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cisco The bridge to possible

Cisco Solutions for Mission-Critical Mobile Infrastructure in Industrial IOT Environments

A case study in real-world network design

Alex Lynn, Consulting Engineer, Cisco Systems

BRKIOT-2356

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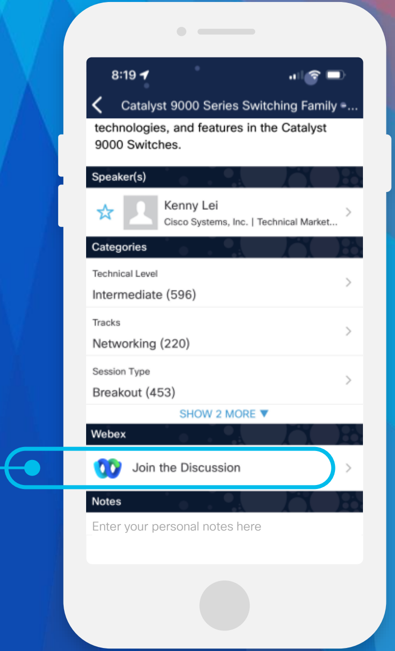

8:19

Catalyst 9000 Series Switching Family ...

technologies, and features in the Catalyst 9000 Switches.

Speaker(s)

Kenny Lei
Cisco Systems, Inc. | Technical Market...

Categories

Technical Level
Intermediate (596)

Tracks
Networking (220)

Session Type
Breakout (453)

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Breaking Down Our Track Segments

Head End Router Options

Catalyst Router C83xx
[Datasheet]

Catalyst Router C85xx
[Datasheet]

Catalyst Router IR8340
[Datasheet]

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Spoke Router Options

Catalyst Router IR18xx
Datasheet

Catalyst Router IR1101
Datasheet

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Software Options

Broadcast	Multicast	Unicast	Encryption	Routing	Failure sensing	Failure mitigations
Native	Native	Native	IPSEC	Static	Link State	EEM
L2TPv3	GRE	GRE	IKEv1	EIGRP	BFD	DPD
EoMPLS	DMVPN	FlexVPN	IKEv2	OSPF	Object tracking	Anycast RP
VPLS	FlexVPN	MPLS	None	NHRP	Boolean operands	Routing redundancy
VXLAN	VXLAN	VXLAN		BGP		

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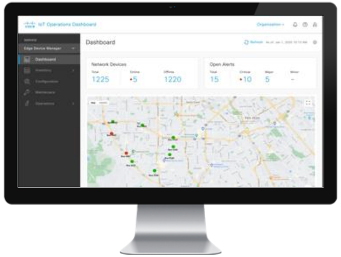
Management Options

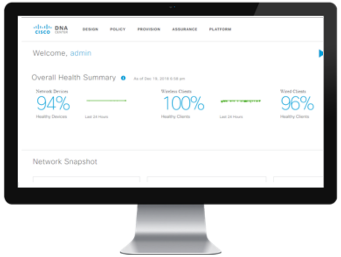
Manage by use case & workflow

Enable management of non-carpeted areas



IoT OD
Operations Dashboard

IoT FND
Field Network Director



Catalyst Center

Catalyst SDWAN

For select Cisco Industrial Routers and Gateways	For select Industrial Routers and FAN deployed by Utilities	Extended Enterprises: Industrial IOT Switches, Wi-Fi and Router	SD-WAN Fabric overlay: Industrial IOT IOS-XE Routers
Cloud-Based	On-Premise	On-Premise	On-Premise or Cloud

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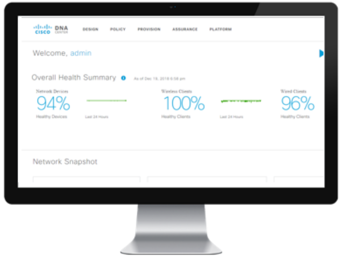
Options Used for our Session

Head End Router: C83xx

Spoke Router: IR18xx



Management: Catalyst Center

Broadcast	Multicast	Unicast	Encryption	Routing	Failure sensing	Failure mitigations
Native	Native	Native	IPSEC	Static	Link State	EEM
L2TPv3	GRE	GRE	IKEv1	EIGRP	BFD	DPD
EoMPLS	DMVPN	FlexVPN	IKEv2	OSPF	Object tracking	Anycast RP
VPLS	FlexVPN	MPLS	None	NHRP	Boolean operands	Route redundancy
VXLAN	VXLAN	VXLAN		BGP		

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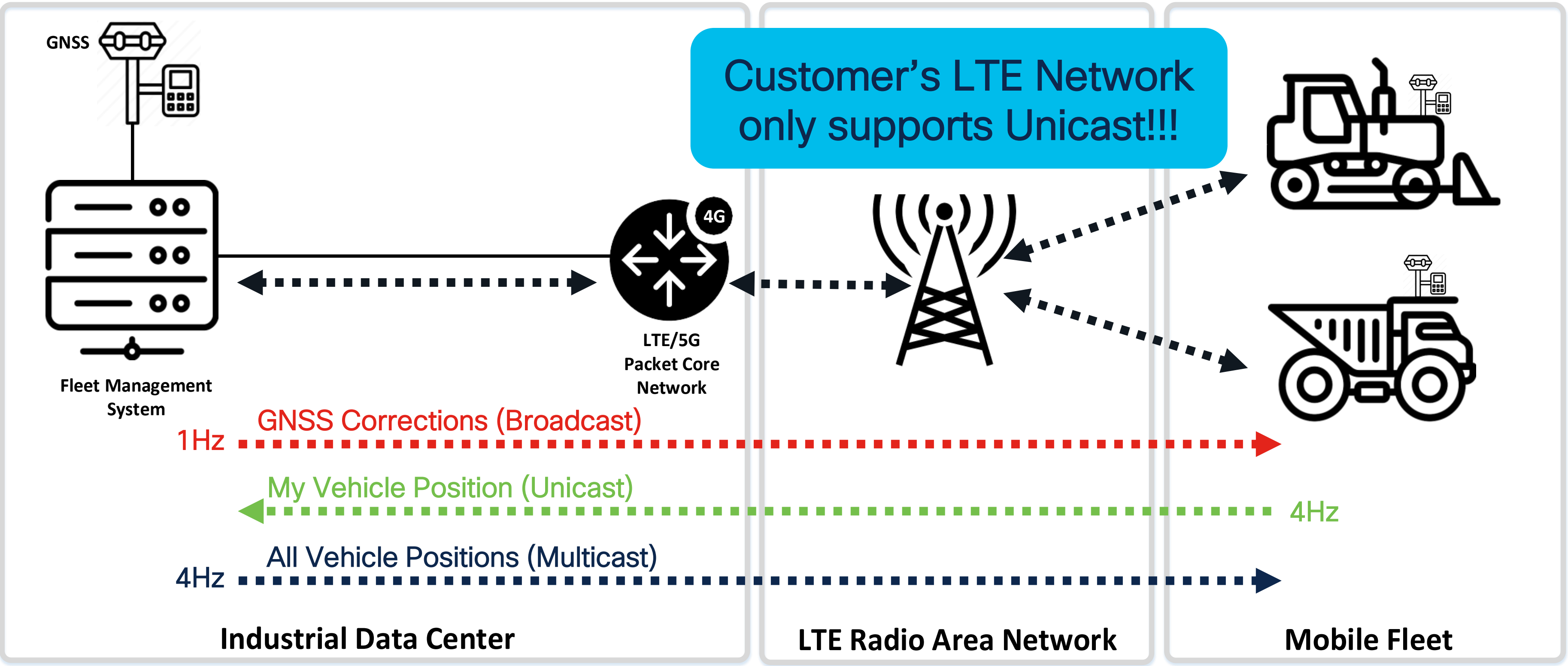
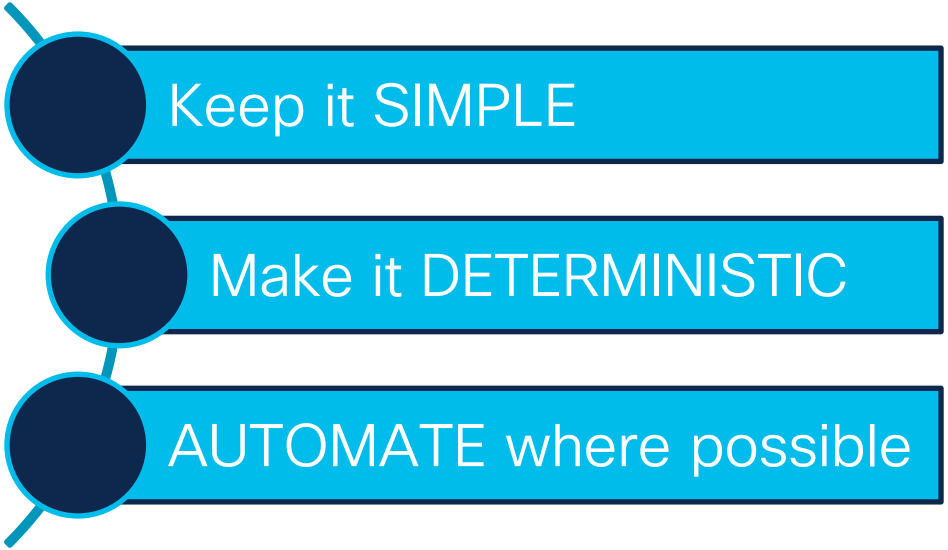
So, Why These Options?

Scenario


GNSS
Customer's LTE Network only supports Unicast!!!
4G
LTE/5G Packet Core Network
Fleet Management System
GNSS Corrections (Broadcast)
1Hz
My Vehicle Position (Unicast)
4Hz
All Vehicle Positions (Multicast)
4Hz
Industrial Data Center
LTE Radio Area Network
Mobile Fleet

Customer Requirements

- Ruggedised LTE UE
- Prioritised unicast, broadcast and multicast
- Highly available infrastructure supporting 1000 endpoints
- Maximum traffic loss 2s
- Zero-touch provisioning



