Lessons Learned

(aka what’s transpired in these halls, but wasn’t intuitively obvious the first time)

Agenda

- Overview/Background
- POP architecture
- IGP design and pitfalls
- BGP design and pitfalls
- MPLS TE design and pitfalls
- Monitoring pointers
- Next steps

Overview

- Pete Templin, pete.templin@texlink.com
  - ‘Chief Card Slinger’ for a telecom/ISP
  - Hybrid engineering/ops position
- Recently acquired, now “strictly” engineering.
  - IP Engineer for a telecom/ISP

Objective: Simplicity

- "Be realistic about the complexity-opex tradeoff." *Dave Meyer*
- Be realistic about the complexity, period.
  – Simple suggests troubleshootable.
  – Simple suggests scalable.
  – Simple suggests you can take vacation.

Be the router.

- When engineering a network, remember to think like a router.
- When troubleshooting a problem, remember to think like a router.
  - Think packet processing sequence, forwarding lookup method, etc. on THIS router.
- Work your way through the network.
  - Router by router.

Background

- {dayjob} grew from four routers (one per POP), DS3 backbone, and 5Mbps Internet traffic in 2003…
- …to 35 routers (4 POPs and a carrier hotel presence), NxDS3 backbone, and 200Mbps Internet in 2006…
- …and another 50Mbps since then.

When I started…

- …I inherited a four-city network
  - Total internet connectivity was 4xT1
  - Static routes to/from the Internet
  - Static routes within the network
  - Scary NAT process for corporate offices

Initial challenges

- Riverstone routers – unknown to everyone
- Quickly found flows-per-second limits of our processors and cards
- We planned city-by-city upgrades, using the concepts to follow.

Starting point

- Everything starts with one router.
- You might run out of slots/ports.
- You might run out of memory.
- You might run out of processor(s).
- Whatever is your limiting factor, it’s then time to plan your upgrade.

Hardware complexity

- Once you grow beyond a single router, you'll likely find that you need to become an expert in each platform you use.
  - Plan for this learning curve.
  - Treat product sub-lines separately
    - VIP2 vs. VIP4 in 7500s
    - GSR Engine revisions
    - Cat6 linecards (still learning here…)

Redundancy

- Everyone wants to hear that you have a redundant network.
- Multiple routers doesn’t ensure redundancy – proper design with those routers will help.
- If you hook router2 to router1, router2 is completely dependent on router1.

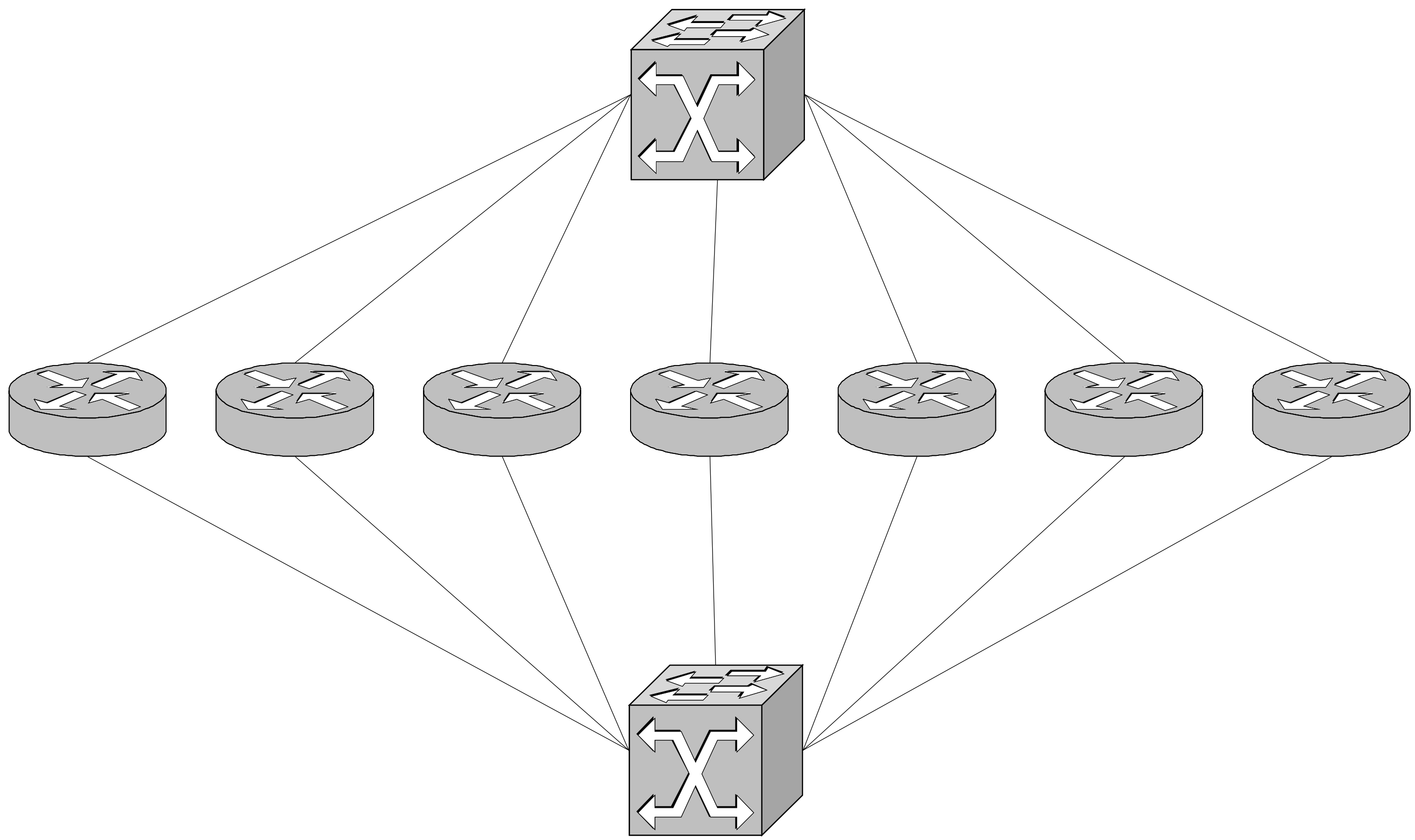
Initial design

- Two-tier model
  - Core tier handled intercity, upstream
    - Two core routers per POP
  - Distribution tier handled customer connections
    - Distinct routers suited for particular connections:
      - Fractional and full T1s
      - DS3 and higher WAN technologies
      - Ethernet services

