Google™ OpenFlow @ Google

Summary

Google

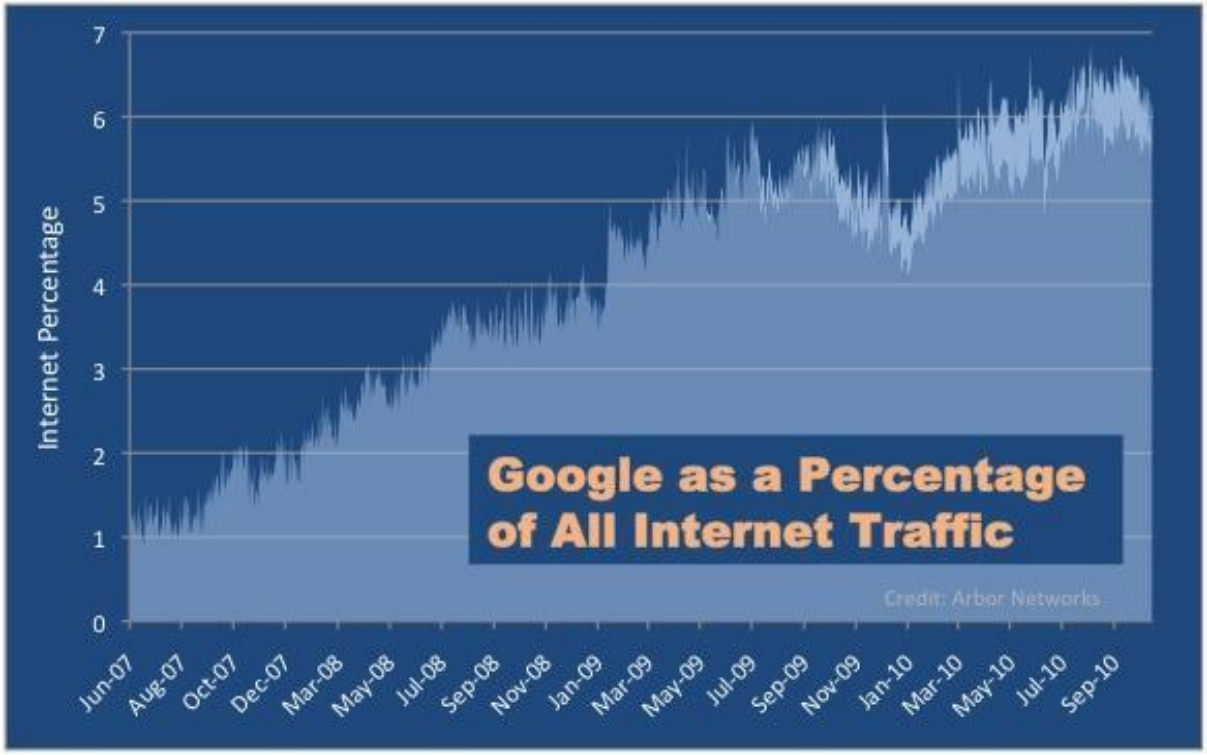
- Google operates two large backbone networks
  - Internet-facing backbone (user traffic)
  - Datacenter backbone (internal traffic)
- Managing large backbones is hard
- OpenFlow has helped us improve backbone performance and reduce backbone complexity and cost
- I'll tell you how

Backbone Scale

Google

"If Google were an ISP, as of this month it would rank as the second largest carrier on the planet."

[ATLAS 2010 Traffic Report, Arbor Networks]



WAN-Intensive Applications

Google™

- YouTube
- Web Search
- Google+
- Photos and Hangouts
- Maps
- AppEngine
- Android and Chrome updates

WAN Economics

Google

- Cost per bit/sec delivered should go down with additional scale, not up
  - Consider analogies with compute and storage

- However, *cost/bit doesn't naturally decrease with size*
  - Quadratic complexity in pairwise interactions and broadcast overhead of all-to-all communication requires more expensive equipment
  - Manual management and configuration of individual elements
  - Complexity of automated configuration to deal with non-standard vendor configuration APIs

Solution: WAN Fabrics

Google

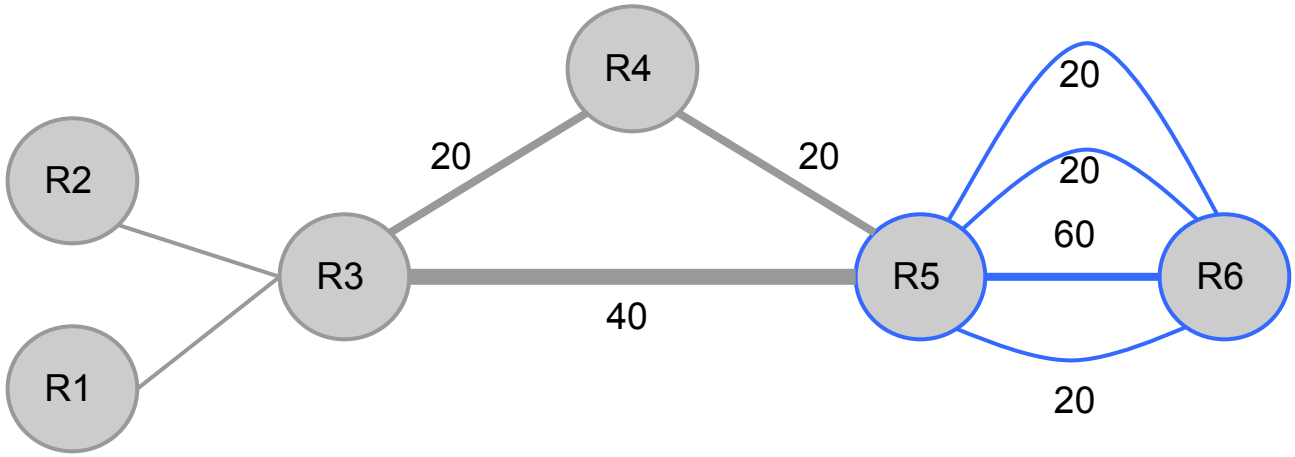
- Goal: manage the WAN as a *fabric* not as a collection of individual boxes
- Current equipment and protocols don't allow this
  - Internet protocols are box centric, not fabric centric
  - Little support for monitoring and operations
  - Optimized for “eventual consistency” in routing
  - Little baseline support for low latency routing and fast failover

