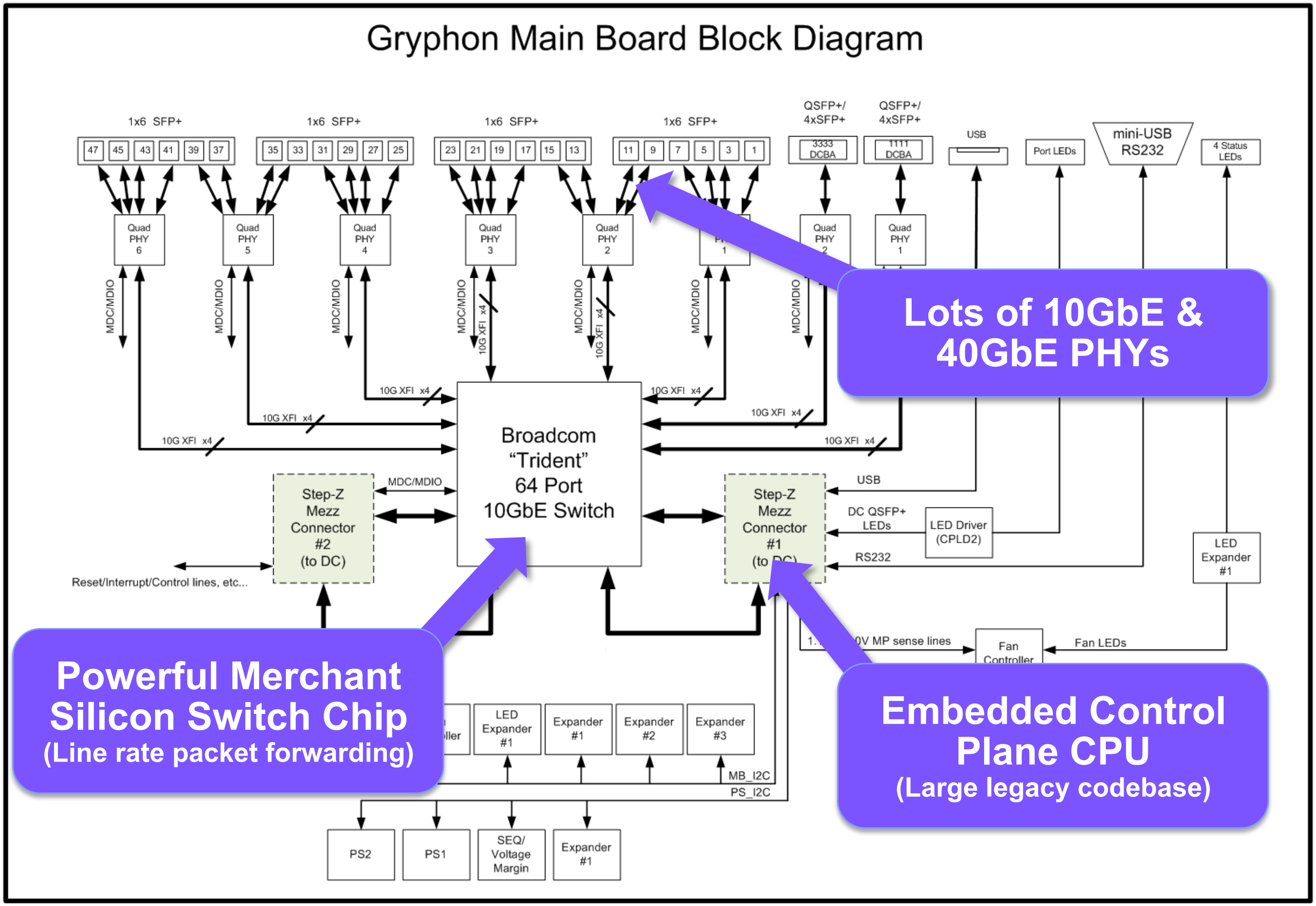
- Characteristics of SPARTA
  - Supports arbitrary (connected) physical topology
  - Exploits all available paths (statistically)
  - Leaves TCAMs for designed purposes (security, policy-based routing, …)
  - Flexible framework for traffic engineering, traffic steering, failure recovery, quality of service management, …

