

Carrier Ethernet



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These slides and audio/video recordings of this class lecture are at:

<http://www.cse.wustl.edu/~jain/cse5700-25/>

Announcements

- ❑ The exam will be in Somers Hall 251 starting at 1 PM sharp.



1. Enterprise vs. Carrier Ethernet
2. UNI vs. Peer-to-Peer Signaling
3. Metro Ethernet
4. Ethernet Provider Bridge (PB)
5. Provider Backbone Network (PBB)
6. Connection-Oriented Ethernet

Note: Although these technologies were initially developed for carriers, they are now used inside multi-tenant data centers (clouds)

Student Questions

Enterprise vs. Carrier Ethernet

Enterprise	Carrier
<input type="checkbox"/> Distance: up to 2km	<input type="checkbox"/> Up to 100 km
<input type="checkbox"/> Scale:	<input type="checkbox"/> Millions of MAC Addresses
➤ Few K MAC addresses	<input type="checkbox"/> Millions of VLANs
➤ 4096 VLANs	Q-in-Q
<input type="checkbox"/> Protection: Rapid Spanning tree	<input type="checkbox"/> Shortest Path Routing
<input type="checkbox"/> Path determined by spanning tree	<input type="checkbox"/> Traffic-engineered path
<input type="checkbox"/> Simple service	<input type="checkbox"/> SLA
<input type="checkbox"/> Priority ⇒ Aggregate QoS	<input type="checkbox"/> Need per-flow QoS
<input type="checkbox"/> No performance/Error monitoring (OAM)	<input type="checkbox"/> Need performance/BER

Student Questions

Carriers vs. Enterprise

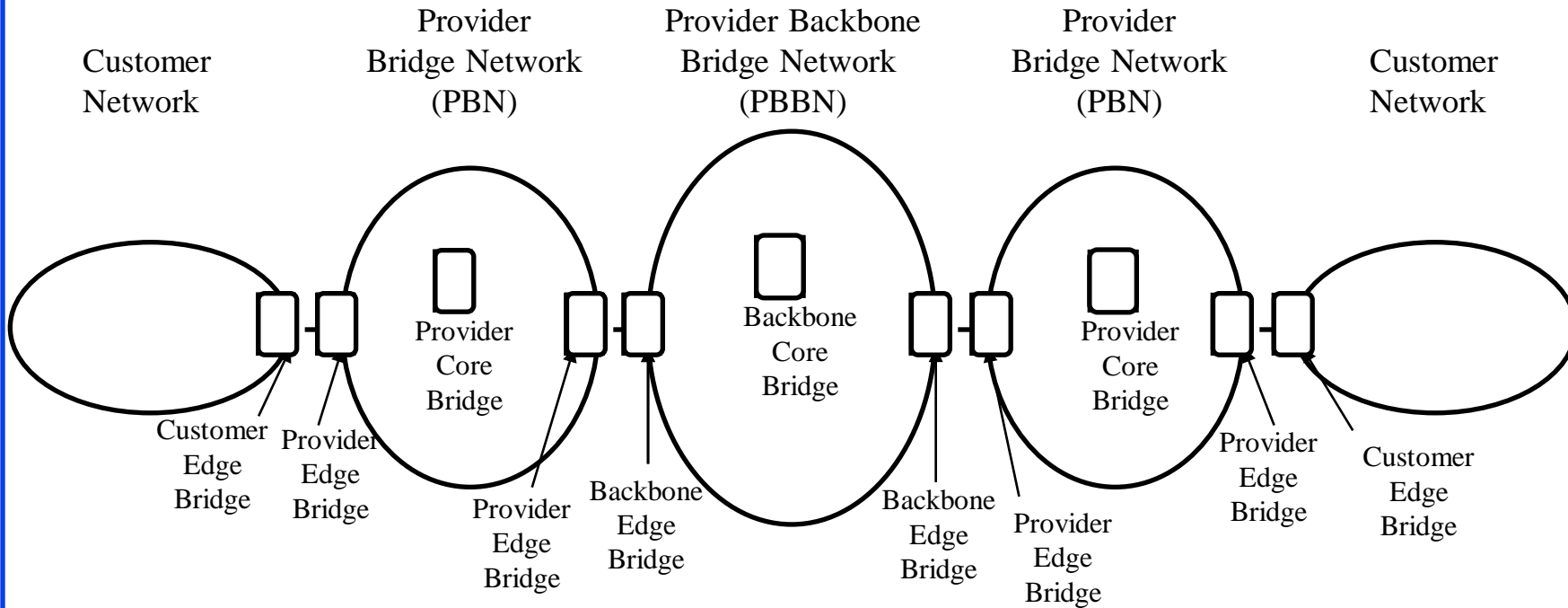
We need to exchange topology for optimal routing.

