Network Integration

scale, stability and automation

Level 3 Communication – Who are we ?

- Headquartered in Broomfield Colorado
- Fiber based Facilities Telecommunication
- Tier I ISP – AS#3356
- Global Transport and Wave Services
- Global Layer 2 and Layer 3 VPN Services
- Voice
- Video and Vyvx
- Content Distribution Network (CDN)

Company Overview

OUR **COMPANY**

	Over **$8B** Pro Forma LTM Revenue (3Q 2013 - 2Q 2014)
	**13,000+** Employees
	**200,000+** Route Miles of Fiber Globally
	Connecting **60+** Countries and Counting
	Approx. **350** Multi-tenant Data Centers
	**36 Tbps+** Global IP and CDN Capacity
	More Than **12B+** Minutes Per Month In VoIP Traffic

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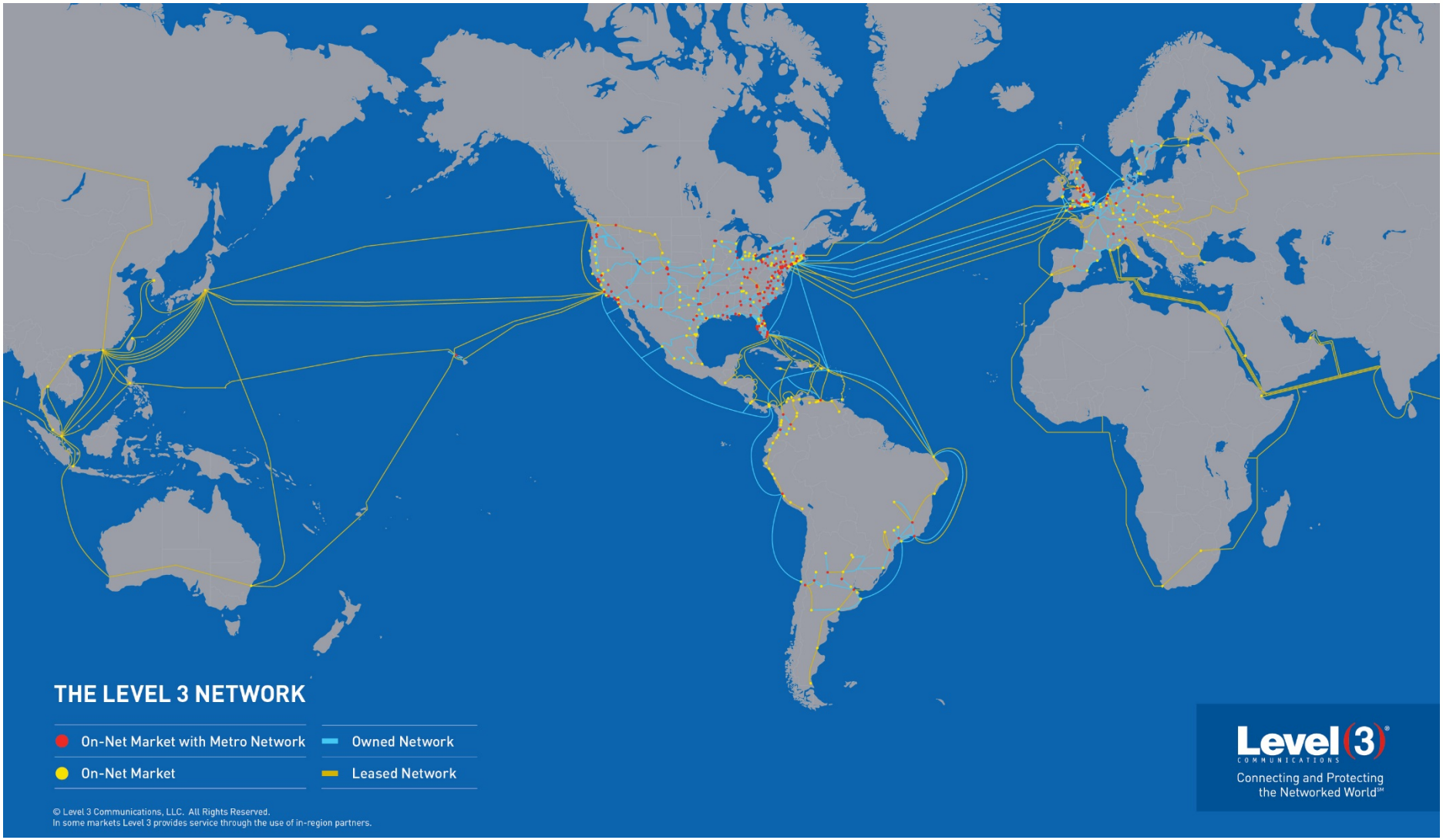
Level 3 Global Network



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Company Overview

OUR CUSTOMERS

- **8** of the Top 10 U.S.Based Banks
- **8** of the Top 10 Internet Service Providers
- **8** of the Top 10 Global Pharmaceutical Companies
- **8** of the Top 10 Cable MSOs
- Over **200** Federal Agencies and Divisions
- **4** of the "Big 6" Movie Studios

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Network Scale

Intercity Route Miles	110,000
Metro Route Miles	64,000
Subsea Route Miles	33,000
Subsea Cables	26
On-Net Buildings	40,000 +
Markets with Metro	350
Data centers	350
Core/Edge Routers	1800 +
Transport Equipment	65000 +
Metro Ethernet Devices	26,000 & growing
Ethernet NIDs	28,000 & growing
Managed CPE	40,000 & growing

Strategy - Two Backbones one Access

One Global Internet Backbone- AS#3356
Scalable for Internet's exponential growth
Globalize CDN, DDOS, Security services, etc

One Global MPLS Services Backbone AS#3549
Support IPVPN, Ethernet Services, Private Cloud, Managed Services, Voice, Video
High availability, Class-of-Service, Flexibility

Carrier Ethernet (Metro 2.0) as the global Access Architecture
High availability, Class-of-Service, Standardized