Data Center Network Design Goals

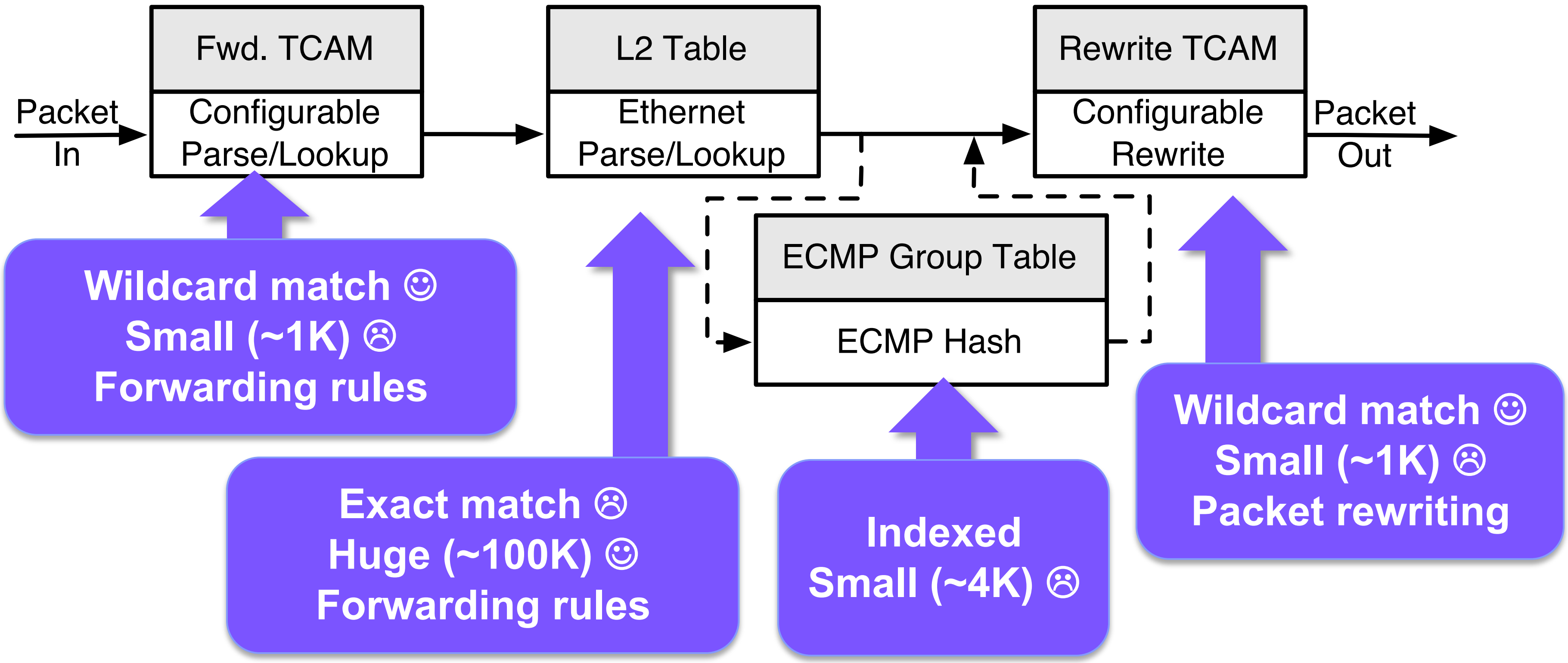
- Scalable
  – 10s to 100s of thousands of hosts
- Efficient use of bandwidth
  – Mesh topologies from HPC?
- Efficient host mobility
- Low latency
- Respect layering
- Multi-tenancy
- Very dynamic → self-configuration
- Compatible with existing / planned hardware
- Converged data and storage networks (CEE)