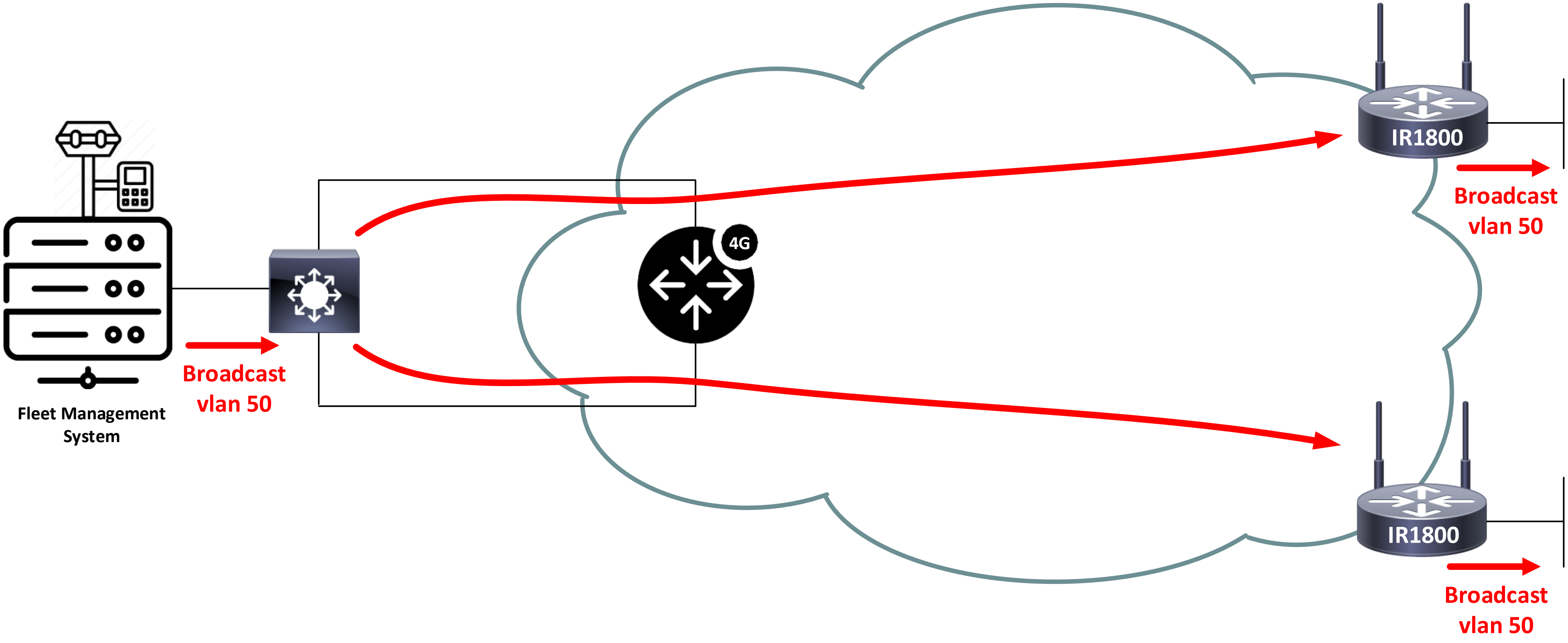
Keep it SIMPLE

Make it DETERMINISTIC

AUTOMATE where possible

Broadcast Transport

Broadcast Transport



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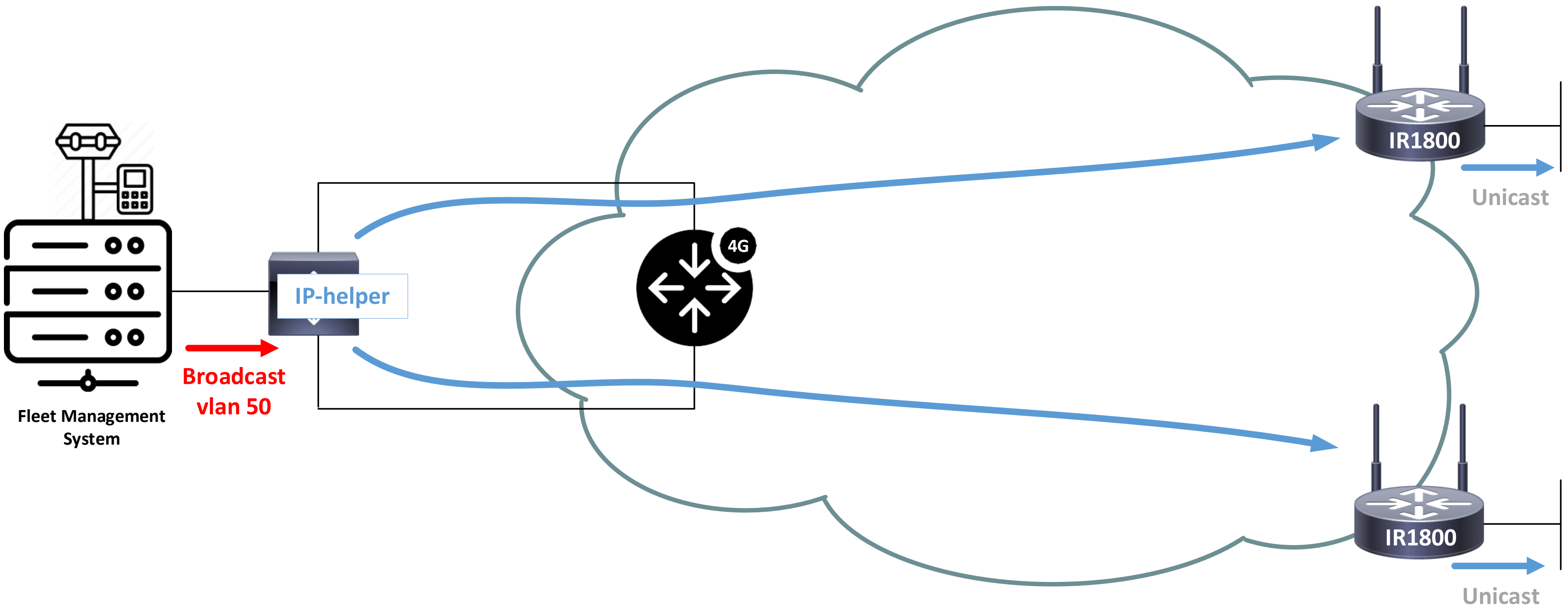
Option 1 – Modify the Application?

- Proprietary software from another vendor that could not be changed
- We were going to have to make the network support the application, regardless

Option 2 – IP Helper



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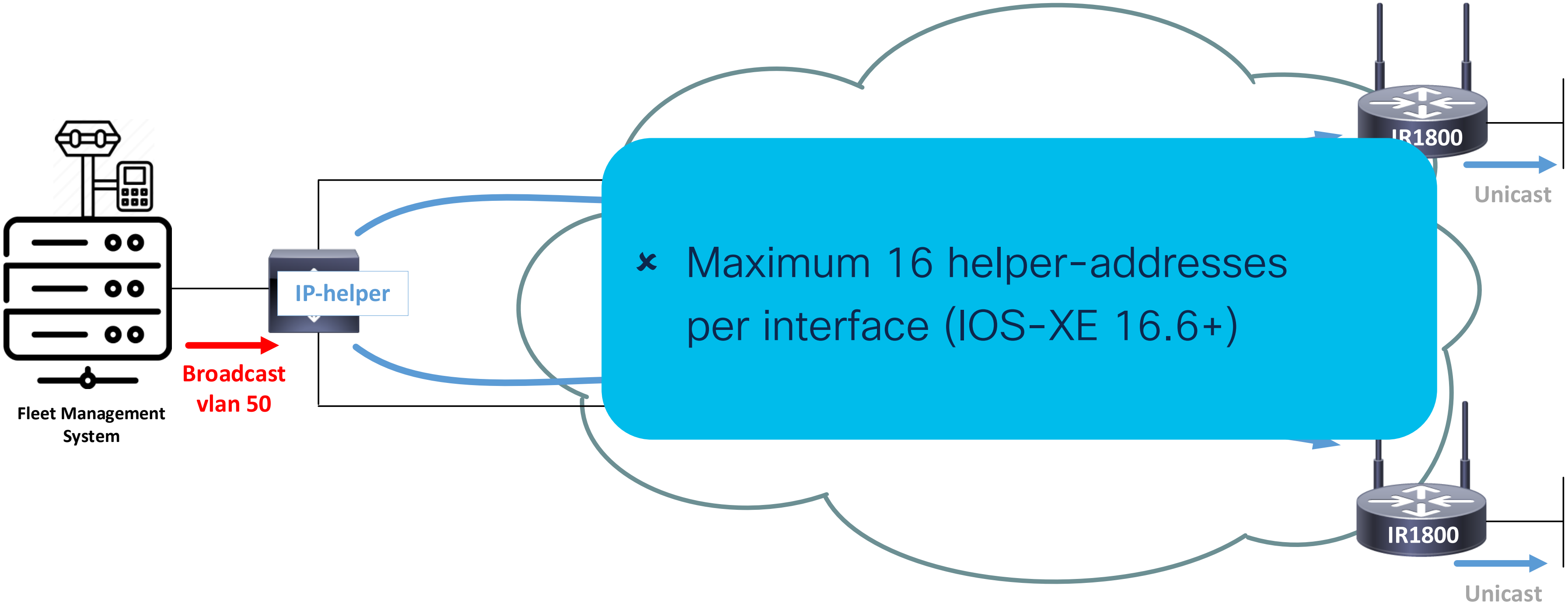
Option 2 - IP Helper



- ✗ Maximum 16 helper-addresses per interface (IOS-XE 16.6+)

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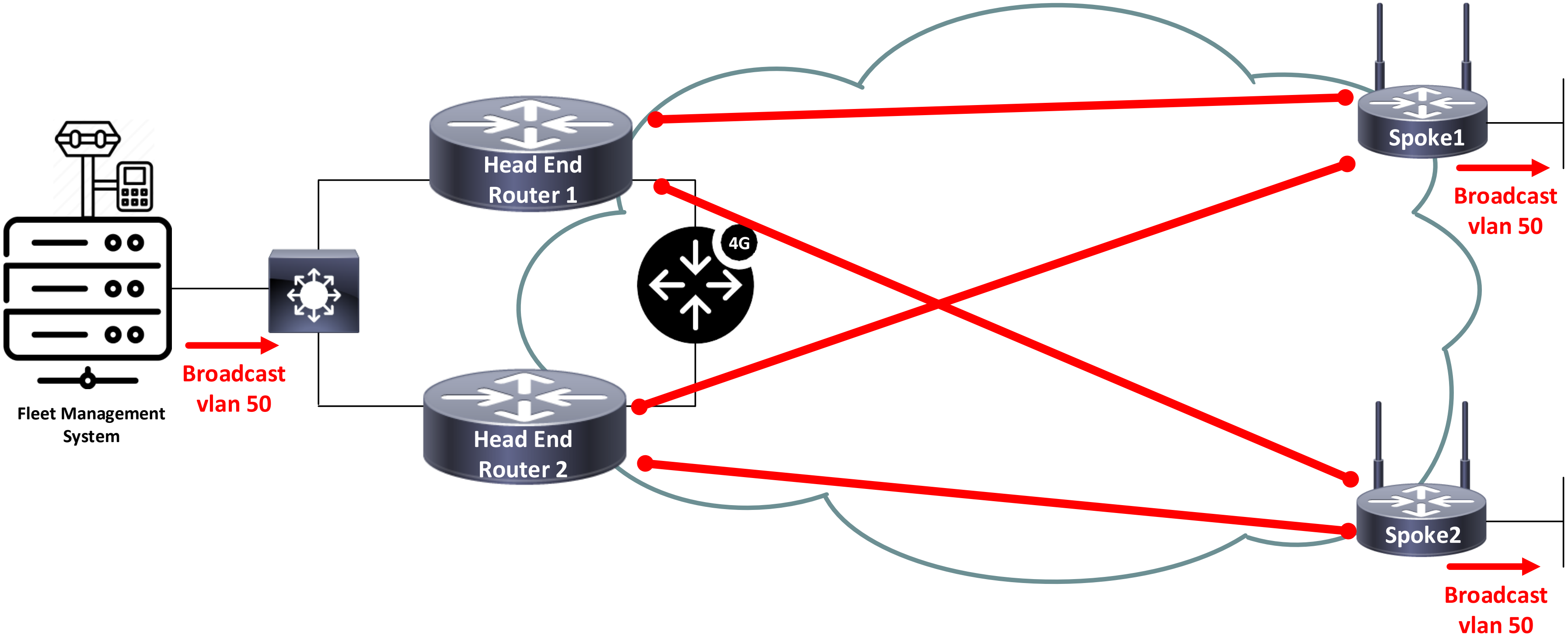
Option 3 – Layer 2 Overlay (Tunnel)



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Layer 2 Overlay Technologies

L2TPv3

- ✓ Simple architecture - EoIP
- ✓ Available on C8300 and IR1800
- ✗ Point-to-point only
- ✗ Extensive manual configuration
  - 1000 interfaces on head-ends
- ✗ VLAN re-writes for common broadcast domain

MPLS

- ✓ Available on C8300 and IR1800
- ✗ EoMPLS is p2p only
- ✗ VPLS not supported on IR1800
- ✗ LTE core network is IP only – require MPLSoX

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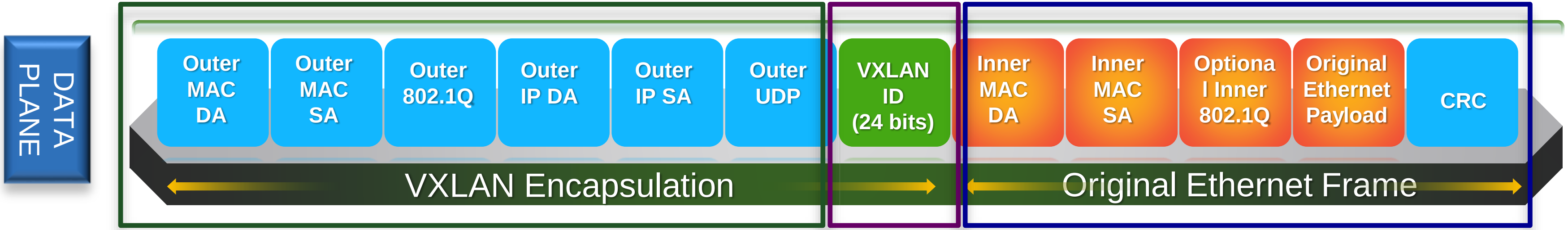
Layer 2 Overlay Technologies - VXLAN

- Virtual eXtensible Local Area Network – RFC 7348
- Originally a DC technology for stretching L2 networks
- Simple ethernet frame encapsulation in UDP packet (50 byte header)
- Point-to-multipoint architecture
- Supported on C8300, Cisco Industrial Routers IOS-XE 17.5.1+