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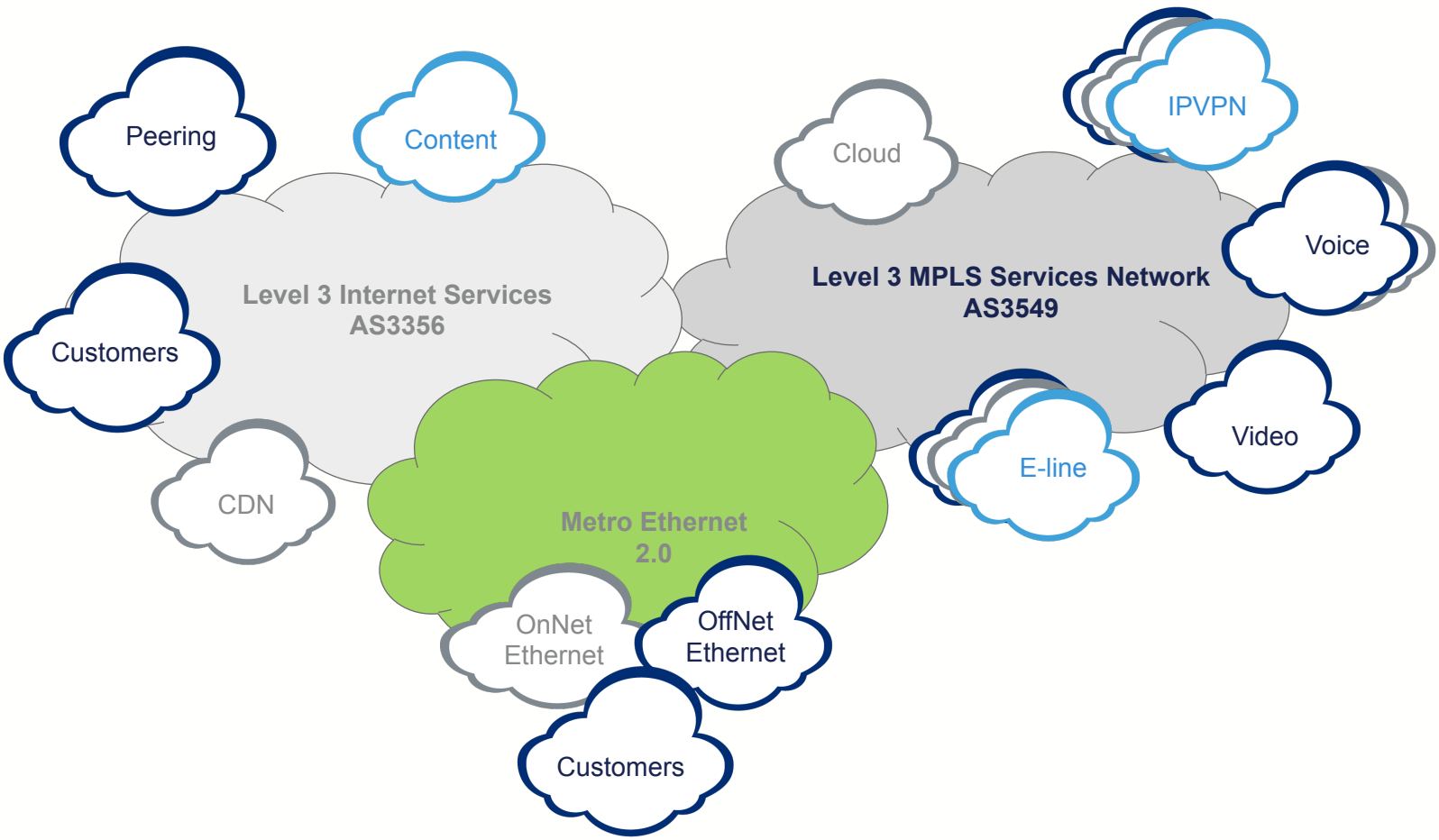
One Network: IP/MPLS/Ethernet



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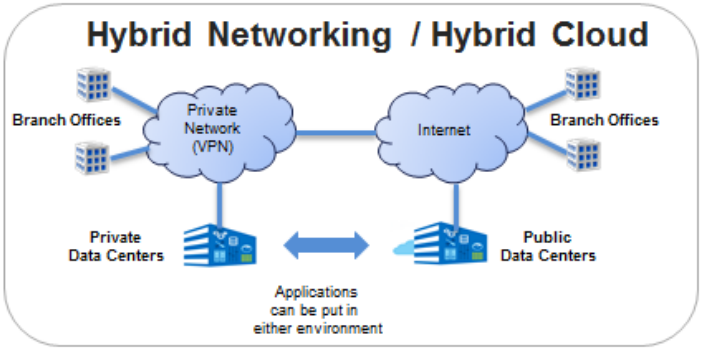
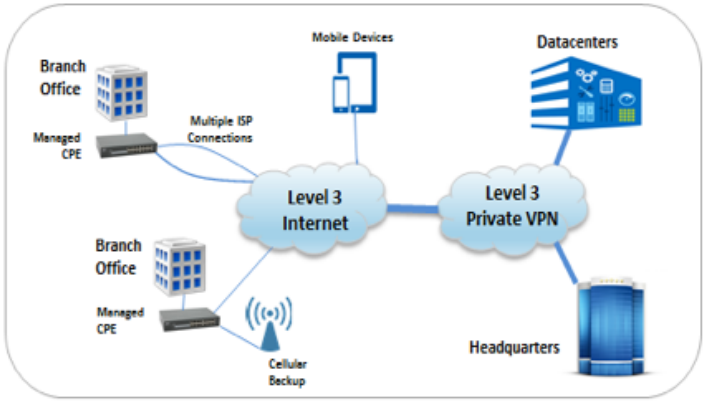
Hybrid WAN & Cloud

- **Growing Enterprise dependence on public Internet**
- Increased access options
- Public cloud resources (Azure, AWS, Google, Salesforce)
- Multi-faceted flexibility

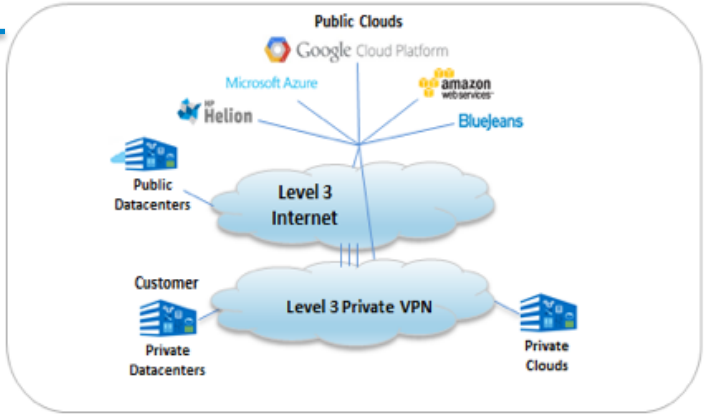


- **Today's Internet networks and technology is deficient in meeting private Enterprise needs**
- Network and Application security must be improved
- Overlays must be tunnel agnostic and automated
- Performance and quality must be Enterprise grade



Level(3) Strategy

- Develop managed edge services that help our customers migrate to hybrid networks
- Improve connectivity options to cloud providers
- Establish industry leading, Enterprise-grade Network and Application Security
- Integrate tightly SDN/NFV and Hybrid WAN
- Set a new standard in Internet performance; drive the industry



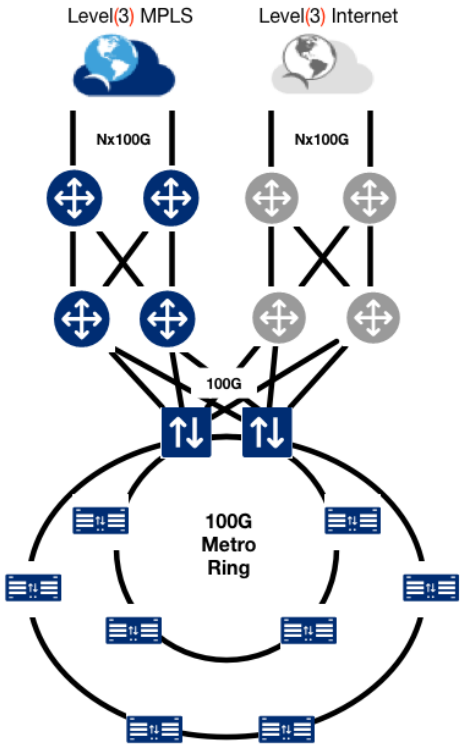
Enterprise VPNs & Ethernet Everywhere

Solid foundational architecture

- Designs have scaled to meet today's needs but limits in protocol and signaling technology have generated industry complexity
- MPLS creates more complexity and fragility end-to-end; we are committed to MPLS but we need alternatives for access.