A Brief Tour Through a Modern 10GbE Switch



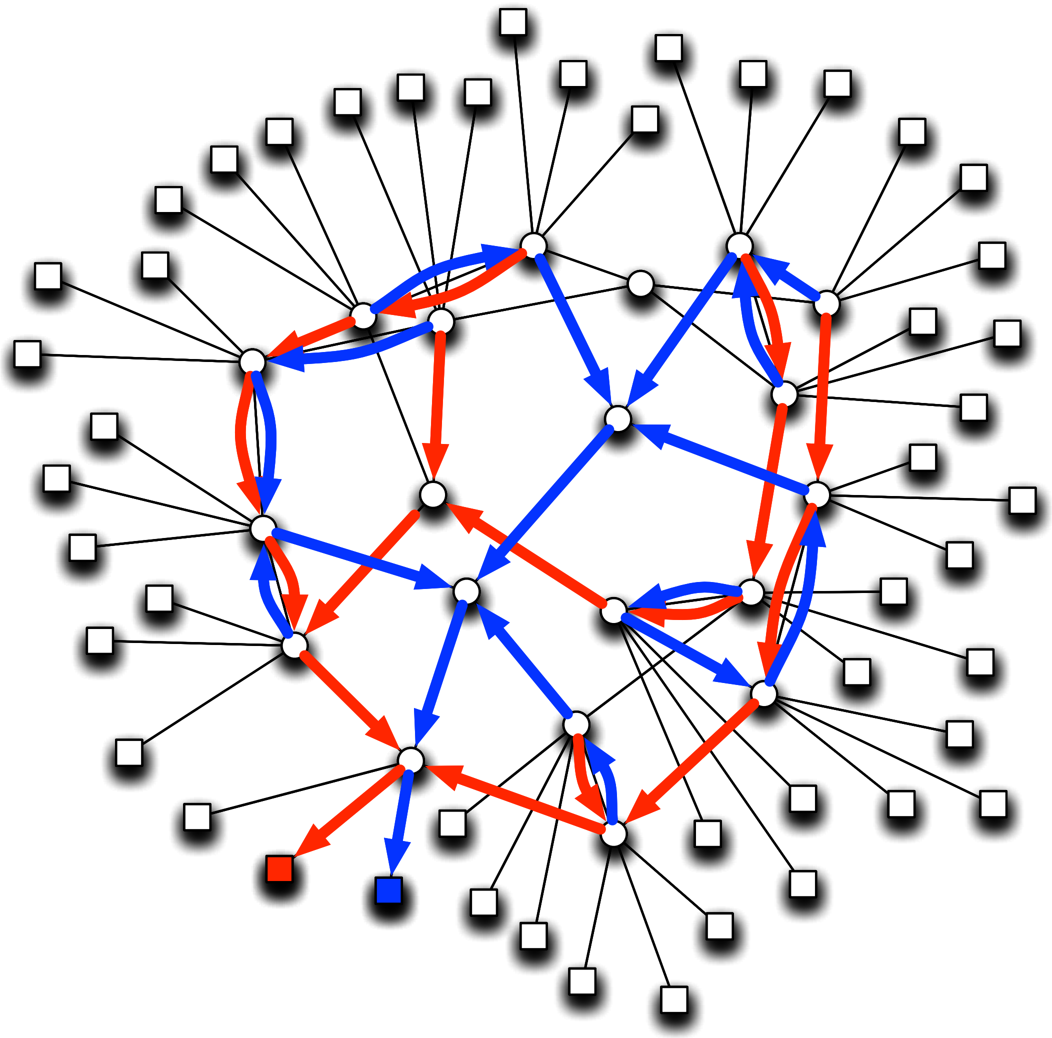

Gryphon Main Board Block Diagram
1x6 SFP+
47 45 43 41 39 37
35 33 31 29 27 25
23 21 19 17 15 13
11 9 7 5 3 1
QSFP+/ 4xSFP+
3333 DCBA
1111 DCBA
USB
Port LEDs
mini-USB RS232
4 Status LEDs
Quad PHY 6
Quad PHY 5
Quad PHY 4
Quad PHY 3
Quad PHY 2
Quad PHY 2
Quad PHY 1
MDC/MDIO
10G XFI x4
Broadcom "Trident" 64 Port 10GbE Switch
Step-Z Mezz Connector #2 (to DC)
Step-Z Mezz Connector #1
Reset/Interrupt/Control lines, etc...
USB
DC QSFP+ LEDs
LED Driver (CPLD2)
RS232
LED Expander #1
V MP sense lines
Fan Controller
Fan LEDs
LED Expander #1
Expander #1
Expander #2
Expander #3
MB_I2C
PS_I2C
PS2
PS1
SEQ/ Voltage Margin
Expander #1
Lots of 10GbE & 40GbE PHYs
Powerful Merchant Silicon Switch Chip
(Line rate packet forwarding)
Embedded Control Plane CPU
(Large legacy codebase)