Initial Core Design

- Two parallel LANs per POP to tie things together.
  - Two Ethernet switches
  - Each core router connects to both LANs
  - Each dist router connects to both LANs

Two core L2 switches



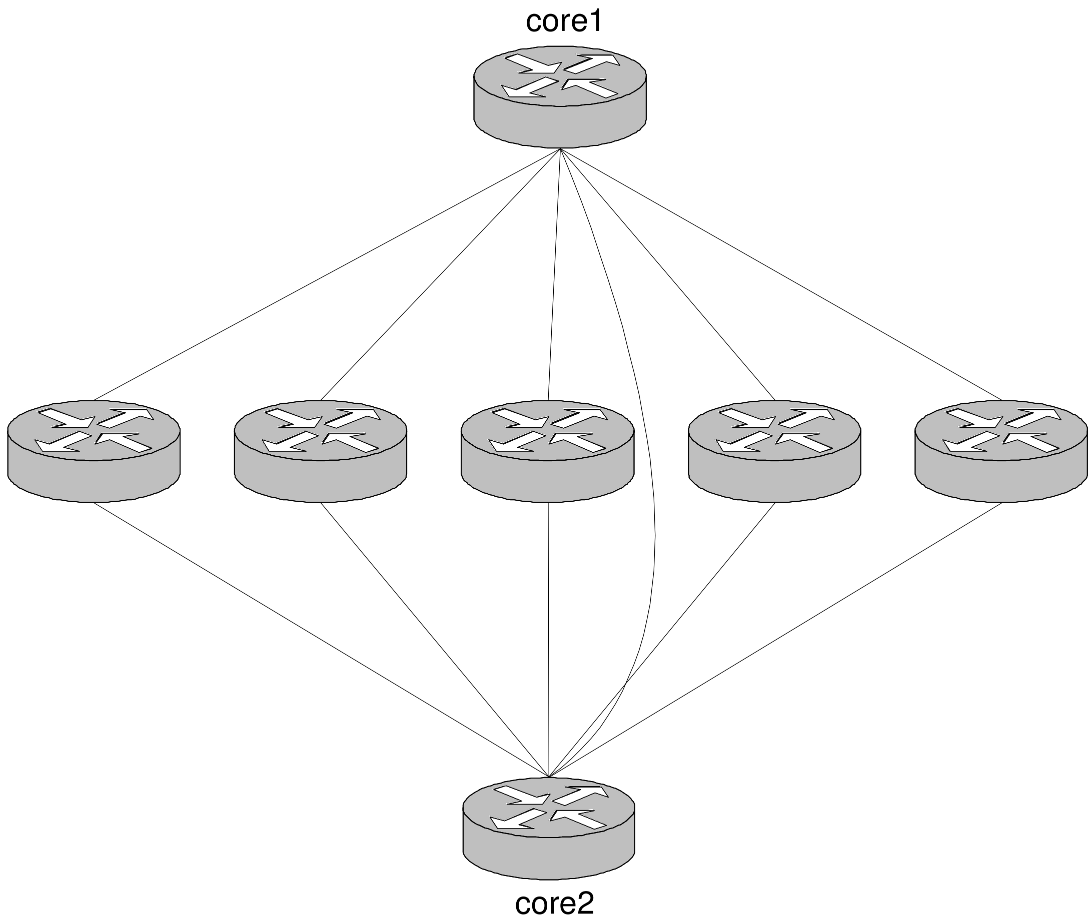
Pitfalls of two core L2 switches

- Convergence issues:
  - R1 doesn’t know that R2 lost a link until timers expire – multiaccess topology.
- Capacity issues:
  - Transmitting routers aren’t aware of receiving routers’ bottlenecks
- Troubleshooting issues:
  - What’s the path from R1 to R2?

Removal of L2 switches

- In conjunction with hardware upgrades, we transitioned our topology:
  - Core routers connect to each other
    - Parallel links, card-independent.
  - Core routers connect to each dist router
    - Logically point-to-point links, even though many were Ethernet.

