LAN Extension and Network Virtualization in Cloud Data Centers

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These slides and audio/video recordings of this class lecture are at:
http://www.cse.wustl.edu/~jain/cse570-21/

Student Questions

Overview

1. TRILL
2. NVGRE
3. VXLAN
4. NVO3
5. Geneve
6. EVPN
7. GUE

Student Questions

# Geographic Clusters of Data Centers

❑ Multiple data centers are used to improve availability

❑ Cold-Standby: Data is backed up on tapes and stored off-site.
In case of disaster, application and data are loaded in standby.
Manual switchover $\Rightarrow$ Significant downtime. (1970-1990)

❑ Hot-Standby: Two servers in different geographically close data
centers exchange state and data continuously.
Synchronous or Asynchronous data replication to standby.
On a failure, the application automatically switches to standby.
Automatic switchover $\Rightarrow$ Reduced downtime (1990-2005)
Only 50% of resources are used under normal operation.

❑ Active-Active: All resources are used. Virtual machines and
data can be quickly moved between sites, when needed.

Student Questions

Ref: G. Santana, "Datacenter Virtualization Fundamentals," Cisco Press, 2014, ISBN: 1587143240
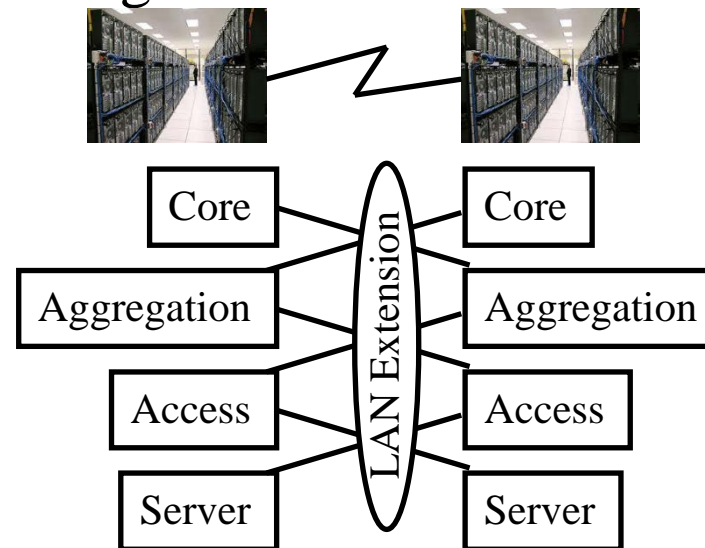
Data Center Interconnection (DCI)

❑ Allows distant data centers to be connected in one L2 domain
- ➢ Distributed applications
- ➢ Disaster recovery
- ➢ Maintenance/Migration
- ➢ High-Availability
- ➢ Consolidation

❑ Active and standby can share the same virtual IP for switchover.

❑ Multicast can be used to send state to multiple destinations.
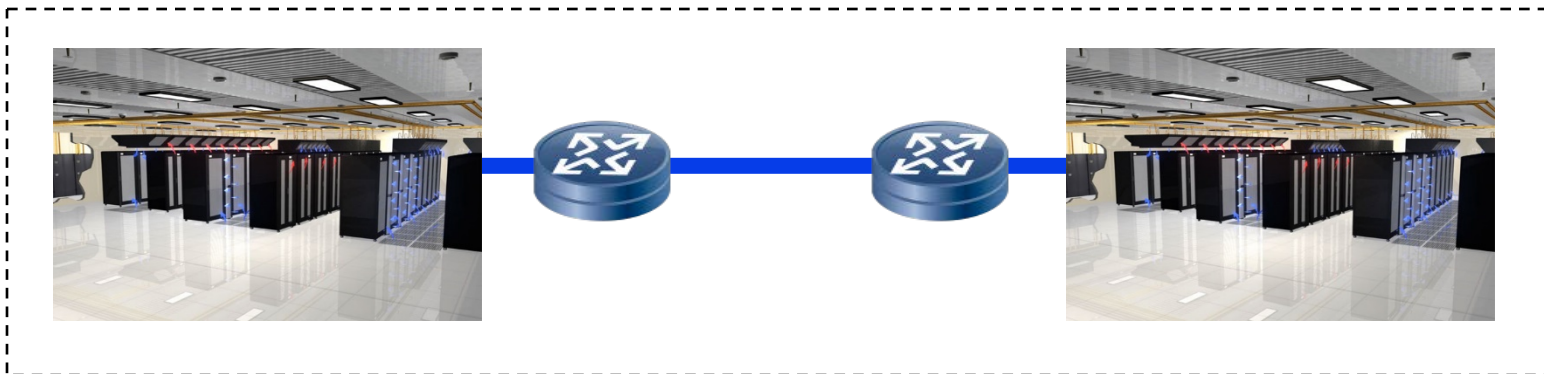
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Challenges of LAN Extension

❑ **Broadcast storms**: Broadcast, Unknown and Multicast (BUM) may create excessive flood

❑ **Loops**: Easy to form loops in a large network.

❑ **STP Issues**:

➢ High spanning tree diameter (leaf-to-leaf): More than 7.

➢ Root can become bottleneck and a single point of failure

➢ Multiple paths remain unused

❑ **Tromboning**: Dual attached servers and switches generate excessive cross traffic

❑ **Security**: Data on LAN extension must be encrypted

LAN

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Core		Core
Aggregation	LAN Extension	Aggregation
Access		Access
Server		Server

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TRILL

❑ Transparent Interconnection of Lots of Links

❑ Allows a large campus to be a single extended LAN

❑ LANs allow free mobility inside the LAN but:

➢ Inefficient paths using Spanning tree

➢ Inefficient link utilization since many links are disabled

➢ Inefficient link utilization since multipath is not allowed.

➢ Unstable: small changes in network $\Rightarrow$ large changes in spanning tree

❑ IP subnets are not good for mobility because IP addresses change as nodes move and break transport connections, but:

➢ IP routing is efficient, optimal, and stable

❑ Solution: Take the best of both worlds
$\Rightarrow$ Use MAC addresses and IP routing

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TRILL Architecture

- Routing Bridges (RBridges) encapsulate L2 frames and route them to destination RBridges which decapsulate and forward

- Header contains a hop-limit to avoid looping

- RBridges run IS-IS to compute pair-wise optimal paths for unicast and distribution trees for multicast

- RBridge learn MAC addresses by source learning and by exchanging their MAC tables with other RBridges

- Each VLAN on the link has one (and only one) designated RBridge using IS-IS election protocol
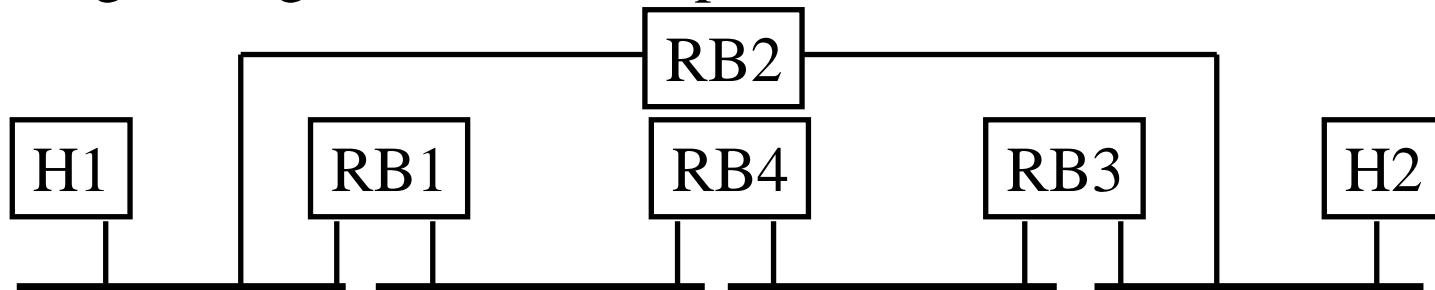
Ref: R. Perlman, "RBridges: Transparent Routing," Infocom 2004

Student Questions

TRILL Encapsulation Format

Outer Header	TRILL header	Original 802.1Q packet

| Version	Res.	Multi-Destination	Options Length	Hops to Live	Egress RBridge	Ingress RBridge	Options
2b	2b	1b	5b	6b	16b	16b	

❑ For outer headers both PPP and Ethernet headers are allowed. PPP for long haul.