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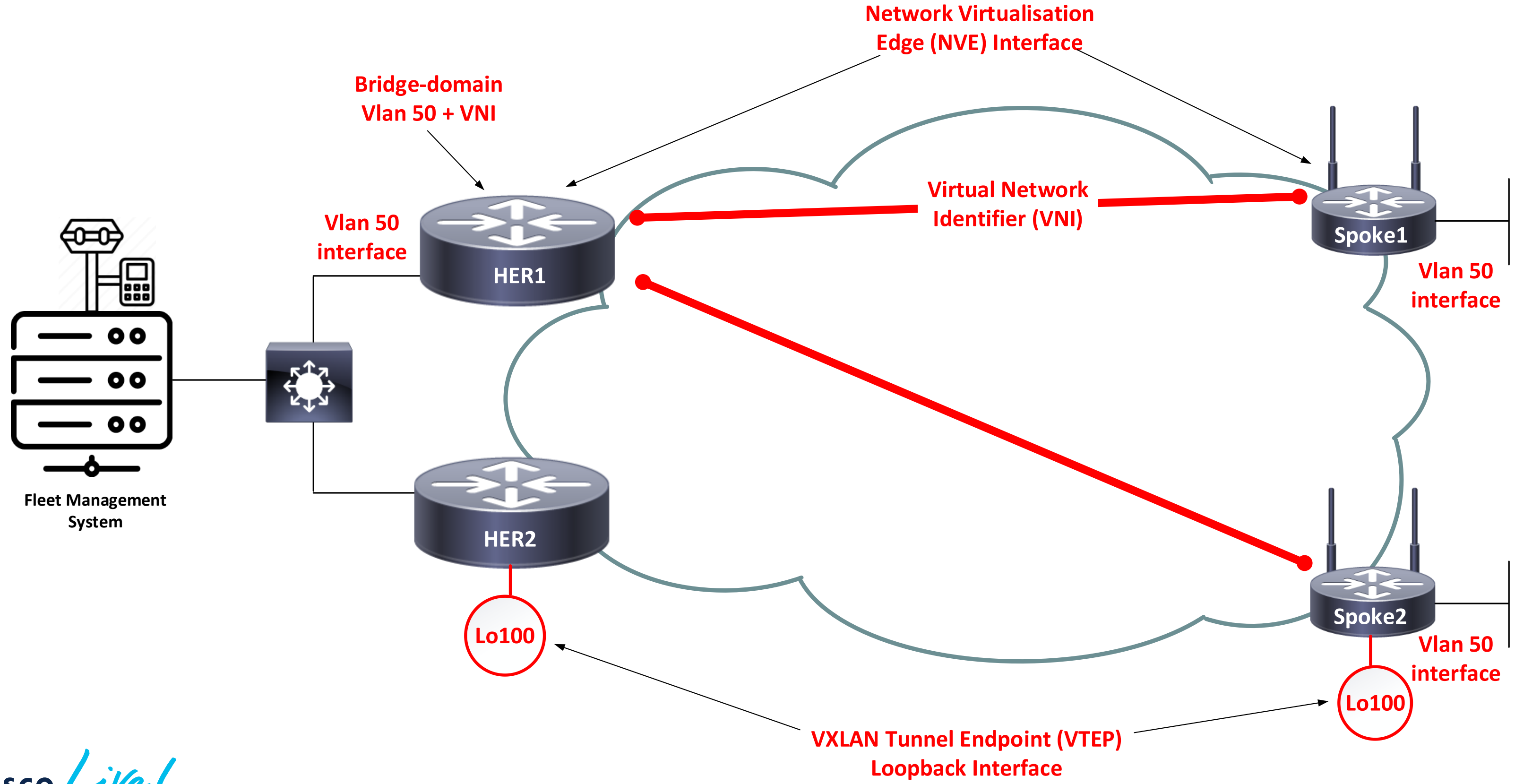
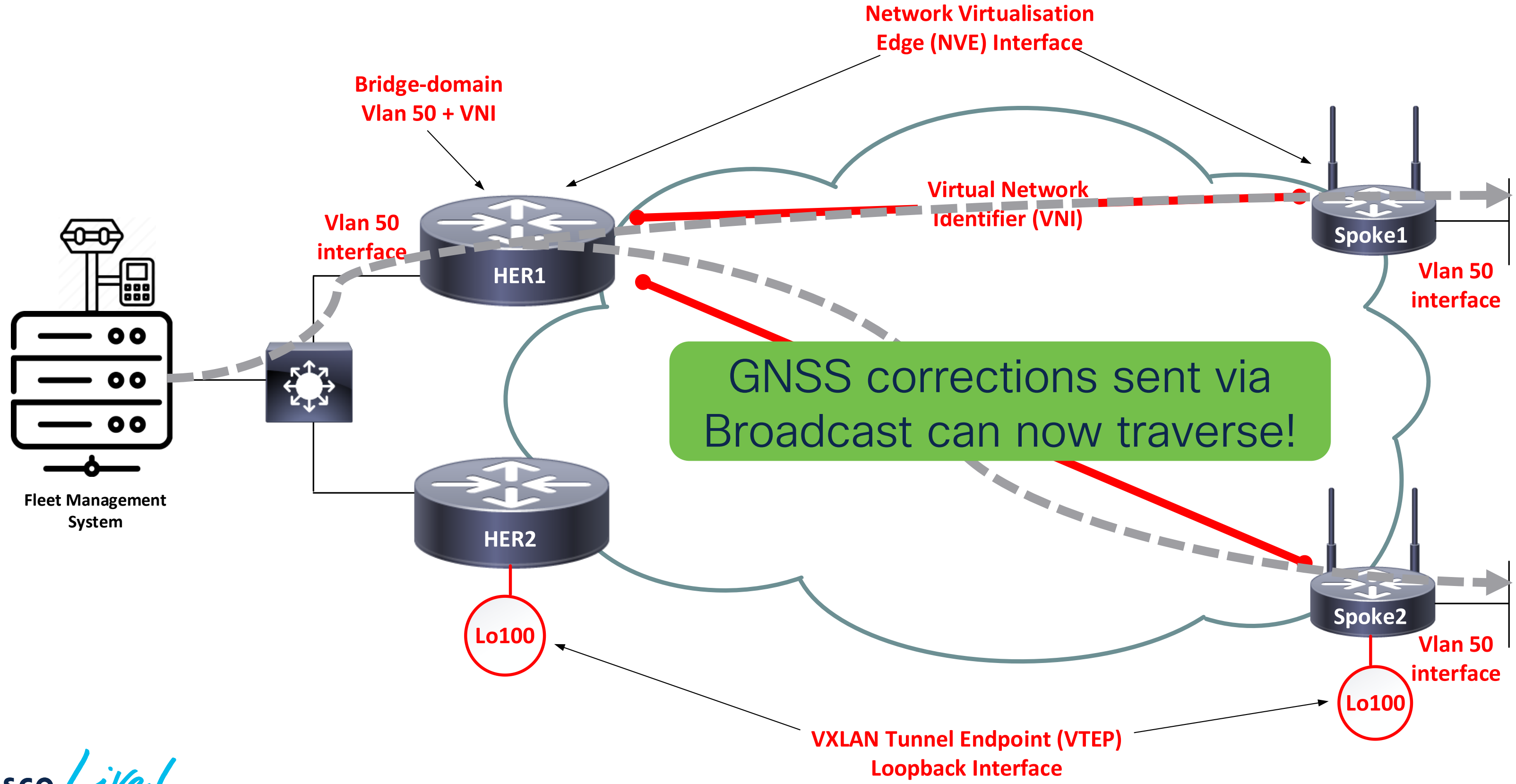
Layer 2 Overlay Technologies - VXLAN



Layer 2 Overlay Technologies - VXLAN



Network Virtualisation Edge (NVE) Interface
Bridge-domain Vlan 50 + VNI
Vlan 50 interface
Virtual Network Identifier (VNI)
HER1
Spoke1
Vlan 50 interface
Fleet Management System
HER2
Spoke2
Vlan 50 interface
Lo100
Lo100
VXLAN Tunnel Endpoint (VTEP) Loopback Interface

GNSS corrections sent via Broadcast can now traverse!

VXLAN – Control Plane

Control Plane Purpose – To discover VTEPs and learn remote MAC addresses.

BGP Signalling

- BGP peering between endpoints advertises MAC-to-host mapping
- Known as BGP EVPN

✗ Not supported on IR1800 at time of solution development.

Flood & Learn

- Broadcast, Unknown unicast, Multicast (BUM) traffic is sent to all endpoints
- Traditional ARP resolution for known unicast
- Unicast and Multicast replication

✓ C8300 and IR1800 support

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VXLAN Configuration - Ingress Replication

HER-1,2

```
interface GigabitEthernet0/0/0
 service instance 1 ethernet
  description Local vlan
  encapsulation dot1q 50

interface nve1
 source-interface Loopback100
 member vni 5050
  ingress-replication <Spoke1 Lo100>
  ingress-replication <Spoke2 Lo100>

bridge-domain 1
 member vni 5050
 member GigabitEthernet0/0/0 service-
  instance 1
```

Spoke-1,2

```
interface GigabitEthernet0/0
 service instance 1 ethernet
  description Local vlan
  encapsulation dot1q 50

interface nve1
 source-interface Loopback100
 member vni 5050
  ingress-replication <HER1 Lo100>
  ingress-replication <HER2 Lo100>

bridge-domain 1
 member vni 5050
 member GigabitEthernet0/0/0 service-
  instance 1
```

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VXLAN Configuration - Ingress Replication

HER-1,2

```
interface GigabitEthernet0/0/0
 service instance 1 ethernet
  description Local vlan
  encapsulation dot1q 50

interface nve1
 source-interface Loopback100
 member vni 5050
  ingress-replication <Spoke1 Lo100>
  ingress-replication <Spoke2 Lo100>
  …
  ingress-replication <Spoke32 Lo100>
```

Spoke-1,2

```
interface GigabitEthernet0/0
 service instance 1 ethernet
  description Local vlan
  encapsulation dot1q 50

interface nve1
 source-interface Loopback100
 member vni 5050
  ingress-replication <HER1 Lo100>
  ingress-replication <HER2 Lo100>
```

- Maximum 32 destination VTEPs for IOS-XE

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VXLAN Configuration – Multicast Replication

HER-1,2

```
interface GigabitEthernet0/0/0
 service instance 1 ethernet
  description Local vlan
  encapsulation dot1q 50

interface nve1
 source-interface Loopback100
 member vni 5050
  mcast group 239.1.1.1

ip pim bidir-enable
```

Spoke-1,2

```
interface GigabitEthernet0/0
 service instance 1 ethernet
  description Local vlan
  encapsulation dot1q 50

interface nve1
 source-interface Loopback100
 member vni 5050
  mcast-group 239.1.1.1

ip pim bidir-enable
```

- ✓ No limit on destination VTEPs
- ✗ Requires multicast across LTE core

Multicast Transport

VXLAN - Multicast Replication

- Requires multicast support in the underlay using PIM-bidir for scalability
- Necessitates creation of an overlay to provide multicast transport

GRE

✓ Multicast-capable using PIM-bidir

✓ C8300/IR1800 IOS-XE support

✓ Per-spoke policies (e.g. QoS)

✗ Point-to-point architecture requires config of 1000 interfaces

mGRE/DMVPN

✓ Point-to-multipoint architecture

✓ Simple HER configuration – single interface

✓ C8300/IR1800 IOS-XE support

✗ No PIM-bidir support

✗ No per-spoke policies

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Enter FlexVPN

FlexVPN

IKEv2-based unified VPN technology that combines the following topologies as needed, automatically:

- Site-to-site
- Remote-access
- Hub-spoke
- Spoke-to-spoke

- Point-to-point architecture
- Simple Head End configuration
- Dynamic spoke addressing
- Multicast-capable using PIM-bidir
- Per-spoke policies
- IKEv2 protocol features

  HER redundancy

  HER intelligent load-balancing

  Dead peer detection

  IKEv2 routing

  AAA integration

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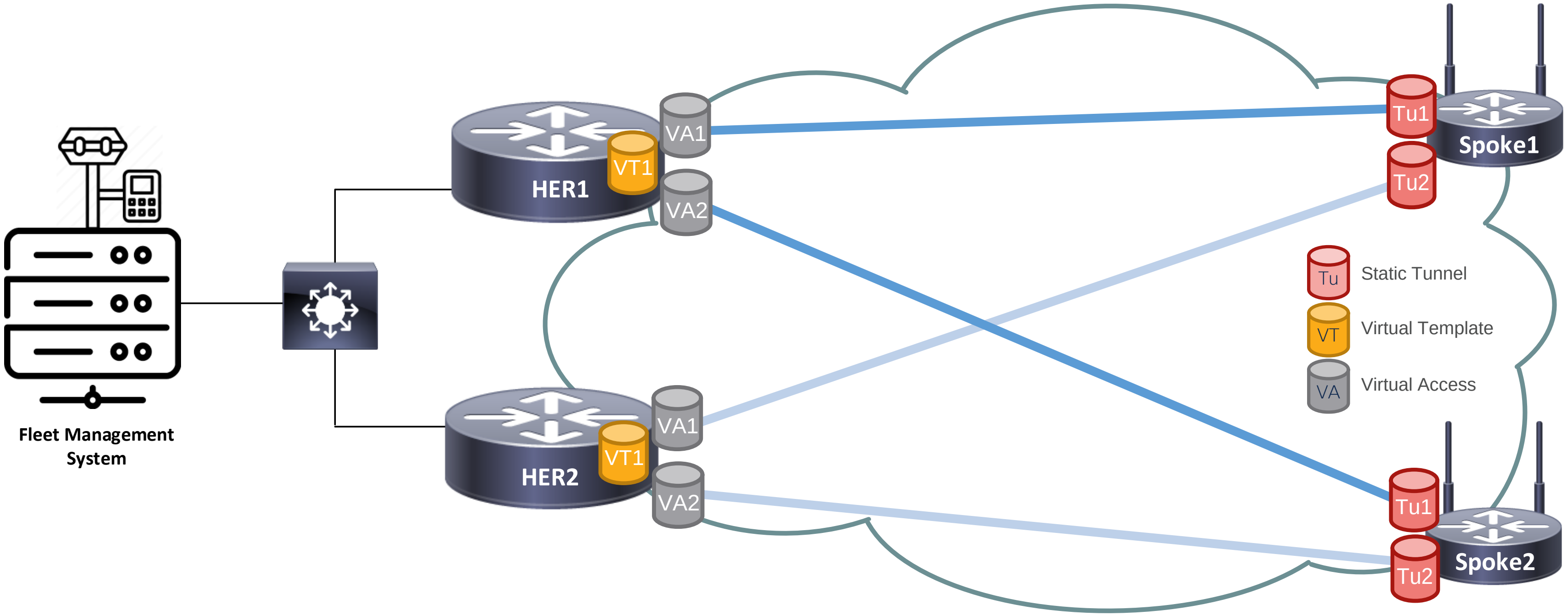
FlexVPN Topology