Two core routers



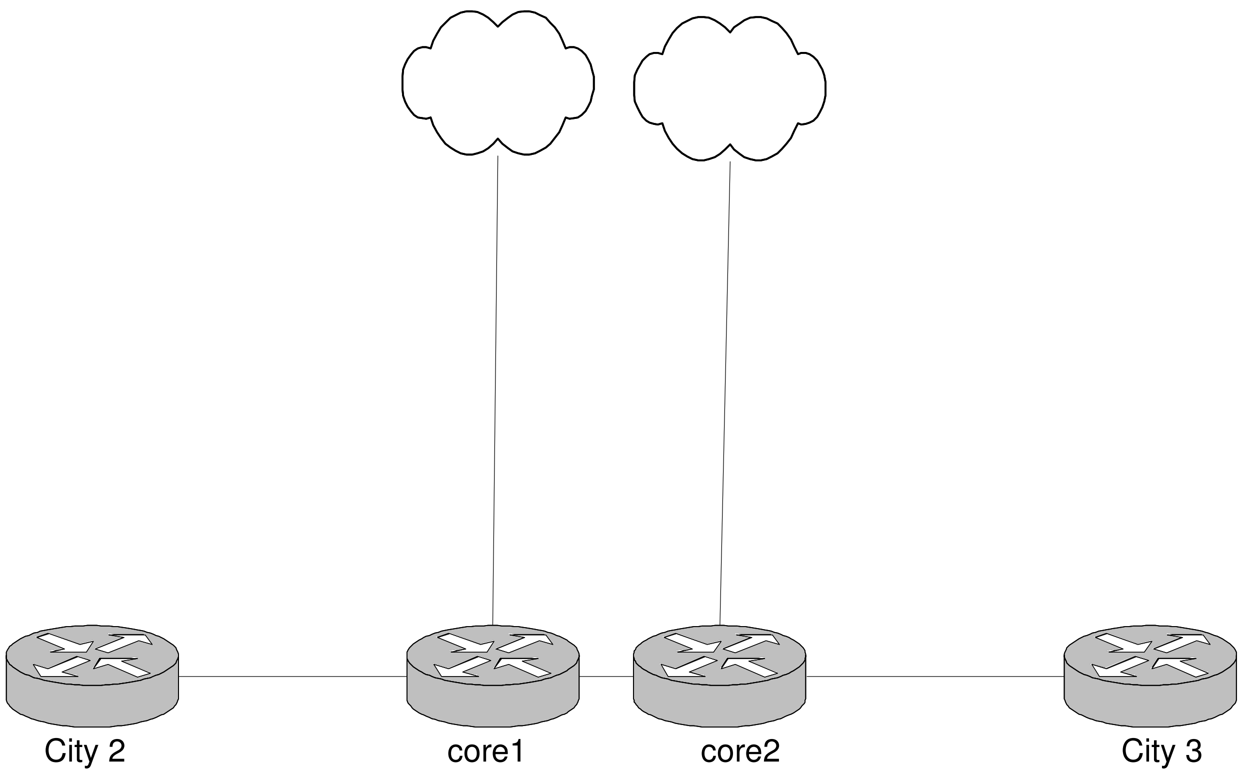
Results of topology change

- Core routers know the link state to every other router.
  - Other routers know link state to the core, and that's all they need to know.
- Routing became more predictable.
- Queueing became more predictable.

Core/Edge separation

- Originally, our core routers carried our upstream connections.
- Bad news:
  - IOS BGP PSA rule 9: “Prefer the external BGP (eBGP) path over the iBGP path.”
  - Inter-POP traffic left by the logically closest link unless another link was drastically better.

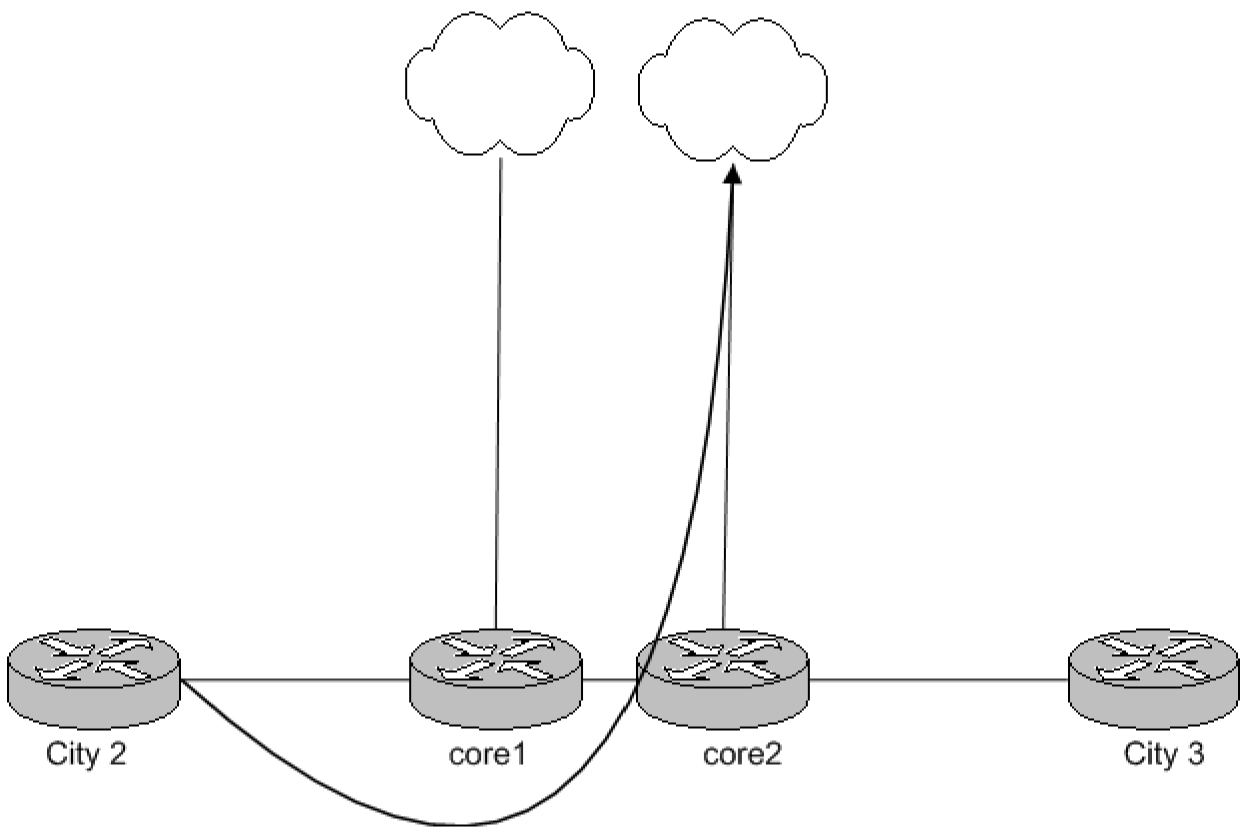
Lack of Core/Edge separation



Lack of Core/Edge separation

- Traffic inbound from city 2 wanted to leave via core1's upstream, since it was an eBGP path.
  - City2 might have chosen a best path from core2's upstream, but since each router makes a new routing decision, core1 sends it out its upstream.

