SDN Traffic Engineering with Segment Routing

The Next Evolution

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Traffic Engineering (TE)

- Minimize the worst link utilization
  - Alleviate traffic congestion
  - Better/longer use of equipment/port/fiber
- Route traffic around congested links
  - Put traffic on non-shortest paths

Evolution of Traffic Engineering

- Offline traffic engineering
  - Optimal, but not adaptive
- On-device traffic engineering
  - Adaptive, but not optimal
- *Software defined networking*
  - Best of both worlds, yet simpler; simplicity enabled by:
    - Segment routing
    - Push-based telemetry
    - SDN Traffic Engineering application

Offline Traffic Engineering

- Topology model
- Traffic demand matrix
- Optimization algorithm computes routes so that the worst link utilization is minimized
  - Linear programming

Pros/Cons of Offline Traffic Engineering

- Very good link utilization values

- Network model is hard to keep accurate
- Traffic demand matrix is hard to compute
- Optimization algorithm is very slow
  - Hours to days
- Can not adapt to failures
- Too many tunnels (N^2)
- Some paths may be surprisingly long

On-Device Traffic Engineering RSVP-TE/CSPF

- Routers flood available bandwidth of links in IGP
- Each router
  - Sets up one (or more) tunnels to other routers
  - Monitors the utilization of these tunnels (auto-bandwidth)
  - Triggers re-optimization when utilization changes
  - Uses CSPF (constraint-based shortest path first) to compute the paths
  - Signals the path and reserves bandwidth using RSVP

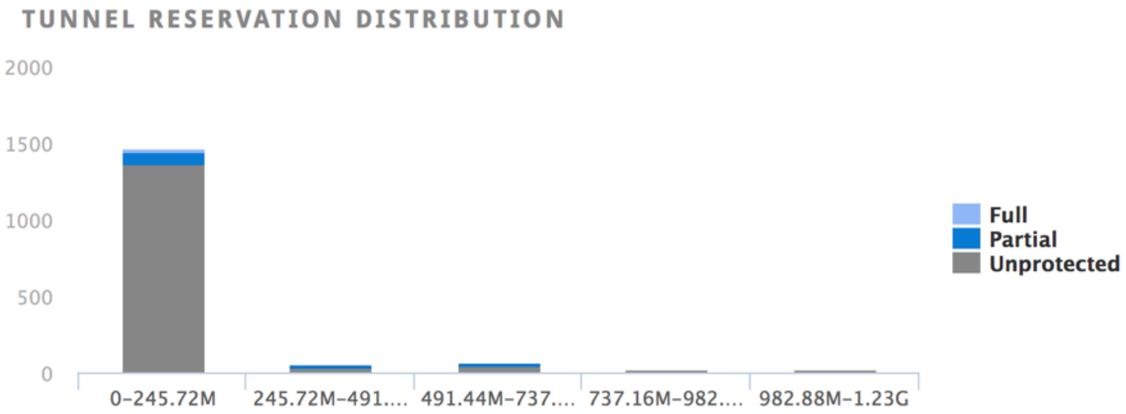
Pros/Cons of On-Device Traffic Engineering

- Not so good link utilization values
  - Each router is selfish in optimization
  - No network-wide optimization

- Network model is readily available
- Traffic demand matrix is easy with auto-bandwidth
- CSPF is fast
- Can adapt to failures
- Too many tunnels (N^2)
- Some paths may be surprisingly long
- Flooding available bandwidth impacts IGP, particularly convergence time
- Race conditions after failures
  - Long-lived FRR
- RSVP-TE overhead is high due to N^2 tunnels
  - Protocol and management overhead

Example Deployments

	Small	Medium	Large
Routers	75	450	1,900
Links	300	2,000	8,000
Tunnels	1,600	20,500	132,000



