Jupiter rising: A decade of Clos topologies and centralized control in Google’s datacenter networks

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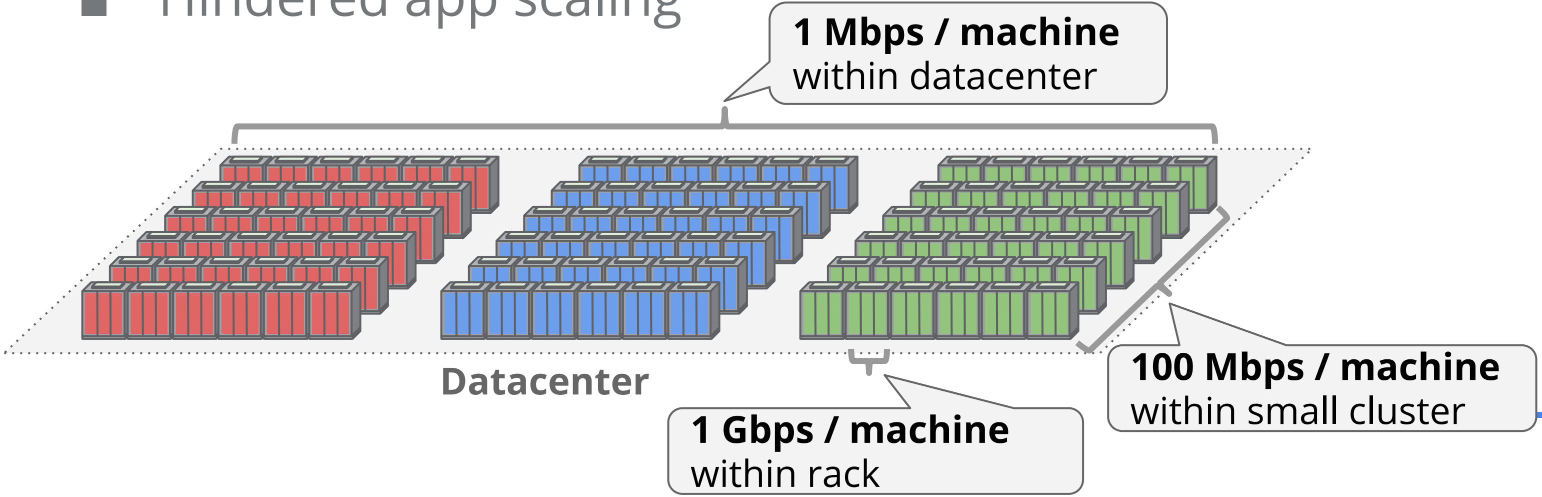
On behalf of several teams in Google:

Platforms Networking Hardware and Software Development, Platforms SQA, Mechanical Engineering, Cluster Engineering, NetOps, Global Infrastructure Group (GIG), and SRE.

Grand challenge for datacenter networks

- Tens of thousands of servers interconnected in clusters
- *Islands of bandwidth* a key bottleneck for Google a decade ago
    - Engineers struggled to optimize for b/w locality
    - Stranded compute/memory resources
    - Hindered app scaling

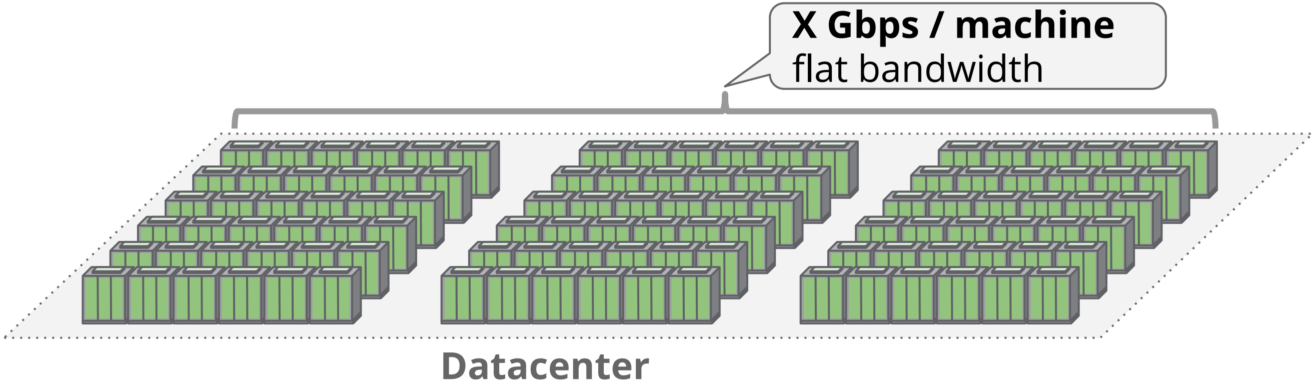

1 Mbps / machine
within datacenter

100 Mbps / machine
within small cluster

1 Gbps / machine
within rack

Grand challenge for datacenter networks

- **Challenge: Flat b/w profile across all servers**
  - Simplify job scheduling (remove locality)
  - Save significant resources via better bin-packing
  - Allow application scaling



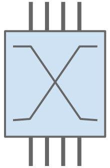
Motivation

- **Traditional network architectures**
  - Cost prohibitive
  - Could not keep up with our bandwidth demands
  - Operational complexity of “box-centric” deployment

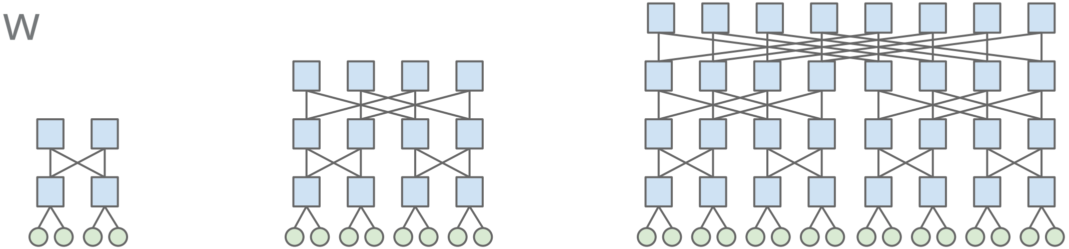
- **Opportunity: A datacenter is a single administrative domain**
  - One organization designs, deploys, controls, operates the n/w
  - ...And often also the servers

Three pillars that guided us

Merchant silicon: General purpose, commodity priced, off the shelf switching components



Clos topologies: Accommodate low radix switch chips to scale nearly arbitrarily by adding stages



Centralized control / management

SDN: The early days

- Control options
    - Protocols: OSPF, ISIS, BGP, etc; *Box-centric* config/management
    - Build our own