Lack of Core/Edge separation



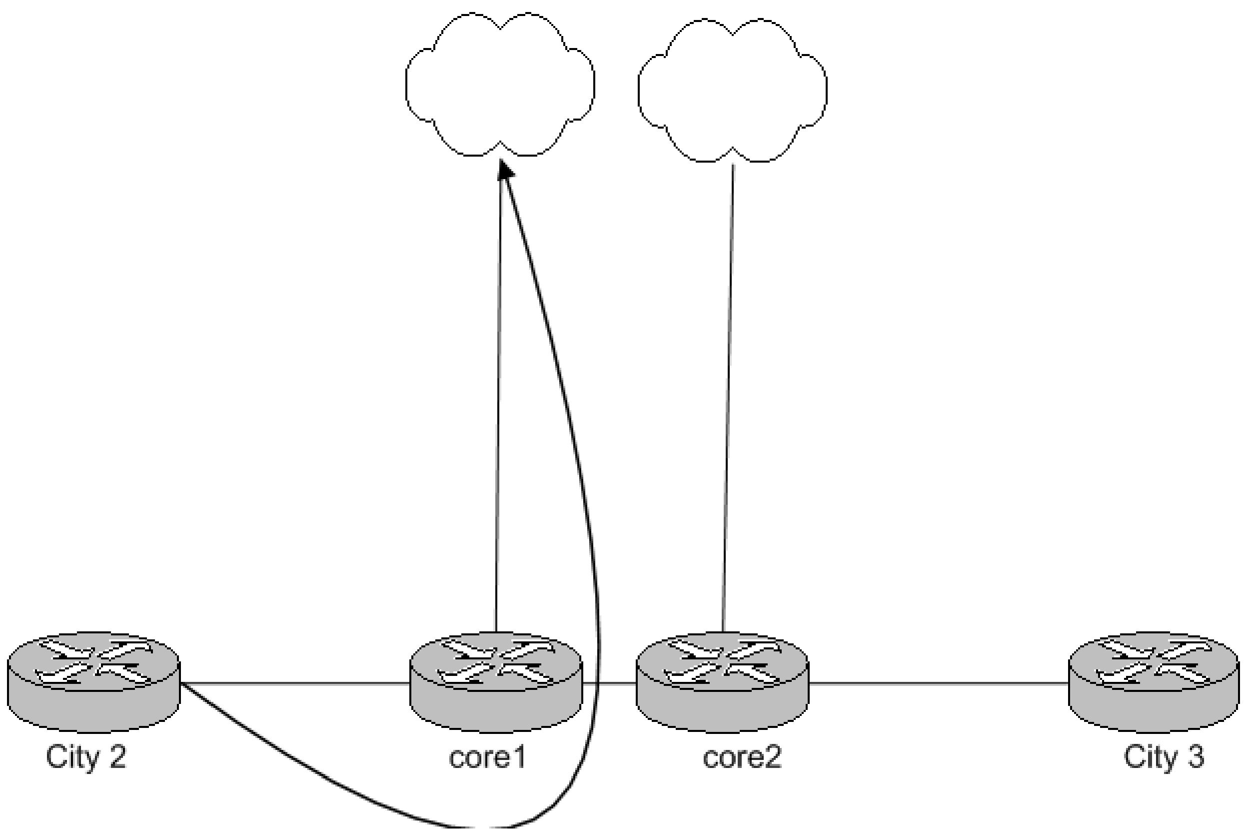
Problem analysis

- City1 core1 prefers most paths out its upstream, since it's an external path.
- City1 core2 prefers most paths out its upstream, since it's an external path.
- City2 core routers learn both paths via BGP.
- City2 core routers select best path as City1 core2, for one reason or another.

Problem analysis

- City2 sends packets destined for Internet towards City1 core1.
  - BGP had selected City1 core2's upstream
  - IGP next-hop towards C1c2 was C1c1.
- Packets arrive on City1 core1
- City1 core1 performs IP routing lookup on packet, finds best path as its upstream link.