Motivating Examples

Convergence After Failure

Google™

- Flows: R1->R6: 20; R2->R6: 20; R4->R6: 20



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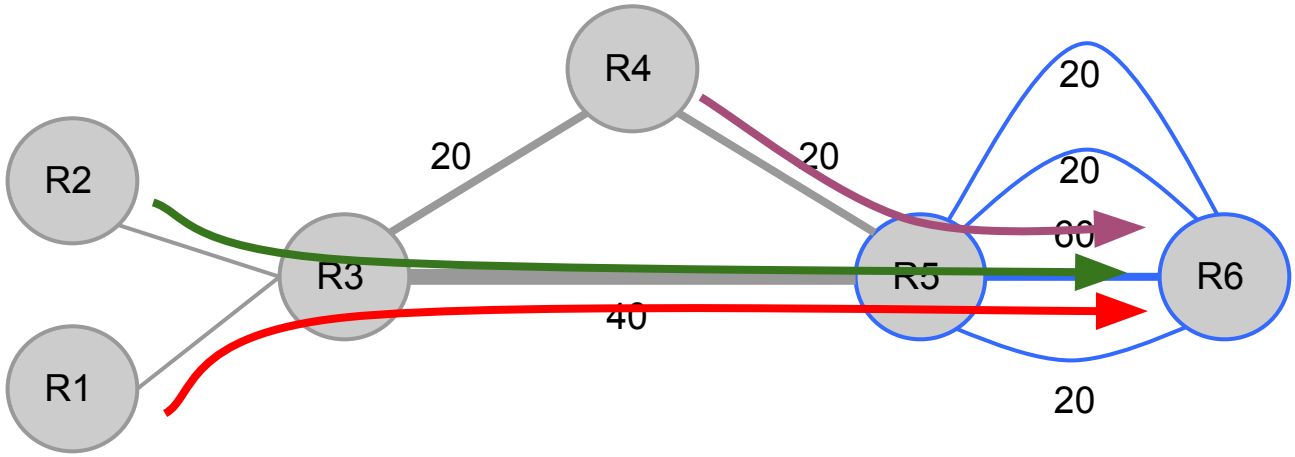

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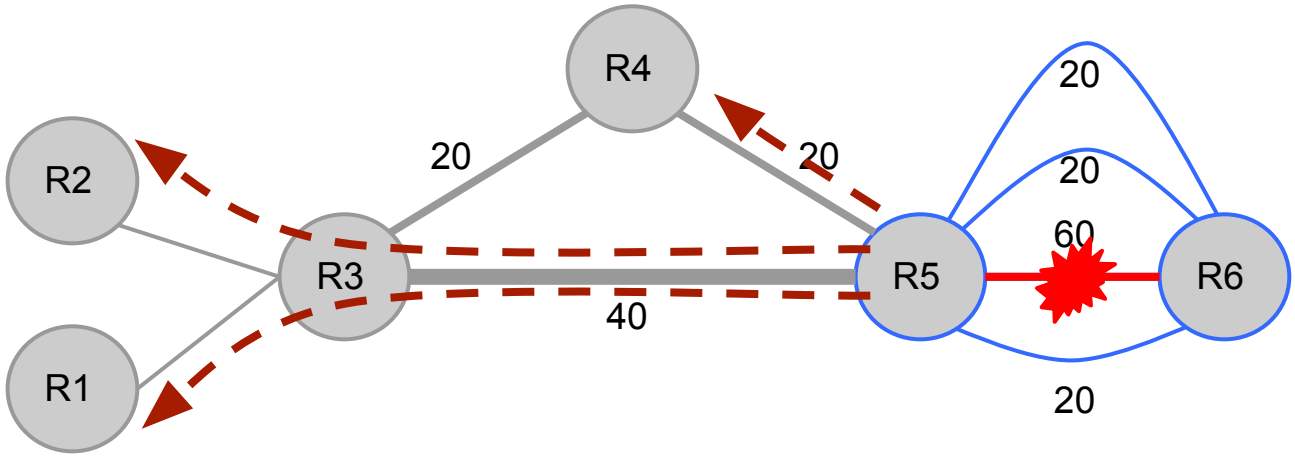