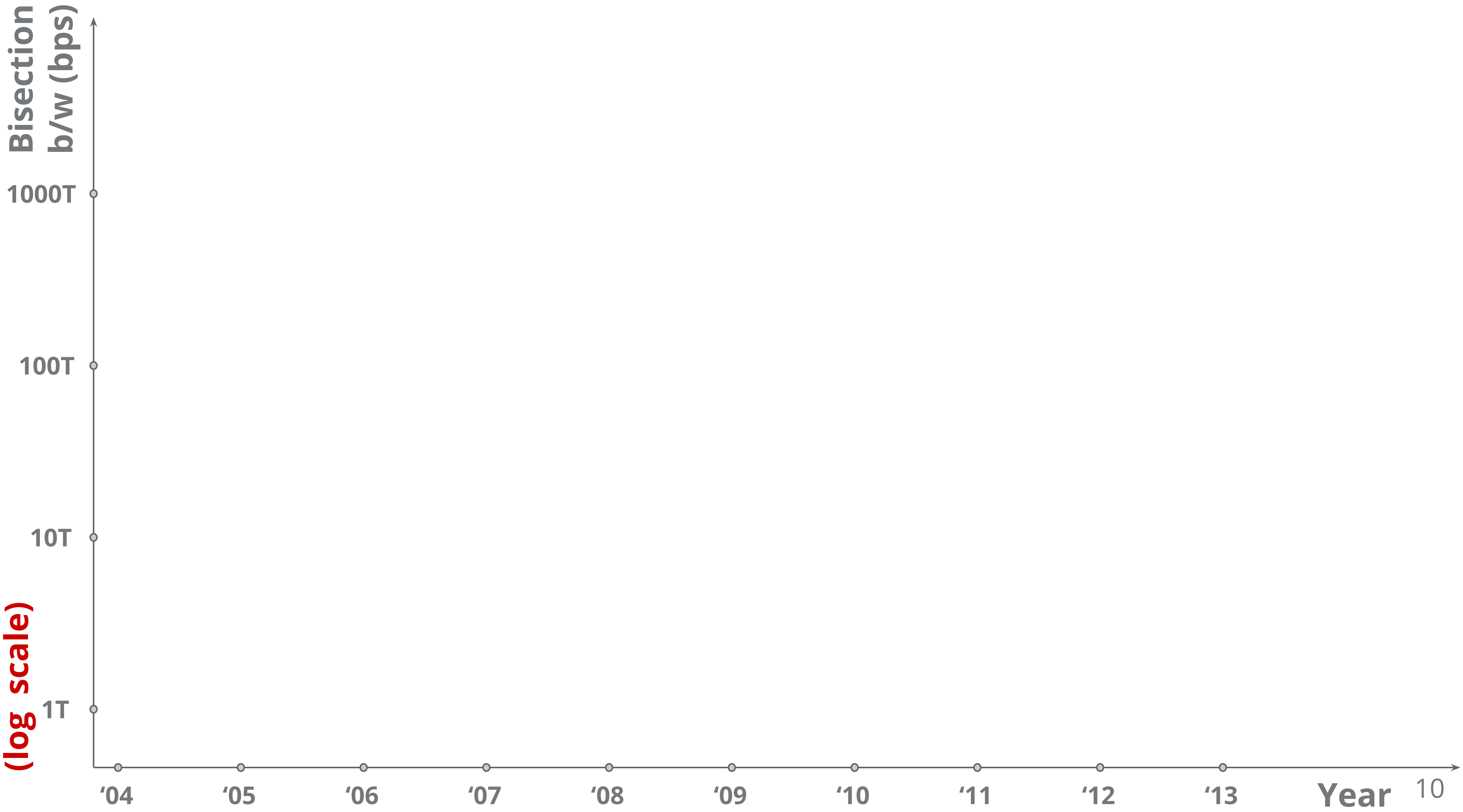
- Reasons we chose to build our own central control/management:
    - Limited support for **multipath forwarding**
    - No **robust** open source stacks
    - **Broadcast** protocol scalability a concern at scale
    - Network **manageability** painful with individual switch configs

Challenges faced in building our own solution

- **Topology and deployment**
  - Introducing our network to production
  - Unmanageably high number of cables/fiber
  - Cluster-external burst b/w demand
- **Control and management**
  - Operating at huge scale
  - Routing scalability / routing with massive multipath
  - Interop with external vendor gear
- **Performance and reliability**
  - Small on-chip buffers
  - High availability from cheap/less reliable components

Outline

- Motivation
- **Network evolution**
- Centralized control / management
- Experience


Bisection b/w (bps)
1000T
100T
10T
1T
(log scale)
'04
'05
'06
'07
'08
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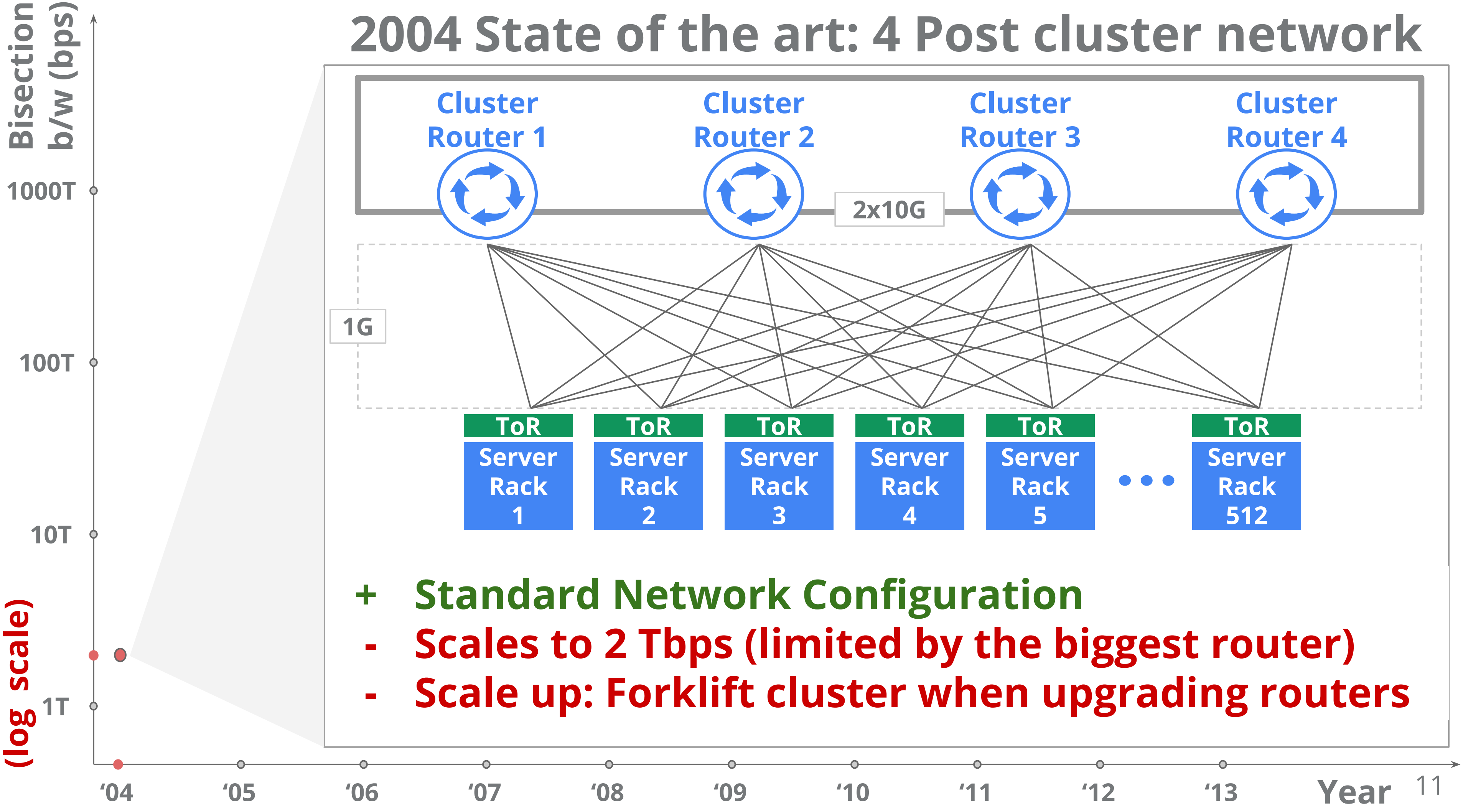
'10
'11
'12
'13
Year