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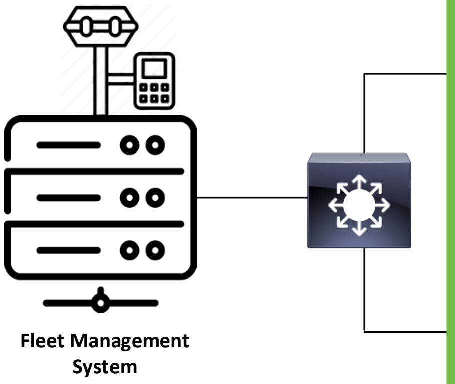
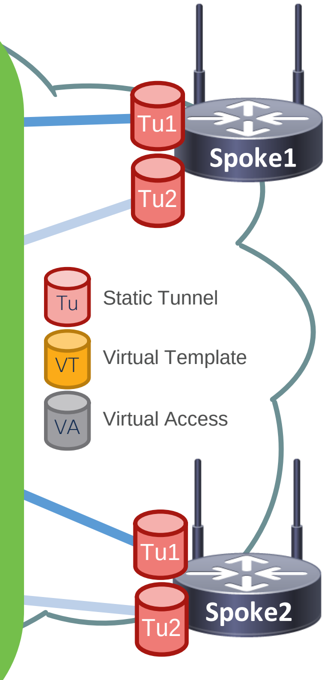
FlexVPN – Spoke Configuration



Spokes

```
interface Tunnel1
 description FlexVPN_HER1
 ip address negotiated
 tunnel source Cellular0/4/0
 ip pim sparse-mode
 tunnel destination <HER1 core ipaddr>
 tunnel protection ipsec profile default

interface Tunnel2
 description FlexVPN_HER2
 ip address negotiated
 tunnel source Cellular0/4/0
 ip pim sparse-mode
 tunnel destination <HER2 core ipaddr>
 tunnel protection ipsec profile default
```



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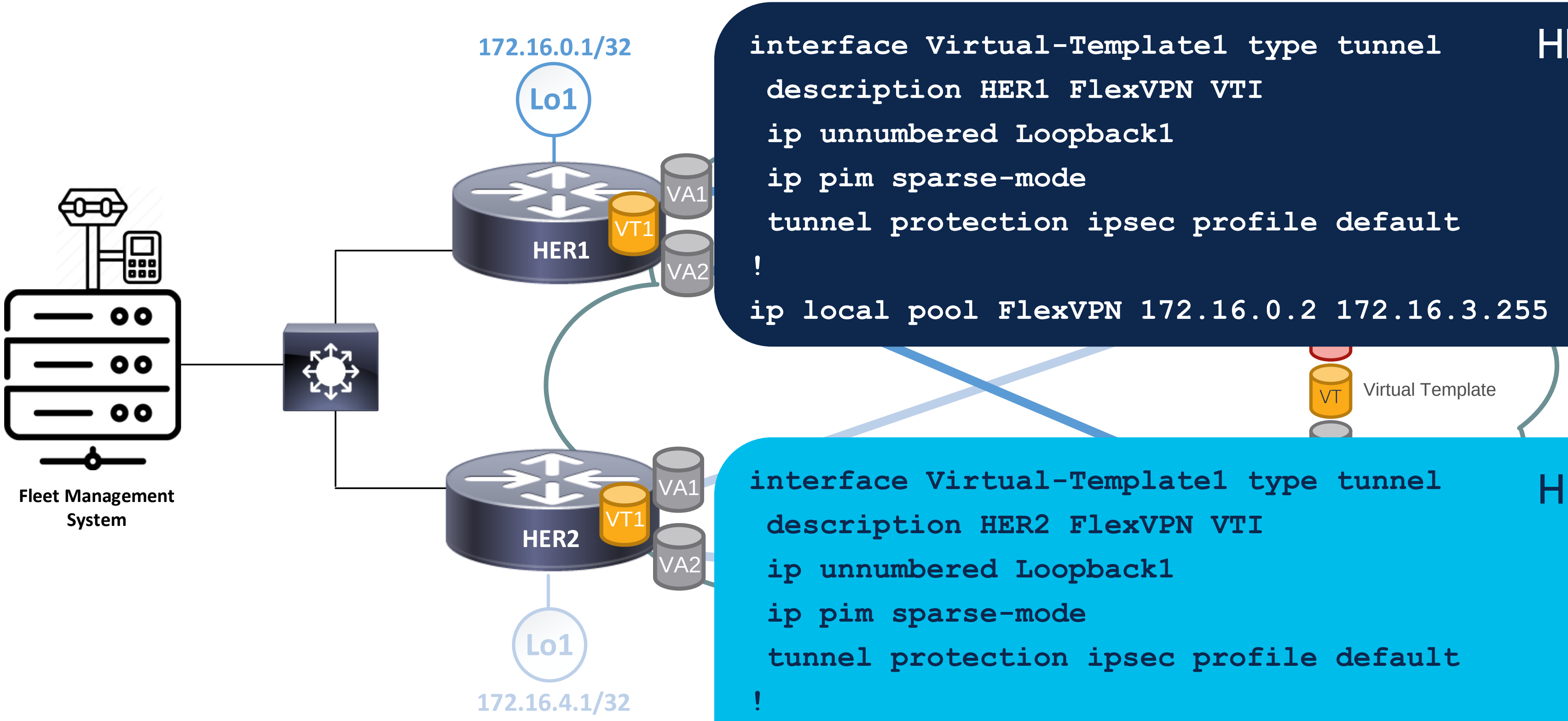
FlexVPN – Head End Configuration



HER1

```
interface Virtual-Template1 type tunnel
 description HER1 FlexVPN VTI
 ip unnumbered Loopback1
 ip pim sparse-mode
 tunnel protection ipsec profile default
!
ip local pool FlexVPN 172.16.0.2 172.16.3.255
```

HER2

```
interface Virtual-Template1 type tunnel
 description HER2 FlexVPN VTI
 ip unnumbered Loopback1
 ip pim sparse-mode
 tunnel protection ipsec profile default
!
ip local pool FlexVPN 172.16.4.2 172.16.7.255
```

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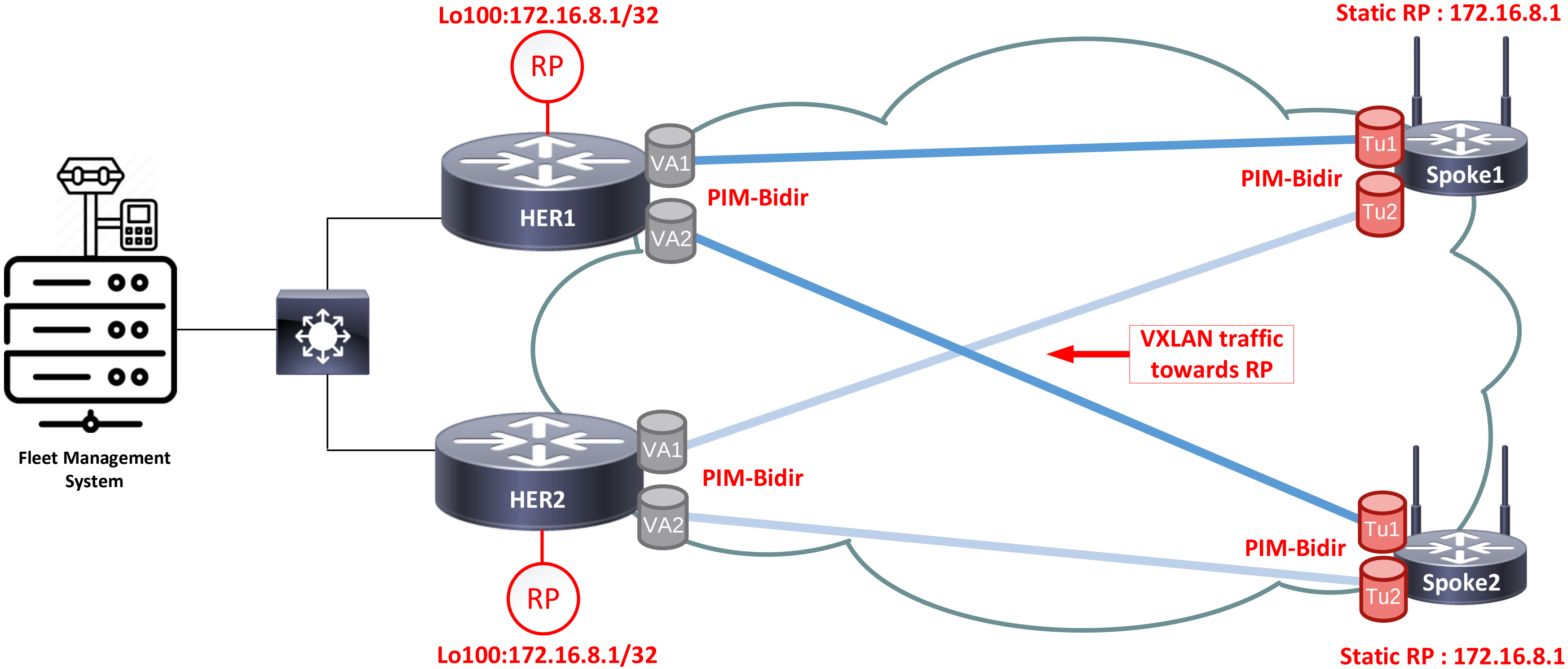
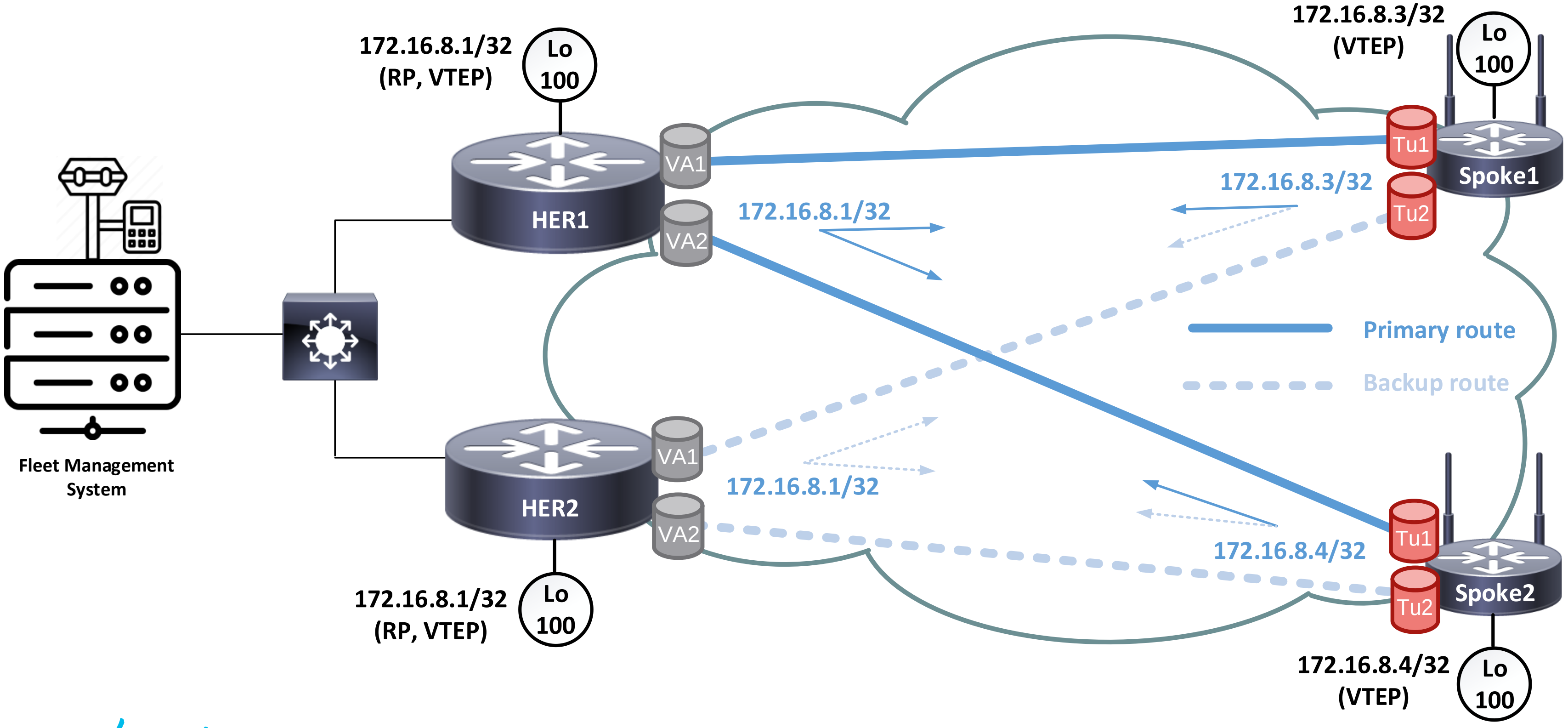
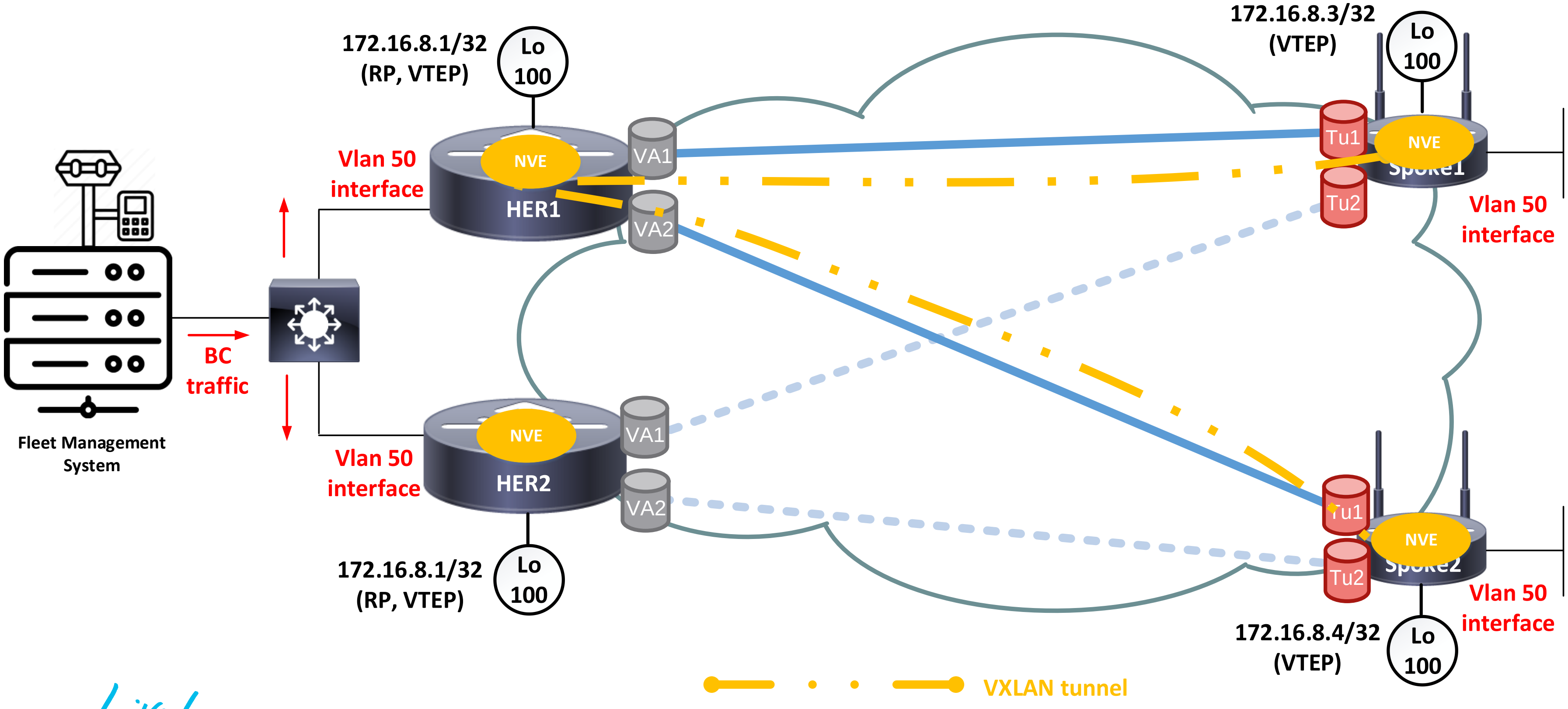
FlexVPN – Bidir PIM with Static Anycast RP