- Majority of the tunnels have very small amount of traffic
  - No TE needed

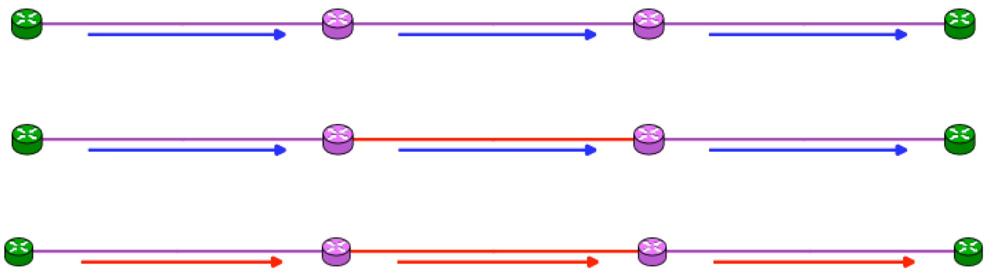
Link / Tunnel Distribution

LINK/TUNNEL DISTRIBUTION

Tunnels	Links
0-192 Tunnels	808
192-384 Tunnels	55
384-576 Tunnels	13
576-768 Tunnels	1
768-960 Tunnels	1

- Most links carry a small number of tunnels
- Small number of links carry a lot of tunnels

A Tunnel Path - Before, During and After a Link Failure



2015-12-27 12:04:05

2015-12-27 12:04:05.200490

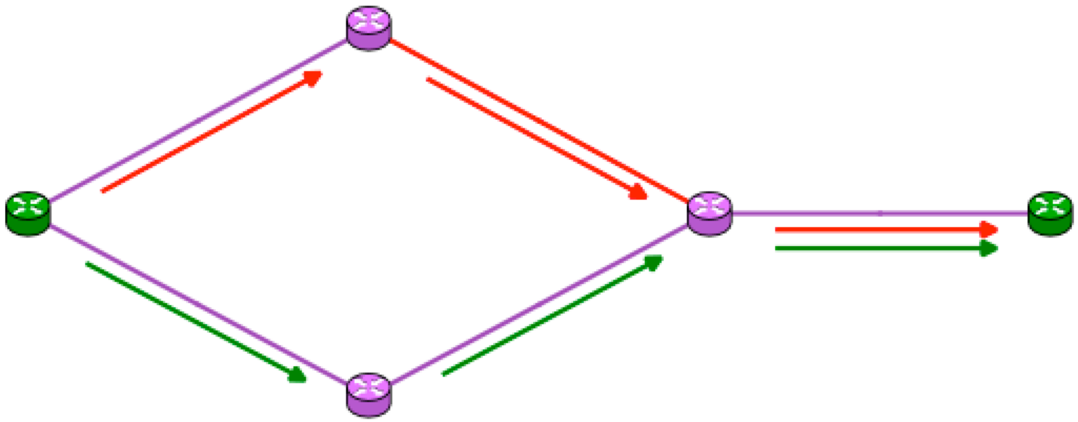
2015-12-27 12:14:00

- A wide-area link fails at 2015-12-27 12:04:05.200490
  - It was carrying 327 tunnels from 22 head-end routers
- The tunnel above fails to optimize, but why?

Re-Optimization after Link Failure

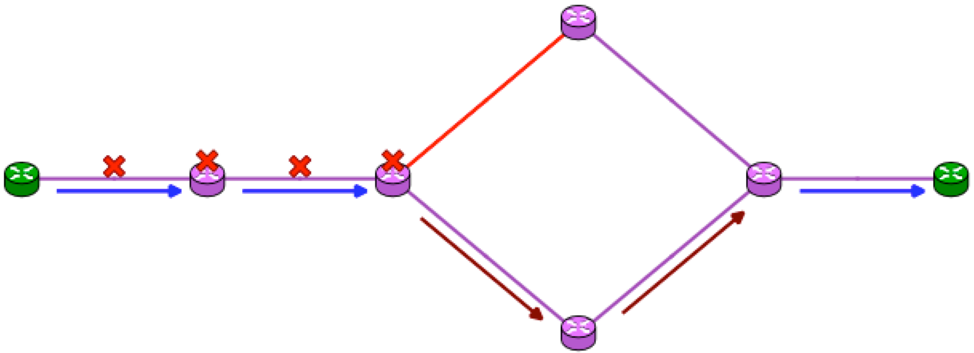
- 22 head-end routers get a signal via RSVP-TE and try to re-optimize
  - Race to available bandwidth
- Each router optimizes for itself
  - It does not know what the other 21 routers need
  - It doesn't even know there are other routers/tunnels interested in this bandwidth
- 9 tunnels fail to optimize
  - 5 head-end routers
  - The example tunnel is one of the unlucky ones
- *This could have been avoided with network-wide optimization!*