2004 State of the art: 4 Post cluster network

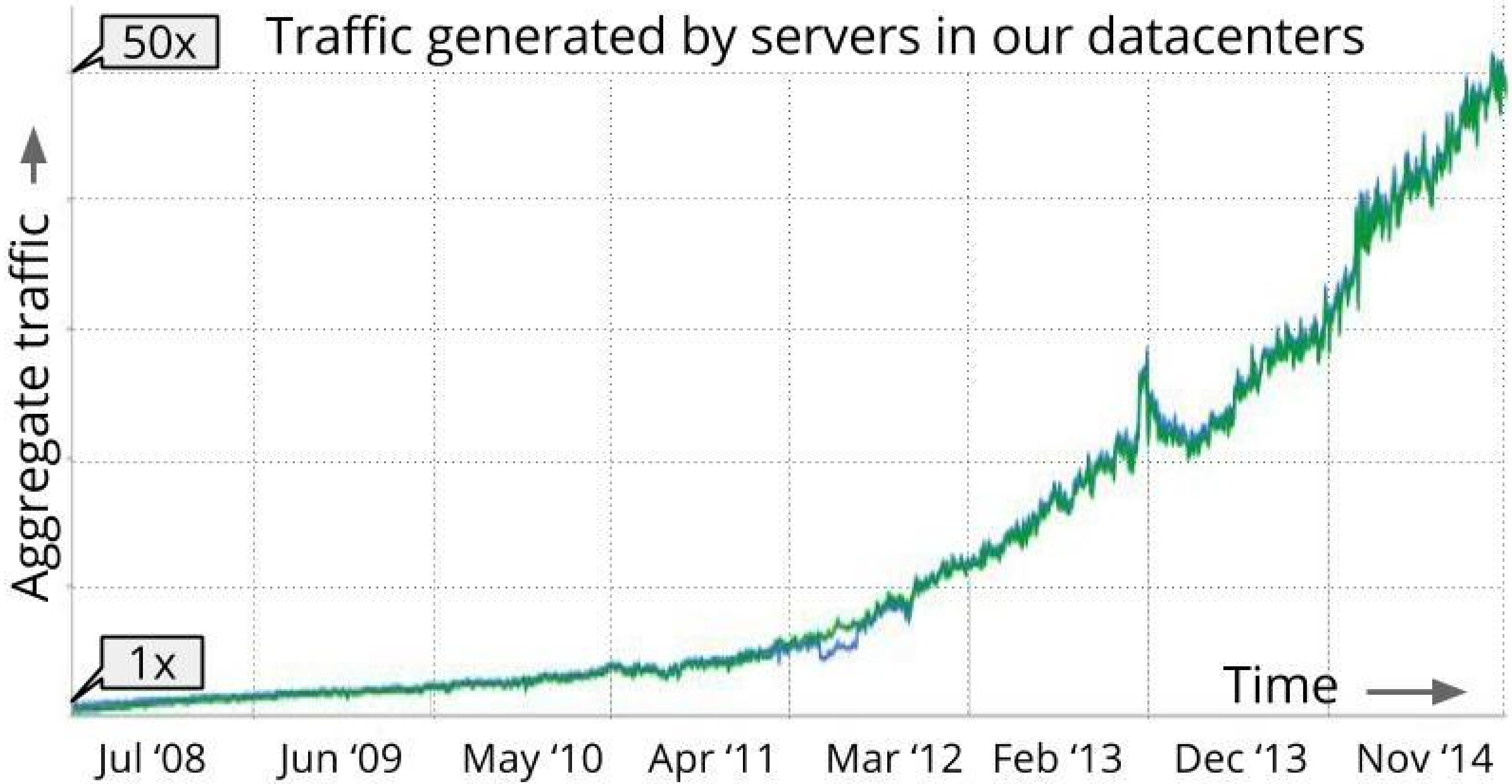


+ Standard Network Configuration

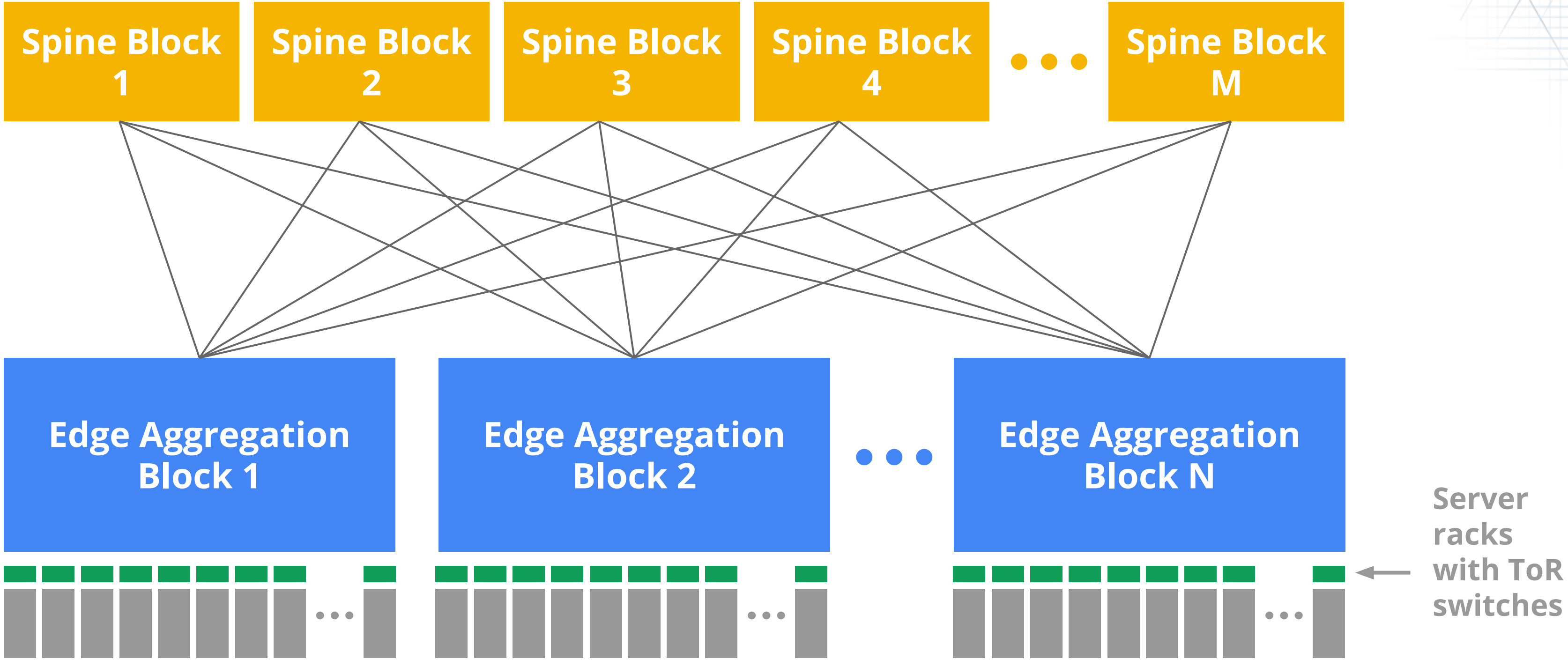
- Scales to 2 Tbps (limited by the biggest router)