- R5-R6 link fails
  - R1, R2, R4 *autonomously* try for next best path

Convergence After Failure

Google

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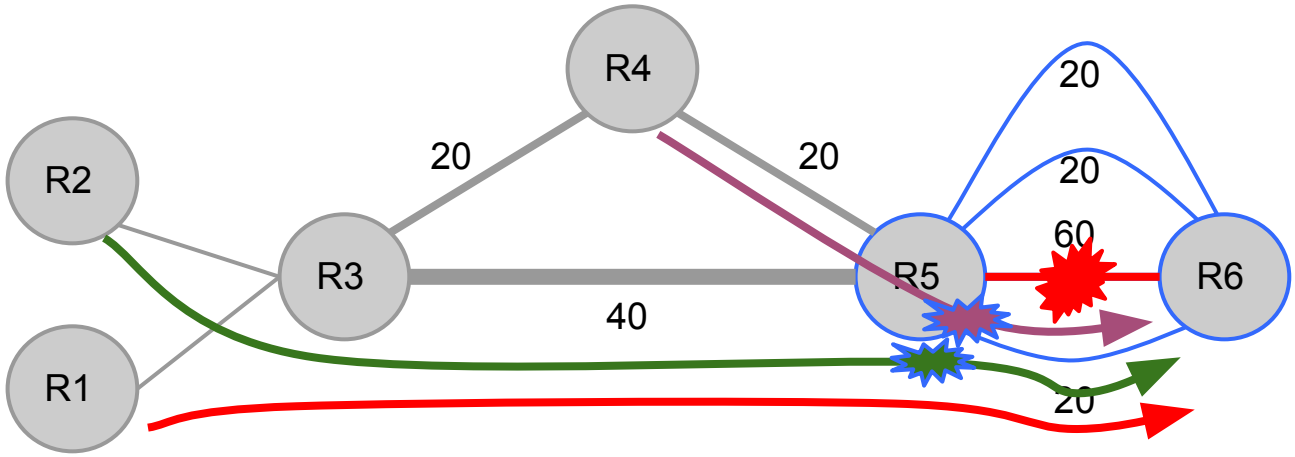

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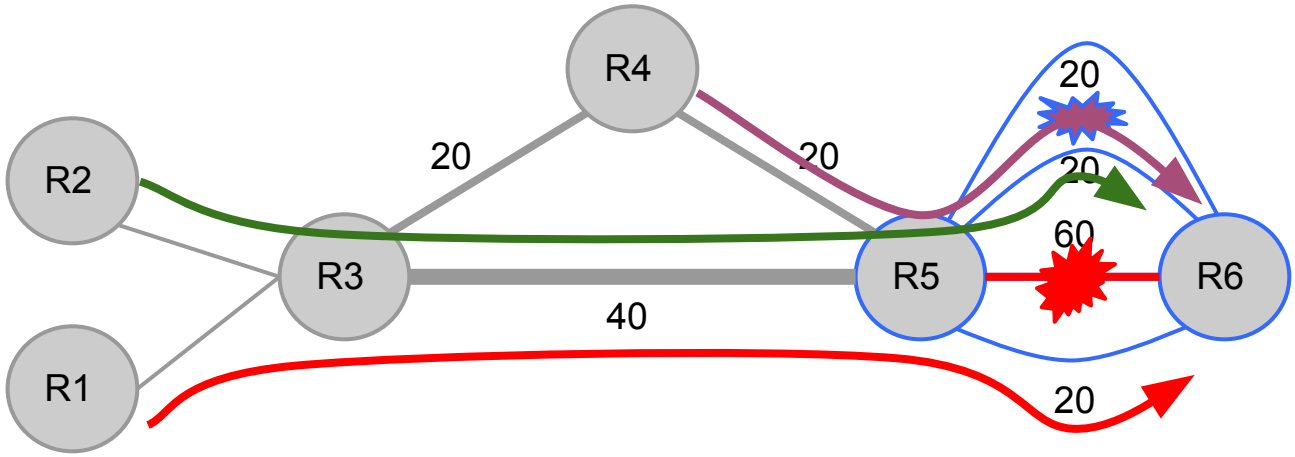

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Google

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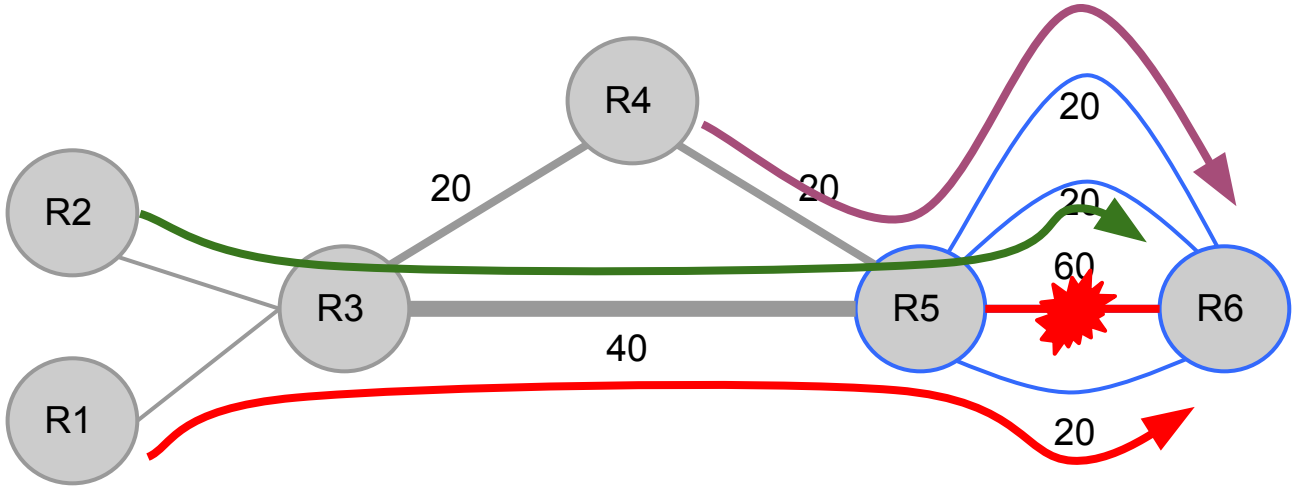