Simplified Switch Pipeline (BRCM Trident)



- **TCAMs**: Designed for limited use (security ACLs, PBR, …)
- **L2/FDB table**: Huge, plentiful, simple to expand (RAM)
- **ECMP and multicast tables**: Additional flexibility

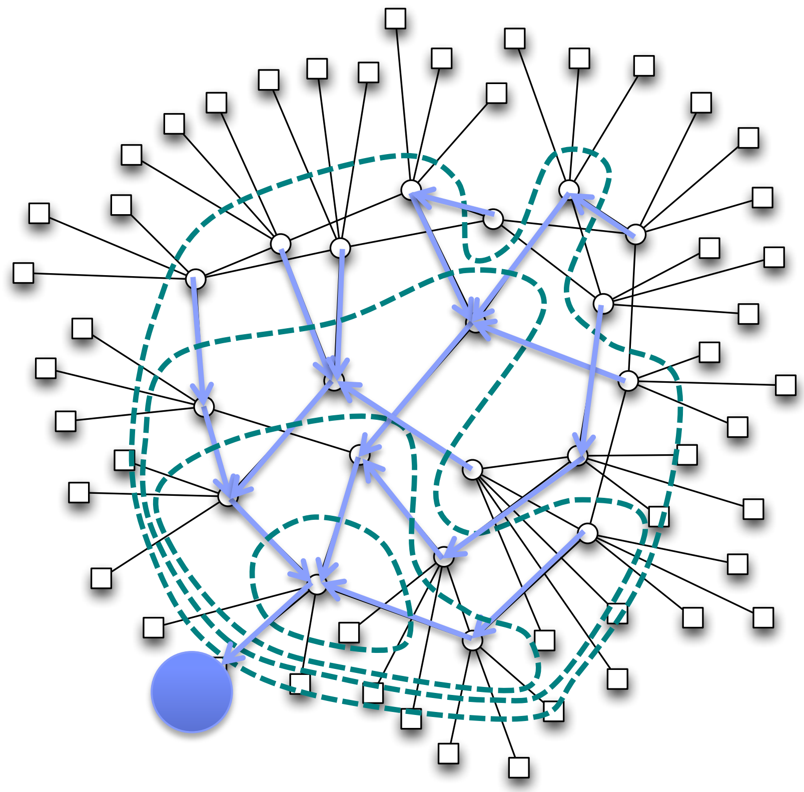
Basic SPARTA routing



- **Goal**: Route using large L2 table on arbitrary (mesh) topology
- **Solution**: Build spanning tree rooted at each destination
- All links used → approximate load balancing w/o ECMP