- Scale up: Forklift cluster when upgrading routers

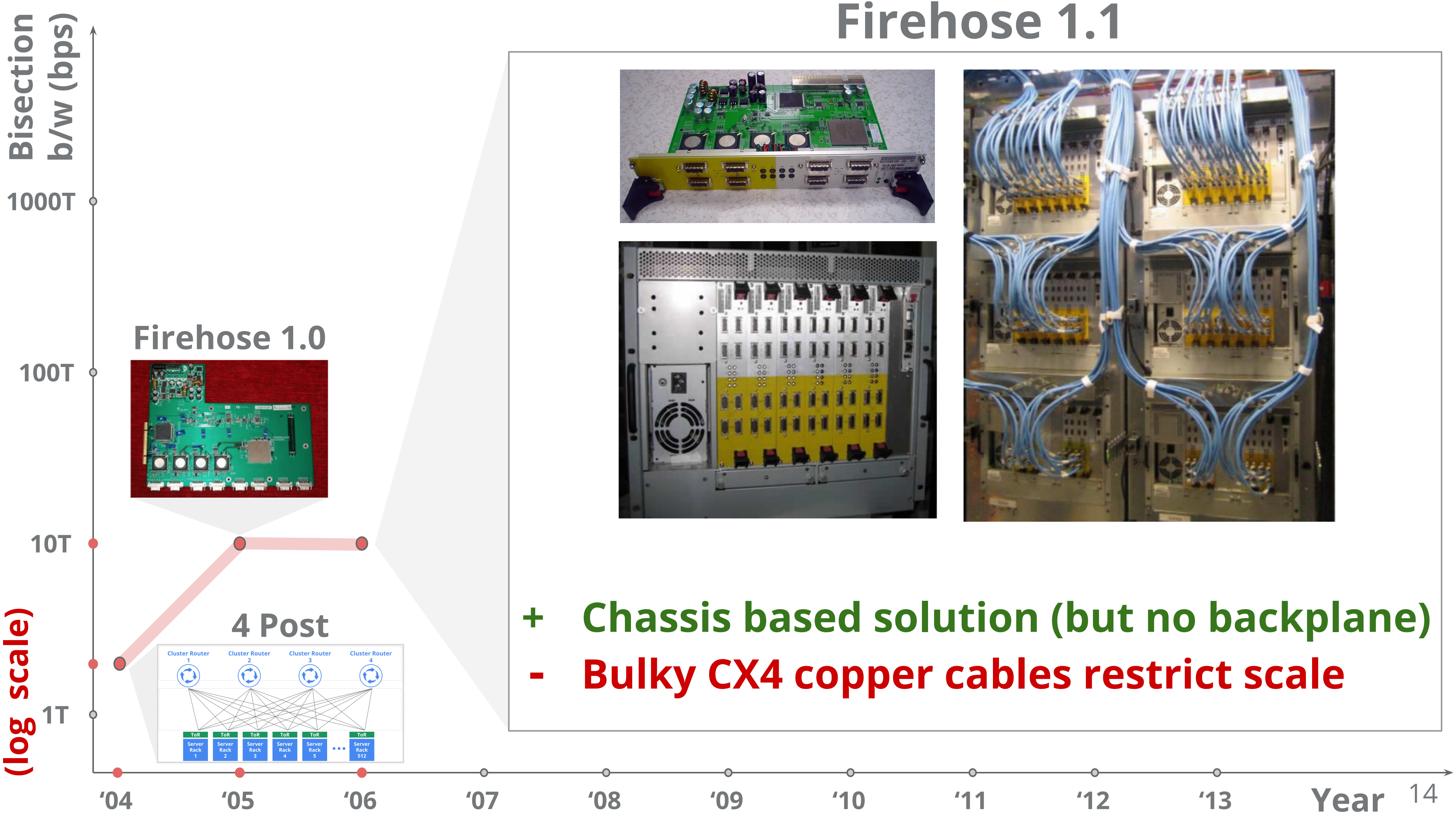
DCN bandwidth growth demanded much more



Five generations of Clos for Google scale



Firehose 1.1



+ Chassis based solution (but no backplane)