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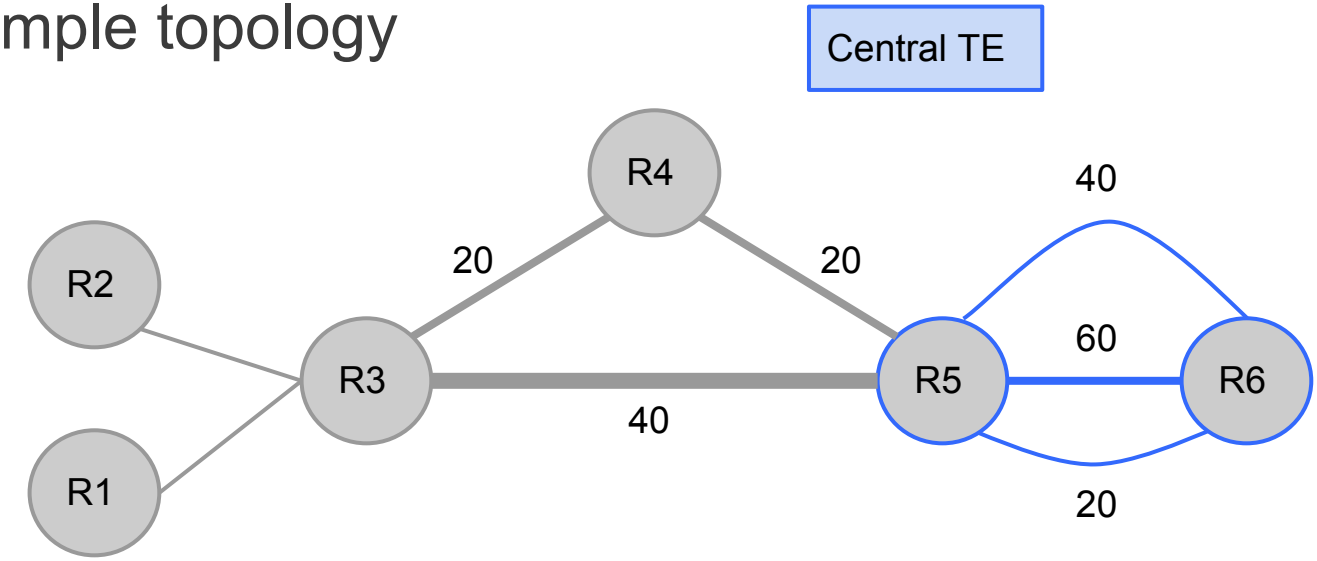
  - R1 wins, R2, R4 retry for next best path
  - R2 wins this round, R4 retries again
  - R4 finally gets third best path

Centralized Traffic Engineering Google™

- Simple topology



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Centralized Traffic Engineering Google™

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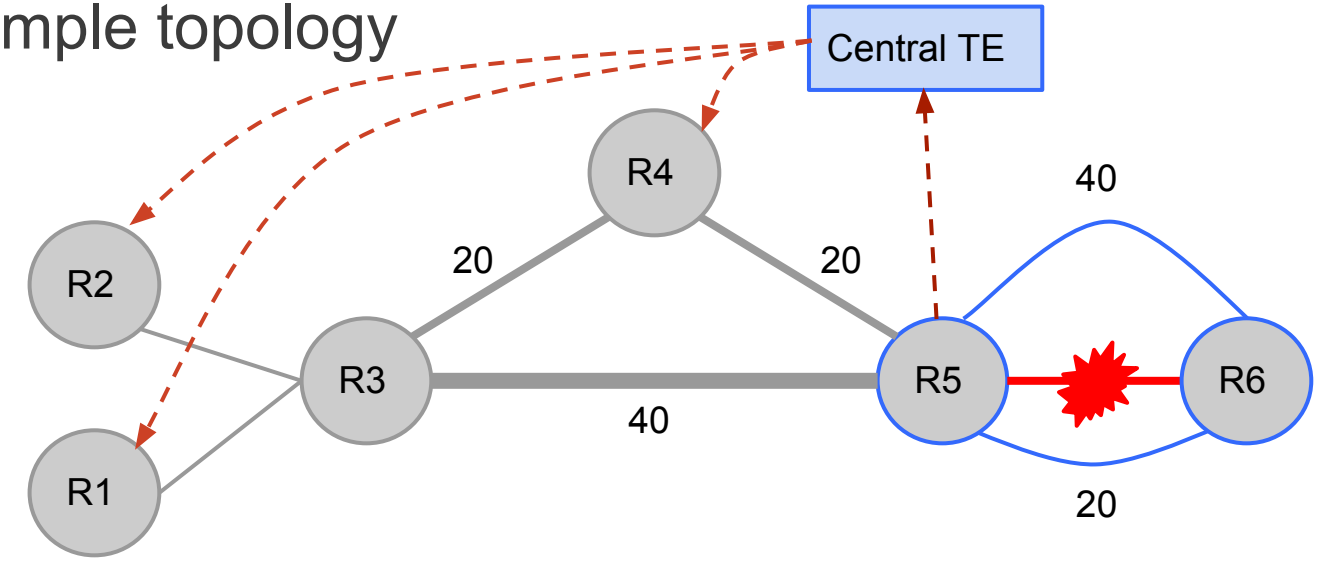

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Centralized Traffic Engineering Google™

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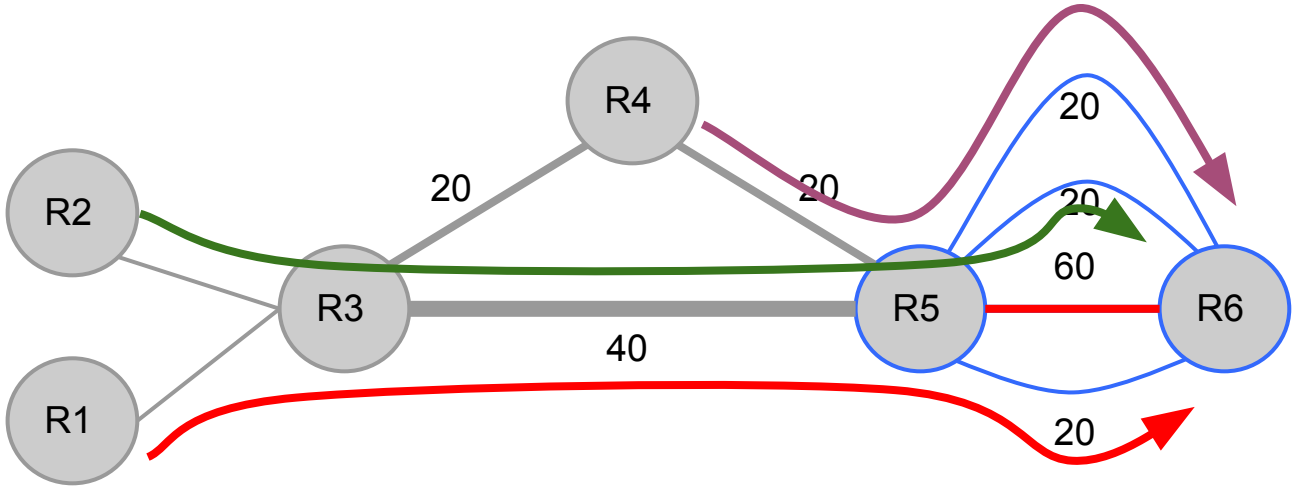