FlexVPN – Routing for active/standby

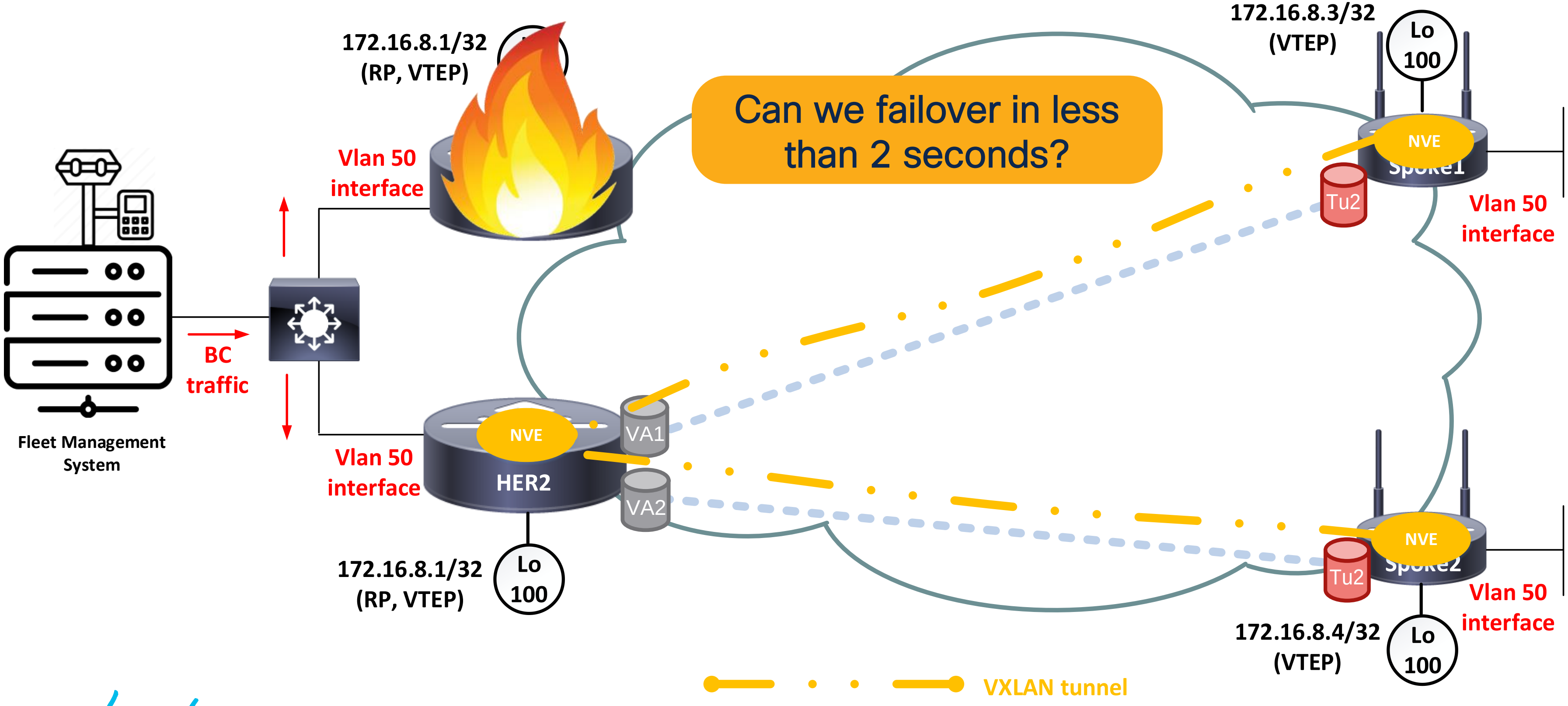


VXLAN Over FlexVPN



High Availability

VXLAN Over FlexVPN – High Availability



Can we failover in less than 2 seconds?

FlexVPN – Routing Options

- Static routing
  - ✗ Dynamic virtual-access interfaces and IP addressing on HER
- EIGRP
  - ✗ Not present in customer’s environment, historically proprietary
- OSPF/ISIS
  - ✗ Scalability concerns with 1000 neighbors on cellular network (Dijkstra)
- IKEv2
  - ✗ Relies on DPD for reachability – minimum convergence time 20-30s (good option where fast convergence is not required)

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FlexVPN – iBGP

- ✓ Scalable – up to 6000 BGP neighbors on Catalyst 8300
- ✓ Extensive route policy control and summarization
- ✓ Simple dynamic neighbor configuration on HER

```
router bgp 66000
 bgp listen range 172.16.0.0/22 peer-group Spoke
 bgp listen limit 1024
 neighbor Spoke remote-as 66000
```

- ✓ Operational experience in customer environment
- × Convergence time
  - BGP default timers 121-180s
  - IKEv2 DPD timers minimum 20-30s

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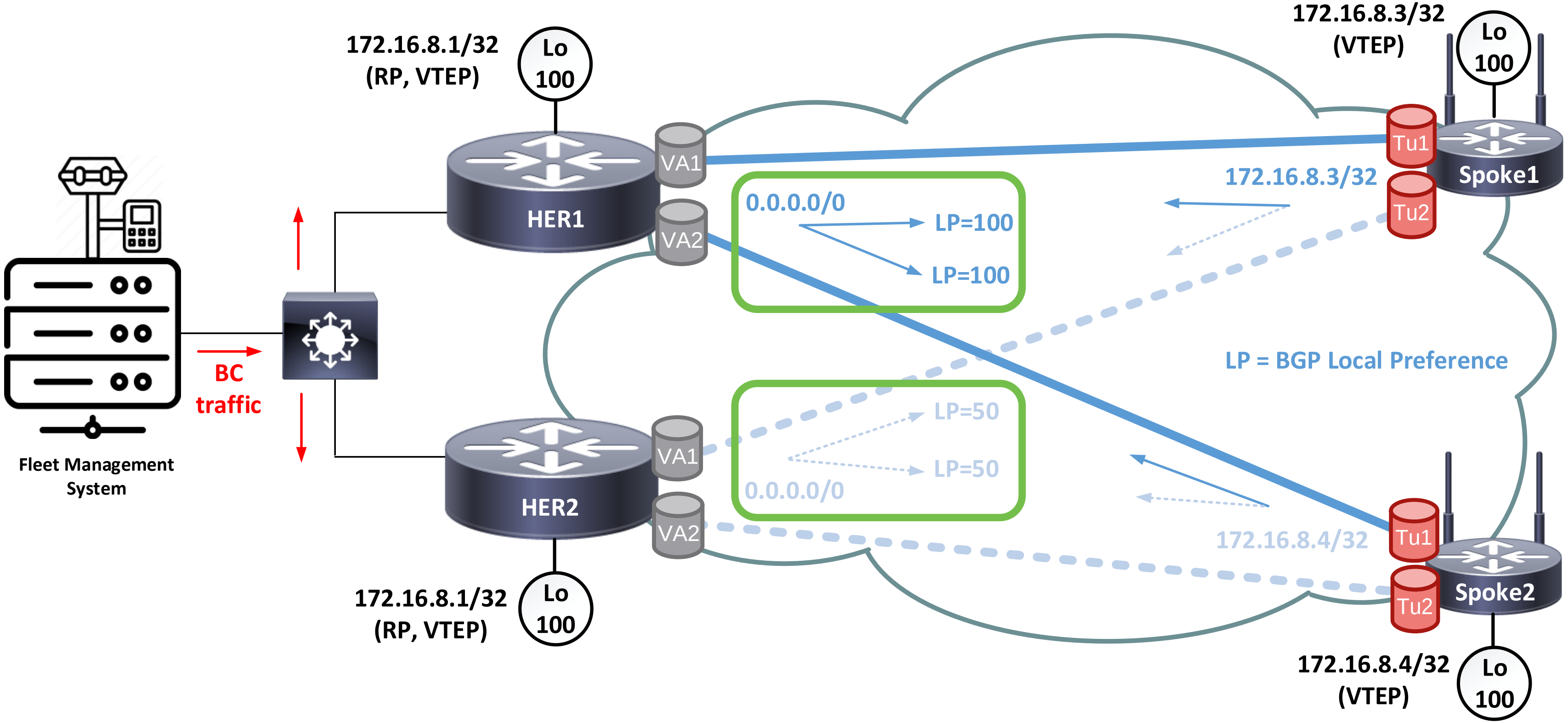
FlexVPN – Fast Convergence Routing



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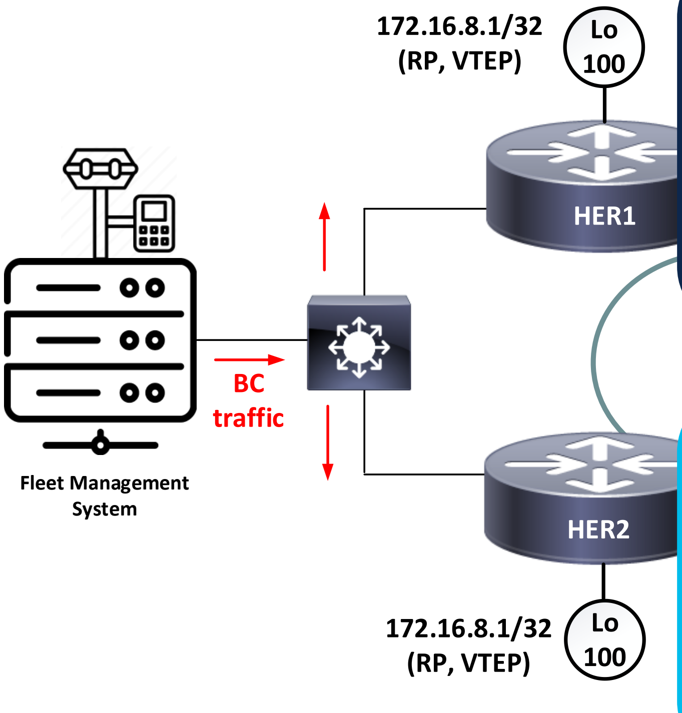
FlexVPN – Fast Convergence Routing



HER1

```
ip route 0.0.0.0 0.0.0.0.0 Null0 tag 100
router bgp 66000
 redistribute static route-map STATIC2BGP
 default-information originate
route-map STATIC2BGP permit 10
 match tag 100
  set local preference 100
```

LP = BGP Local Preference

HER2

```
ip route 0.0.0.0 0.0.0.0.0 Null0 tag 50
router bgp 66000
 redistribute static route-map STATIC2BGP
 default-information originate
route-map STATIC2BGP permit 10
 match tag 50
  set local preference 50
```

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FlexVPN – iBGP Convergence Reduction

BGP timer tuning

```
router bgp 66000
 neighbor Spoke timers 1 1
```

- 1000pps control plane load
- Keepalive packet 155 bytes
- LTE bandwidth used 2.48Mbps
- ✘ 6% of upstream bandwidth (!)