❑ Outer Ethernet header can have a VLAN ID corresponding to the VLAN used for TRILL.

❑ Priority bits in outer headers are copied from inner VLAN

TRILL Features

❑ Transparent: No change to capabilities.
Broadcast, Unknown, Multicast (**BUM**) support. Auto-learning.

❑ Zero Configuration: RBridges discover their connectivity and learn MAC addresses automatically

❑ Hosts can be multi-homed

❑ VLANs are supported

❑ Optimized route

❑ No loops

❑ Legacy bridges with spanning tree in the same extended LAN
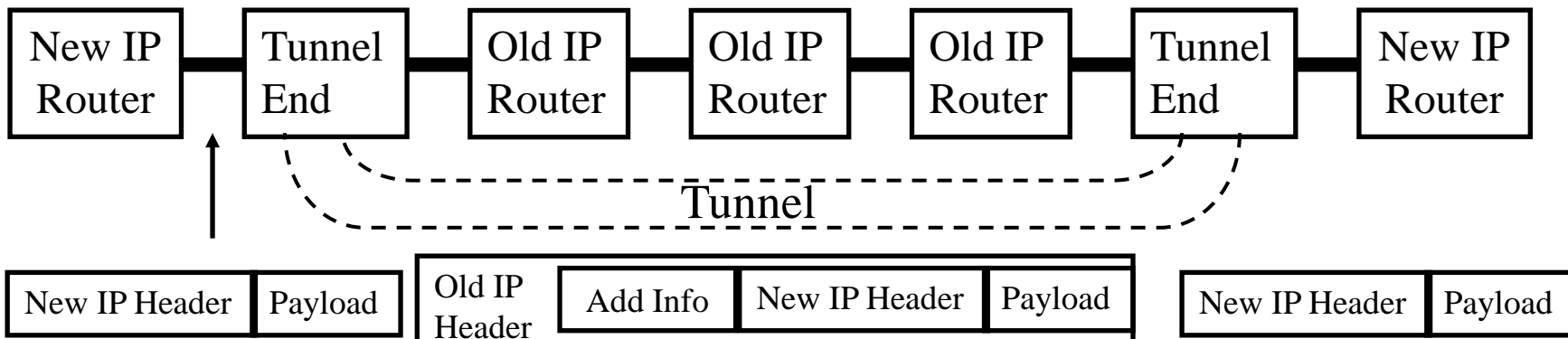
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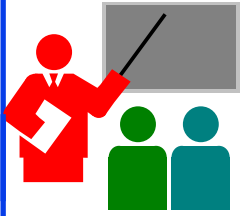
TRILL: Summary

- ❑ TRILL allows a large campus to be a single Extended LAN
- ❑ Packets are encapsulated and routed using IS-IS routing

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GRE

- ❏ Any new feature in IP requires *encapsulation*, a.k.a. *tunneling*
- ❏ Generic Routing Encaptulation (RFC 1701/1702)
- ❏ Generic ⇒ X over Y for any X or Y protocols
- ❏ Given n protocols, we need $O(n^2)$ encapsulation formats, GRE converts this to $O(1)$ format.
- ❏ Encapsulations may require the following services:
  - ➢ Stream multiplexing: Which recipient at the other end?
  - ➢ Source Routing: what path to take?
  - ➢ Packet Sequencing

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New IP Router	Tunnel End	Old IP Router	Old IP Router	Old IP Router	Tunnel End	New IP Router

Tunnel

New IP Header	Payload

Old IP Header	Add Info	New IP Header	Payload

New IP Header	Payload

GRE (Cont)

- GRE provides all of the above encapsulation services
- Over IPv4, GRE packets use a protocol type of 47
- Optional: Checksum, Loose/strict Source Routing, Key
- Key is used either to authenticate the source or to distinguish different substreams
- Recursion Control: # of additional encapsulations allowed.
  $0 \Rightarrow$ Restricted to a single provider network $\Rightarrow$ end-to-end
- Offset: Points to the next source route field to be used
- IP or IPSec are commonly used as delivery headers

Delivery Header	GRE Header	Payload

Check-sum Present	Routing Present	Key Present	Seq. # Present	Strict Source Route	Recursion Control	Flags	Ver. #	Prot. Type	Offset	Check sum (Opt)	Key (Opt)	Seq. # (Opt)	Source Routing List (Opt)
1b	1b	1b	1b	1b	3b	5b	3b	16b	16b	16b	32b	32b	Variable

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EoMPLSoGRE

❑ Ethernet over MPLS over GRE (point-to-point)
VPLS over MPLS over GRE (Multipoint-to-multipoint)

❑ Used when provider offers only L3 connectivity
Subscribers use their own MPLS over GRE tunnels

❑ VPLSoGRE or Advanced-VPLSoGRE can also be used

❑ GRE offers IPSec encryption option

| IP | GRE | MPLS | Ethernet |

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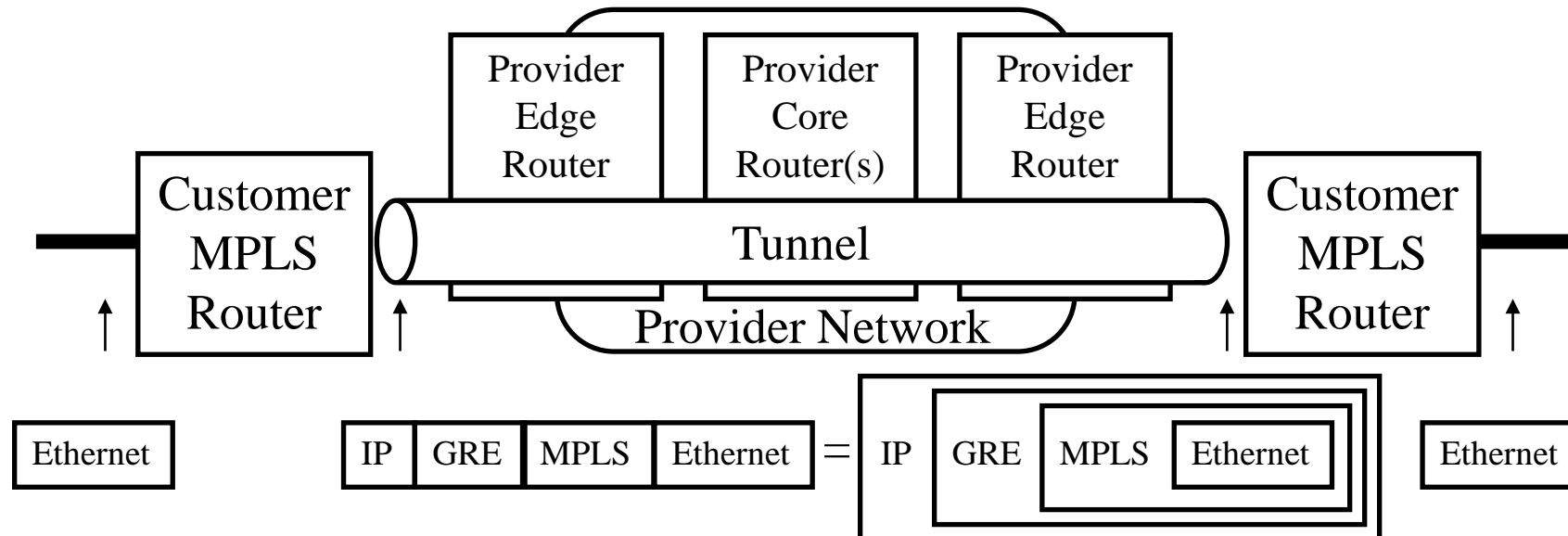
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NVGRE