- Flows:
  - R1->R6: 20; R2->R6: 20; R4->R6: 20
- R5-R6 link fails
  - R5 informs TE, which programs routers in one shot
  - Leads to faster realization of target optimum

Advantages of Centralized TE

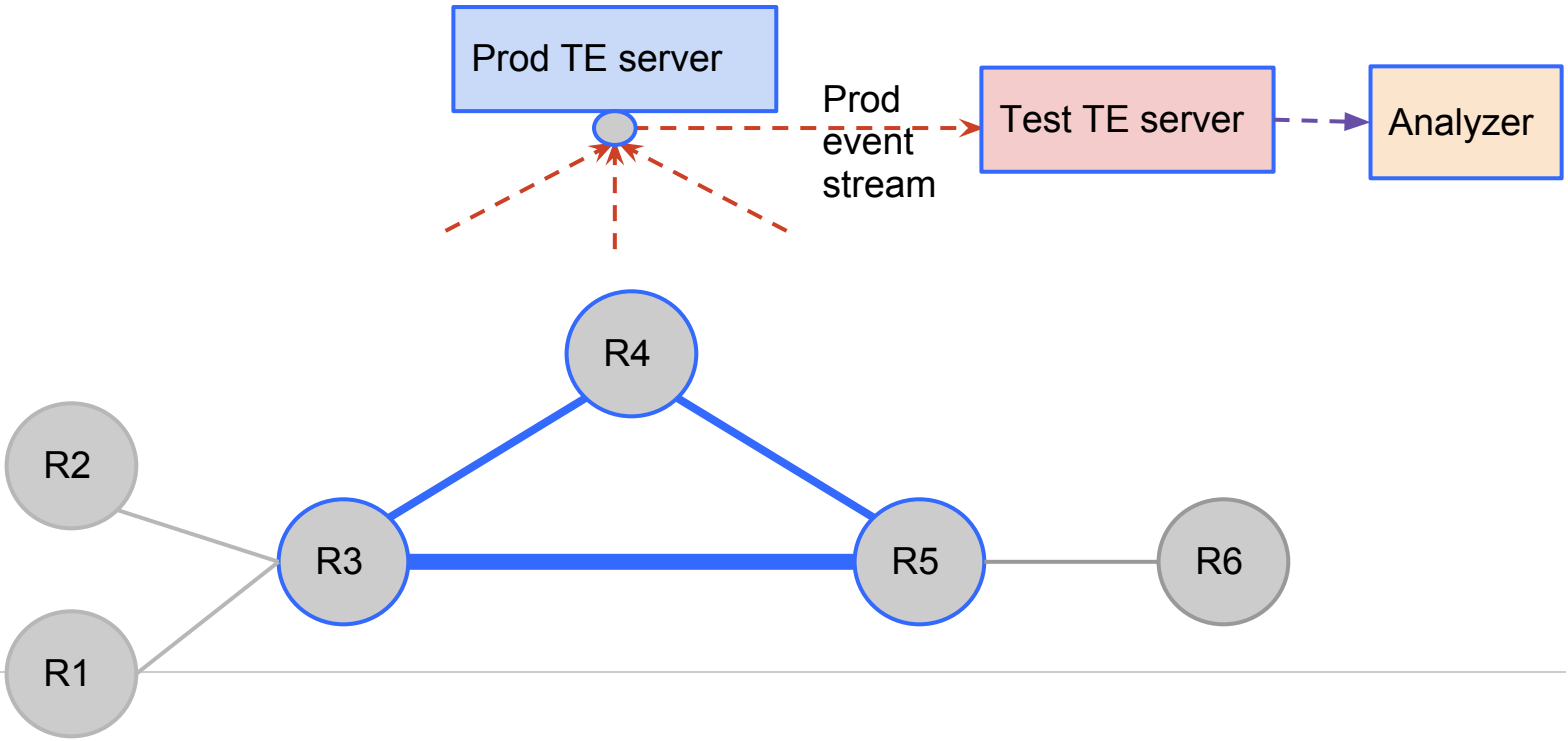
Google™

- Better network utilization with global picture
- Converges faster to target optimum on failure
- Allows more control and specifying intent
  - Deterministic behavior simplifies planning vs. overprovisioning for worst case variability
- Can mirror production event streams for testing
  - Supports innovation and robust SW development
- Controller uses modern server hardware
  - 50x (!) better performance

Testability Matters

Google

- Decentralized requires a full scale replica of a real testbed to test new TE features.
- Centralized can tap real production input to research new ideas and to test new implementations



SDN Testing Strategy

Google

- Various logical modules enable testing in isolation
- Virtual environment to experiment and test with the complete system end to end
  - Everything is real but hardware
- Emphasis on in-built consistency checks (both during testing and in production)
- Tools to validate programming state across all the devices. Validation checks can be done after every update from the central server (in virtual environment)
  - Enforce 'make-before-break' semantics