- Bulky CX4 copper cables restrict scale

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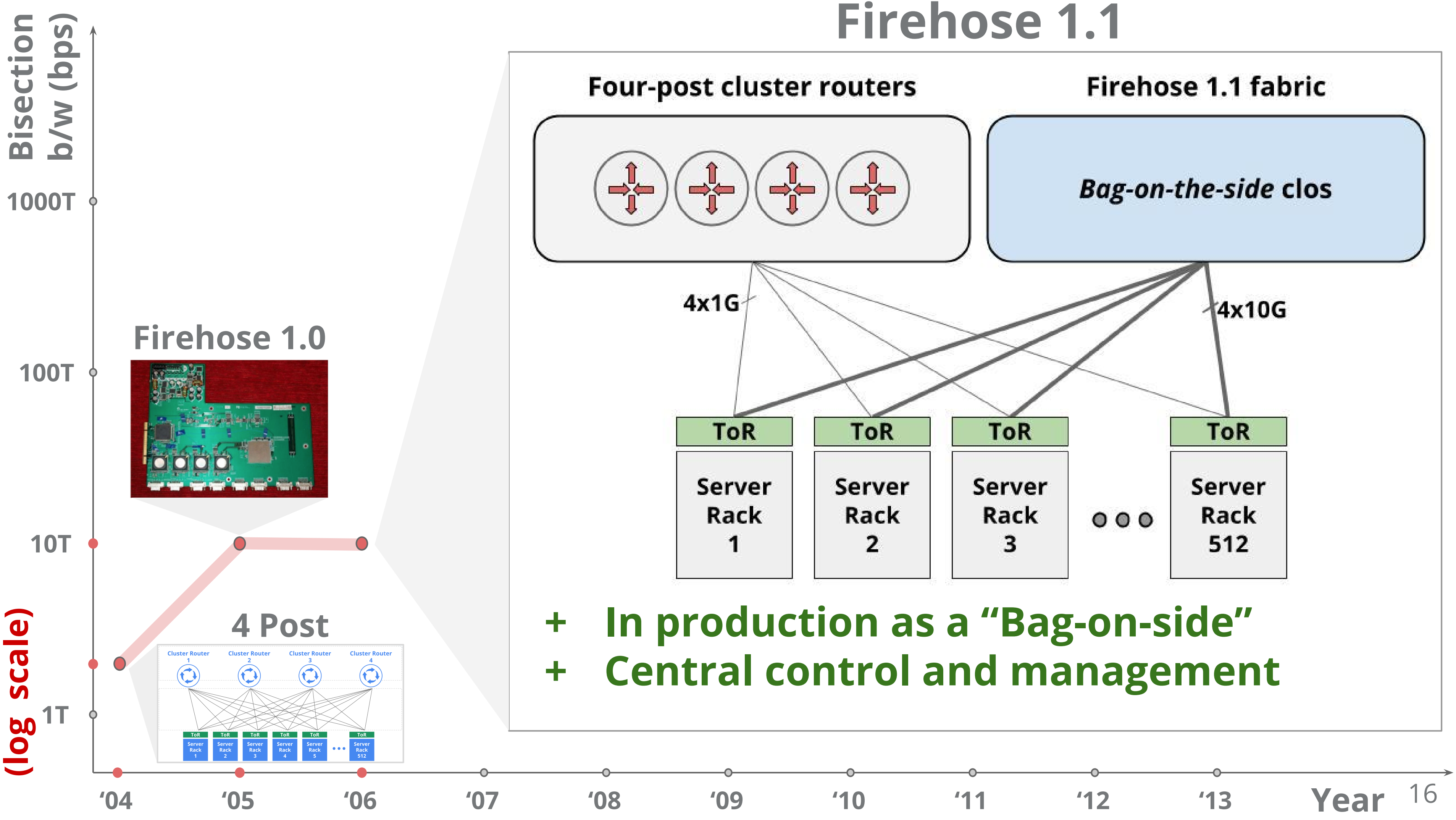
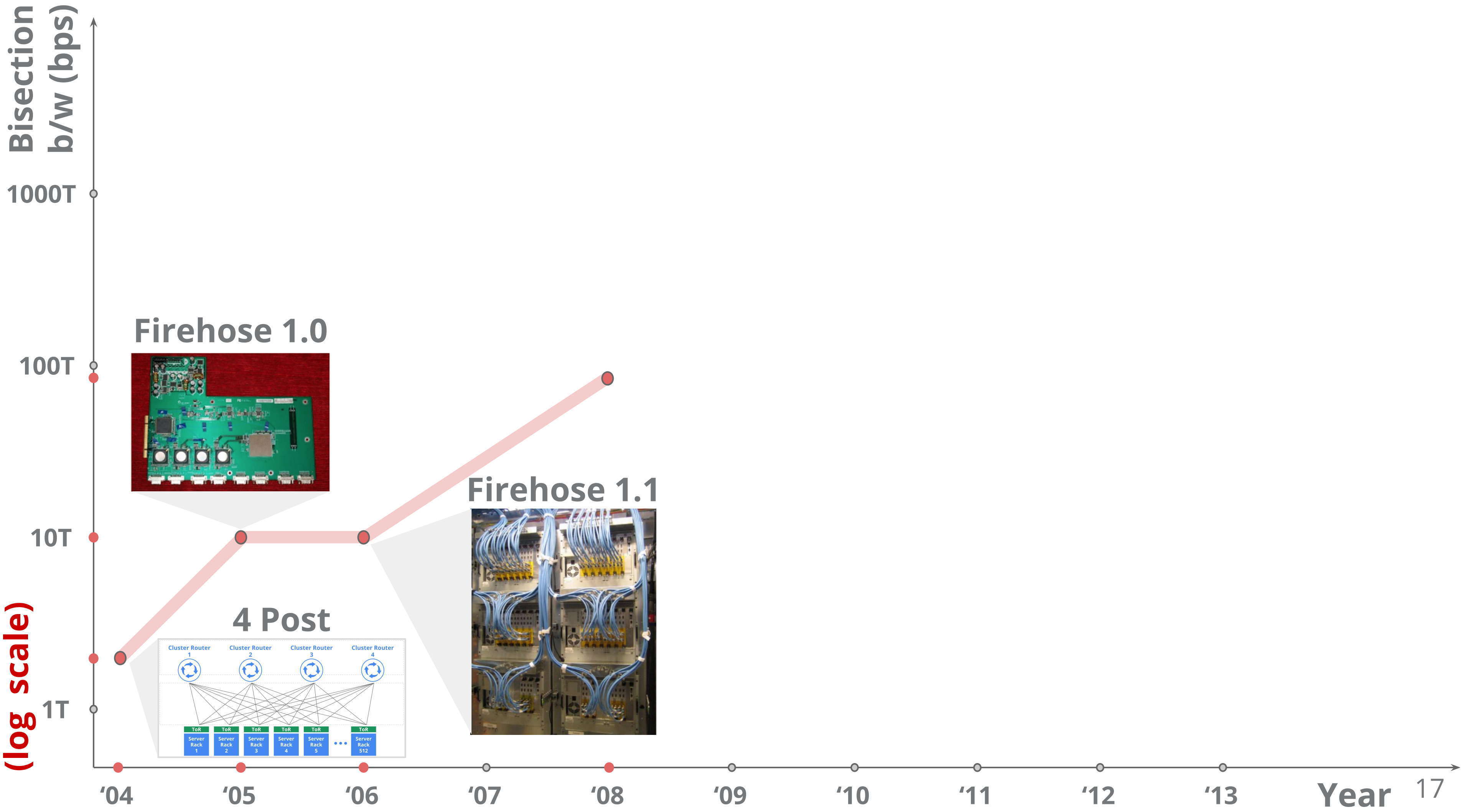


- + In production as a "Bag-on-side"
- + Central control and management


Bisection b/w (bps)
(log scale)
1000T
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Firehose 1.0
Firehose 1.1
4 Post
Cluster Router 1
Cluster Router 2
Cluster Router 3
Cluster Router 4
ToR
Server Rack 1
Server Rack 2
Server Rack 3
Server Rack 4
Server Rack 5
Server Rack 512
'04
'05
'06
'07
'08
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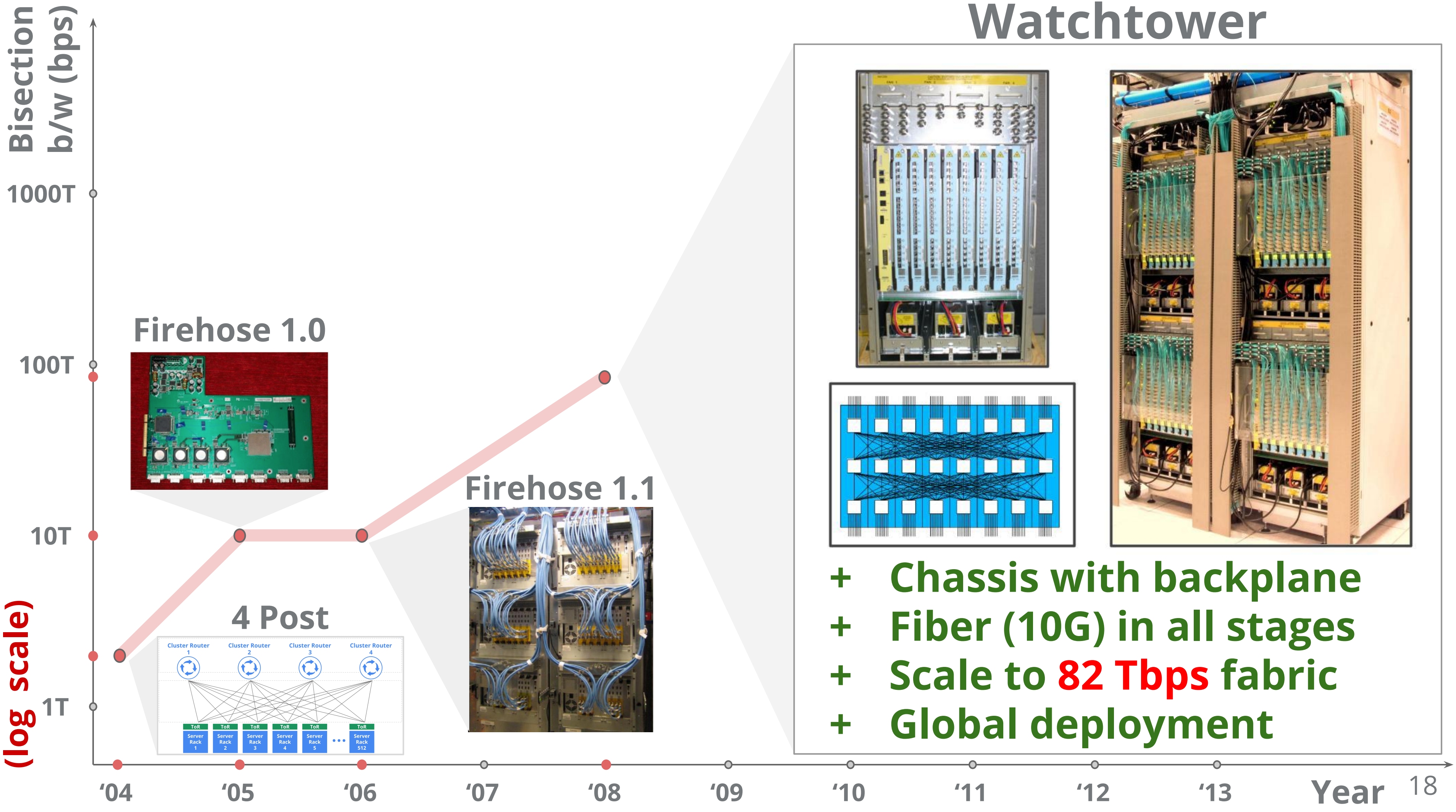
'10
'11
'12
'13
Year