Sorry, We can't tell you anything about our internal network.



Student Questions

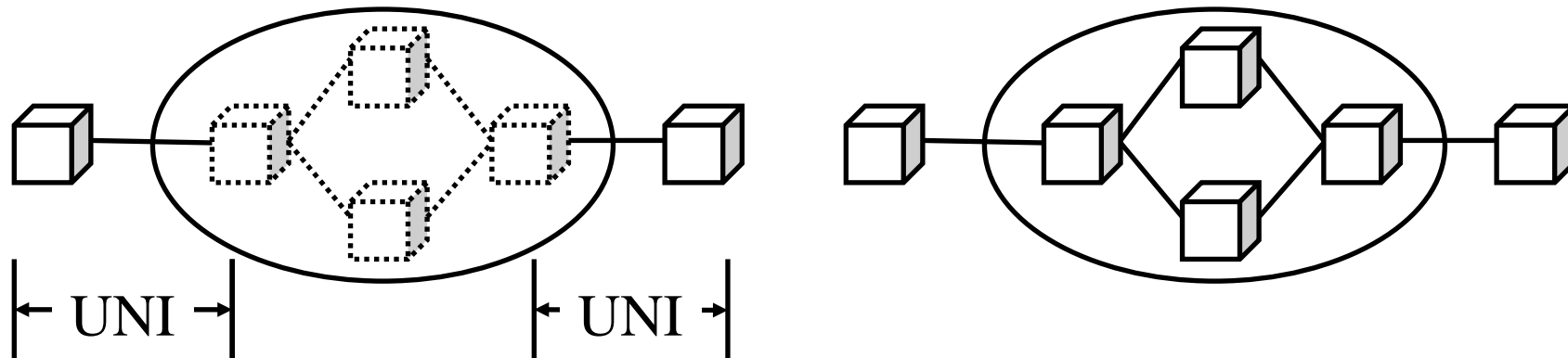
Network Hierarchy



Student Questions

Issue: UNI vs Peer-to-Peer Signaling

- ❑ Two Business Models:
 - Carrier: Overlay or cloud
 - ❑ Network is a black-box
 - ❑ User-to-network interface (UNI)
 - Enterprise: Peer-to-Peer
 - ❑ A complete exchange of information



Student Questions

UNI vs. ENNI

❑ User to Network Interface (UNI):

- Separates responsibilities between the user and the provider. (Troubleshooting, failures, etc.)
- Like the wired phone box outside your home.
- Only one customer's traffic.

❑ External Network-to-Network Interface (ENNI):

- Separates responsibilities between two providers.
- Many customers traffic passes through an ENNI
- Tier 2 *operators* sell services to Tier 3 service providers.



Ref: Fujitsu, "Carrier Ethernet Essentials," <http://www.fujitsu.com/downloads/TEL/fnc/whitepapers/CarrierEthernetEssentials.pdf>

Washington University in St. Louis

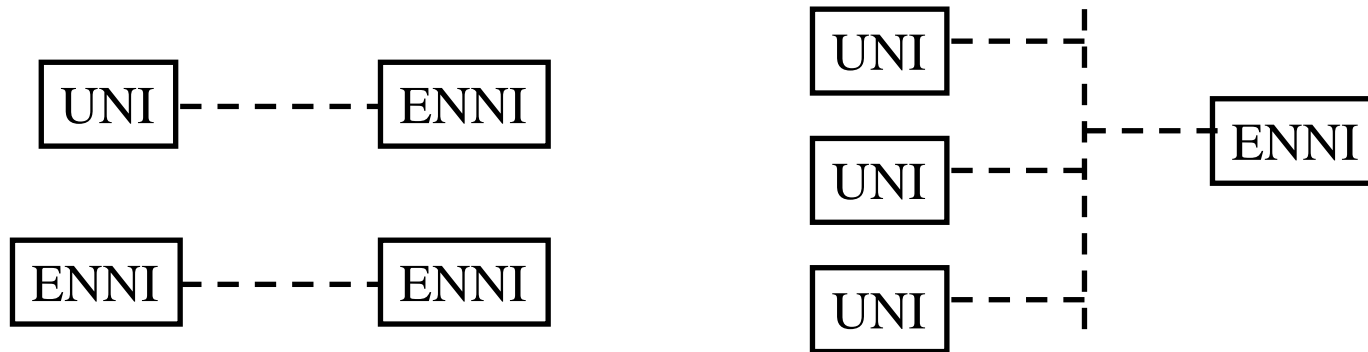
<http://www.cse.wustl.edu/~jain/cse5700-25/>

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Student Questions

Operator Virtual Connection (OVC)

- ❑ Between UNI and ENNI or between two ENNIs.
- ❑ For wholesale service providers
- ❑ Two types: Point-to-Point and Multipoint-to-Multipoint
- ❑ Untagged or single-tagged frames at NNI. Q-in-Q at ENNI
- ❑ UNIs may be 10 to 100 Mbps. ENNIs at 1 to 10 Gbps.