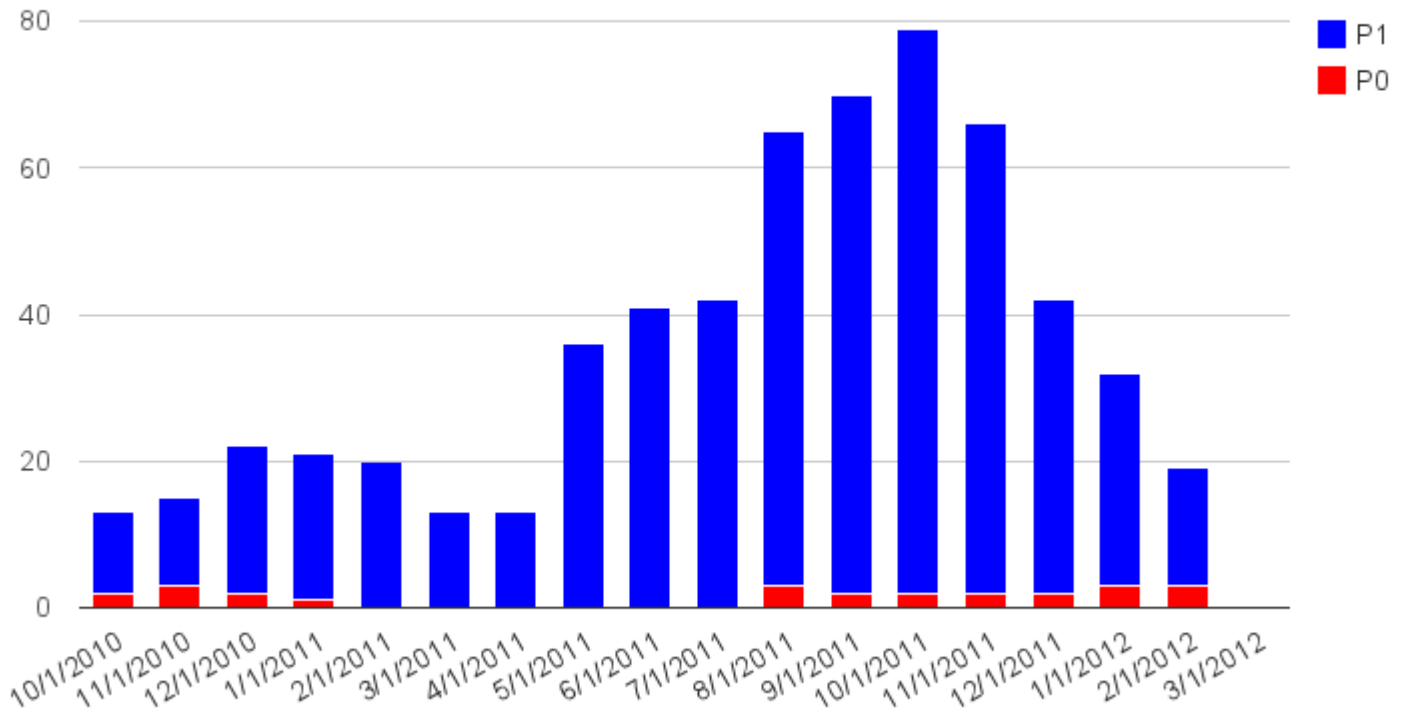
Our Simulated WAN

Google

- Control servers run real binaries
- Switches are virtualized
  - real OpenFlow binary, fake HAL
- Arbitrary topology (can simulate entire backbone)
- Can attach real monitoring and alerting servers

OFC Bug History

Google



Why Software Defined WAN

Google

- Separate hardware from software
  - Choose hardware based on necessary features
  - Choose software based on protocol requirements
- Logically centralized network control
  - More deterministic
  - More efficient
  - More fault tolerant
- Separate monitoring, management, and operation from individual boxes
- *Flexibility and Innovation*