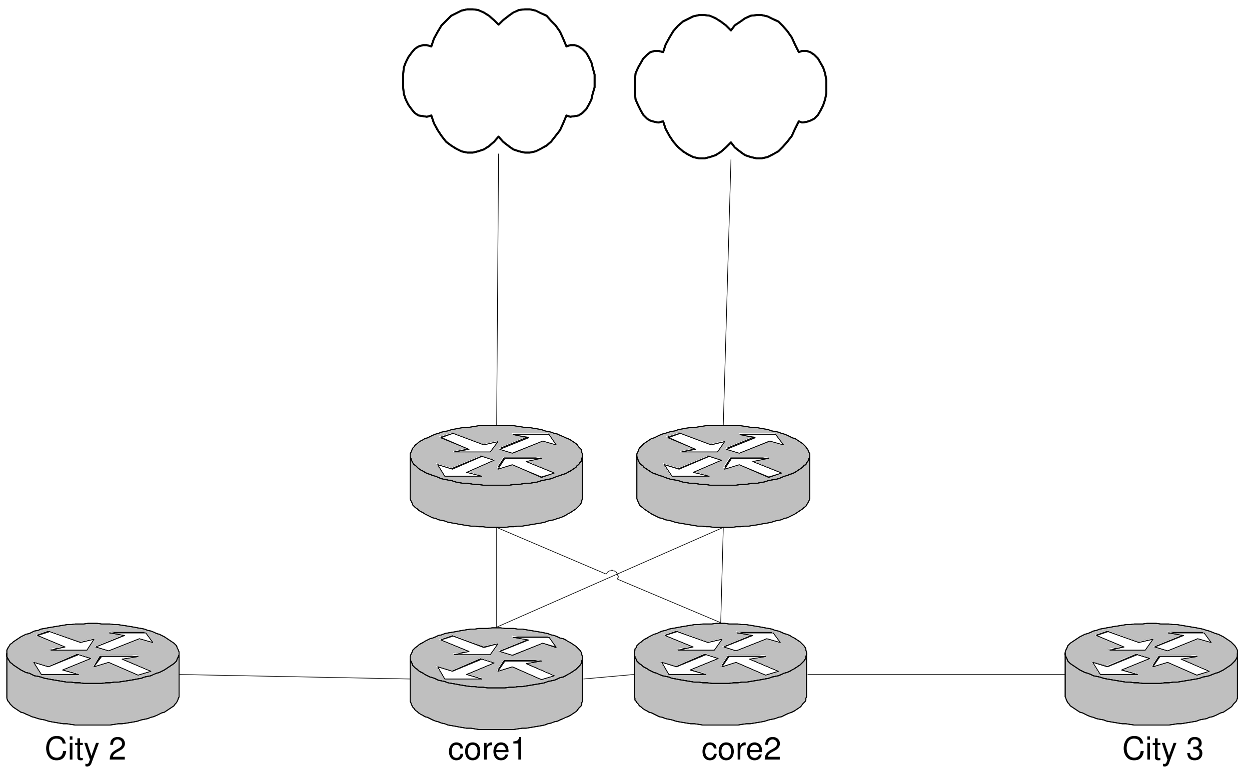
Lack of Core/Edge separation



Problem resolution

- Kept two-layer hierarchy, but split distribution tier into two types:
  - Distribution routers continued to handle customer connections.
  - Edge routers began handling upstream connections.

Core/Edge separation



Resulting topology

- Two core routers connect to each other
  - Preferably over two card-independent links
- Split downstream and upstream roles:
  - Downstream connectivity on “distribution” routers
    - Each dist router connects to both core routers.
  - Upstream connectivity on “edge” routers
    - Each edge router connects to both core routers.

Alternate resolution

- MPLS backbone
  - Ingress distribution router performs IP lookup, finds best egress router/path, applies label corresponding to that egress point.
  - Intermediate core router(s) forward packet based on label, unaware of destination IP address.
  - Egress router handles as normal.

IGP Selection

- Choices: RIPv2, OSPF, ISIS, EIGRP
- Ruled out RIPv2
- Ruled out EIGRP (Cisco proprietary)
- That left OSPF and ISIS
  - Timeframe and (my) experience led us to OSPF
  - Static routed until IGP completed!

IGP Selection

- We switched to ISIS for three supposed benefits:
  - Stability
  - Protection (no CLNS from outside)
  - Isolation (different IGP than MPLS VPNs)
- And have now switched back to OSPF
  - IPv6 was easier, for us, with OSPF

IGP design

- Keep your IGP lean:
  - Device loopbacks
  - Inter-device links
  - Nothing more
- Everything else in BGP
  - Made for thousands of routes
  - Administrative control, filtering

IGP metric design

- Credit to Vijay Gill and the ATDN team…
- We started with their model (OSPF-ISIS migration) and found tremendous simplicity in it.
- Began with a table of metrics by link rate.
- Add a modifier depending on link role.

Metric table

- 1 for OC768/XLE
- 2 for OC192/XE
- 3 for OC48
- 4 for GE
- 5 for OC12
- *We'll deal with CE, CLXE, and/or OC-3072 later!*
- 6 for OC3
- 7 for FE
- 8 for DS3
- 9 for Ethernet
- 10 for DS1

Metric modifiers

- Core-core links are metric=1 regardless of link.
- Core-dist links are 500 + <table value>.
- Core-edge links are 500 + <table value>.
- WAN links are 30 + <table value>.
- Minor tweaks for BGP tuning purposes.
  - Watch equidistant multipath risks!

Metric tweaks

- Link undergoing maintenance: 10000 + <normal value>
- Link out of service: 20000 + <normal value>
- Both tweaks preserve the native metric
  - Even if we've deviated, it's easy to restore

Benefits of metric design

- Highly predictable traffic flow
  - Under normal conditions
  - Under abnormal conditions
- I highly recommend an awareness of the shortest-path algorithm:
  - Traffic Engineering with MPLS, Cisco Press
  - My NANOG37 tutorial (see above book…)