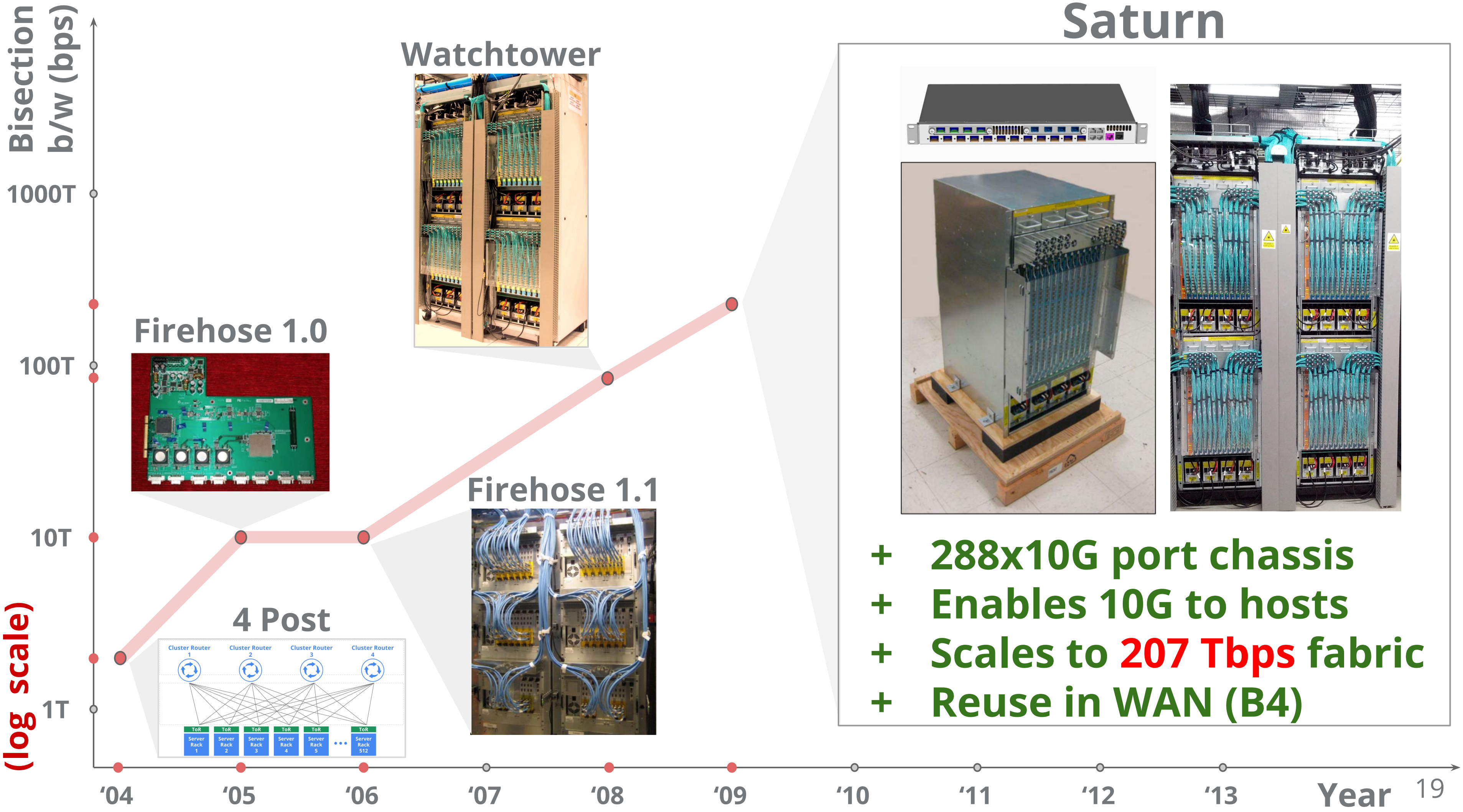
Firehose 1.0

4 Post

Firehose 1.1

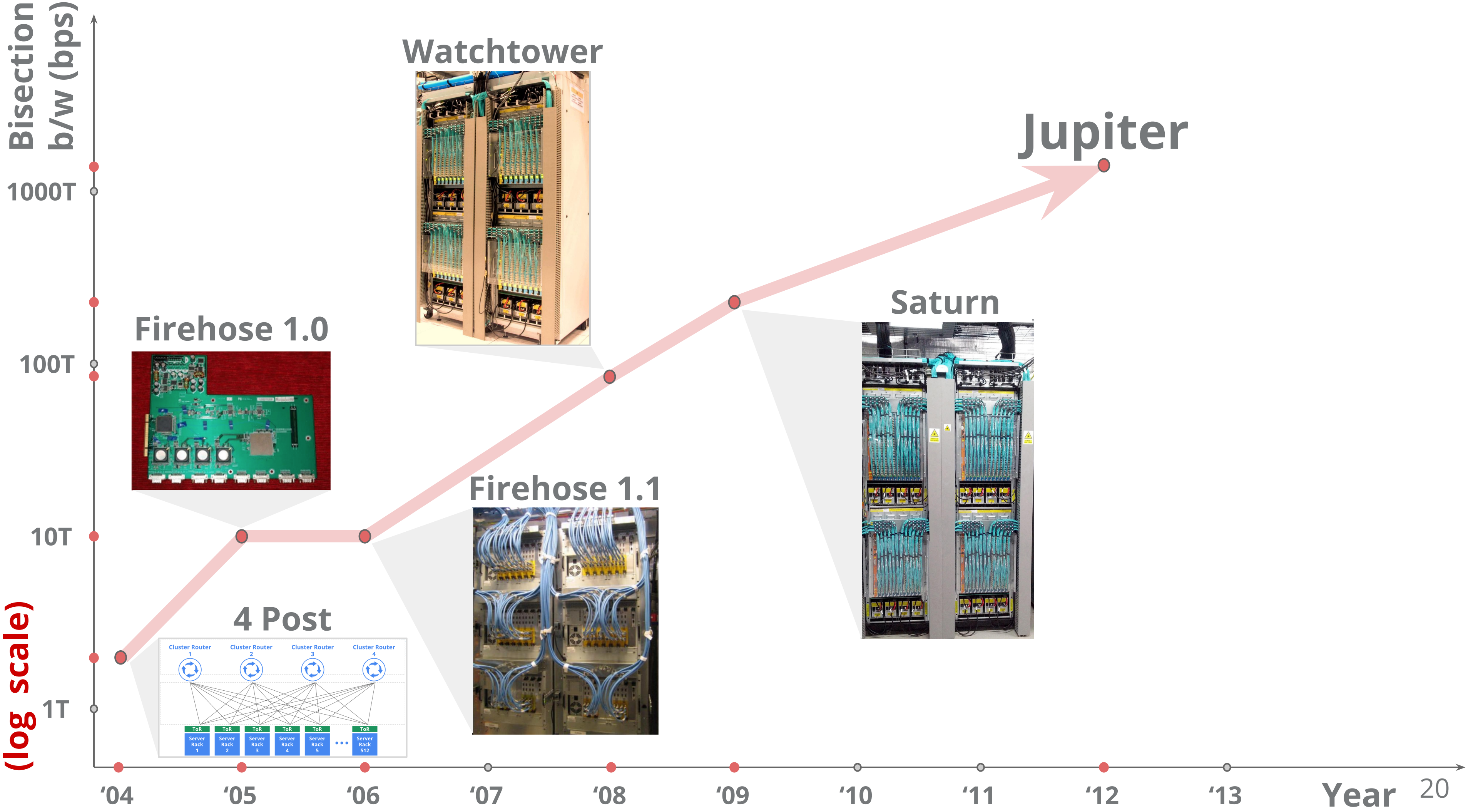
Watchtower

- + Chassis with backplane
- + Fiber (10G) in all stages
- + Scale to 82 Tbps fabric
- + Global deployment



Saturn