What Happens to the Traffic?



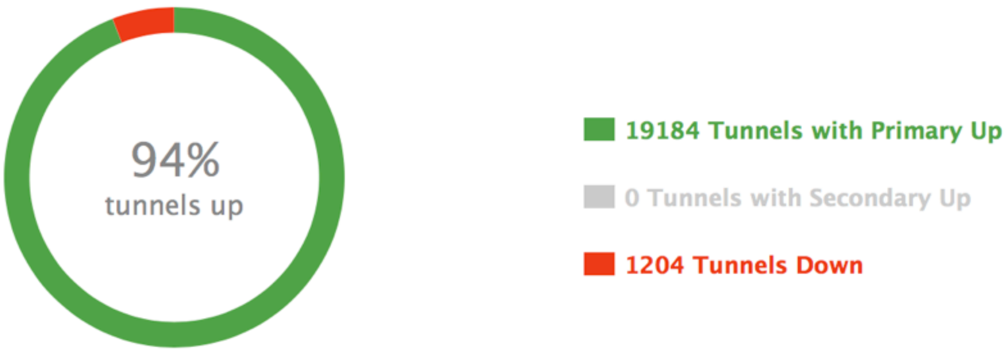
- Traffic now takes the IGP path (green arrows)
- Tunnel needed 34Mbps which is not available anywhere in the network
- The IGP path too does not have this bandwidth available
    - Congestion kicks in

Another Tunnel is Stuck on its FRR



- What happens when a tunnel fails to optimize and it is FRR protected?
  - FRR is stuck
  - Usually no reservations are made on FRR paths
  - Congestion will kick in

N^2 Tunnels - Beyond Human Manageability



- It is not just 9 tunnels that are down
- 1204 down tunnels is too many for any operator to figure out the root cause
  - If these tunnels are for traffic engineering, can we really say we are successfully doing traffic engineering?
  - It is time for software/devops to manage the network

AN SDN APPROACH

What Do We Really Need?

- Real-time model
  - Alleviate congestion, especially after a link failure
- Create as few tunnels as necessary
  - Very small signaling overhead
  - Very small IGP overhead
    - Do not want IGP dynamics due to available bandwidth changes
- Network-wide optimization
- Simple to deploy and operate