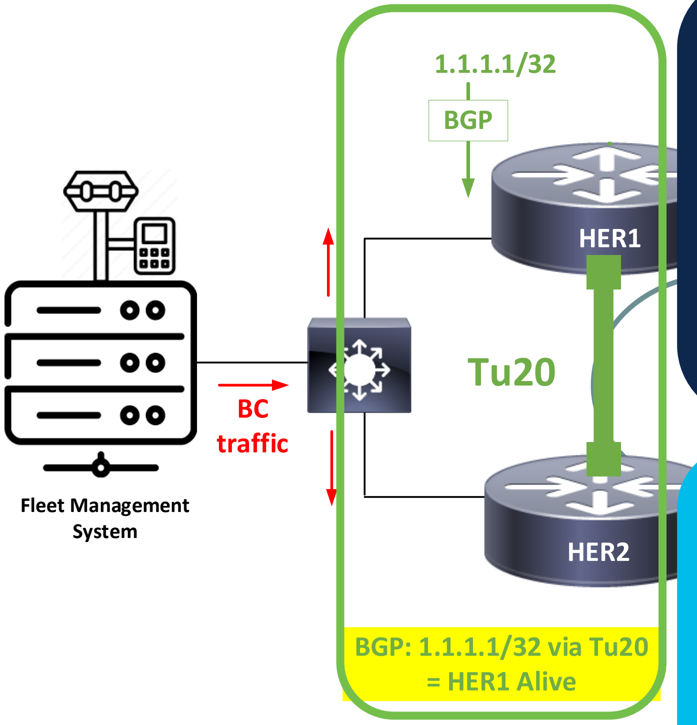
BFD

```
interface Virtual-template 1
~~bfd interval 50 min_rx 50 multiplier 3~~
```

- ✘ Not supported on virtual-template interfaces

IP Routing: BFD Configuration Guide, Cisco IOS XE 17 - Bidirectional Forwarding Detection [Cisco IOS XE 17] - Cisco

FlexVPN – Fast Convergence Solution with BFD



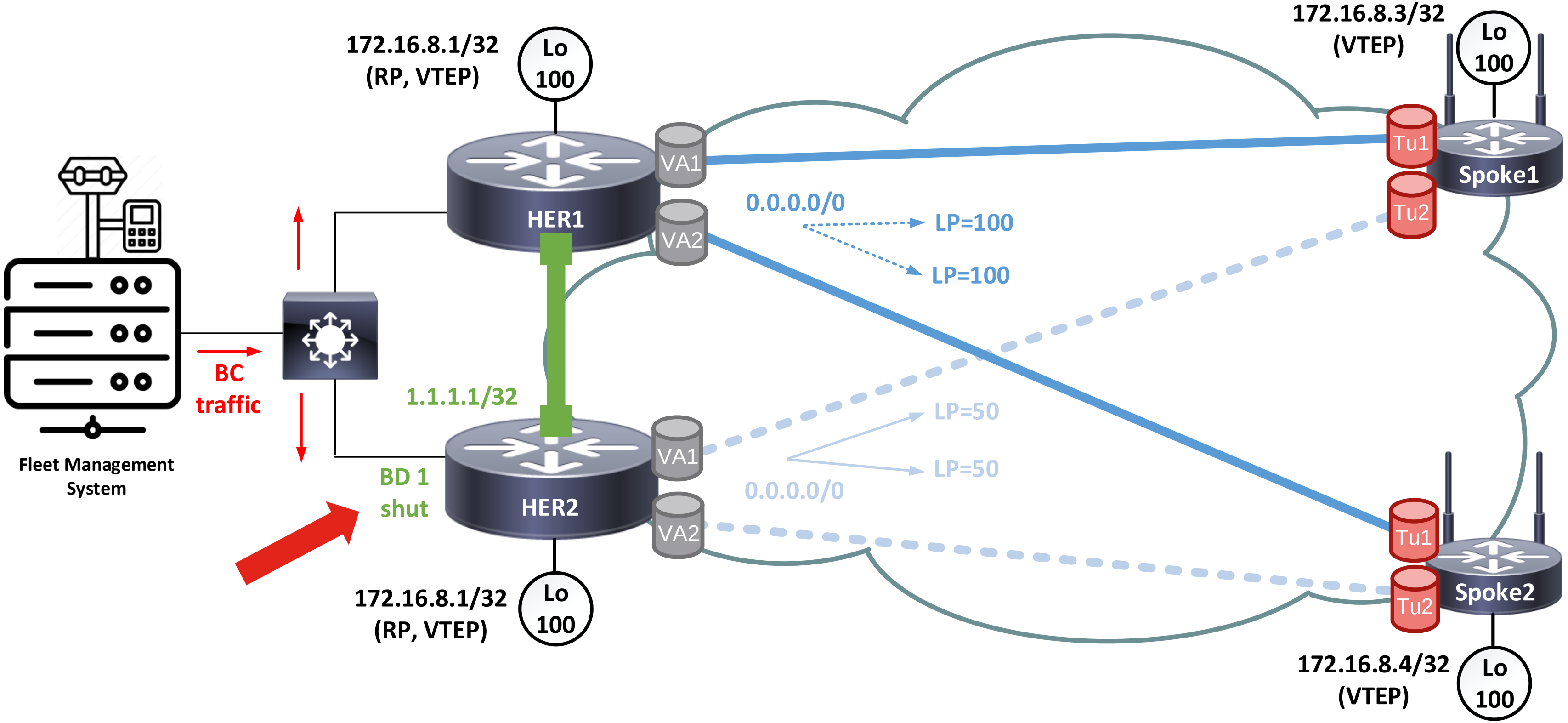
HER1

```
interface Tunnel 20
 ip address 10.0.0.1 255.255.255.252
 bfd interval 50 min_rx 50 multiplier 3
 no bfd echo
 tunnel destination <HER2 LAN ip address>

router bgp 66000
 neighbor 10.0.0.2 fall-over bfd
 network 1.1.1.1 mask 255.255.255.255
```

HER2

```
interface Tunnel 20
 ip address 10.0.0.2 255.255.255.252
 bfd interval 50 min_rx 50 multiplier 3
 no bfd echo
 tunnel destination <HER1 LAN ip address>

router bgp 66000
 neighbor 10.0.0.1 fall-over bfd
```

FlexVPN – Fast Convergence Solution Routing



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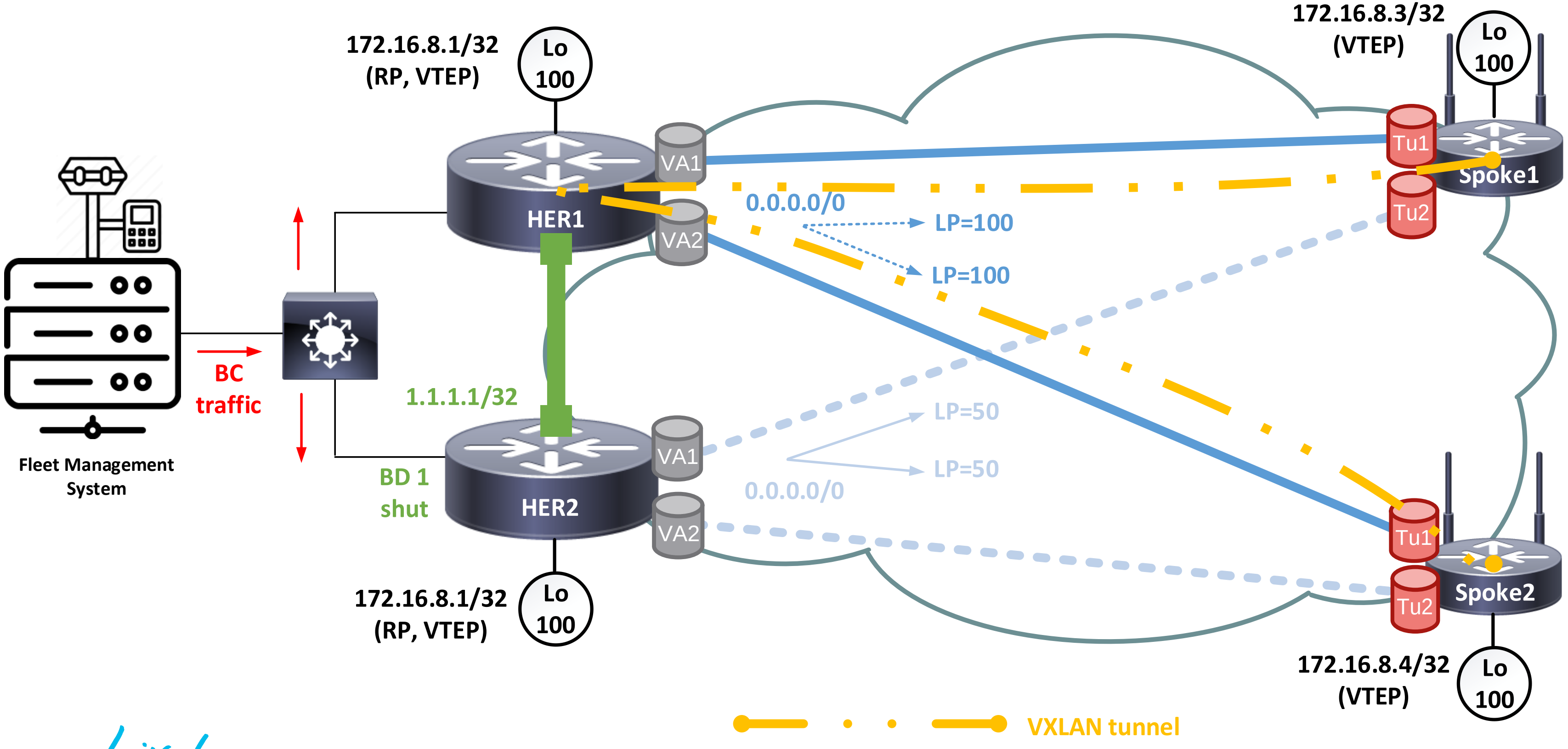
FlexVPN – Fast Convergence Steady State



FlexVPN – Fast Convergence Solution Logic

```
! Monitor the reachability of HER1 via Tunnel20 and HER2 LAN interface
!
track 1 ip route 1.1.1.1 255.255.255.255 reachability
track 2 interface Gi0/0/0 line-protocol
track 3 list boolean and
 object 1 not
 object 2
!
! If 1 is false/DOWN and 2 is true/’Up’, then 3 is ‘Up’.
! Configure a second static route for 0.0.0.0/0 which is only active if the
   Track 3 condition is true/’Up’
!
ip route 0.0.0.0 0.0.0.0 Null0 tag 500 track 3
ip route 0.0.0.0 0.0.0.0 Null0 tag 50
```

HER2

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FlexVPN – Fast Convergence Solution Actions

```
! Increase the local preference to 500 for the 0.0.0.0/0 route
!
route-map STATIC2BGP permit 10
match tag 500
 set local-preference 500
!
route-map STATIC2BGP permit 20
 match tag 50
  set local-preference 50
!
! If HER1 is down, HER2 advertises 0.0.0.0/0 with an LP of 500
! Reduce the track timers from default values for improved convergence
!
track timer ip route msec 500
track timer interface msec 500
```

HER2

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FlexVPN – Fast Convergence Solution Actions