- + 288x10G port chassis
- + Enables 10G to hosts
- + Scales to 207 Tbps fabric
- + Reuse in WAN (B4)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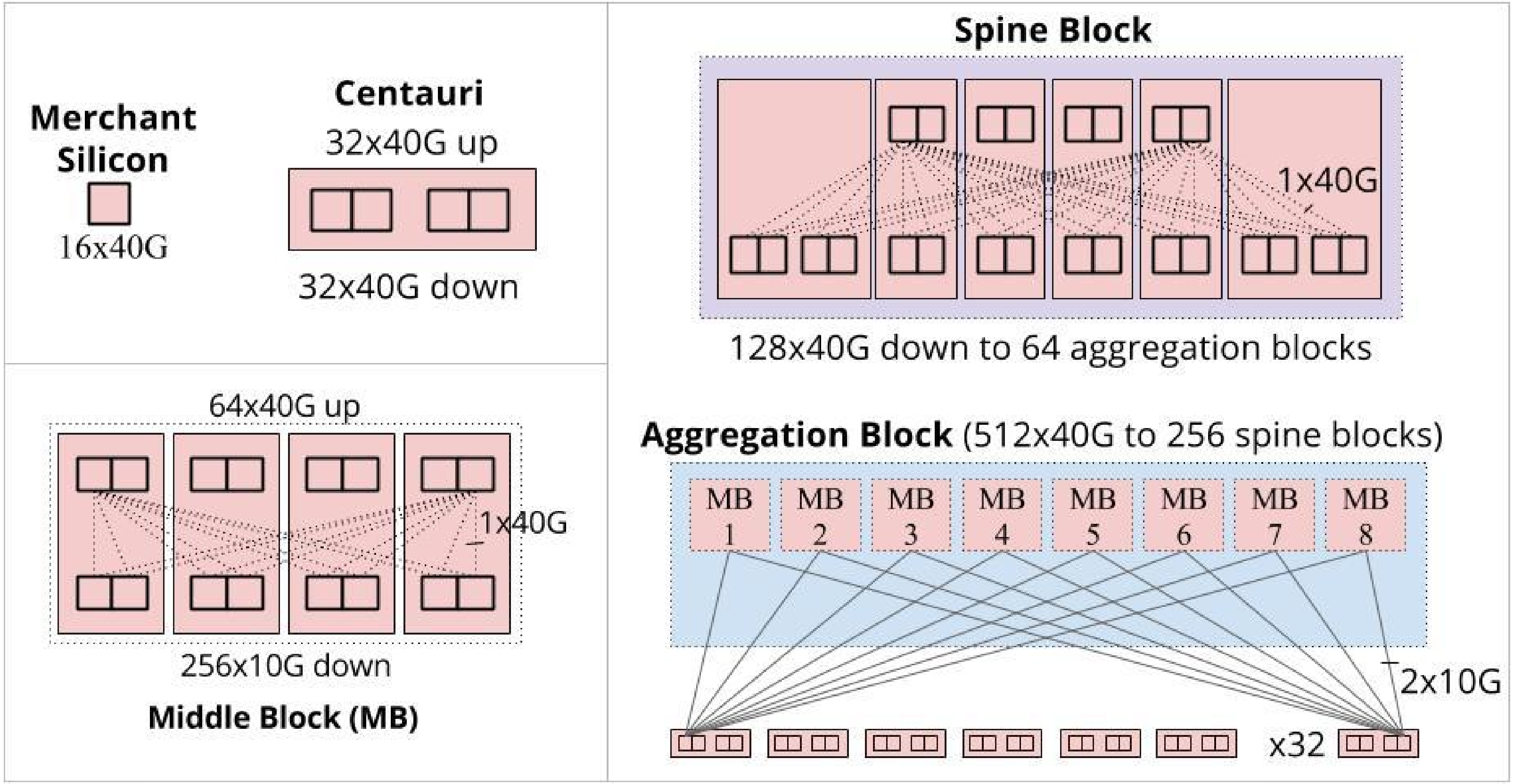
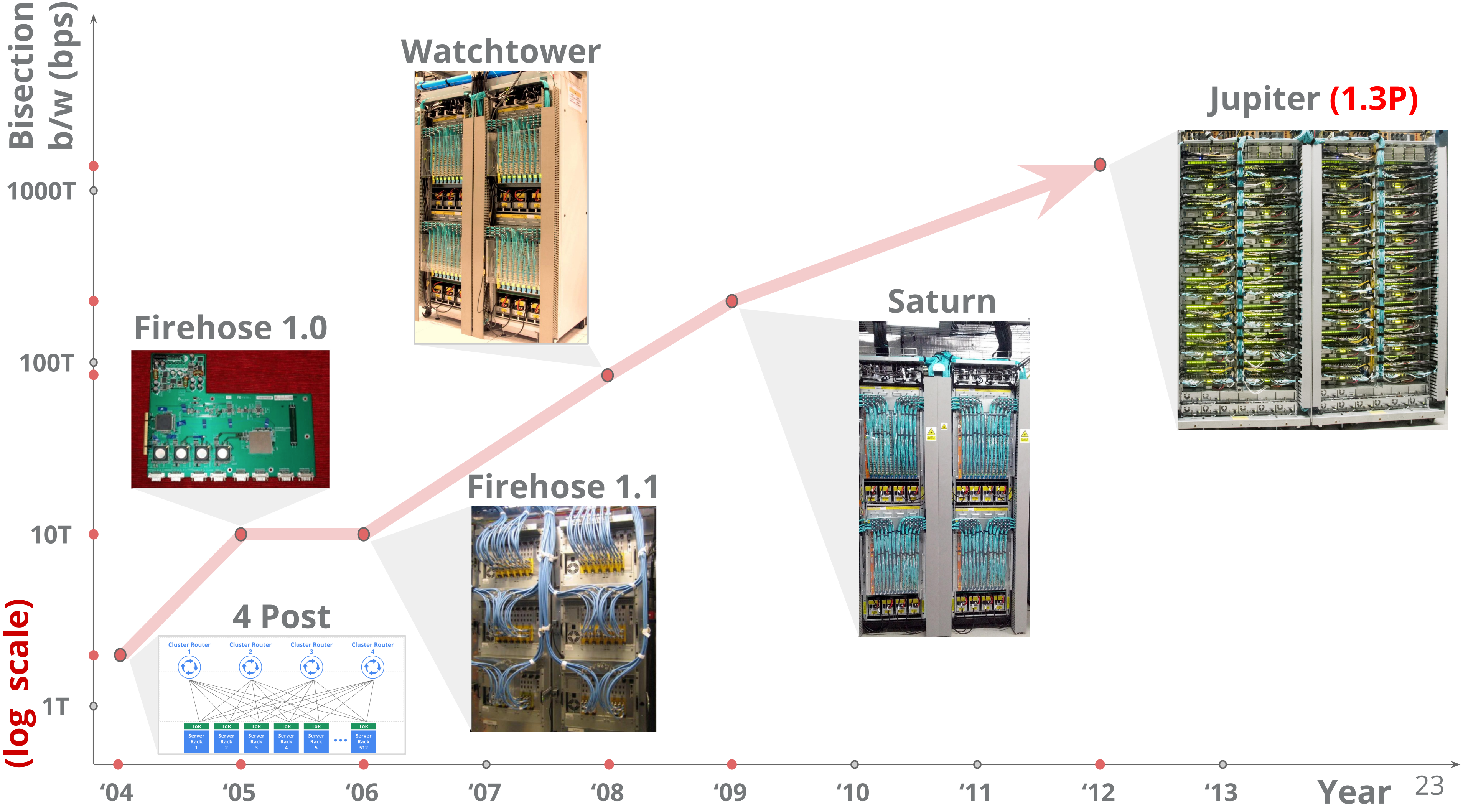
Jupiter topology