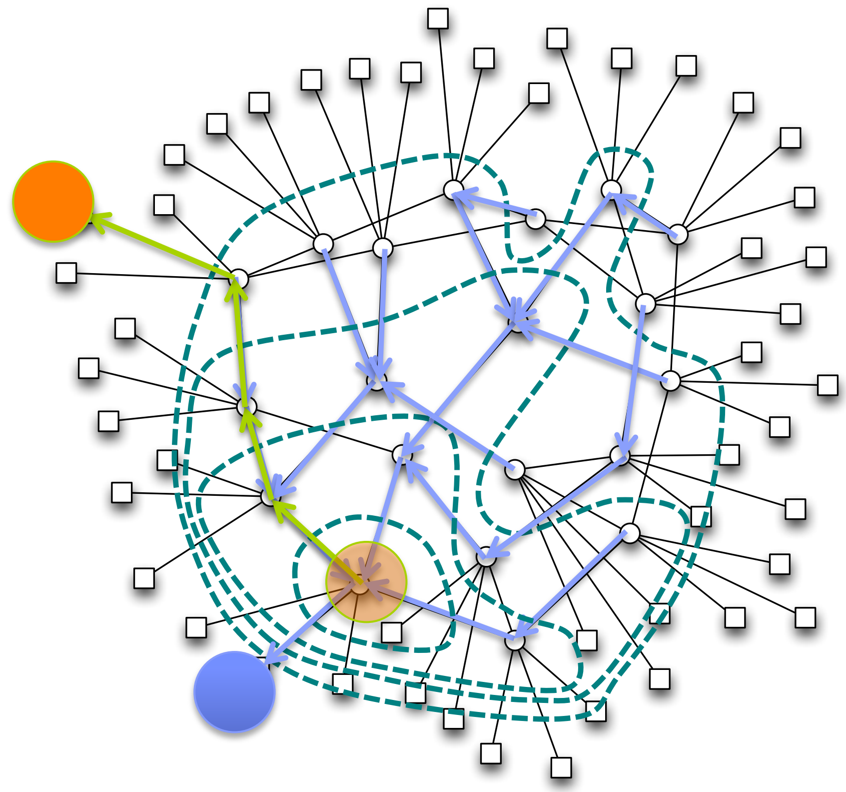
Constructing SPARTA Routes

- Basic option: Use BFS to build min-length paths
  - Random
  - Weight links by load
  - …



Constructing SPARTA Routes

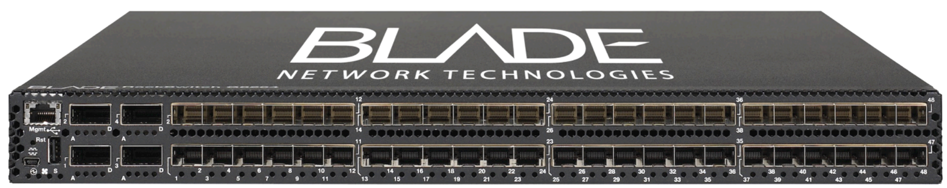
- Basic option: Use BFS to build min-length paths
  - Random
  - Weight links by load
  - …
- Some workloads/topologies benefit from non-min routes
- Non-minimal (NM) PAST
  - Do a BFS from a random switch as the root
  - Change directions on route from root to destination



SPARTA Discussion

- One L2 entry per switch per tree → scales to > 100K hosts
- Consumes no TCAM entries for basic routing
- Obeys layering (does not re-use VLAN tag or other bits)
- Broadcast/multicast: No change → provide via STP or SDN
- Security: Use VLANs as normal (or ACLs)
- Virtualization: Use any higher layer virtualization overlay
  (e.g., NetLord, SecondNet, MOOSE, VXLAN)