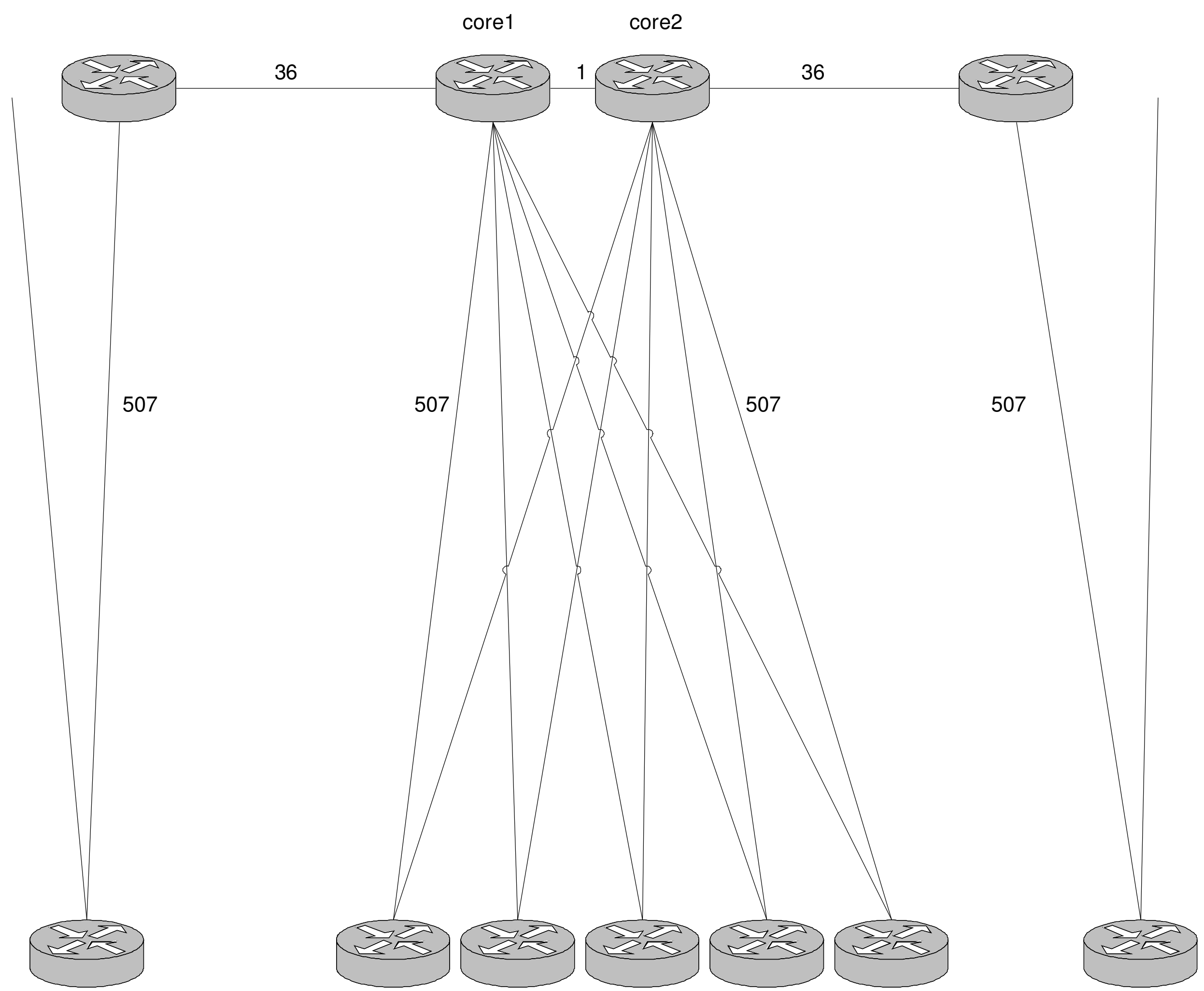
Metric design and link failure

- Distribution/edge routers aren't sized to handle transitory traffic.
- Distribution/edge routers might not have proper transit features enabled/configured.
- If the intra-pop core-core link(s) fail:
  - We want to route around the WAN to stay at the core layer.

Metric design and link failure

- Core-dist-core or core-edge-core cost:
  - At least 1002 (501 core-dist and 501 dist-core)
- Core-WAN-core cost:
  - At least 63 (31 core-cityX, 1 core-core, 31 cityX-core)
  - Additional 32-40 per city
- Traffic would rather traverse 23 cities than go through distribution layer.

IGP metric sample



Pitfalls of metric structure

- Links to AS2914 in Dallas, Houston
  - Remember IOS BGP PSA rule 10: “Prefer the route that can be reached through the closest IGP neighbor (the lowest IGP metric).”
  - SA Core1 was connected to Dallas
    - Preferred AS2914 via Dallas
  - SA Core2 was connected to Houston
    - Preferred AS2914 via Houston

Pitfalls of metric structure

- Dallas was sending some outbound traffic to AS2914/Houston because of IGP metric.
- Houston Edge1 metrics were changed to rebalance traffic.
- SA dist routers had BGP multipath enabled.
- Four dist routers ran out of RAM simultaneously.

BGP design

- BGP is made to scale: use it
  - Customer link subnets
  - Customer LAN subnets
  - External routes
- BGP has great filtering tools: use them
  - Filter at every ingress and route injection point
  - Apply an internal community

BGP scaling pitfalls

- Confederations didn’t work well for us
  - One sub-AS per POP meant each router was its own sub-AS.
  - Convergence was painful; sub AS path tried to be an IGP.
- Removed confederations then deployed route reflectors
  - No client-client reflection for easier scaling.

BGP at distribution layer

- Redistribute connected routes into BGP
  - Exclude the interfaces already handled in IGP
    - Oops: don’t write your route map to exclude by interface name. One failed VIP or LC now causes a deny-all
    - Instead, exclude your IGP interfaces by prefix list.
- Redistribute static routes into BGP
- No customer configurations are needed anywhere else

BGP local-pref design

- Transit: cost$ money
- Peering: usually low or no cost
- Customers: revenue
- Treat prefixes appropriate to dollars
  - Prefer to send to customer rather than through peering or transit
  - Often used: local preference

Local preference design

- Customer LP = 400
- Peer LP = 300
- Transit LP = 200
- Backup LP = 50
- Since default LP is 100, a forgotten or flawed route map will result in routes that aren’t used.
  - The error will become apparent!

Customer filtering plan

- Filter once on ingress
- Do so **aggressively**:
  - We filter on {prefix, AS-path}
  - We allow customer to prepend freely
  - We allow customer to truncate the AS-path
    - Second and subsequent AS is optional
  - We tell customer about filtering rules (and lots more) at turn-up.

Customer route filtering, part 1

- Accept null-routed aggregate
  - Set next-hop for null
  - Propagate normally
- Accept aggregate
  - Propagate normally

Customer more-specifics filter

- Accept null-routed specific
  - Set next-hop for null, mark as no-export
  - Propagate internally
- Accept specific w/ ‘override’ community
  - Treats as aggregate (propagated out)
  - Hopes transits filter on ‘le 24’
  - Best-effort option

Customer more-specifics, cont.

- Accept specific
  - Mark as no-export
  - Propagate internally
  - Used as uRPF opening for traffic engineering

Customer filtering logic

- Customer can announce aggregate.
- Customer can announce aggregate with null-routed specifics.
- Customer can announce aggregate AND null-route it, announce more-specifics to forward.
  - And can null-route further specifics.

Customer filtering sample

- 72.18.90.0/22 with 11457:0
  - Aggregate is null-routed, but is announced to the world.
- 72.18.92.0/23
  - More-specific is shared within AS, traffic is forwarded to customer
- 72.18.93.0/24 with 11457:0
  - More-specific is null-routed.
- Only 72.18.92.0/24 is forwarded to customer.