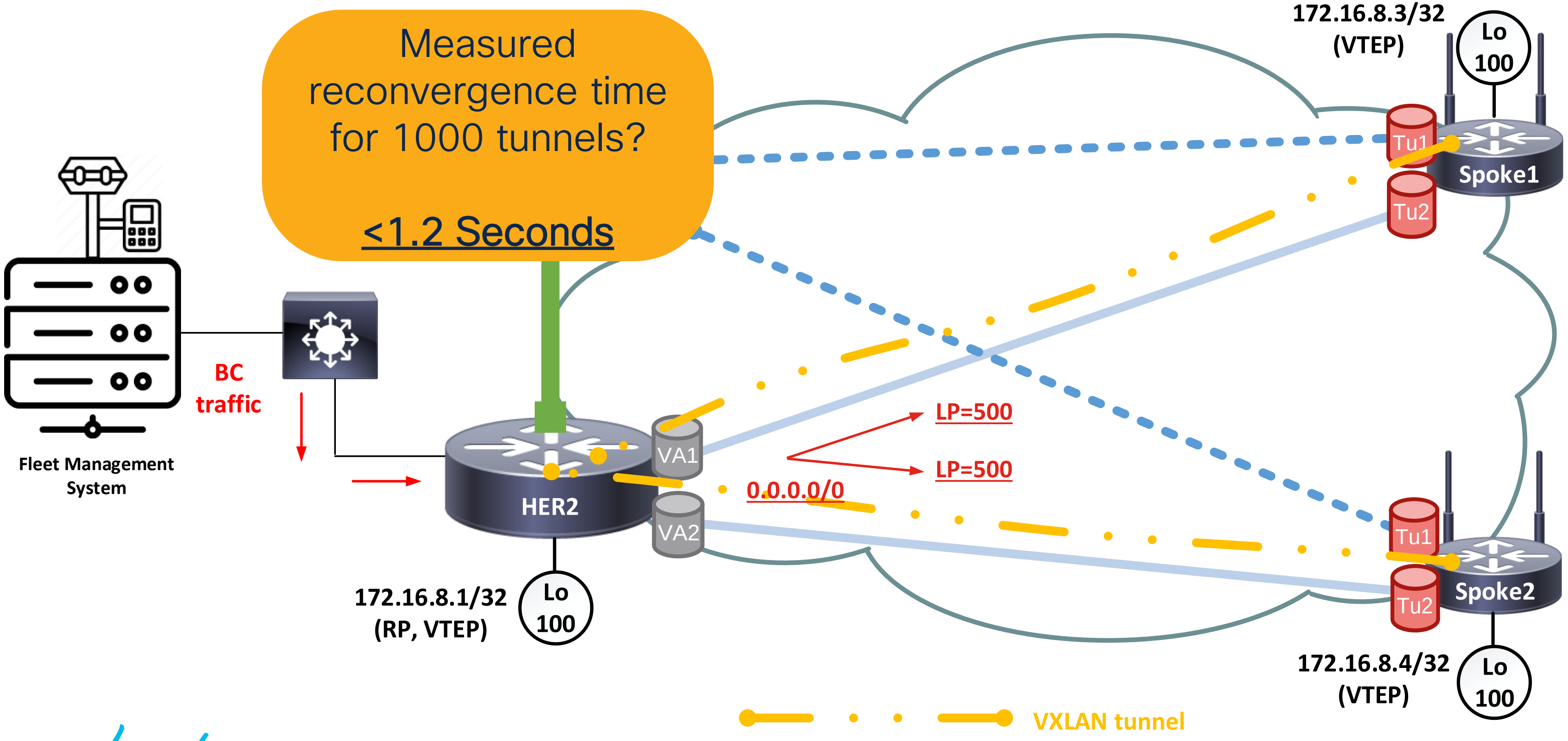
```
! Activate the local bridge-domain interface on failover; shut on fail-back
event manager applet HER2-Active
 event track 3 state up
 action 001 syslog msg "HER1 tracking route withdrawn, enabling BD1"
 action 002 cli command "enable”
 action 003 cli command "conf t"
 action 004 cli command "bridge-domain 1"
 action 005 cli command "no shut"
 action 006 cli command "end"
event manager applet HER2-Standby
 event track 3 state down
 action 001 syslog msg "HER1 tracking route sensed, shutting BD1"
 action 002 cli command "enable"
 action 003 cli command "conf t"
 action 004 cli command "bridge-domain 1"
 action 005 cli command "shut"
 action 006 cli command "end
```

HER2

FlexVPN – Fast Convergence Failover

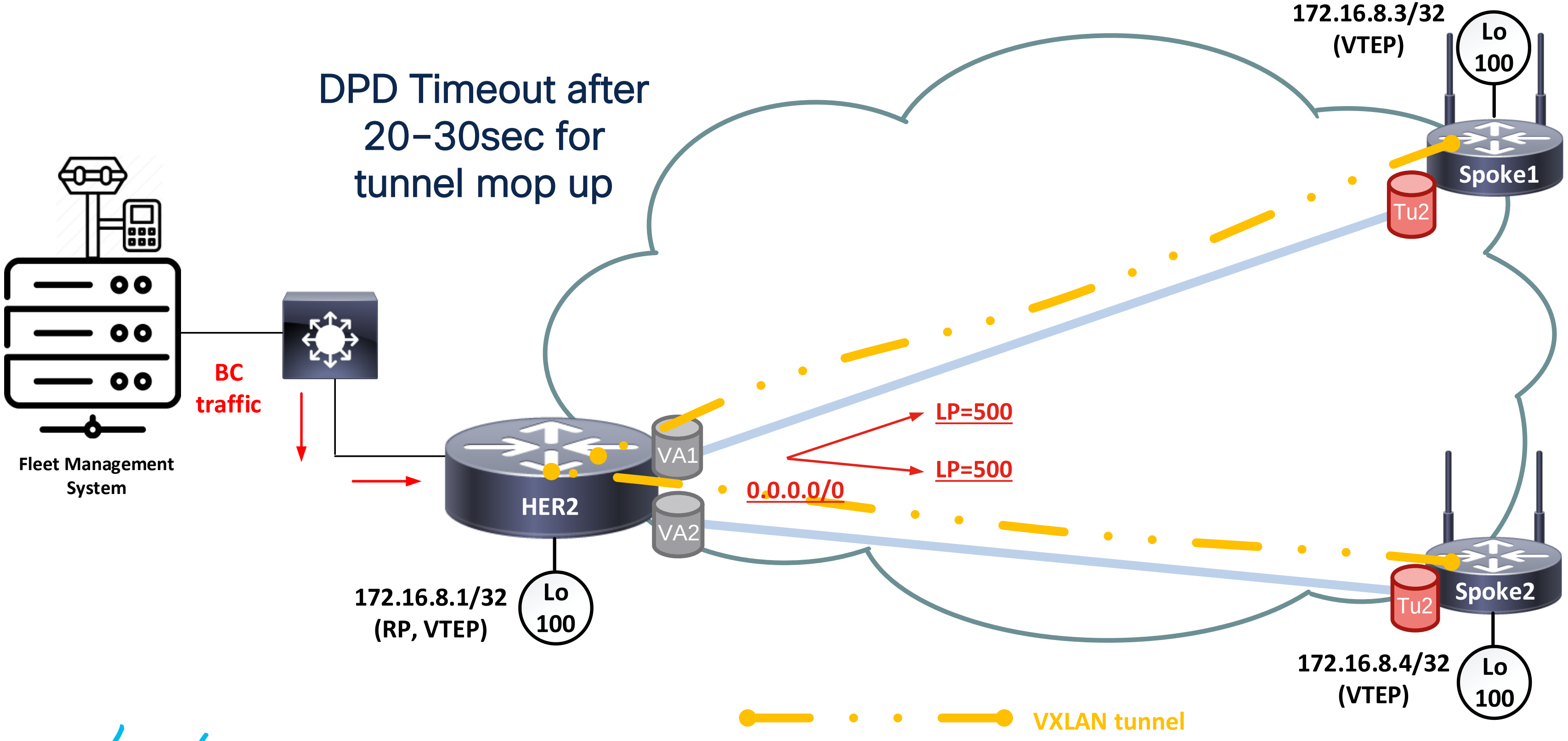
Measured reconvergence time for 1000 tunnels?

<1.2 Seconds

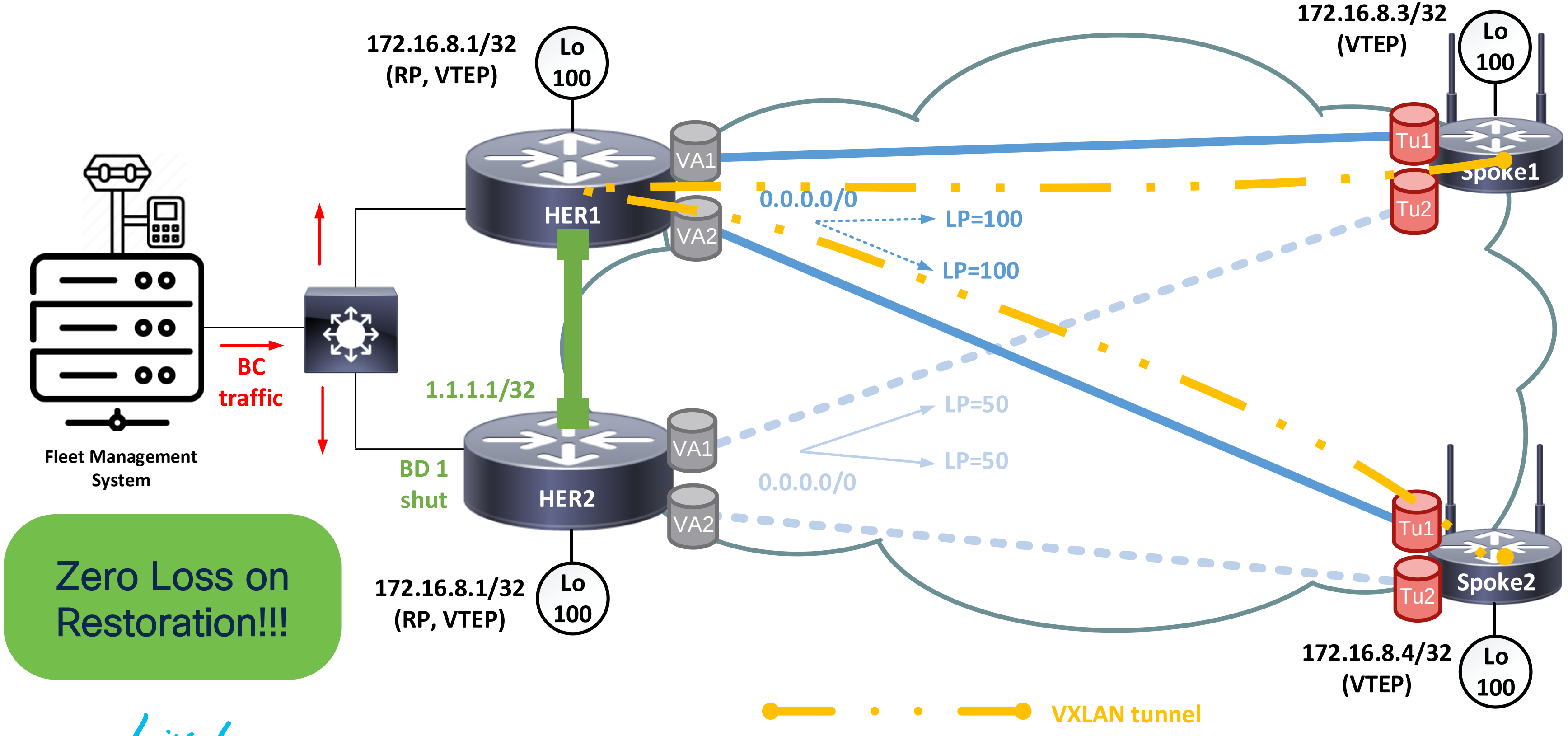


FlexVPN – Fast Convergence Mop Up

DPD Timeout after 20–30sec for tunnel mop up



FlexVPN – Service Restoration



Zero Loss on Restoration!!!

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2 Second HA Requirements

Broadcast	Multicast	Unicast	Encryption	Routing	Failure sensing	Failure mitigations
Native	Native	Native	[✓ IPSEC]	Static	Link State	[✓ EEM]
L2TPv3	GRE	GRE	IKEv1	EIGRP	[✓ BFD]	[✓ DPD]
EoMPLS	DMVPN	[✓ FlexVPN]	[✓ IKEv2]	OSPF	[✓ Object tracking]	[✓ Anycast RP]
VPLS	[✓ FlexVPN]	MPLS	None	NHRP	[✓ Boolean operands]	[✓ Route redundancy]
[✓ VXLAN]	VXLAN	VXLAN		[✓ BGP]		

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Versus a 30 second HA requirement?

Broadcast	Multicast	Unicast	Encryption	Routing	Failure sensing	Failure mitigations
Native	Native	Native	IPSEC	Static	Link State	~~EEM~~
L2TPv3	GRE	GRE	IKEv1	EIGRP	~~BFD~~	DPD
EoMPLS	DMVPN	FlexVPN	IKEv2	OSPF	~~Object tracking~~	Anycast RP
VPLS	FlexVPN	MPLS	None	NHRP	~~Boolean operands~~	Route redundancy
VXLAN	VXLAN	VXLAN		~~BGP~~		

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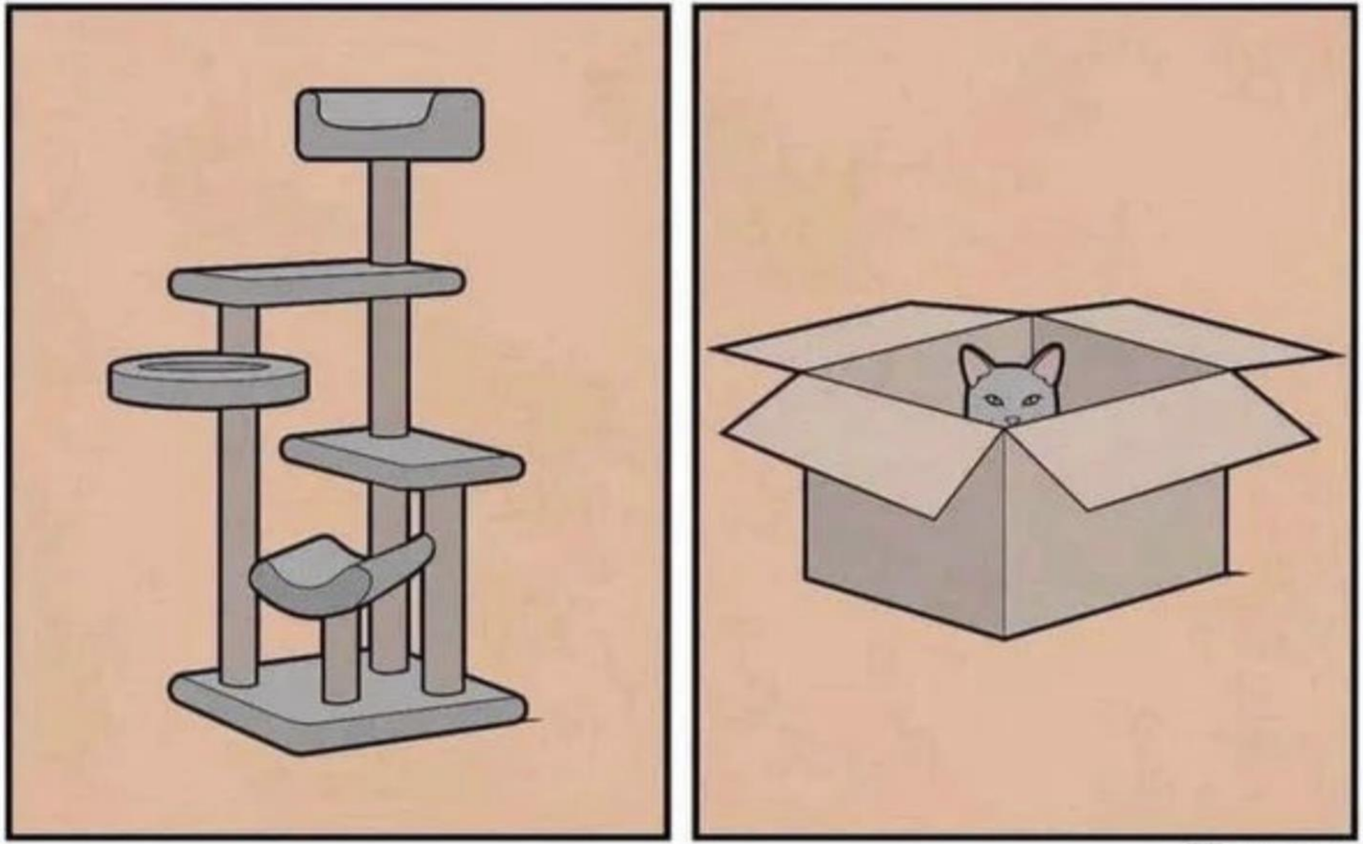
~~All of the features!~~ All the user needs?