❑ Ethernet over GRE over IP (point-to-point)

❑ A unique 24-bit Virtual Subnet Identifier (VSID) is used as the lower 24-bits of GRE key field $\Rightarrow 2^{24}$ tenants can share

❑ Unique IP multicast address is used for BUM (Broadcast, Unknown, Multicast) traffic on each VSID

❑ Equal Cost Multipath (ECMP) allowed on point-to-point tunnels
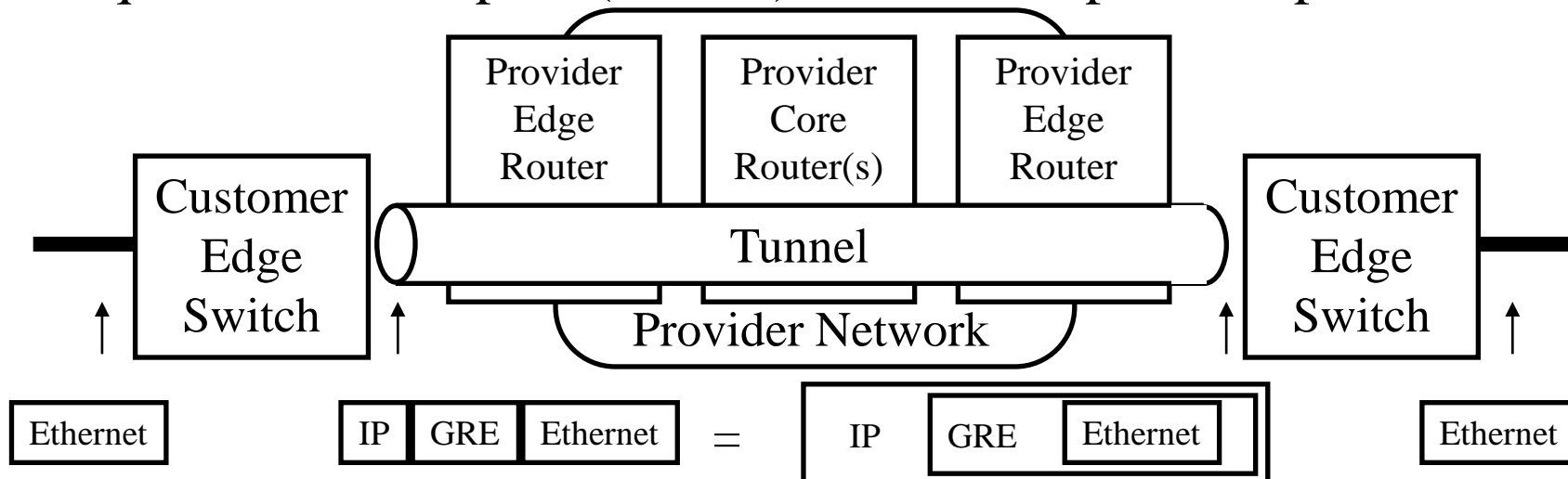
Ref: P. Garg, Y. Wang, et al. "NVGRE: Network Virtualization Using Generic Routing Encapsulation Encapsulation", RFC 7637, IETF, September 2015.
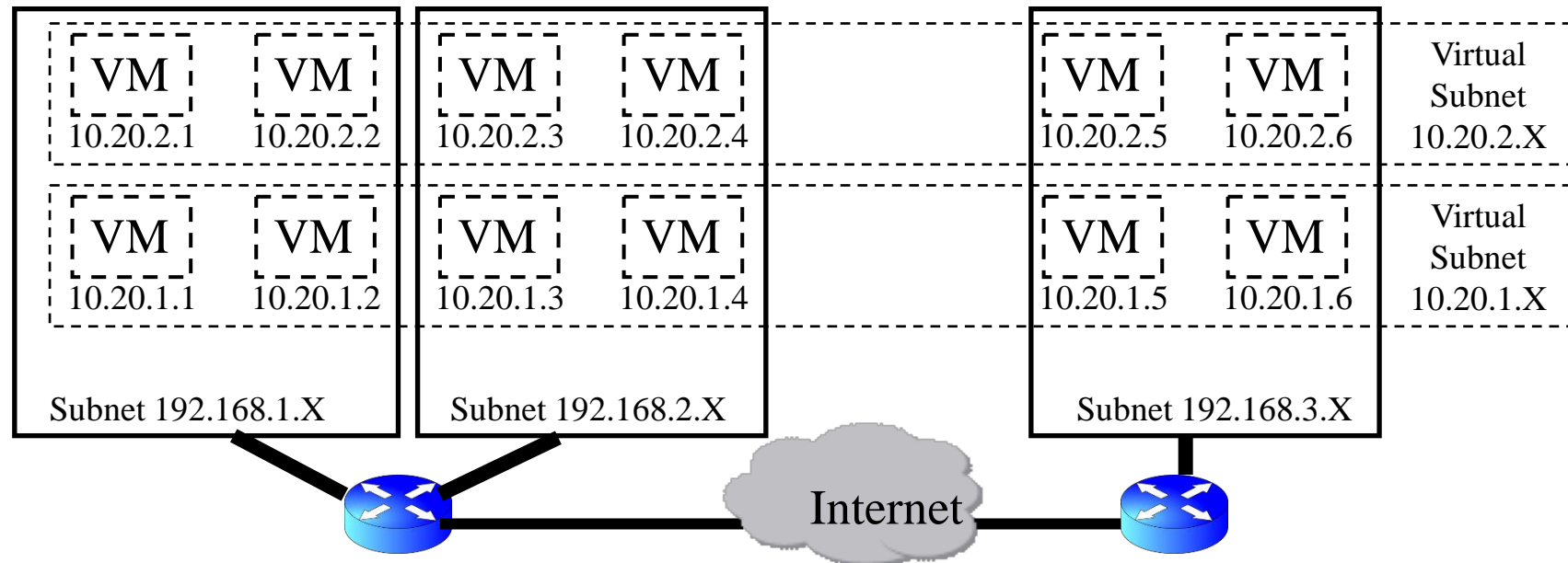
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NVGRE (Cont)

❑ In a cloud, a pSwitch or a vSwitch can serve as tunnel endpoint

❑ VMs need to be in the same VSID to communicate

❑ VMs in different VSIDs can have the same MAC address

❑ Inner IEEE 802.1Q tag, if present, is removed.

Ref: Emulex, "NVGRE Overlay Networks: Enabling Network Scalability," Aug 2012, 11pp.,
http://www.emulex.com/artifacts/074d492d-9dfa-42bd-9583-69ca9e264bd3/elx_wp_all_nvgre.pdf

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NVO3

❑ Network Virtualization Overlays using L3 techniques

❑ **Problem**: Data Center Virtual Private Network (DCVPN) in a multi-tenant datacenter

❑ Issues:

  ➢ Scale in Number of Networks: Hundreds of thousands of DCVPNs in a single administrative domain

  ➢ Scale in Number of Nodes: Millions of VMs

  ➢ VM (or pM) Migration

  ➢ Support both L2 and L3 VPNs

  ➢ Dynamic provisioning

  ➢ Addressing independence: Each tenant should be able select its address space

  ➢ Virtual Private $\Rightarrow$ Other tenants do not see your frames

  ➢ Optimal Forwarding: VMs should not be tied to a single designated router that may be far away.