Impact of filtering

- We have at least two prefix lists per customer:
  - One exact-match list per allowed AS path
  - One ‘le 32’ list for null routing and overrides
- We can optionally inject ‘tuning communities’ in the customer inbound route-map

BGP community design

- Tag **every** prefix with an internal community at ingress.
  - Identify POP of origin
  - Identify requested egress handling
  - Identify type of route (customer, ours, external)
- Use the tag intelligently:
  - Use the POP of origin to adjust MED
    - “Simple” geo-routing for customer prefixes saved us significant WAN costs.

Our internal community design

- 11457:ABCDE
  - A is route type (1=cust, 2=ours, 3=upstream, etc.)
  - BC is POP of origin
  - D is desired tuning (0=as-tuned, 1=provider-default, 2=backup, 7=maintenance)
  - E is georouting (0=aggregate, hot potato, 1=POP-specific, cold potato)

Internal community, sample

- 11457:10200
  - A=1, so it's a customer route
  - BC=02, so it came from POP#2 (Dallas)
  - D=0, so we propagate based on default tuning (possibly prepends and/or localpref tweaks)
  - E=0, so we announce as hot-potato (equal default MED in all cities)

Georouting

- Each provider port has a community list that matches “nearby” POPs.
  - If internal community matches 11457:….1 and nearby POPs, MED=200.
  - If internal community matches 11457:….1 but not nearby POPs, MED=400.
  - If internal community matches 11457:….0, MED=200.

BGP community design

- Develop a set of communities that you or your customers can apply to routes for tuning within your network:
  - Set local preference
  - Null route
- Customers can create cust/cust-backup or peer/peer-backup by using MED and LP.

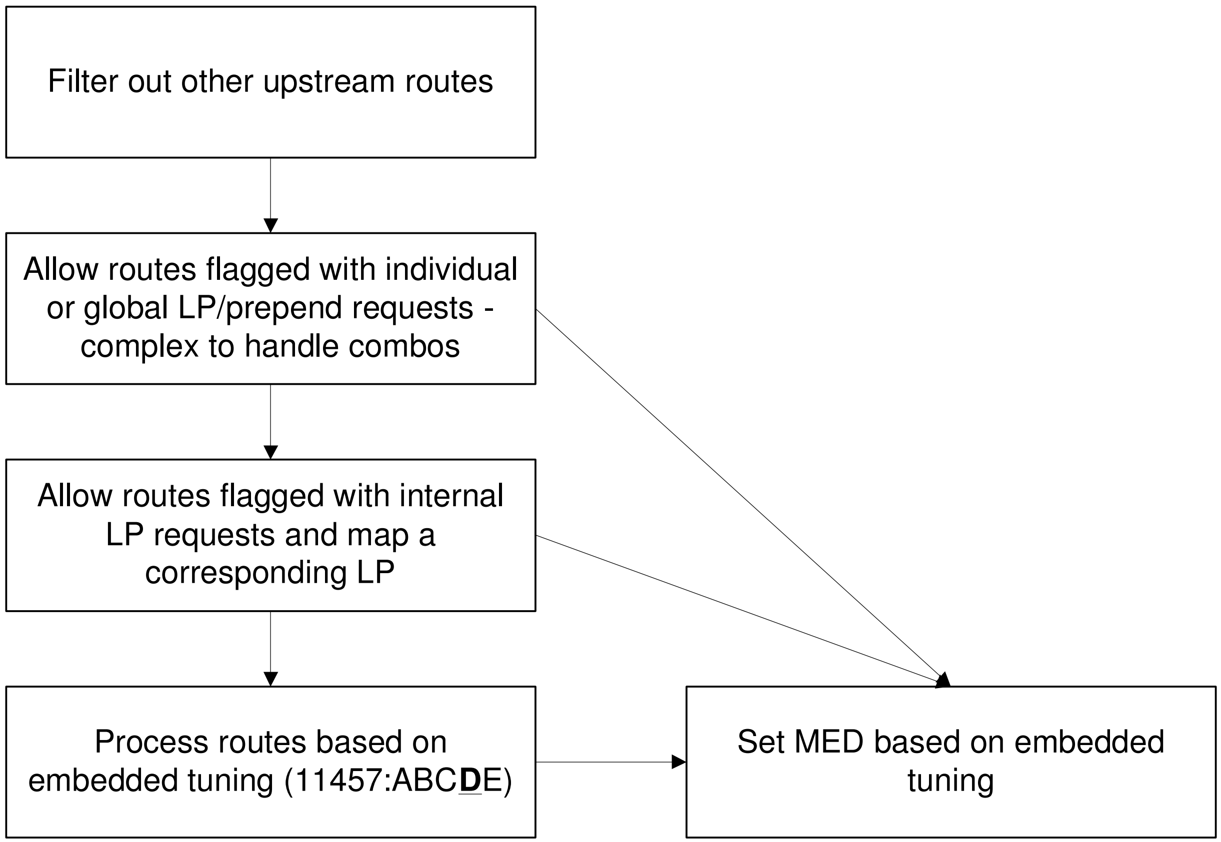
Our customer community design

- 11457:localpref
  - For limited versions of localpref (200, 300, 400)
- 11457:0
  - For null routing

BGP tuning design

- Develop another set of communities that you or your customers can apply to routes for tuning outside your network:
  - No-advertise
  - Set prepends
  - Request local preference

Announcement tuning logic



BGP outbound tuning

- We “enjoy” parallel connectivity to three transit providers
  - For each, one link in Dallas, one link in Houston.
- Cold potato to transit providers’ space and their customers
- Hot potato beyond their network

BGP outbound logic

- In normal state, cold potato is only one hop longer than hot potato for us.
  - We know our network
  - They know their network
  - But, we know our network better than we know their network.
  - If they’re telling us a particular POP is better, we’ll use it.

BGP outbound logic

- Assumption is MED learned reflects IGP distance to point of (aggregate) injection.
  - For transit providers' routes, point us towards the point of aggregate origination.
  - For transit provider's customers, since MED won't traverse directly, assume provider has chosen a best path (based either on customer MED or hot/cold potato) and MED leads us there.