+ Scales out building wide 1.3 Pbps

Jupiter racks

- + Enables 40G to hosts
- + External control servers
- + OpenFlow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  - High availability from cheap/less reliable components

Network control and config

New conventional wisdom from engineering systems at scale

- **Logically centralized control** plane beats full decentralization
- **Centralized configuration and management** dramatically simplifies system aspects
- **Scale out** >> Scale up

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- **Performance and reliability**
  - **Small on-chip buffers** → **Tune switches (eg ECN) and Hosts (DCTCP)**
  - High availability from cheap/less reliable components

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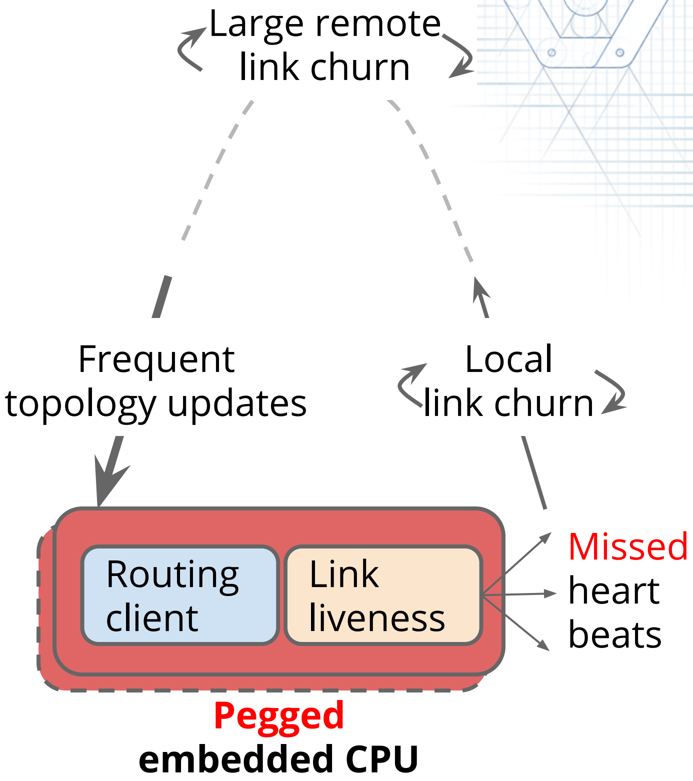
↳ **Redundancy; diversity; implement only what was needed**

Experience: Outages

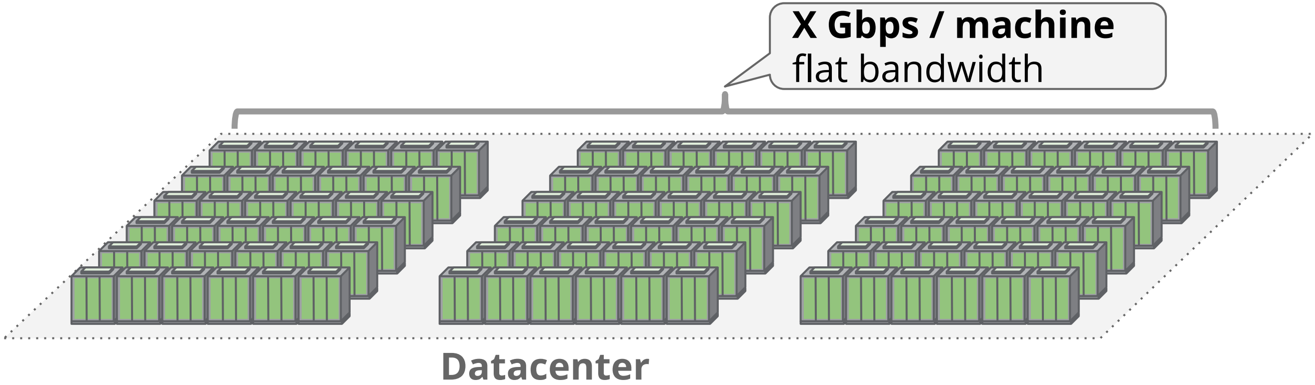
Three broad categories of outages:

- **Control software failures at scale**
  - Cluster-wide reboot did not converge
    - Liveness protocol contended for cpu with routing process
  - Cannot test at scale in a hardware lab
    - Developed virtualized testbeds
- **Aging hardware exposes corner cases**
- **Component misconfigurations**



Grand challenge for datacenter networks

- **Challenge: Flat b/w profile across all servers**
  - Simplify job scheduling (remove locality)
  - Save significant resources (better bin-packing)
  - Allow application scaling
- Scaled datacenter networks to Petabit scale in under a decade
- Bonus: reused solution in campus aggregation and WAN


X Gbps / machine
flat bandwidth
Datacenter