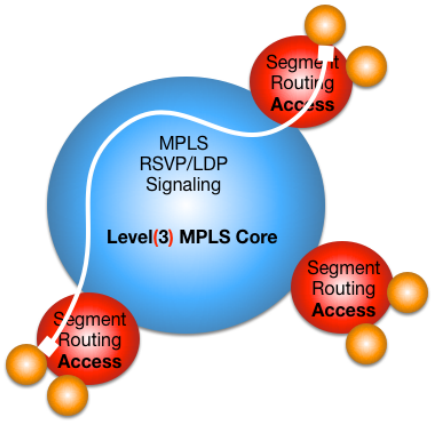
Adopted strong Ethernet Architecture (Metro 2.0)

- Improves Layer-2 redundancy and Services scale
- Platform supports EPL-Packet and Circuit Em
- Significant automation in control systems

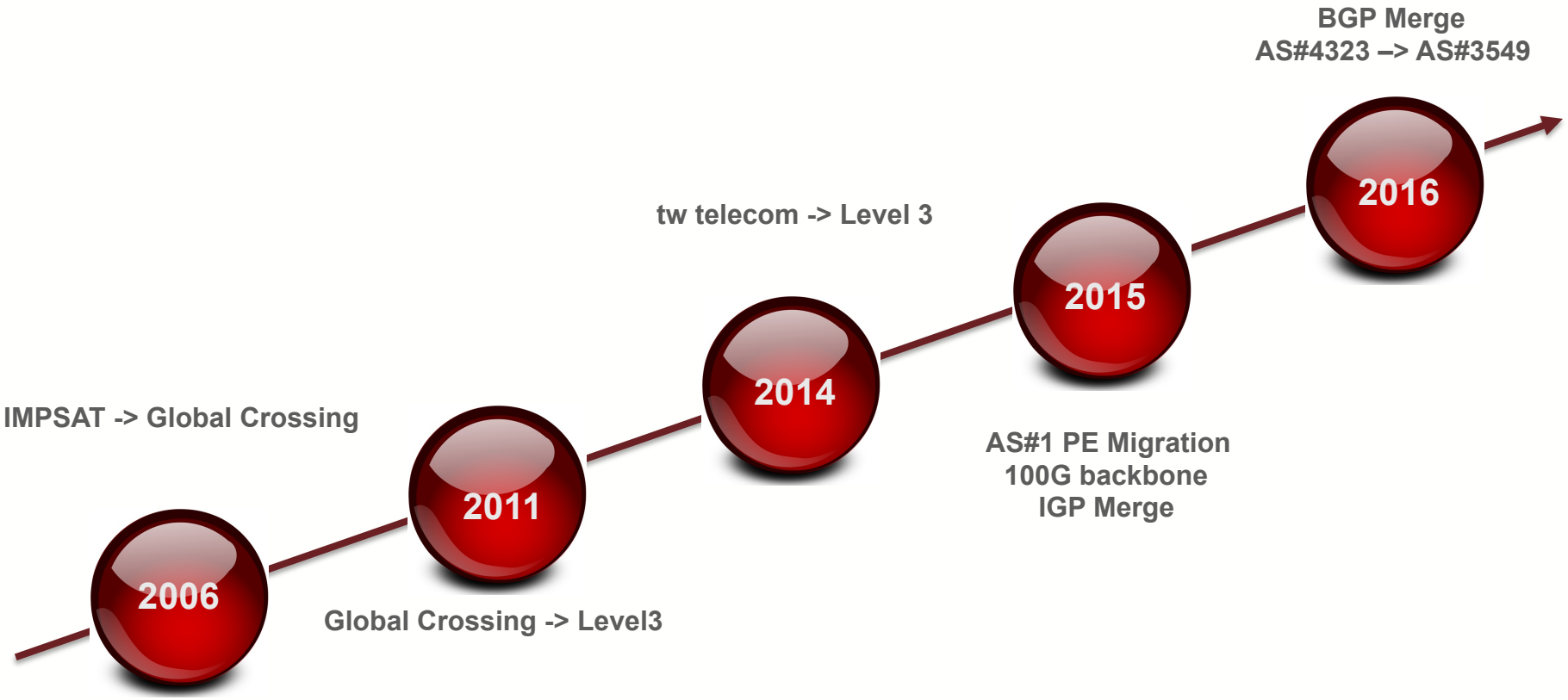


Level(3) Strategy

- Drive to 100% Ethernet packet environment
- Innovate and develop technology in the access network (Segment Routing and Generic Service Label) to scale end-points to millions.
- Leverage protocol development to improve pseudowire protection mechanisms without complex overhead.
- Expand Metro 2.0 footprint globally
- Leverage automated control systems supporting Metro 2.0 and VPN
- Improve PE resiliency architecture



Level 3's Network Integration



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AS4323 → AS3549 BGP Merge

What

- *Creating a unified network architecture*

- Logical Migration of VPN / Internet PE's from AS4323 to AS3549
- Taking two independent BGP networks and combine them under one AS domain allowing for a common set of configurations, routing standards & policies and rules to adhere to.

Why

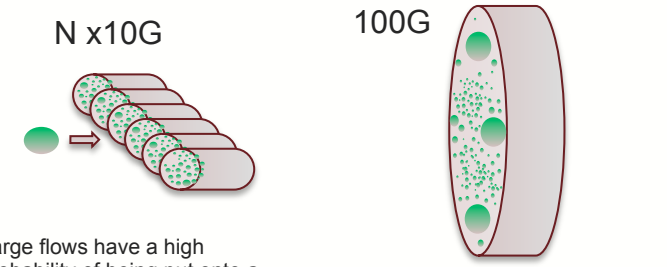
One network with common set of capabilities

- Single backbone for all VPN Services *(via IGP Merge)*
- Creates a single Service network, single VPN/BGP routing domain
- Global reachability for Ethernet Services
- Global IPVPN services