Customer BGP experience

- We respect that many (all?) of our customers have little to no BGP experience.
- As long as customer sends their aggregate with a reasonable AS path and not too many routes to bump against max-prefix, OK.
- We’ll apply reasonable tweaks at customer request, but otherwise let them know they have all the knobs they’ll need.

Traffic Engineering

- Redundancy is hard to plan
  - Do you conduct regular simulations?
  - Some networks aren’t conducive to efficient redundancy.
- “Two means one, one means none”
  - From the movie “GI Jane”
- 2/1 means half of your capacity is excess.
  - Ugh.

MPLS Traffic Engineering

- MPLS TE saved our network
  - Normal IGP/EGP routing is completely unaware of traffic saturation, until enough keepalives are lost.
  - MPLS TE enables routers to spread traffic over multiple paths, including those that are not the shortest IGP path.
  - Built using one-way tunnels between routers.

MPLS TE deployment

- Initial deployment:
  - Full mesh of tunnels between dist and edge routers, with 1-2 tunnels depending on traffic loads.
  - Aggressive (15-minute) auto-bandwidth timers meant that the network was adjusting rapidly.
  - Our backbone, versus the size of the major flows, required this approach.

MPLS TE pitfalls

- NNTP: few large-bandwidth flows would get glued to a tunnel.
  - Add tunnels for granularity.
- Redundant capacity can easily get used by accident – no easy tracking.
  - However, excess capacity can get used during momentary surprises!

MPLS TE long-term

- IOS issues eventually caught us
  - End solution is entirely within the core layer, and only across WAN links.
  - Standard deployment of four tunnels per link.
  - Roughly 25% of traffic swings at a time
  - Traffic follows lowest-metric topology except during congestion.

Monitoring

- Consider home-grown tools to research many/all facets of a particular customer's port/service
  - Consolidate relevant information for your help desk
  - Minimize the need to share 'enable'

Monitoring

- Three problems to solve:
  - What is up/down at this moment?
  - What happened when?
  - How many [bits, packets, errors, etc.] are flowing?
- Usually different tools to solve each problem.

Monitoring

- For us, the two biggest things were MRTG with home-brew enhancements and syslog.
  – Our MRTG has simple links per port for a cutesy network diagram, telnet to CPE, and how-to-configure a CPE
  – Our syslog has a Perl wrapper that color-codes up/down and substitutes in the interface description so the entry has local meaning.

Sample diagram

Network Diagram for Wall Homes

Local WAN Address (IAD Far End)
66.118.5.149

WAN Network
66.118.5.148/30

Remote WAN Address (IAD Local)
66.118.5.150

(T1)

(dist4 S3/0 T1#7)
(timeslots 1-15)

(Customer Network)

LAN Network
(Subnet Masks)
66.118.21.208/28

Likely LAN Gateway
66.118.21.209

Admin Distance

Internal Tag

Sample log watcher

```
Jan 22 13:03:16 dist6-dlls 976: Jan 22 19:03:11.645 GMT: %LINK-3-UPDOWN: Serial2
/1/4:1 (PM Realty - Dallas Parkway), changed state to down
Jan 22 13:03:16 dist6-dlls 977: Jan 22 19:03:12.645 GMT: %LINEPROTO-5-UPDOWN: Li
ne protocol on Serial2/1/4:1 (PM Realty - Dallas Parkway), changed state to down
Jan 22 13:03:48 dist6-dlls 978: Jan 22 19:03:44.233 GMT: %CONTROLLER-5-UPDOWN: C
ontroller T3 2/1 T1 4, changed state to UP
Jan 22 13:03:50 dist6-dlls 979: Jan 22 19:03:45.945 GMT: %LINK-3-UPDOWN: Serial2
/1/4:1 (PM Realty - Dallas Parkway), changed state to up
Jan 22 13:03:51 dist6-dlls 980: Jan 22 19:03:46.949 GMT: %LINEPROTO-5-UPDOWN: Li
ne protocol on Serial2/1/4:1 (PM Realty - Dallas Parkway), changed state to up
Jan 22 13:05:32 dist6-dlls 981: Jan 22 19:05:27.669 GMT: %CONTROLLER-5-UPDOWN: C
ontroller T3 2/1 T1 4, changed state to DOWN
Jan 22 13:05:34 dist6-dlls 982: Jan 22 19:05:29.668 GMT: %LINK-3-UPDOWN: Serial2
/1/4:1 (PM Realty - Dallas Parkway), changed state to down
Jan 22 13:05:34 dist6-dlls 983: Jan 22 19:05:30.668 GMT: %LINEPROTO-5-UPDOWN: Li
ne protocol on Serial2/1/4:1 (PM Realty - Dallas Parkway), changed state to down
Jan 22 13:06:03 dist6-dlls 984: Jan 22 19:05:59.036 GMT: %CONTROLLER-5-UPDOWN: C
ontroller T3 2/1 T1 4, changed state to UP
Jan 22 13:06:05 dist6-dlls 985: Jan 22 19:06:00.816 GMT: %LINK-3-UPDOWN: Serial2
/1/4:1 (PM Realty - Dallas Parkway), changed state to up
Jan 22 13:06:06 dist6-dlls 986: Jan 22 19:06:01.820 GMT: %LINEPROTO-5-UPDOWN: Li
ne protocol on Serial2/1/4:1 (PM Realty - Dallas Parkway), changed state to up
```

Security

- Prevent bad traffic
  - BCP38 (anti-spoofing)
  - Use uRPF unless you can’t, please
  - Allows a simple but effective inbound ACL (less complexity in older GSR cards)
- Block it before it ever gets into your network!

Security

- Black hole routing
  - Cannibalize a 2511 as a black hole trigger
  - Google “RTBH”
- Build at least the most basic NetFlow infrastructure
  - Learn how to find DDOS (think “sort by packets in flow”) and black hole fast

Closing

- That's my story, and I'm sticking to it.
  - It's worked **very well** for us. My phone rings with a "stumper" every three months or so.
- Configuration snippets from any part of our network are available by email request.
- Questions?