Tying the Transport Modes Together

Unicast / Multicast Transport

VXLAN only

- All traffic over VXLAN

✓ Operationally simple

✗ Inefficient data plane

108 bytes of header

✗ Legacy architecture if broadcast support no longer required

VXLAN+FlexVPN

- BC over VXLAN
- UC / MC via FlexVPN

✓ Avoid 50 bytes of VXLAN header for MC

✗ Inefficient for UC

58 bytes of IPSec header

VXLAN+FlexVPN+Native

- BC over VXLAN
- MC via FlexVPN
- UC routed natively

✓ Most efficient data plane

✗ Complex traffic flows

✗ No security for UC

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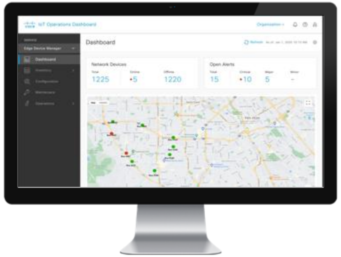
Zero Touch Deployment (ZTD)

Management Options

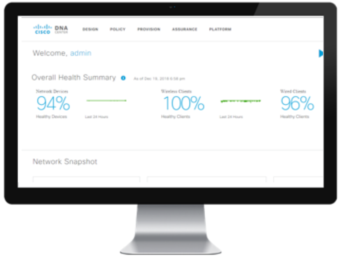
Manage by use case & workflow

Enable management of non-carpeted areas



IoT OD
Operations Dashboard

IoT FND
Field Network Director



Catalyst Center

Catalyst SDWAN

For select Cisco Industrial Routers and Gateways	For select Industrial Routers and FAN deployed by Utilities	Extended Enterprises: Industrial IOT Switches, Wi-Fi and Router	SD-WAN Fabric overlay: Industrial IOT IOS-XE Routers
Cloud-Based	On-Premise	On-Premise	On-Premise or Cloud

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Catalyst-C ZTD Discovery Options

Automated

1 DHCP with options 60 and 43

2 DNS Domain Name System

DNS lookup
pnpserver.localdomain resolves to Cisco Catalyst Center IP Address

3 Redirect

Cloud re-direction https://devicehelper.cisco.com/device-helper
Cisco hosted cloud, re-directs to on-prem Cisco Catalyst Center IP Address

Manual

4 USB-based bootstrapping
router-confg/router.cfg/ciscortr.cfg

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USB Bootstrapping

- Standard ciscortr.cfg file on USB
- If no startup-config, IR1800 boots from USB
- Day 0 config from Catalyst-C
- USB removed once device booted
- IR1800 config now managed by Catalyst-C templates
- Unique Loopback/Hostname only

```
controller Cellular 0/4/0
 ! Set private LTE APN
 profile id 1 apn Customer_APN
interface Cellular0/4/0
 ip address negotiated
 dialer in-band
 dialer idle-timeout 0
 dialer watch-group 1
 dialer-group 1
 pulse-time 1
ip route 0.0.0.0 0.0.0.0 Cellular0/4/0
! Specify IP address of the Catalyst-C server
pnp profile BOOTSTRAP
 transport http ipv4 192.0.2.1 port 80
```

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Catalyst-C Config Automation

Example Jinja Template

```
hostname {{ hostname }}

Interface Loopback100
 ip address {{ vtep-loopback }} 255.255.255.255

interface Tunnel1
 description FlexVPN_HER1
 ip address negotiated
 tunnel source Cellular0/4/0
 ip pim sparse-mode
 tunnel destination 172.16.0.1
 tunnel protection ipsec profile default

interface GigabitEthernet0/0
 service instance 1 ethernet
  description Local vlan
  encapsulation dot1q 50

interface nve1
 source-interface Loopback100
 member vni 5050
  mcast-group 239.1.1.1

ip pim bidir-enable
```

Example CSV for Provisioning

Serial	hostname	vtep-loopback
FDO2527M652	Spoke_0451	172.16.253.156/32
FDO2528G298	Spoke_0452	172.16.253.155/32
FDO2528X892	Spoke_0453	172.16.253.154/32
FDO2C284235	Spoke_0454	172.16.253.153/32
FDK2C233539	Spoke_0455	172.16.253.152/32
FDK2V26K235	Spoke_0456	172.16.253.151/32

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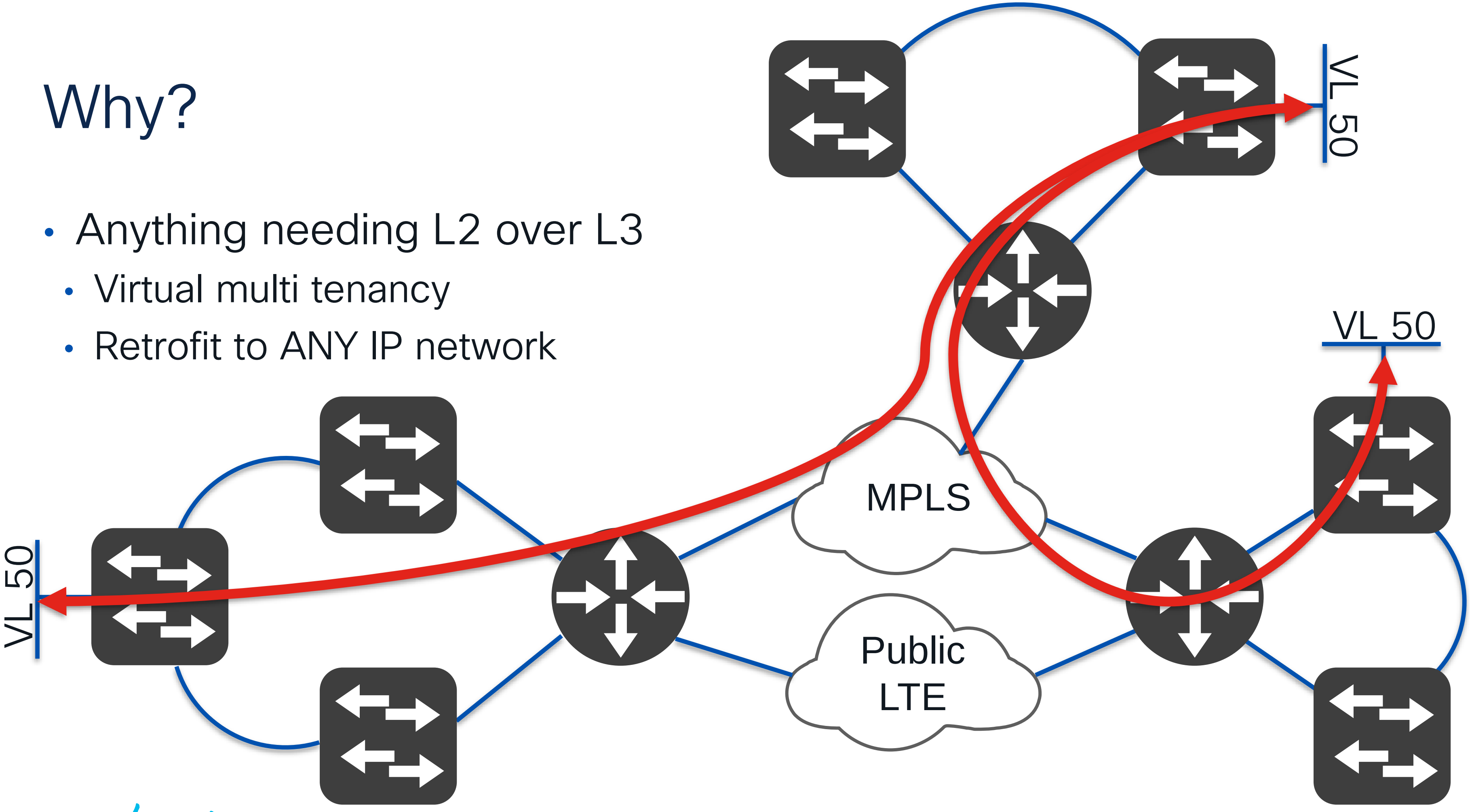
Where Else Can We Apply This?

Why?

- Anything needing L2 over L3
  - Virtual multi tenancy
  - Retrofit to ANY IP network



Mining Terrestrial & Underground Services

- Skid IP radio & GNSS updates
- Environmental monitoring
- Blast radio & signaling
- Workforce location safety

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Transport Infrastructure

- Traffic light signaling
- Emergency response signaling
- Rail signaling & driver comms

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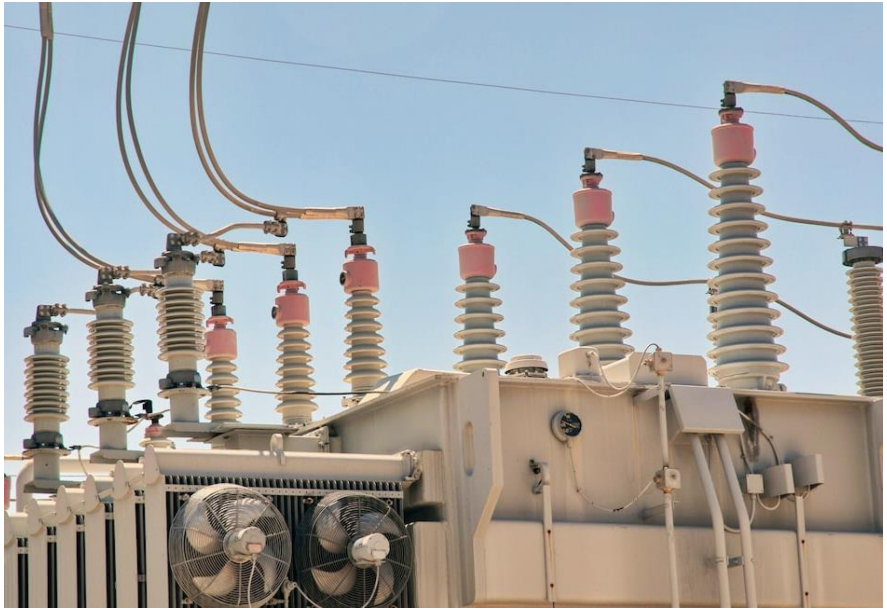
Utility Infrastructure

- Powerline protection & reclosers
- Gas pipeline monitoring
- Remote water mains monitoring



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Wrapping up I want you to ask yourself:

“What challenge can I now solve?”

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Summary

- VXLAN over FlexVPN for layer 2 transport
- FlexVPN for layer 3 multicast and unicast applications
- BGP with route tracking and EEM scripting delivers fast convergence
- Catalyst Center provides on-prem ZTP and Day 2 operations
- Scale tested to 1000 endpoints (limited by PIM adjacencies)
- Design considerations with MTU
  - VXLAN overhead 50 bytes
  - FlexVPN overhead of 58 bytes

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Additional Information

- Reach out to me. Cisco Live! mobile app or alelynn@cisco.com
  - Cisco Catalyst IR1800 Rugged Series Routers Data Sheet – Cisco
  - Cisco Catalyst IR1101 Rugged Series Routers Data Sheet – Cisco
  - Cisco Catalyst IR8300 Rugged Series Routers Data Sheet – Cisco
  - Cisco Catalyst 8300 Rugged Series Routers Data Sheet – Cisco
  - Cisco Catalyst 8500 Rugged Series Routers Data Sheet – Cisco
- VXLAN
  - Configure VXLAN Feature on Cisco IOS XE Devices - Cisco
- FlexVPN
  - FlexVPN and Internet Key Exchange Version 2 Configuration Guide, Cisco IOS XE 17 – Cisco

    FlexVPN HA Dual Hub Configuration Example - Cisco
- Catalyst Center
  - Cisco DNA Center User Guide, Release 2.3.5 - Onboard and Provision Devices with Plug and Play [Cisco DNA Center] – Cisco

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The bridge to possible

Thank you

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Let’s go

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