100G MPLS Services Backbone

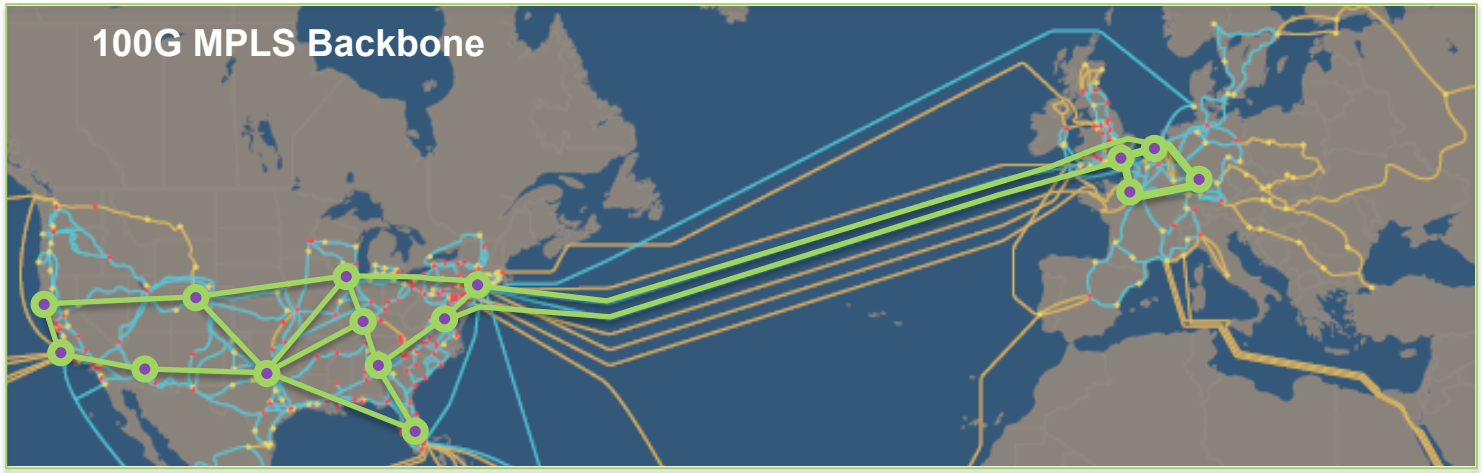
- Simplified operations for troubleshooting customer issues
- Reduce (MPLS Service) network complexity (nx10GE topology)
- Reduces load balancing designs and traffic engineering complexity; deterministic failure/re-route design
- Simplified capacity planning

Link Aggregation Groups vs Larger Links



Large flows have a high probability of being put onto a link that will overflow and drop packets

Large flows don't put other traffic at risk



Protocol	AS#3549	AS#4323	End State
IGP	ISIS level #2	Single Area OSPF	ISIS level#2
BGP	AS#1 AS#3549	AS#4323	AS#3549
L2VPN L3VPN	LDP with BGP Auto Discovery	RSVP with BGP Signaled VPLS	LDP with BGP Auto Discovery
RSVP	LDP PE – P Mesh P – P Mesh	PE-PE RSVP Mesh	LDP PE – P Mesh P – P Mesh
	SRLG Auto-bandwidth + FRR Tunnels ~15K	SRLG Auto-bandwidth + FRR Tunnels ~ 85K	SRLG Auto-bandwidth + FRR Tunnels ~ 103K
Node Count	94 – P Routers 520 – PE Routers	150 – P Routers 290 – PE Routers	240 – P Routers 810 – PE Routers

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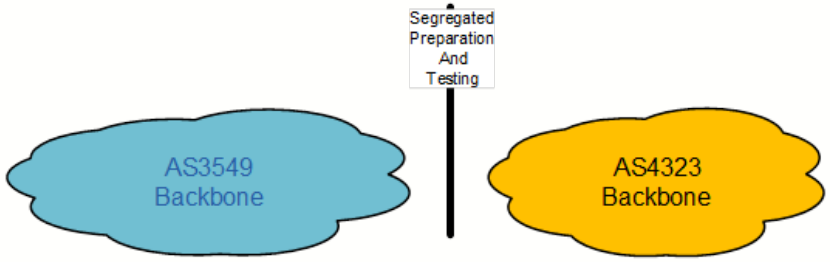
IGP Merge

Network and Infrastructure Preparation 1Q-2Q 2015

- Key Steps / Activities

1. AS3549: Core and Edge Engineering testing scale and feature interop.
2. AS4323: We will begin converting the network to AS3549 standards including LDP and P to P RSVP. For now these elements will be overlaid and not used for production traffic.
3. 100G buildout required for traffic growth
4. Transport: physical connectivity between [6|8] core markets is to be built in preparation for the merge.

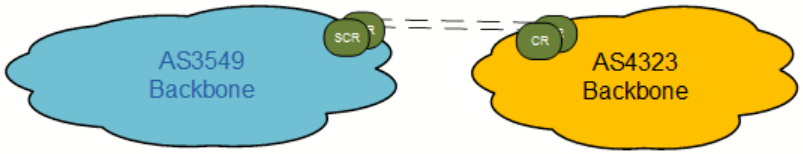


IGP Merge

Network Ready Test – Phase 1 (Seattle) – June 2015

- Key Steps / Activities

1. The first contact for the two AS's will be enabling ISIS between the Seattle CR's and SCR's as well as down to the AS4323 PE's (AR).
2. LDP, P to PE LSP's, and P to P LSP's should already be in place.
3. As we enable each city build a full P – P LSP mesh.
4. No traffic between AS4323 PE's will use the new protocols as OSPF and PE to PE RSVP will be preferred.
5. Limited testing will be available such as verifying LDP/RSVP path from AS4323

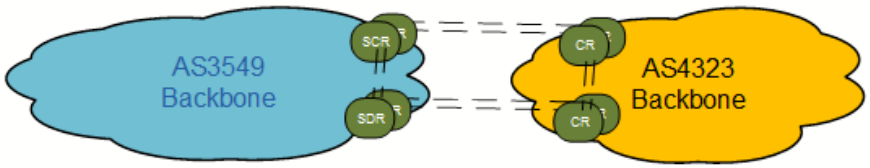


IGP Merge

Network Ready Test – Phase 2 (Oakland) – July 2015

- Key Steps / Activities

1. After an extended soak following first contact, allows a redundant path between AS's, again limiting scope as much as possible.
2. Enable ISIS on the Oakland CR/SCRs as well as down to the AS4323 PE's (AR) and the city CR to CR interconnects.
3. Let the network soak with this limited exposure for some time.
4. To test inter-as connectivity, build a test EPL customer between cities using a static LSP that traverses the AS boundary.