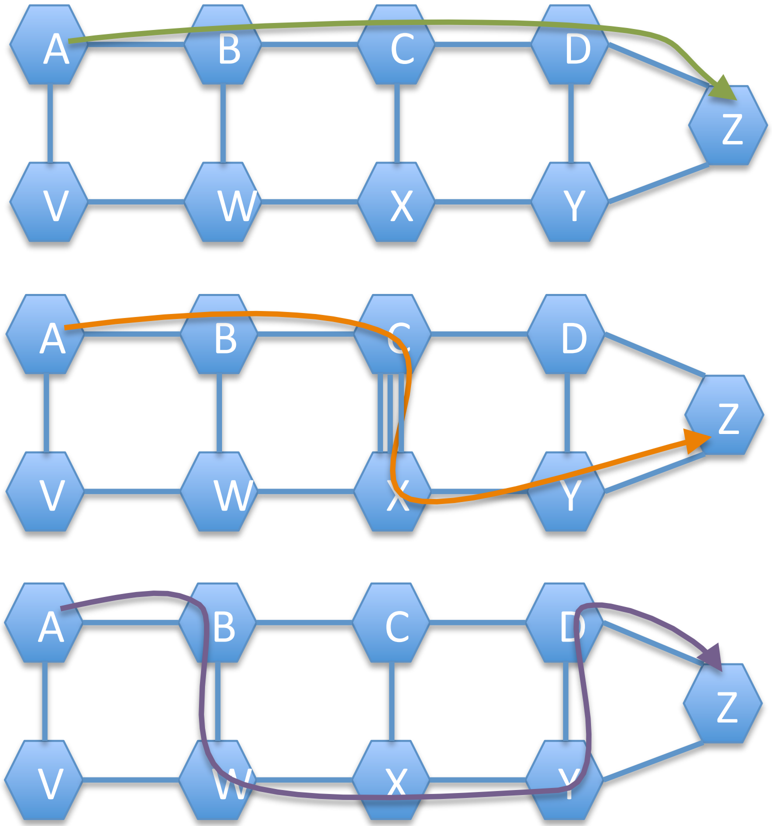
SDN Promises a Solution

- Segment routing (SR) replaces RSVP
  - Provides uncompromised functionality
  - Simple control plane with very low overhead
- Push-based telemetry for traffic matrices
  - YANG model based
  - Frees IGP
- SDN controller is part of the network control plane
  - Has real-time topology
  - Enables manipulating paths on the devices using standard south bound protocols
- Traffic Engineering becomes an SDN application
  - Optimizes paths network-wide
  - As few tunnels as necessary

Segment Routing

- Segment routing *simplifies* IP/MPLS control plane
  - No need to run LDP or RSVP-TE
- Functionality is not compromised
  - Can forward traffic on non-shortest paths for traffic engineering
  - Detour, bypass FRR (fast re-route), and IP LFA protection
  - Secondary paths
  - SLA-conforming service specific paths (e.g. L2/L3 VPNs)
  - SDN programmability

TE Needs Shortest and Non-Shortest Paths; SR Can Encode Any Path



1 Segment (shortest IGP path)
- Go to Z on shortest path *(node segment)*

3 Segments
- Go to C on shortest path
- Go to X on link 3 *(adjacency segment)*
- Go to Z on shortest path

5 Segments
- Go to B on shortest path
- Go to W on shortest path
- Go to Y on shortest path
- Go to D on shortest path
- Go to Z on shortest path

Push-Based Telemetry Eases Traffic Demand Matrix Generation

- How much customer traffic enters the network in Hanoi and is destined for Tokyo?
  - Demand does not change based on internal routing
- Traditionally, NetFlow is used for this and can still be used
- Push- and model-based telemetry have very promising features, including real-time traffic visibility

YANG Model Pushed by Ingress Routers

```
+--ro traffic-collector
  +--ro afs
    +--ro af* [af-name]
      +--ro counters
        +--ro prefixes
          +--ro prefix*
            +--ro ipaddr?                     string
            +--ro mask?                       string
            +--ro label?                      Tc-oper-local-label
            +--ro base-counter-statistics
            |  +--ro transmit-packets-per-second-switched?   uint64
            |  +--ro transmit-bytes-per-second-switched?     uint64
            |  +--ro count-history*
            |     +--ro event-start-timestamp?               uint64
            |     +--ro event-end-timestamp?                 uint64
            |     +--ro transmit-number-of-packets-switched?   uint64
            |     +--ro transmit-number-of-bytes-switched?     uint64
            |     +--ro is-valid?                            boolean
            +--ro traffic-matrix-counter-statistics
            |  +--ro transmit-packets-per-second-switched?   uint64
            |  +--ro transmit-bytes-per-second-switched?     uint64
            |  +--ro count-history*
            |     +--ro event-start-timestamp?               uint64
            |     +--ro event-end-timestamp?                 uint64
            |     +--ro transmit-number-of-packets-switched?   uint64
            |     +--ro transmit-number-of-bytes-switched?     uint64
            |     +--ro is-valid?                            boolean
            +--ro prefix?                     string
```

- Similar content to NetFlow for traffic matrix generation
  - Misses port/proto level detail
- Pushed from the routers
  - Few seconds to minutes
- Efficient transfer of data
  - Binary encoded using ProtoBuf

Traffic Engineering as an SDN App.