SPARTA Implementation



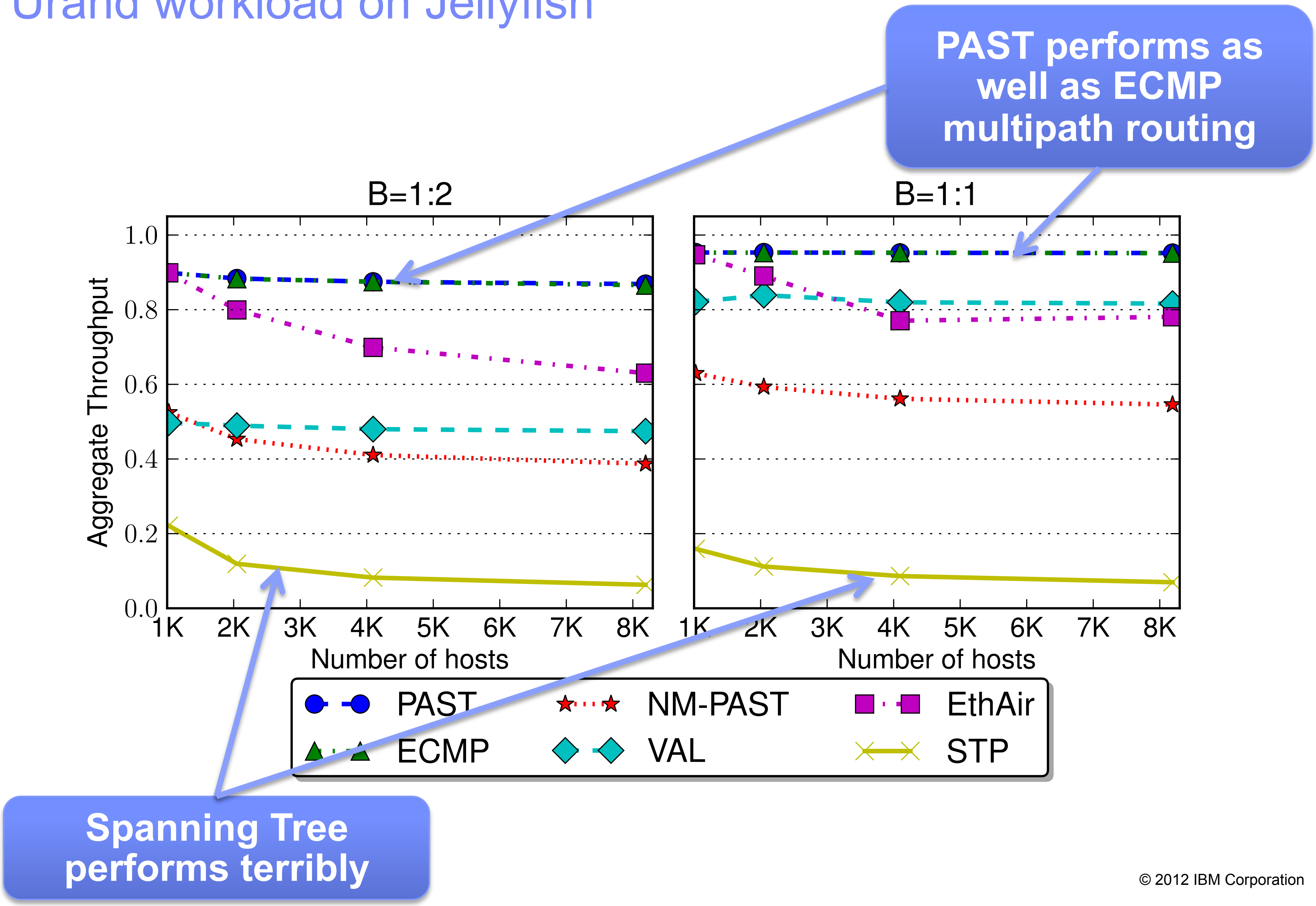
SPARTA Implementation Details

- Address detection and resolution:
  - Uses controller for ARP, DHCP, IPv6 ND, and RS for scalability
- Route computation:
  - 8,000 hosts → 40μsecs – 1ms per tree (300ms per network)
  - 100,000 hosts → 500μsecs – 5ms per tree (40s per network)
- Route installation:
  - 700-1600 new rules per second per switch
  - 2-12ms rule install latency → eagerly install routes
- Failure recovery:
  - Should patch affected portions of trees first
  - Randomly rebuild trees for link joins