Result: A WAN that is higher performance, more fault tolerant, and cheaper

Google's OpenFlow WAN

Google's WAN

Google

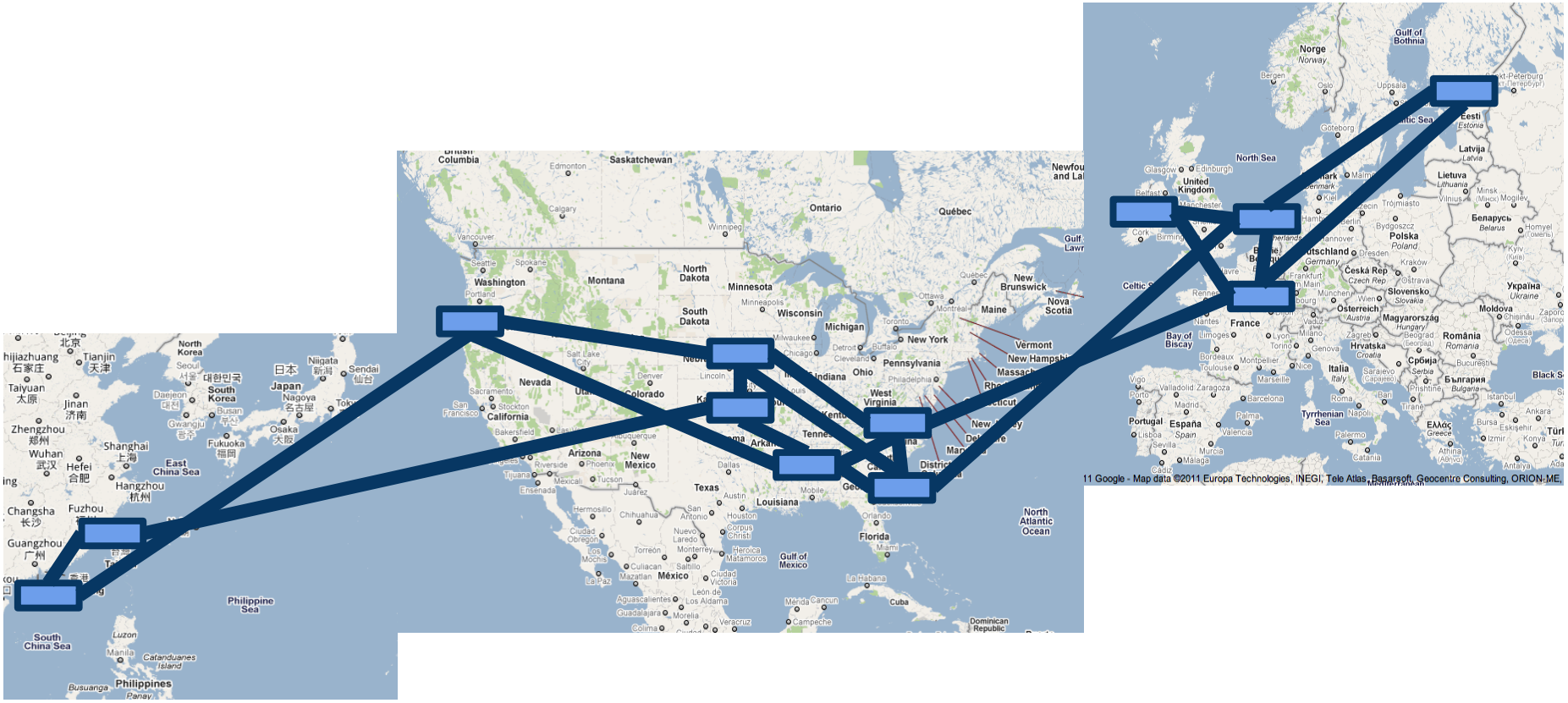
- Two backbones
  - Internet facing (user traffic)
  - Datacenter traffic (internal)

- Widely varying requirements: loss sensitivity, availability, topology, etc.

- Widely varying traffic characteristics: smooth/diurnal vs. bursty/bulk

- Therefore: built two separate logical networks
  - I-Scale (bulletproof)
  - G-Scale (possible to experiment)

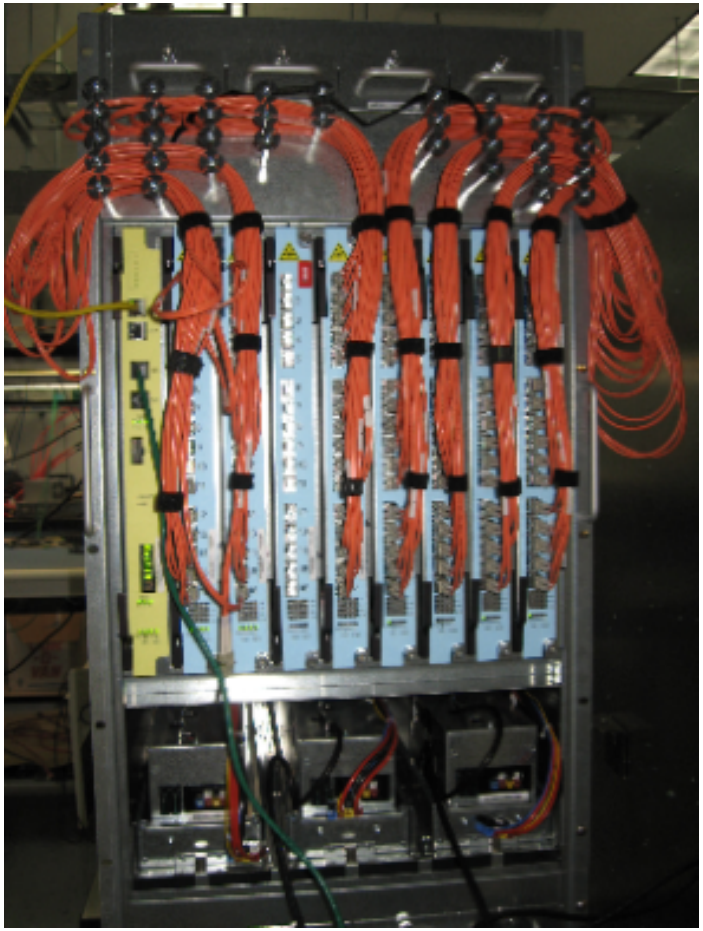
Google's OpenFlow WAN



G-Scale Network Hardware

Google

- Built from merchant silicon
  - 100s of ports of nonblocking 10GE
- OpenFlow support
- Open source routing stacks for BGP, ISIS
- Does not have all features
  - No support for AppleTalk...
- Multiple chassis per site
  - Fault tolerance
  - Scale to multiple Tbps



G-Scale WAN Deployment

Google

- Multiple switch chassis in each domain
  - Custom hardware running Linux
- Quagga BGP stack, ISIS/IBGP for internal connectivity

Deployment History

Google

- Phase 1 (Spring 2010):
  - Introduce OpenFlow-controlled switches but make them look like regular routers
    - No change from perspective of non-OpenFlow switches
    - BGP/ISIS/OSPF now interfaces with OpenFlow controller to program switch state
- Pre-deploy gear at one site, take down 50% of site bandwidth, perform upgrade, bring up with OpenFlow, test, repeat for other 50%
- Repeat at other sites

Deployment History

Google

- Phase 2 (until mid-2011): ramp-up
- Activate simple SDN (no TE)
- Move more and more traffic to test new network
- Test transparent roll-out of controller updates