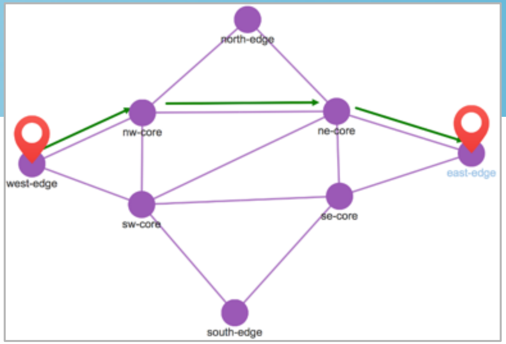
- SDN application manages traffic demand
  - Current as well as future reservations
  - IGP does not have to signal available bandwidth
  - Push-based telemetry or NetFlow-based matrices can be generated
- SDN application computes paths and allocates bandwidth
  - Centralization yields network-wide resource optimization
  - Creates the fewest tunnels necessary
- SDN application adapts to failures and repairs
  - SDN controller provides real-time topology view
  - No race conditions after failures and repairs
- Segment routing can be used for network simplification
  - SDN controller makes this an abstraction for the application
  - RSVP-TE can still be used where SR is not available

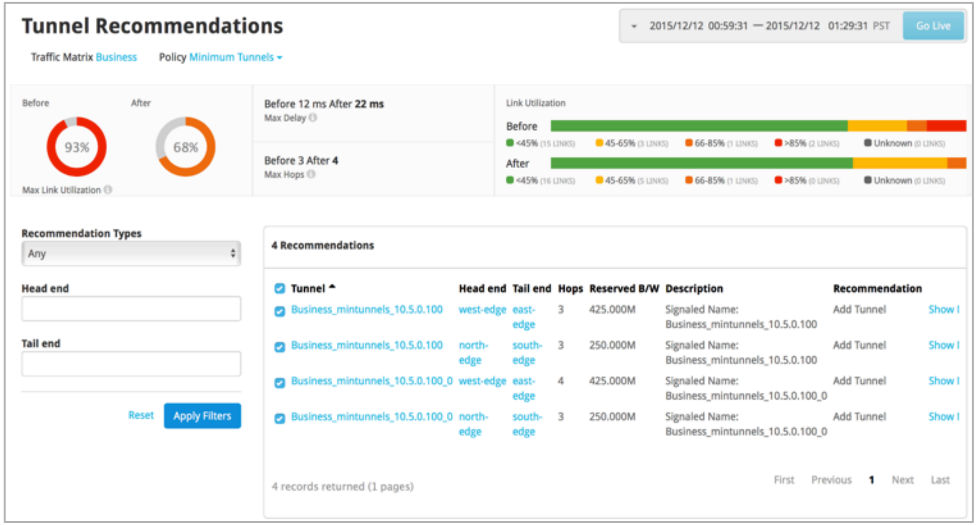
Reducing the N^2 Tunnels

- Only generates tunnels for traffic going over congested links
  - Tunnels no longer need to be configured a priori at the routers
    - Only create them if they will have a positive impact
  - Special case:
    - Under normal conditions don't generate any tunnels
    - Under failure conditions generate enough to alleviate congestion
- Do not create tunnels when IGP path satisfies the constraints
- Easy to implement in software with a global view, but hard to do one device at a time

Illustration

- 1 Gbps links
- Two elephant flows
  - 850Mbps west to east
  - 500Mbps north to south
- Lots of mice flows





Concluding Remarks

- SDN simplifies running a traffic engineered network
  - Application is the SDN revolution
- SDN application needs enablers from the infrastructure
  - Controller
  - Segment routing (or RSVP-TE when not available)
  - Push-based telemetry
  - NETCONF/YANG, PCEP, and other southbound protocols