Ref: T. Narten, Ed., "Problem Statement: Overlays for Network Virtualization," IETF RFC 7364, Oct 14, 23 pp.

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NVO3 Terminology

- **Tenant System (TS)**: VM or pM
- **Virtual Network (VN)**: L2 or L3 Tenant networks
- **Network Virtualization Edges (NVEs)**: Entities connecting TSs (virtual/physical switches/routers)
- NVEs could be in vSwitches, external pSwitches or span both.
- **Network Virtualization Authority (NVA)**: Manages forwarding info for a set of NVEs
- NVA could be distributed or centralized and replicated.
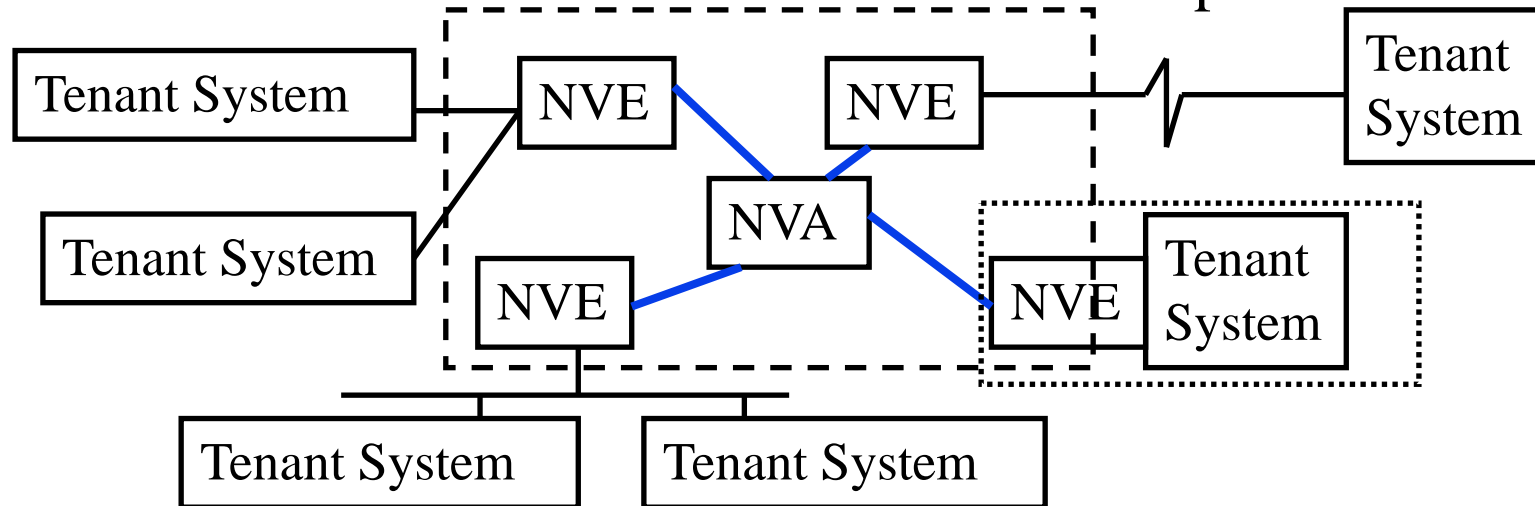
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NVO3 Terminology (Cont)

- **Virtual Network (VN):** Provides L2/L3 services to a set of tenants
- **VN Context ID**: A field in the header that identifies a VN instance (VNI).
- **Overlay header** = inner header = Virtual Network Header
- **Underlay header** = outer header = Physical Network Header
- **Tenant Separation**: A tenant's traffic cannot be seen by another tenant

Overlay

Underlay

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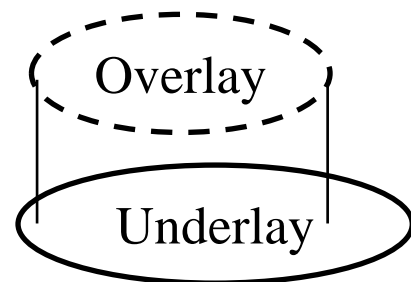
Current NVO Technologies

- BGP/MPLS IP VPNs: Widely deployed in enterprise networks. Difficult in data centers because hosts/hypervisors do not implement BGP.

- BGP/MPLS Ethernet VPNs: Deployed in carrier networks. Difficult in data centers.

- **802.1Q**, PB, PBB VLANs

- **Shortest Path Bridging**: IEEE 802.1aq

- Virtual Station Interface (VSI) Discovery and Configuration Protocol (VDP): IEEE 802.1Qbg

- Address Resolution for Massive numbers of hosts in the Data Center (ARMD): RFC6820

- **TRILL**

- **L2VPN**: Provider provisioned L2 VPN

- Proxy Mobile IP: Does not support multi-tenancy

- LISP: RFC 6830

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VXLAN

❑ Virtual eXtensible Local Area Networks (VXLAN)

❑ L3 solution to isolate multiple tenants in a data center
(L2 solution is Q-in-Q and MAC-in-MAC)

❑ Developed by VMware. Supported by many companies in IETF NVO3 working group

❑ Problem:

➢ 4096 VLANs are not sufficient in a multi-tenant data center

➢ Tenants need to control their MAC, VLAN, and IP address assignments ⇒ Overlapping MAC, VLAN, and IP addresses

➢ Spanning tree is inefficient with large number of switches
⇒ Too many links are disabled

➢ Better throughput with IP equal cost multipath (ECMP)

Student Questions

Ref: M. Mahalingam, D. G. Dutt, et al. "VXLAN: A Framework for Overlaying Virtualized Layer 2 Networks over Layer 3 Networks," IETF RFC 7348, August 2014.

VXLAN Architecture

❑ Create a virtual L2 overlay (called VXLAN) over L3 networks

❑ 2^{24} Virtual Network Instances (VNIs)

❑ Only VMs in the same VXLAN can communicate

❑ vSwitches serve as VTEP (VXLAN Tunnel End Point).
$\Rightarrow$ Encapsulate L2 frames in UDP over IP and send to the destination VTEP(s).