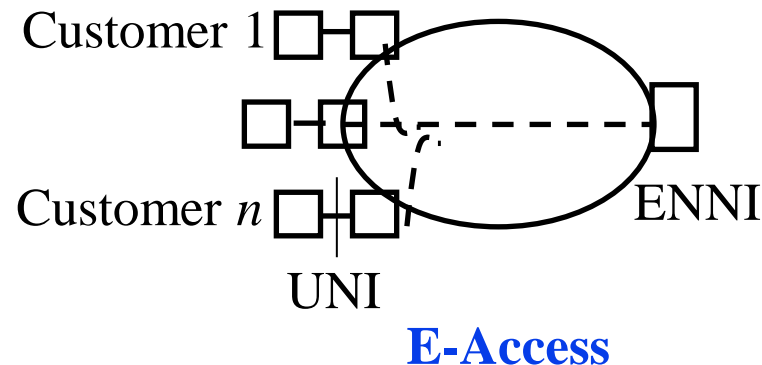


Student Questions

Metro Access Ethernet Private Line

□ Access Ethernet Private Line (Access-EPL):

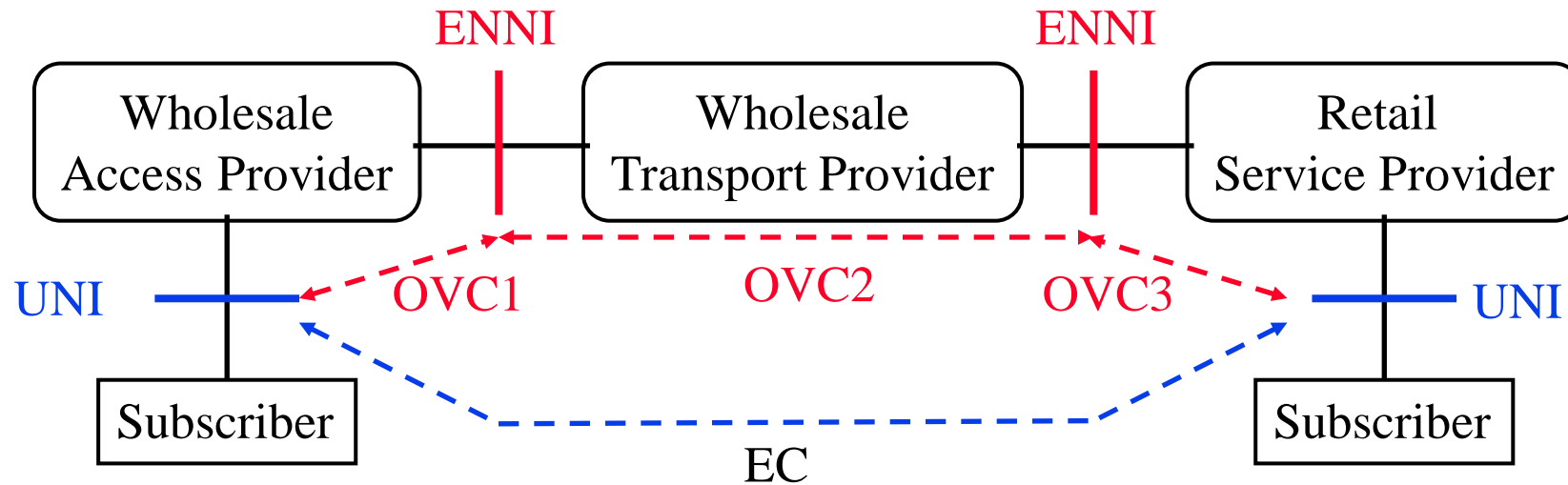
- Port-based service for Internet access
Like the service at your home.
- Ends at your access provider, where many other Access-EPLs may end
- Access provider has only one interface
Shared by many Access-EPLs \Rightarrow Different from p2p EPL.