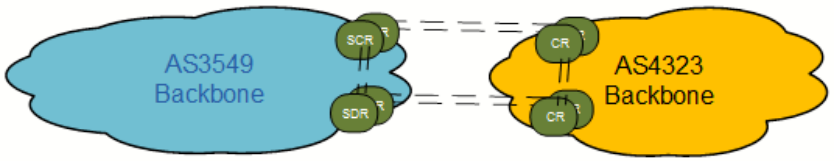


IGP Merge

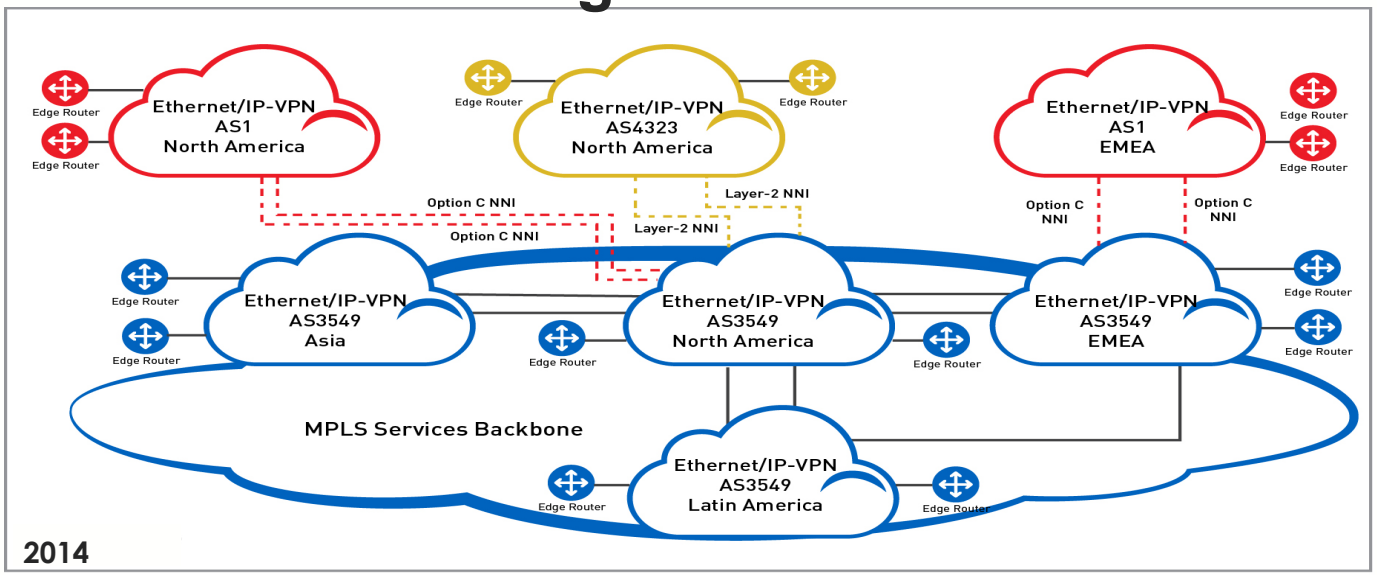
Full Network Rollout – Sept 2015

- Key Steps / Activities

1. ISIS can propagate to all routers in the network in a controlled, responsible fashion
2. Each city completed will have a full CR to SCR/SDR LSP mesh created as we go
3. Once ISIS has propagated to all routers in AS4323, we will have reachability between AS4323 PE's and a seeded PE in AS3549.
4. Initial customers in the seeded markets help us to pre-stress the go-forward architecture on a limited set of customers while leaving intra-AS4323 customers on the legacy, stable architecture.
5. Change protocol preference for ISIS
6. Tear down PE – PE RSVP Mesh
7. Remove OSPF

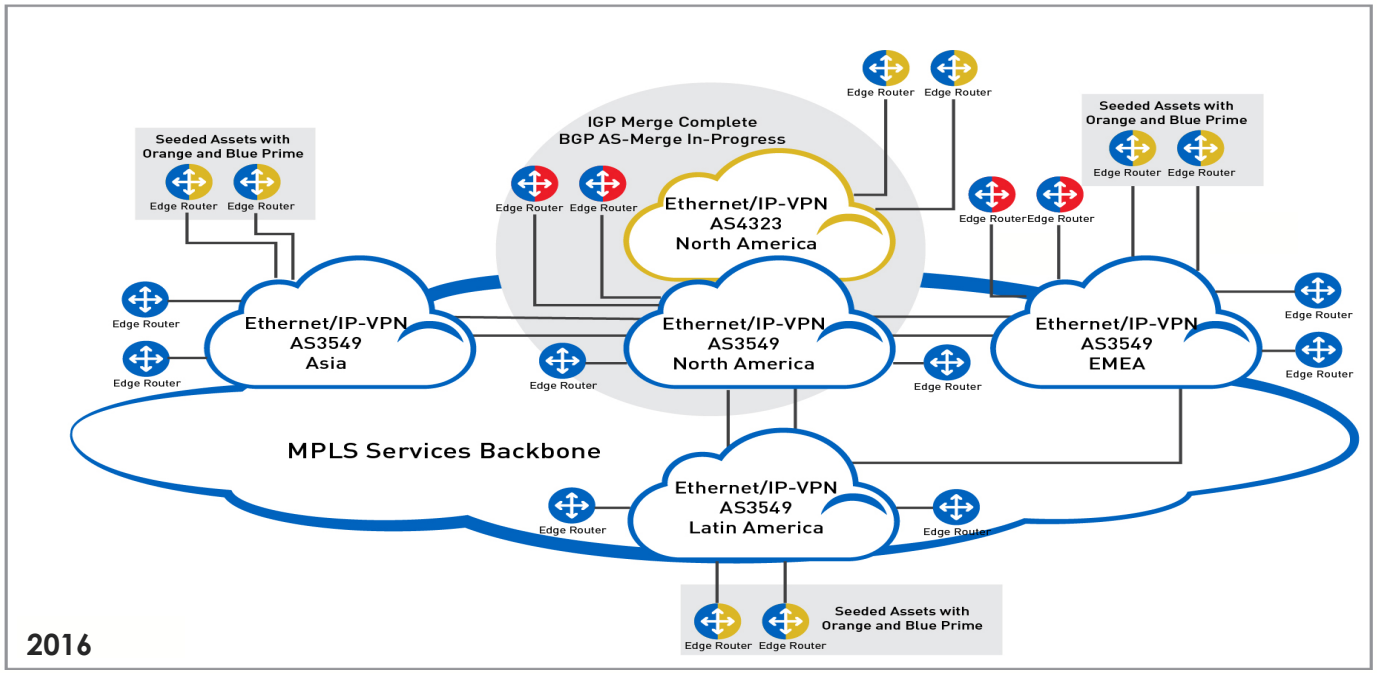


VPN Network Integration



BEFORE:

- Three distinct Backbones & Edges
- AS1 <-> AS3549 - Layer 3 and Layer 2 NNI's used for cross network connectivity
- AS4323 <-> AS3549 - Layer 2 NNI's ONLY used for cross network connectivity

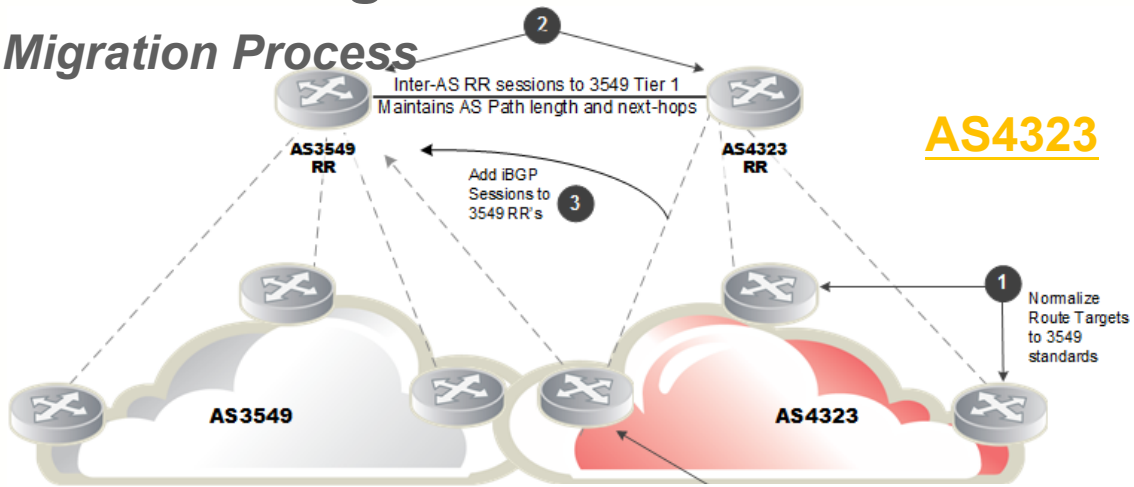


AFTER:

- One Core Backbone for VPN Services
- Two logical Edges still exist, 4323 and 3549
- No NNI's required for connectivity between red/blue devices (single routing and RD/RT domain)
- Layer 2 NNI's ONLY used for Metro connectivity to 3549

AS1 PE Migration vs. AS4323 BGP Merge

Migration Process



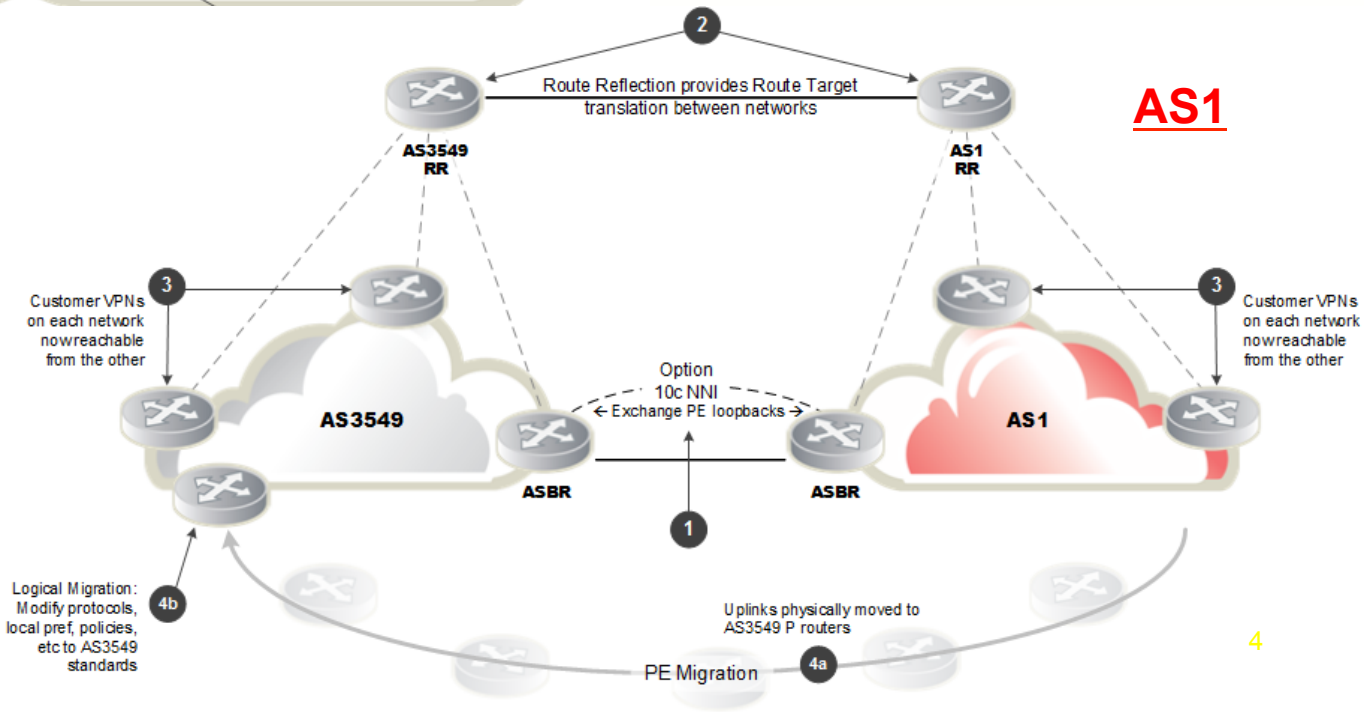
AS4323

BGP Merge:

Logically connecting the PEs to the AS3549 backbone through an InterAS session between the Route Reflectors

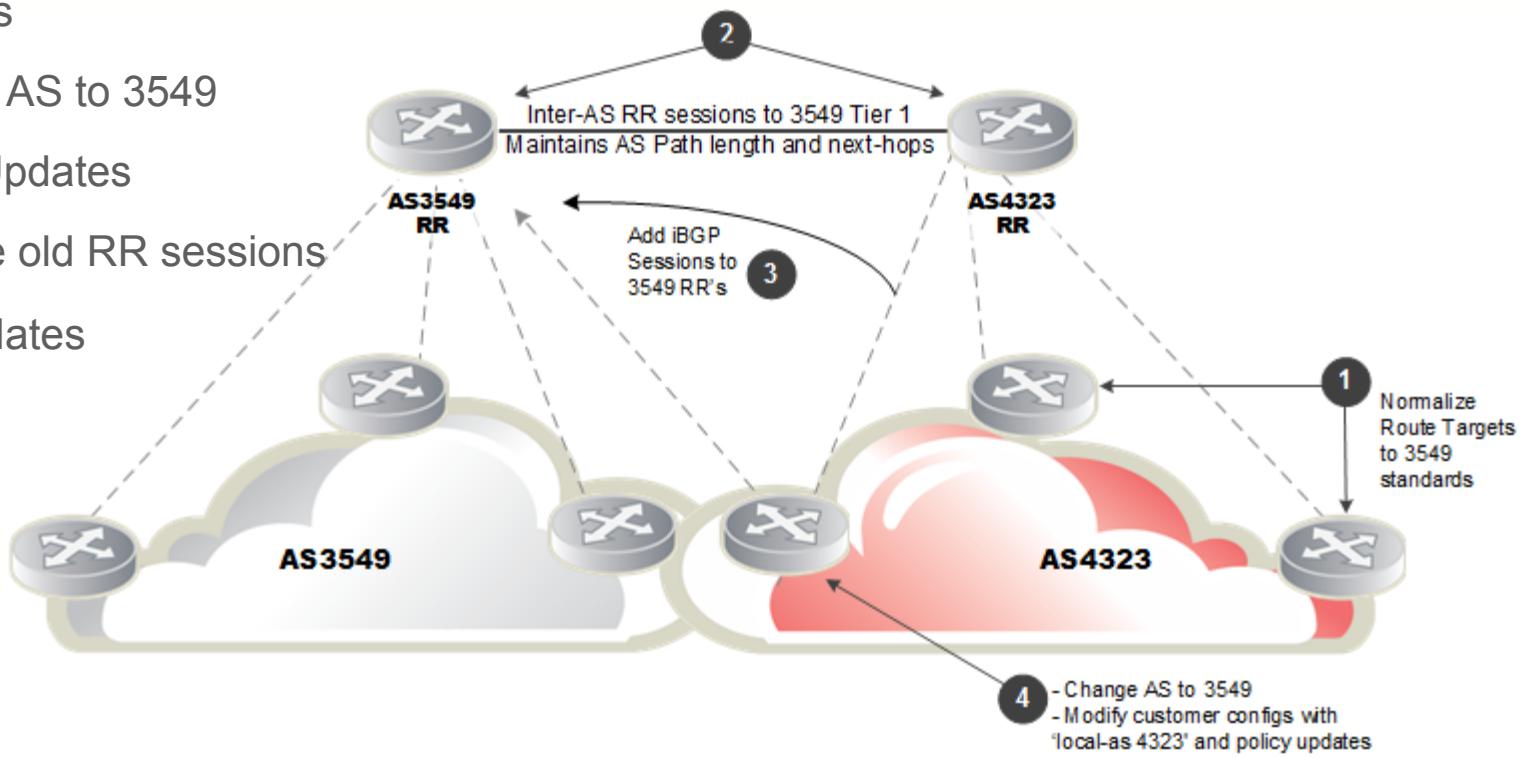
PE Migration:

Physically connected the PEs to the AS3549 backbone

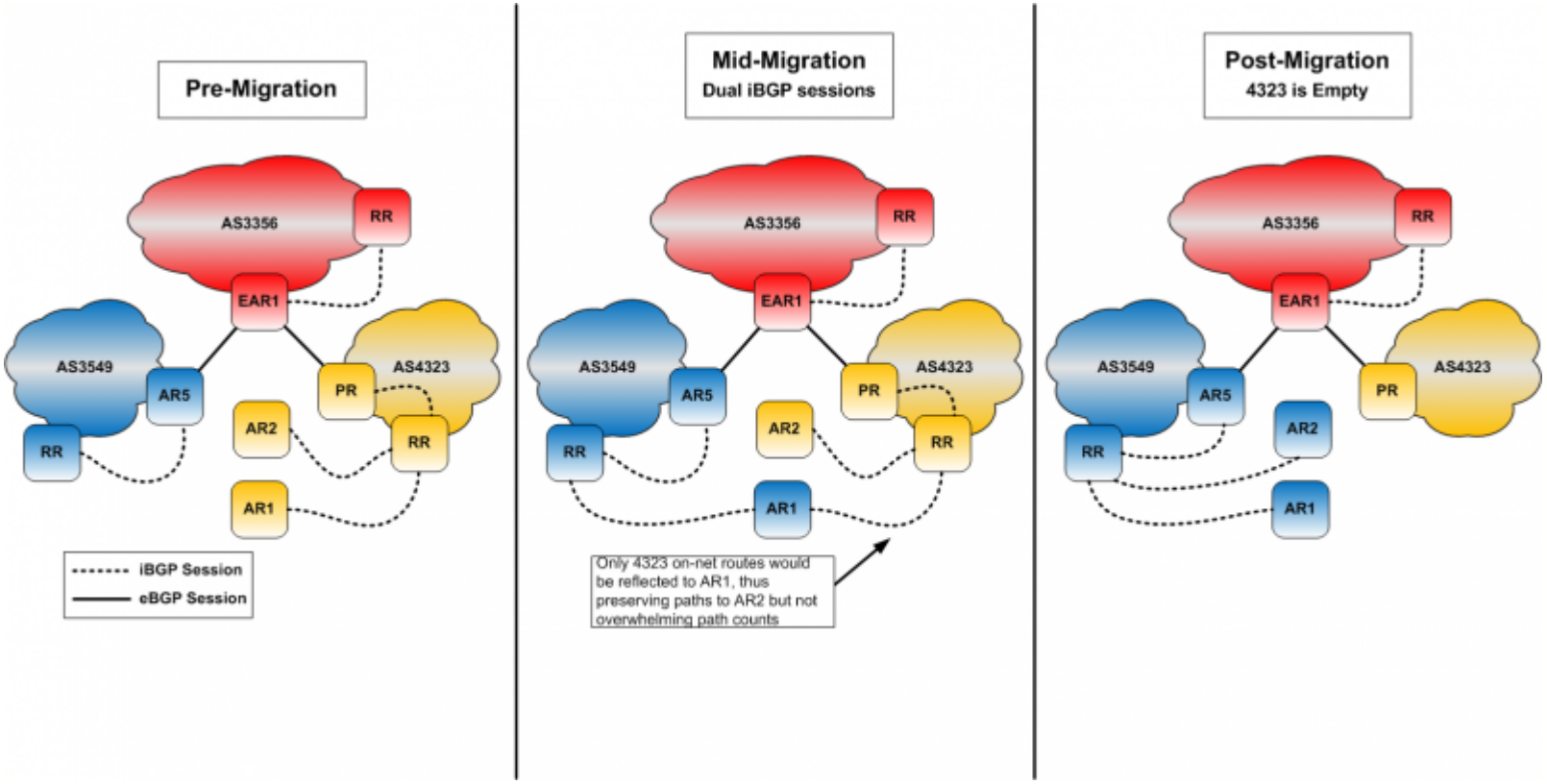


High Level BGP Merge Steps

1. Route Target Migration to 3549 RT's
2. Inter AS Route Reflector Sessions
3. iBGP Sessions to the 3549 RR's
4. PE Merge
    1. Apply local-as 4323 to all customer sessions
    2. Change AS to 3549
    3. Policy Updates
    4. Remove old RR sessions
5. Systems Updates



BGP Merge – Internet



- Existing BGP sessions to the 4323 RRs for Internet (family inet and inet6) routes will be preserved from the ARs.
- This will enable a migrated PE to still prefer paths to other 4323 PEs that have not been migrated yet.
- Without this in place, 4323 routes would be learned via 3356, but would be an extra AS-hop away.