❑ Segments may have overlapping MAC addresses and VLANs but L2 traffic never crosses a VNI

Tenant 3 Virtual L2 Network

Tenant 1 Virtual L2 Network

Tenant 2 Virtual L2 Network

L3 Network
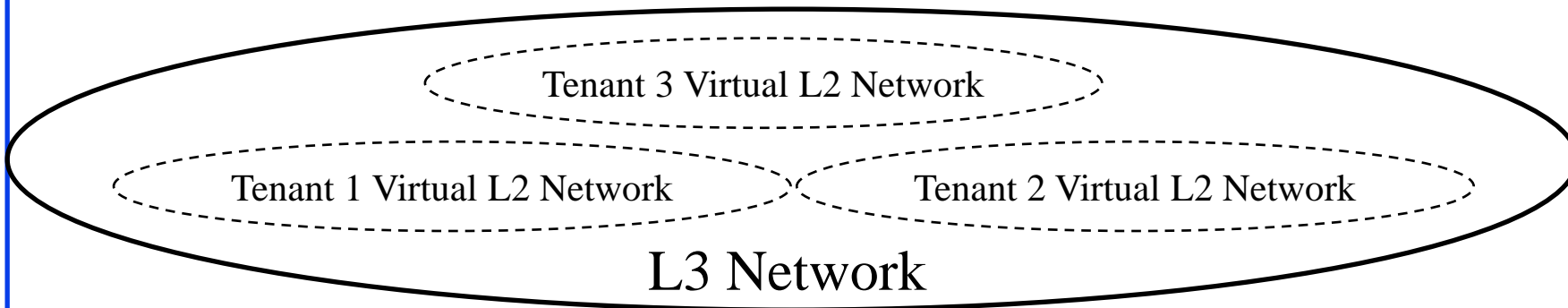
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VXLAN Deployment Example
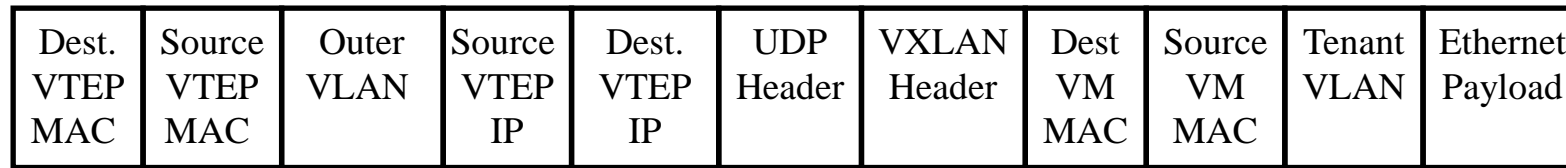
Example: Three tenants. 3 VNIs. 4 Tunnels for unicast.
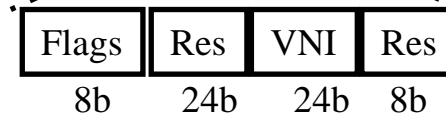   + 3 tunnels for multicast (not shown)
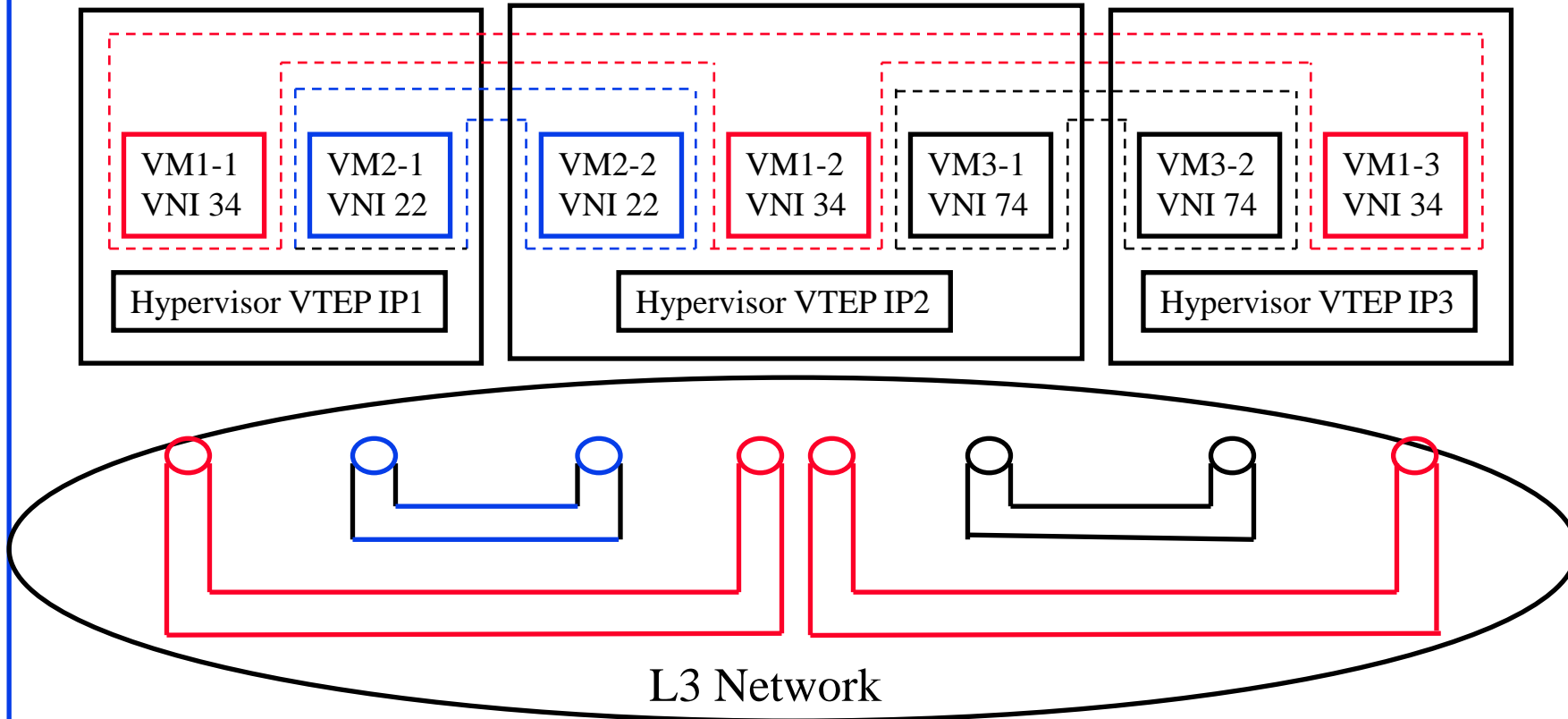
VXLAN Encapsulation Format

❑ Outer VLAN tag is optional.
Used to isolate VXLAN traffic on the LAN

❑ Source VM ARPs to find Destination VM's MAC address.
All L2 multicasts/unknown are sent via IP multicast.
Destination VM sends a standard IP unicast ARP response.

❑ Destination VTEP learns Inner-Src-MAC-to-Outer-Src-IP
mapping $\Rightarrow$ Avoids unknown destination flooding for returning
responses

Dest. VTEP MAC	Source VTEP MAC	Outer VLAN	Source VTEP IP	Dest. VTEP IP	UDP Header	VXLAN Header	Dest VM MAC	Source VM MAC	Tenant VLAN	Ethernet Payload

Only key fields are shown

Flags	Res	VNI	Res
8b	24b	24b	8b

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VXLAN Encapsulation Format (Cont)

- Internet Group Multicast Protocol (IGMP) is used to prune multicast trees

- 7 of 8 bits in the flag field are reserved.
  One flag bit is set if VNI field is valid

- UDP source port is a hash of the inner MAC header
  $\Rightarrow$ Allows load balancing using Equal Cost Multi Path using L3-L4 header hashing

- VMs are unaware that they are operating on VLAN or VXLAN

- VTEPs need to learn MAC address of other VTEPs and of client VMs of VNIs they are handling.

- A VXLAN gateway switch can forward traffic to/from non-VXLAN networks. Encapsulates or decapsulates the packets.

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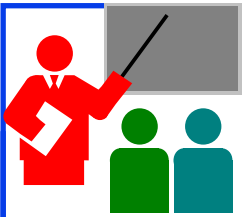
VXLAN: Summary

❑ VXLAN solves the problem of multiple tenants with overlapping MAC addresses, VLANs, and IP addresses in a cloud environment.

❑ A server may have VMs belonging to different tenants

❑ No changes to VMs. Hypervisors responsible for all details.

❑ Uses UDP over IP encapsulation to isolate tenants

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Stateless Transport Tunneling Protocol (STT)

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❑ Ethernet over **TCP-Like** over IP tunnels.
   GRE, IPSec tunnels can also be used if required.