SPARTA Performance

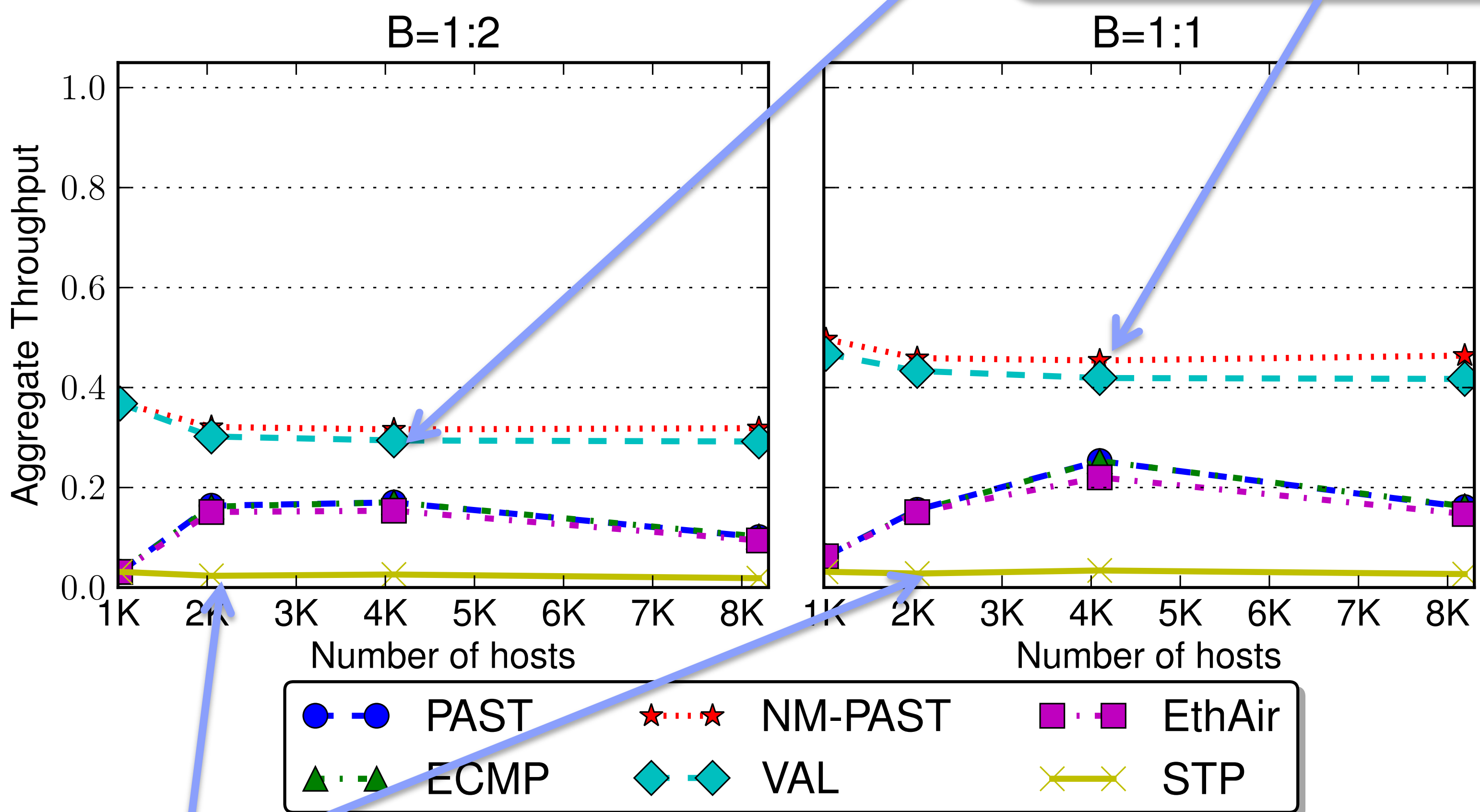
- Simulated to allow evaluation at scale
  - Assume max-min TCP fairness to make simulation feasible
- Compared against:
  - STP, Valiant routing, ECMP (multipath routing)
- Workloads:
  - Urand: Uniform random — benign
  - Stride-S: Host i sends to host ((i+S)%N) — adversarial (intra-rack)
  - Shuffle-K: 128MB to all hosts, random order, K active connections
  - MSR: Synthetically generated from MSR data (light load)
- Topologies: Equal bisection bandwidth (oversubscription ratios) of…
  - EGFT (fat tree), Hyper-X (flattened butterfly), Jellyfish (random)

Urand workload on Jellyfish



Stride workload on Jellyfish

Non-Minimal PAST performs better than Valiant load balancing



Spanning Tree performs terribly

Summary for SPARTA

- Meets all of our requirements for a DCN by exploiting only the most basic Ethernet forwarding hardware
- Scalable, low-latency, high-bandwidth network from COTS ToR switches *(So we can exploit HPC-style mesh topologies!)*
- Can provide 1-2X performance of ECMP
- Implemented on existing hardware w/ OF 1.0 (!!!)
- Leaves TCAM entries for designed uses: PBR, security, …
- Flexible framework for traffic engineering, traffic steering, QoS management, resiliency, …
- For full results, see CoNEXT 2012 paper (next week)

Suggestions for SDN Research

- Understand and exploit what is in the actual hardware
  - Do not let OpenFlow specification restrict your vision…
  - … but don't assume magical hardware ("*unicorns and rainbows*")
- Consider what can be done by running "SDN-aware" functions on the control processor (ala HP Labs' DevoFlow)
  - Controller understands "big picture" → guides switch-local decisions
  - Switch firmware can respond in μsecs, not msecs
  - Opportunity: Indigo or similar open source OpenFlow switch firmware
  - Pushing it to the limit → switchlets (Active Networking reborn?)
- Why just networks? Software-defined *everything*
  - SDS: software-defined storage (lots of startups claiming this)
  - SDC: software-defined computation (VMs kind of do this)
  - SDDC: software-defined data center

TCP Bolt: Faster small flows with lossless Ethernet

Bonus Result

- Lossless ➔ no congestion collapse
- Send at line-rate immediately
- 1.5-3X better than vanilla TCP for 64K–8M
  – many real DC flows are this size