Student Questions

End-to-End Metro Ethernet Connection

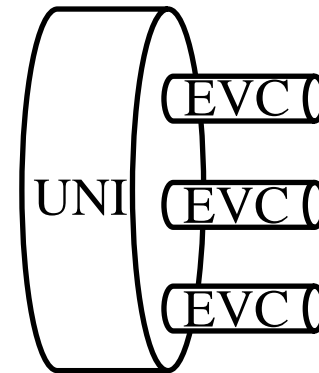
- An EC may go through multiple service providers
⇒ Multiple OVCs can be concatenated to create an EC



Student Questions

Ethernet Virtual Connections (EVCs)

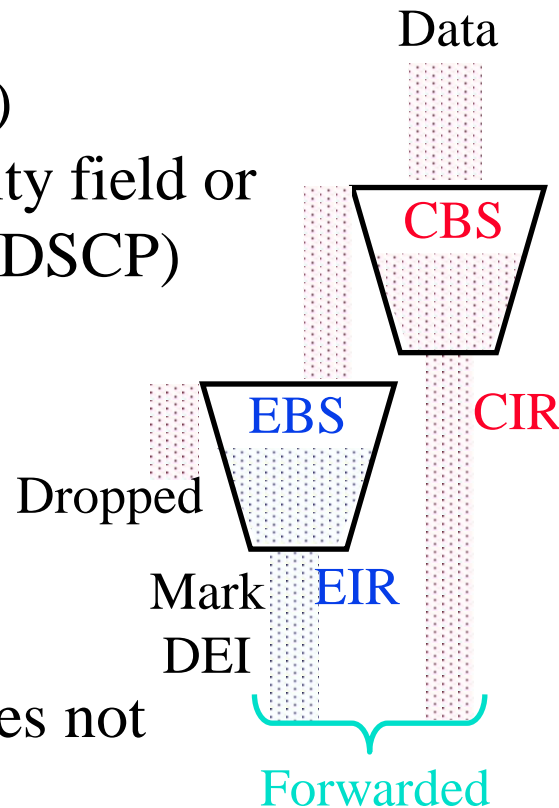
- ❑ **Port-based ECs:** Forwarding not based on VLANs. Frames delivered to remote UNI/ENNI for P2P or Based on the destination address for P2MP
- ❑ **VLAN-based ECs:** Forwarding based on VLAN tag.
 - ⇒ Multiple Virtual UNIs
 - ⇒ Ethernet *Virtual* Connection (*EVC*)
 - More cost-effective for Enterprise customers
- ❑ Types of EVCs:
 1. Ethernet Virtual Private Line (EVPL)
 2. Ethernet Virtual Private Tree (EVP-Tree)
 3. Ethernet Virtual Private LAN (EVPLAN)
 4. Access Ethernet Virtual Private Line (Access EVPL)
- ❑ Note: Service providers always share an ENNI for multiple connections ⇒ OVCs are always virtual



Student Questions

Metro Ethernet Service Attributes

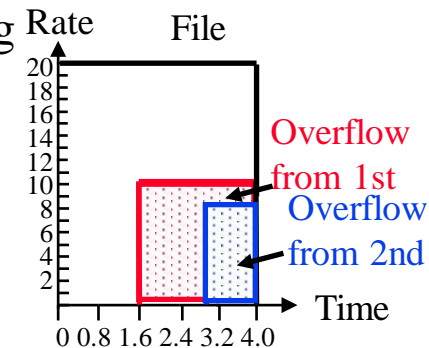
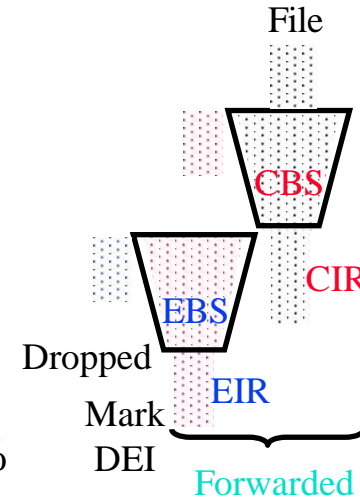
- ❑ Bandwidth Profiles: Limits on data rates
 - Ingress Profile: Incoming data rate
 - Egress Profile: Outgoing data rate
- ❑ Per UNI, Per EVC or OVC, or Per EVC/OVC per Class of Service (CoS)
- ❑ CoS is indicated by the 3-bits in the priority field or 4-bit Differentiated Services Code Point (DSCP)
- ❑ The rate specified by five parameters
 1. Committed Information Rate (CIR)
 2. Committed Burst Size (CBS)
 3. *Excess* Information rate (EIR)
 4. Excess Burst Size (EBS)
 5. Color Mode (CM): Customer does/does not mark drop eligibility indicator (DEI)