❑ Designed for large storage blocks **64kB**. Fragmentation
   allowed.

❑ Most other overlay protocols use UDP and disallow
   fragmentation ⇒ Maximum Transmission Unit (MTU) issues.

❑ TCP-Like: Stateless TCP ⇒ Header identical to TCP (same
   protocol number 6) but **no 3-way handshake**, no connections,
   no windows, no retransmissions, no congestion state
   ⇒ Stateless Transport (recognized by standard port number).

❑ Internet draft expired ⇒ Of historical interest only.
   New work on Geneve.

Ref: B. Davie and J. Gross, "A Stateless Transport Tunneling Protocol for Network Virtualization (STT)," Sep 2013,
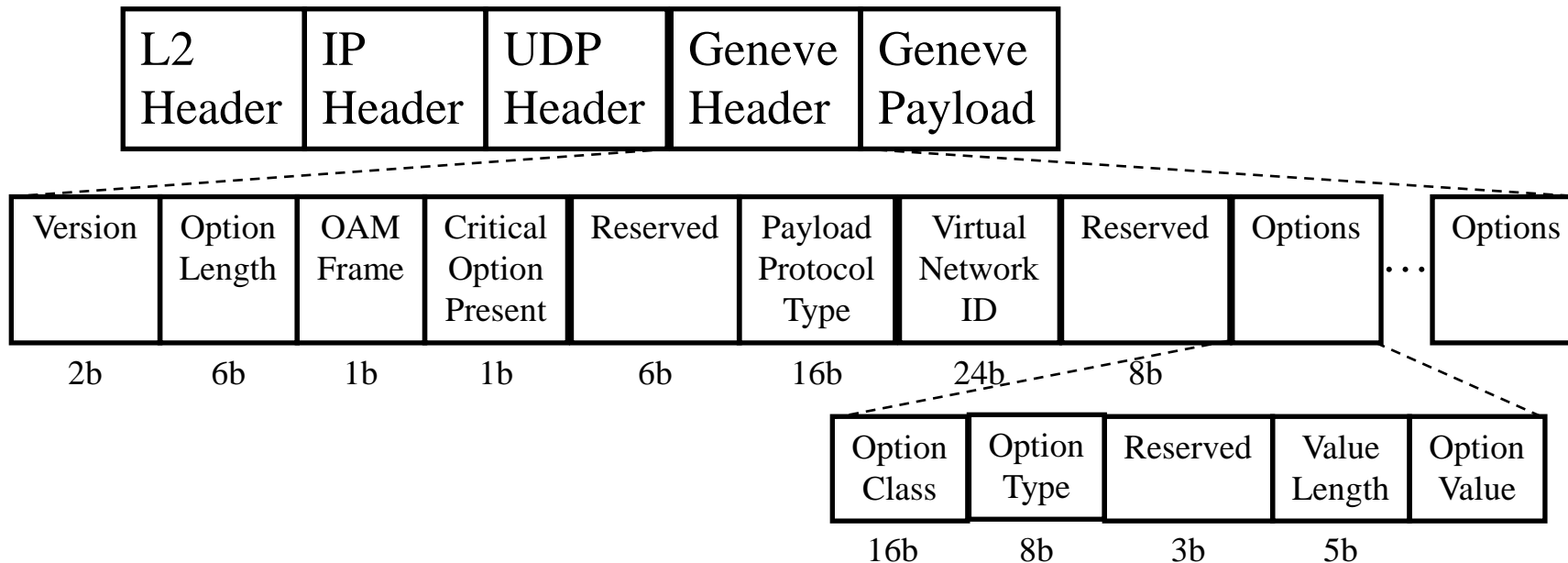http://tools.ietf.org/html/draft-davie-stt-04

Geneve

❑ Generic Network Virtualization Encapsulation

❑ Best of NVGRE, VXLAN, and STT

❑ **Generic** $\Rightarrow$ Can virtualize any (L2/L3/…) protocol over IP

❑ **Tunnel Endpoints**: Process Geneve headers and control packets

❑ **Transit Device**: do not need to process Geneve headers or control packets

Student Questions

Ref: J. Gross, et al, "Geneve: Generic Network Virtualization Encapsulation" IETF Internet Draft, draft-ietf-nvo3-geneve-14, Sep. 12, 2019, https://tools.ietf.org/pdf/draft-ietf-nvo3-geneve-14.txt

Geneve Frame Format

❑ **Highly Extensible**: Variable number of variable size options

❑ Any vendor can extend it in its own way by getting an "Option Class" from IANA (Internet Assigned Number Authority)

❑ Options are encoded in a **TLV** (Type-Length-Value) format

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L2 Header	IP Header	UDP Header	Geneve Header	Geneve Payload

Version	Option Length	OAM Frame	Critical Option Present	Reserved	Payload Protocol Type	Virtual Network ID	Reserved	Options	...	Options
2b	6b	1b	1b	6b	16b	24b	8b			

Option Class	Option Type	Reserved	Value Length	Option Value
16b	8b	3b	5b	

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Geneve Frame Format (Cont)

❑ **Option Length** (6 bits): Length of options field in 4B (does not include the rest of the Geneve header)

❑ **OAM Frame** (1 bit): Control packet. Does not contain user data. Must be passed on to the control plane CPU

❑ **Critical Options Present** (1 bits): One or more options are critical.
Drop the packet if you don't understand a critical option

❑ **Payload Protocol Type** (16 bits): 0x6558 for Ethernet

❑ **Virtual Network ID** (24 bits): Tenant ID

❑ **Option Class** (16 bits): Who designed this option. Vendor, technologies, organizations, …

❑ **Option Type** (8 bits) : msb (most significant bit) =1 => Critical

❑ **Option Value Length** (5 bits): in units of 4-bytes

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LSO and LRO

- **Large Send Offload** (LSO): Host hands a large chunk of data to NIC and meta data. NIC makes MSS size segments, adds checksum, TCP, IP, and MAC headers to each segment.

- **Large Receive Offload** (LRO): NICs attempt to reassemble multiple TCP segments and pass larger chunks to the host. Host does the final reassembly with fewer per packet operations.
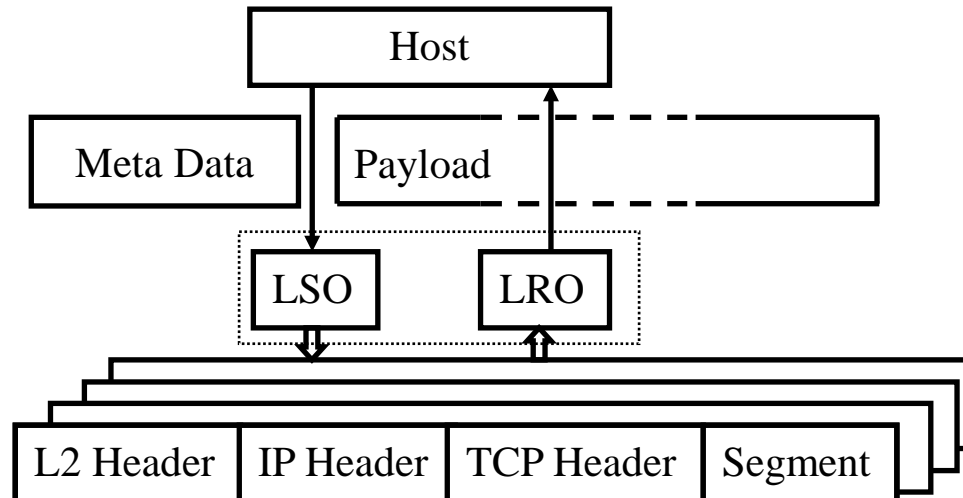
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Geneve Implementation Issues

❑ **Fragmentation**: Use Path MTU (Maximum Transmission Unit) discovery to avoid fragmentation on the path

❑ **DSCP** (Differentiated Services Control Point): DSCP bits in the outer header may or may not be the same as in the inner header. Decided by the policy of the network service provider

❑ **ECN** (Explicit Congestion Notification): ECN bits should be copied from inner header on entry to the tunnel and copied back to the inner header on exit from the tunnel

❑ **Broadcast and Multicast**: Use underlying networks multicast capabilities if available. Use multiple point to point tunnels if multicast is not available.