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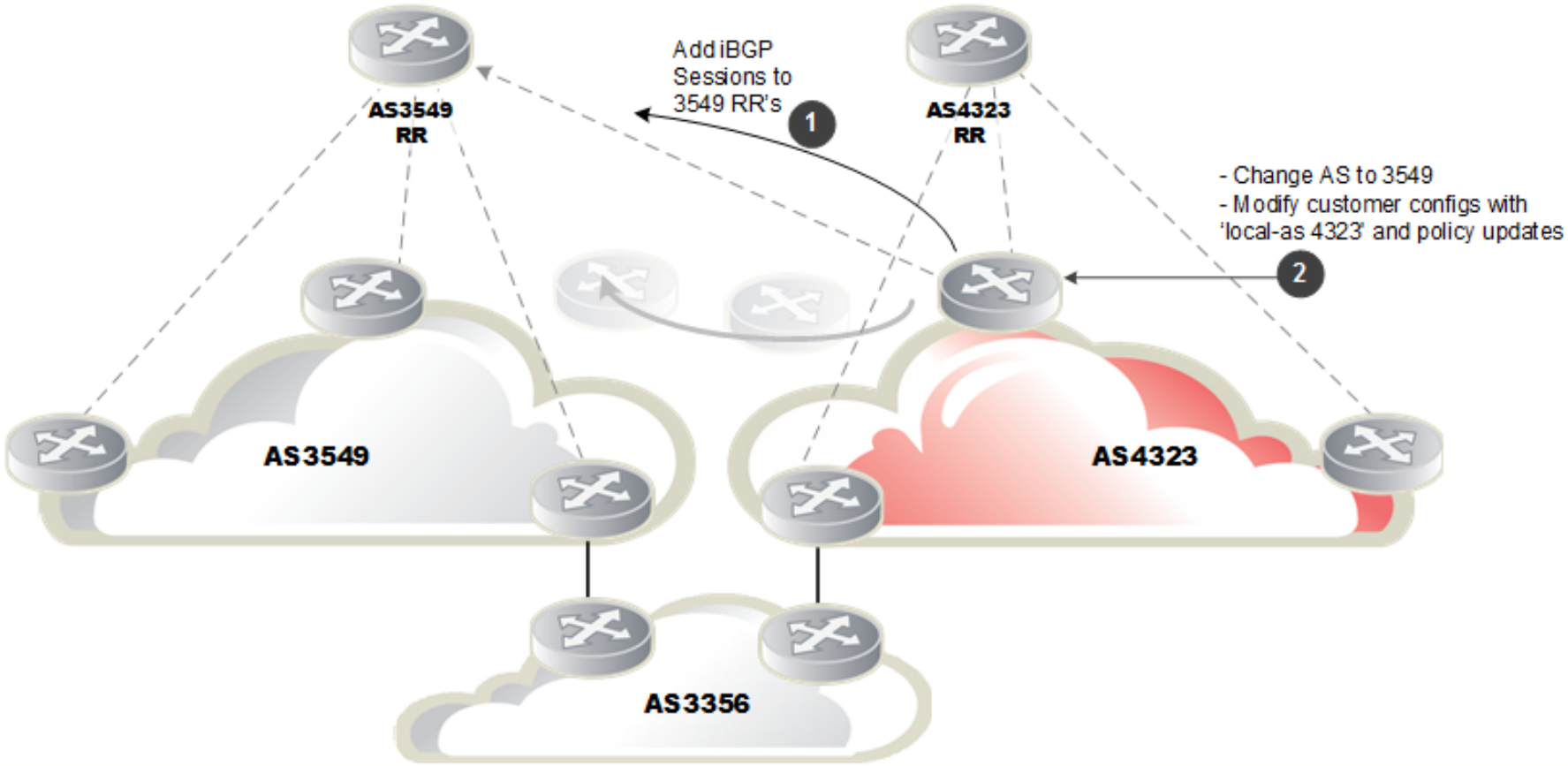
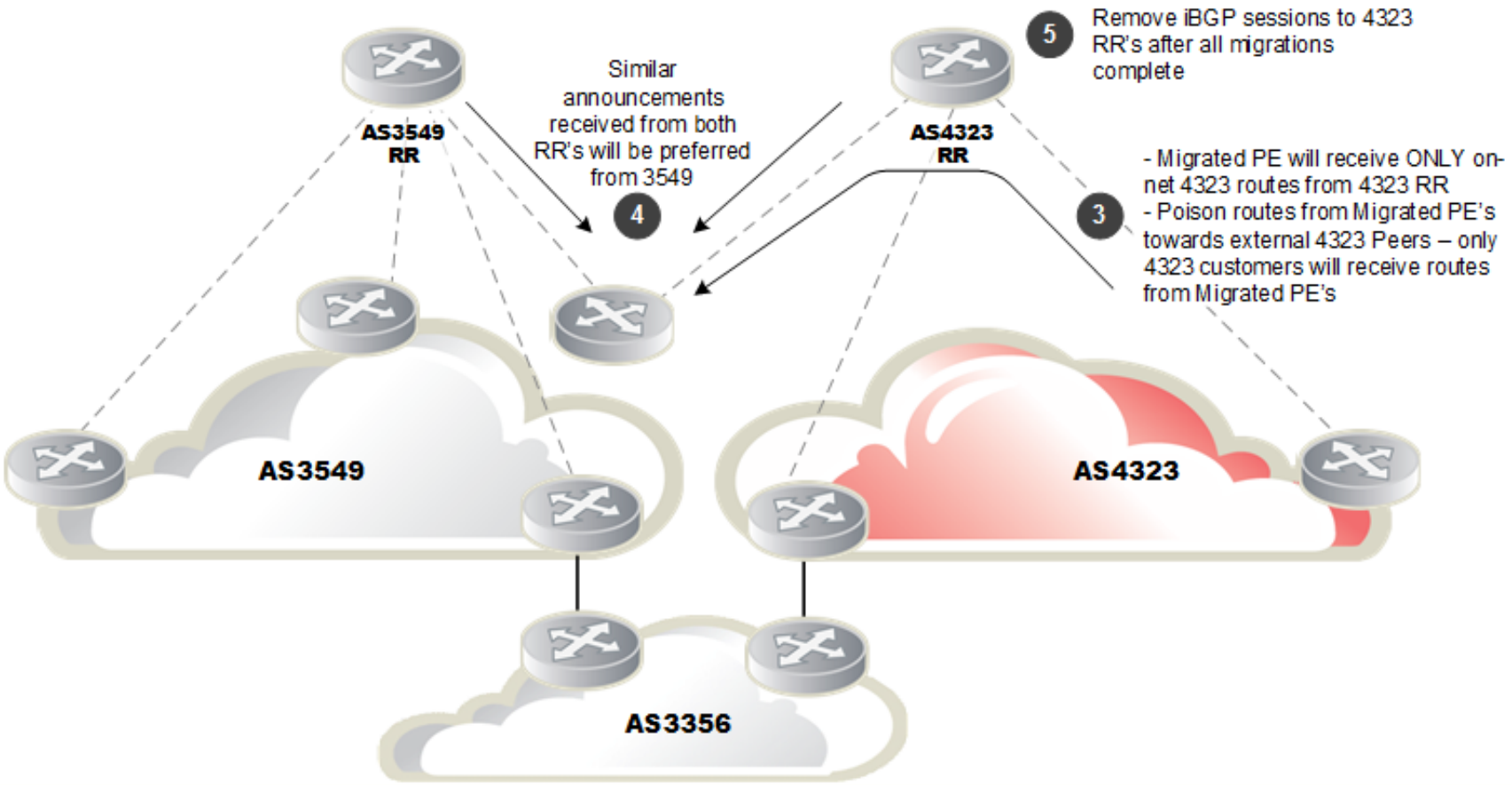
High Level BGP Merge Steps

Internet



High Level BGP Merge Steps
Internet (cont'd)



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MPLS Backbone Challenges

- Backbones are Multi-vendor
- Standard based protocols and inter-operability are a MUST
- Scaling the P routers is easier!
- Scaling the Service Edge and the service plane is the primary challenge
  - 64 Bit OS – IPv4 route table 590K +
  - Real world Multi-Service scaling
  - RSVP has it scale limits and we continue to push this boundary
  - SNMP - statistics gathering are a bottle neck – need a push Model
- Proactive Device Health
- Network Health and Predictive Management
- Netconf / Yang for device interaction
- “Hand off the Network” – Automation
  - Large portions of outages/Trouble Tickets are Human Error related

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