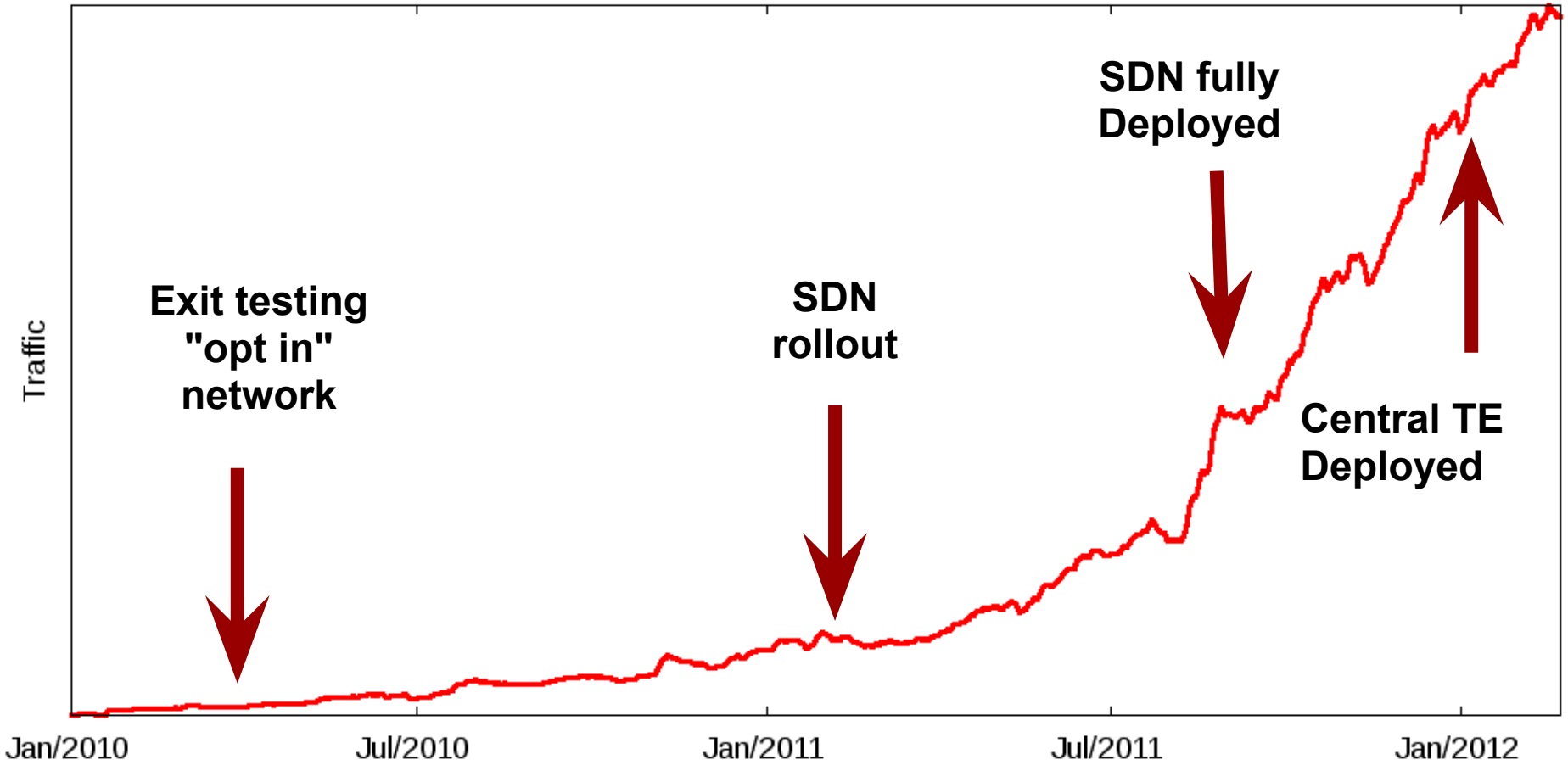
Deployment History

Google

- Phase 3 (early 2012): full production at one site
- All datacenter backbone traffic carried by new network
- Rolled out centralized TE
  - Optimized routing based on application-level priorities (currently 7)
  - Globally optimized placement of flows
- External copy scheduler interacts with OpenFlow controller to implement deadline scheduling for large data copies

G-Scale WAN Usage

Google



Google SDN Experiences

Google

- Much faster iteration time: deployed production-grade centralized traffic engineering in two months
  - fewer devices to update
  - much better testing ahead of rollout
- Simplified, high fidelity test environment
  - Can emulate entire backbone in software
- Hitless SW upgrades and new features
  - No packet loss and no capacity degradation
  - Most feature releases do not touch the switch

Google SDN Experiences

Google

- Already seeing higher network utilization
  - Flexible management of end-to-end paths for maintenance
  - Deterministic network planning
- Generally high degree of stability
  - One outage from software bug
  - One outage triggered by bad config push
- Too early to quantify the benefits
  - Still learning

Confirmed SDN Opportunities Google™

- Unified view of the network fabric
- Traffic engineering
  - Higher QoS awareness and predictability
  - Latency, loss, bandwidth, deadline sensitivity
  - Application differentiation
- Improved routing
  - Based on a priori knowledge of the topology
  - Based on a priori knowledge of L1 and L3 connectivity
- Improved monitoring and alerts

SDN Challenges

Google

- Infancy of OF protocol
  - Still barebones but good enough
- Master election/control plane partition is challenging to handle
- What to keep on box what to remove? Not a perfect science
  - For things that remain on the box, how to configure?
- Flow programming can be slow for large networks
- All of the above are surmountable

Conclusions

Google

- OpenFlow is ready for real-world use
- SDN is ready for real-world use
  - Enables rapid rich feature deployment
  - Simplifies network management
- Google's datacenter WAN successfully runs on OpenFlow
  - Largest production network at Google
  - Improved manageability
  - Improved cost (too early to have exact numbers)

Thank You!