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Geneve Implementation Issues (Cont)

❑ **LSO**: Replicate all Geneve headers and options on all outgoing packets.

❑ **LRO**: Merge all packets with the identical Geneve headers

❑ **Option Order**: Not significant. Options can be in any order.

❑ **Inner VLAN**: Tunnel endpoints decide whether to differentiate packets with different inner VLAN values.
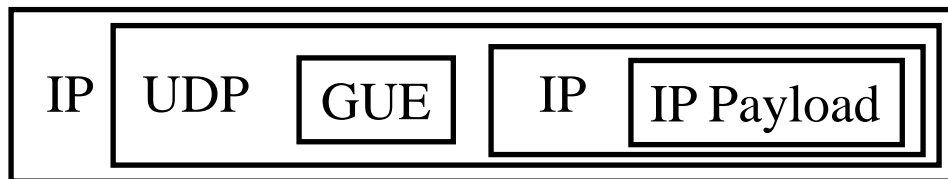
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Geneve Summary

1. UDP over IP encapsulation
2. Geneve header is extensible by vendors
3. Generally variable length headers are considered hard for hardware implementation
4. Vendor extensibility requires a system to register options and may result in interoperability issues
5. All of this is subject to change since it is in the draft stage.

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Generic UDP Encapsulation (GUE)

❑ Using UDP to encapsulate IP protocols

❑ Allows using efficient hardware implementations of UDP

❑ Generic ⟹ Any IP payload

❑ Optional data in header: VNI, Authentication, Security, congestion control, vendor extensions, etc.

❑ Allows carrying Non-TCP/Non-UDP IP payloads over networks that filter all non-TCP/non-UDP packets.

| IP | UDP | GUE | IP | IP Payload |

Student Questions

Ref: T. Herbert, L. Yong, and O. Zia, "Generic UDP Encapsulation," IETF Draft, March 7, 2019, draft-ietf-intarea-gue-07

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GUE Packet Format

❏ Source Port: 6080 or any other port

❏ Dest Port: 6080 or any other port

❏ Len: Length of UDP header and payload in 4B unit

❏ Checksum: Standard UDP checksum

❏ Version: 0 and 1 are standardized. Version 0 shown below.

❏ Hlen: Extenstion Field + Private Data length in 32-bit words
Total GUE header length = HLEN*4+4 bytes

❏ Protocol/Control Type: C=1 ⇒ Control, C=0 ⇒ Protocol type of the payload

❏ Flags indicate the presence of various extension fields and private data

❏ Version 1: No Extension or private data. First 4 bits of IP header are version 0100 or 0110. First 2 bits indicate GUE version.

Source Port	Dest Port	Len	Check sum	Ver	C	Hlen	Proto/ Ctype	Flags	Extension Fields (Opt)	Private Data (Opt)
16b	16b	16b	16b	2b	1b	5b	8b	16b		

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Virtual Private LAN Service (VPLS)

❑ Allows *multi-point* Ethernet services over MPLS networks using a *full-mesh point-to-point pseudo-wires*

❑ **Virtual Forwarding Instance (VFI)**: A virtual LER instance in the provider edge router specific to each customer LAN

❑ **VPLS Instance**: Set of VFIs and PWs connecting them. Creates a single "VLAN" broadcast domain connecting VFIs.

❑ Widely deployed but does not meet data center requirements ⇒ BGP MPLS-Based Ethernet VPN (EVPN)
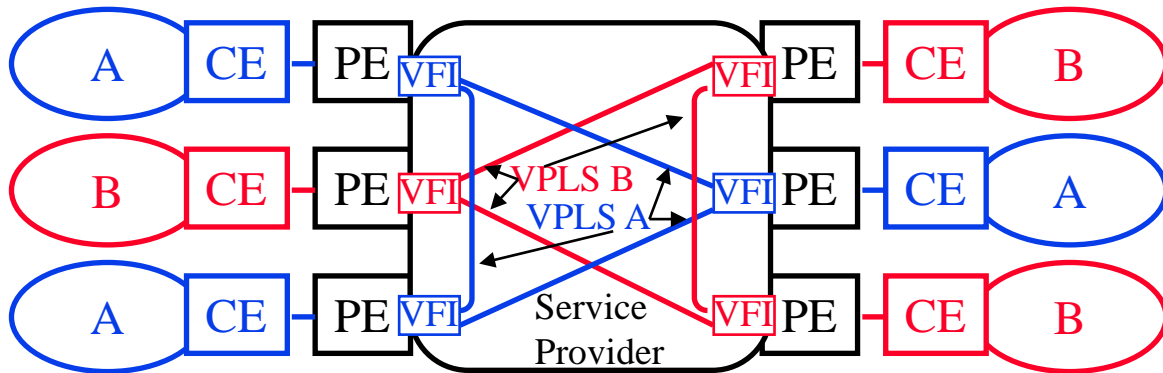
CE: Customer Edge
PE: Provider Edge

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EVPN Features

❑ Multicast Optimization: MP2MP LSPs

❑ Ease of Provisioning: Auto-discovery of PEs, Customer Site ID, Automated designated Forwarder election among PEs, MPLS parameters based on VLAN parameters

❑ New Service Interface: Port = VLAN, Multiple VLANs per port, VLAN bundles are treated as one VLAN

❑ Fast Convergence

❑ Flood Suppression

❑ Flexible VPN topologies and Policies

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EVPN Redundancy Features

❑ Flow-based load balancing: CE connected to multiple PEs. Select path by hashing 7-tuple (L2, L3, L4 addresses, VLAN)

❑ Flow-based multi-pathing: Multiple LSPs between PEs

❑ Geo-Redundant PE Nodes: CE connected to multiple PEs in different PoPs

❑ Optimal Traffic Forwarding: Single/multi-homed CE to Single/multi-homed CE. Packet not forwarded to PEs not connected to the destination CE

❑ Flexible Redundancy Grouping: PEs are grouped for redundancy.

❑ Multi-homed Network: Entire Ethernet is connected to multiple PEs.

Student Questions
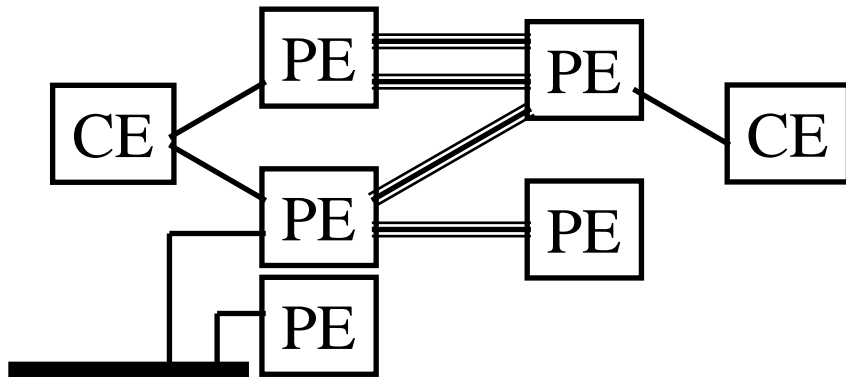
Ref: J. Rabadan, et al., "Applicability of EVPN to NVO3 Networks," IETF Draft, July 8, 2019,
https://tools.ietf.org/html/draft-ietf-nvo3-evpn-applicability
A Sajassi, et al., "BGP MPLS-Based Ethernet VPN," IETF RFC 7432, Feb 2015, https://tools.ietf.org/html/rfc7432
A. Sajassi, et al., "Requirements for Ethernet VPN (EVPN)," May 2014, https://tools.ietf.org/html/rfc7209
http://www.cse.wustl.edu/~jain/cse570-21/

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Summary

| | **Student Questions** |
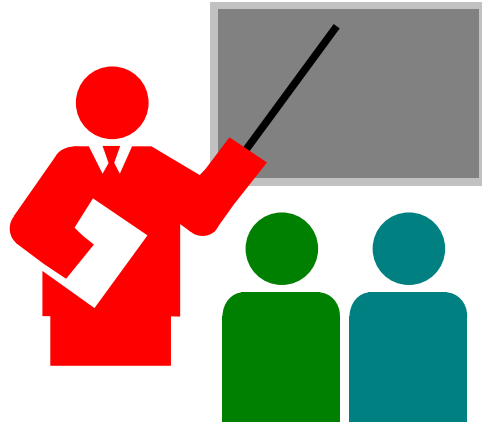
1. TRILL uses "Routing Bridges" to transport Ethernet packets on a campus network. RBs use IS-IS to find the shortest path.

2. NVO3 is a generalized framework for network virtualization and partitioning for multiple tenants over L3. It covers both L2 and L3 connectivity.

3. NVGRE uses Ethernet over GRE for L2 connectivity.

4. VXLAN uses Ethernet over UDP over IP

5. Geneve uses Any protocol over UDP over IP encapsulaton.

References

❑ Emulex, "NVGRE Overlay Networks: Enabling Network Scalability," Aug 2012, 11pp., http://www.emulex.com/artifacts/074d492d-9dfa-42bd-958369ca9e264bd3/elx_wp_all_nvgre.pdf

❑ G. Santana, "Datacenter Virtualization Fundamentals," Cisco Press, 2014, ISBN: 1587143240 (Safari Book)

❑ J. Gross, et al, "Geneve: Generic Network Virtualization Encapsulation" IETF Internet Draft, Sep. 12, 2019, https://tools.ietf.org/pdf/draft-ietf-nvo3-geneve-14.txt

❑ M. Lasserre, et al., "Framework for Data Center (DC) Network Virtualization," IETF RFC 7365, Oct 2014, 26 pp., https://tools.ietf.org/pdf/rfc7365

❑ M. Mahalingam, et al, *VXLAN: A Framework for Overlaying Virtualized Layer 2 Networks over Layer 3 Networks*," IETF RFC 7348, https://tools.ietf.org/pdf/rfc7348

❑ P. Garg, Y. Wang, "NVGRE: Network Virtualization using GRE," Sep 2015, IETF RFC 7637, https://tools.ietf.org/pdf/rfc7637

Student Questions

References (Cont)

❑ R. Perlman, "RBridges: Transparent Routing," Infocom 2004

❑ TRILL RFCs 5556, 6325, 6326, 6327, 6361, 6439

❑ T. Narten, Ed., "Problem Statement: Overlays for Network Virtualization," IETF RFC 7364, Oct 14, 23 pp., https://tools.ietf.org/html/rfc7364

Student Questions

Wikipedia Links

❑ http://en.wikipedia.org/wiki/Generic_Routing_Encapsulation

❑ http://en.wikipedia.org/wiki/Locator/Identifier_Separation_Protocol

❑ http://en.wikipedia.org/wiki/Large_segment_offload

❑ http://en.wikipedia.org/wiki/Large_receive_offload

❑ https://en.wikipedia.org/wiki/Virtual_Extensible_LAN

Student Questions

Acronyms

- ARMD — Address Resolution for Massive numbers of hosts in the Data center
- ARP — Address Resolution Protocol
- BGP — Border Gateway Protocol
- BUM — Broadcast, Unknown, Multicast
- CPU — Central Processing Unit
- DC — Data Center
- DCI — Data Center Interconnection
- DCN — Data Center Networks
- DCVPN — Data Center Virtual Private Network
- DSCP — Differentiated Services Control Point
- ECMP — Equal Cost Multi Path
- EoMPLSoGRE — Ethernet over MPLS over GRE
- ECN — Explicit Congestion Notification
- EVPN — Ethernet Virtual Private Network
- GRE — Generic Routing Encapsulation

Student Questions

http://www.cse.wustl.edu/~jain/cse570-21/

Acronyms (Cont)

- IANA   Internet Address and Naming Authority
- ID   Identifier
- IEEE   Institution of Electrical and Electronic Engineers
- IETF   Internet Engineering Task Force
- IGMP   Internet Group Multicast Protocol
- IP   Internet Protocol
- IPSec   IP Security
- IPv4   Internet Protocol V4
- IS-IS   Intermediate System to Intermediate System
- LAN   Local Area Network
- LISP   Locator ID Separation Protocol
- LRO   Large Receive Offload
- LSO   Large Send Offload
- MAC   Media Access Control
- MPLS   Multi Protocol Label Switching
- MSS   Maximum Segment Size

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Acronyms (Cont)

- MTU   Maximum Transmission Unit
- NIC   Network Interface Card
- NV   Network Virtualization
- NVA   Network Virtualization Authority
- NVEs   Network Virtualization Edge
- NVGRE   Network Virtualization Using GRE
- NVO3   Network Virtualization over L3
- OAM   Operation, Administration and Management
- OTV   Overlay Transport Virtualization
- PB   Provider Bridges
- PBB   Provider Backbone Bridge
- pM   Physical Machine
- pSwitch   Physical Switch
- QoS   Quality of Service
- RB   Routing Bridge
- RFC   Request for Comment

Student Questions

Acronyms (Cont)

- RS   Routing System
- STT   Stateless Transport Tunneling Protocol
- TCP   Transmission Control Protocol
- TLV   Type-Length-Value
- TRILL   Transparent Routing over Lots of Links
- TS   Tenant System
- UDP   User Datagram Protocol
- VDP   VSI Discovery and Configuration Protocol
- VLAN   Virtual Local Area Network
- VM   Virtual Machine
- VN   Virtual Network
- VNI   Virtual Network Instance/Virtual Network Context ID
- VPLS   Virtual Private LAN Service
- VPLSoGRE   Virtual Private LAN Service over GRE
- VPN   Virtual Private Network

Student Questions

Acronyms (Cont)

❑ VRRP   Virtual Router Redundancy Protocol
❑ VSI   Virtual Station Interface
❑ VSID   Virtual Subnet Identifier
❑ vSwitch   Virtual Switch
❑ VTEP   VXLAN Tunnel End Point
❑ VXLAN   Virtual Extensible Local Area Network

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http://www.cse.wustl.edu/~jain/cse570-21/m_08dmt.htm

Related Modules

CSE567M: Computer Systems Analysis (Spring 2013),

https://www.youtube.com/playlist?list=PLjGG94etKypJEKjNAa1n_1X0bWWNyZcof

CSE473S: Introduction to Computer Networks (Fall 2011),

https://www.youtube.com/playlist?list=PLjGG94etKypJWOSPMh8Azcgy5e_10TiDw

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Video Podcasts of Prof. Raj Jain's Lectures,

https://www.youtube.com/user/ProfRajJain/playlists

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