Student Questions

Example

1. A user with CIR=10 Mbps, CBS=2 MB, EIR=2 Mbps, EBS=1MB sends a 10 MB file at 20 Mbps. What percent of packets will be dropped? What percent will be marked?
2. CBS = 2 MB = 16 Mb, EBS = 1 MB = 8 Mb, File size = 80 Mb
3. File time = File Size/File rate = 80 Mb/20 Mbps = 4 s
4. 1st Bucket fill rate = Input rate-Leak rate=20-10 = 10 Mbps, 1st Bucket fill time = Bucket size/Fill rate = 16/10 = 1.6s
Total output from 1st bucket = Output before it is full + full bucket size = 4*10 Mbps + 16 Mb = 56 Mb (committed) = 70%
5. 1st Bucket Overflow time = total time – fill time= 4-1.6 = 2.4s
1st bucket Overflow amount = 2.4 s*(20-10) Mbps = 24 Mb
6. 2nd bucket fill Rate = Input rate – Leak rate = 10-2 = 8 Mbps
2nd bucket fill time = Size/Rate = 8 Mb/8 Mbps = 1 s
Total output from 2nd bucket = Output when nothing is coming in + Output before it is full + full bucket size = 0*1.6 + 2*(4 - 1.6) + 8 = 12.8 Mb (Marked) = 16%
7. 2nd Bucket overflow time = Total time – time when nothing is coming in – time when bucket was full = 4 - 1.6 - 1 = 1.4s
2nd bucket overflow amount = Overflow rate * overflow time = (10-2)*1.4 = 11.2 Mb (Dropped) = 14%
8. Check: Total = 56+12.8+11.2 = 80 Mb



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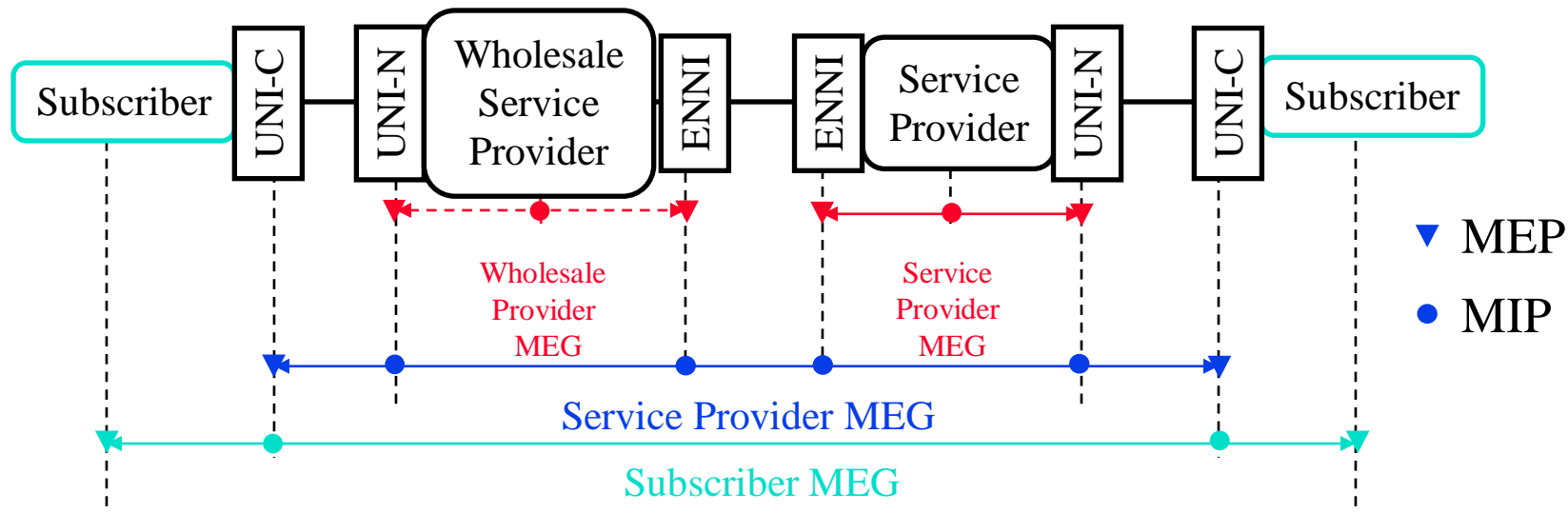
Homework 6

- A user with CIR=25 Mbps, CBS=2 MB, EIR=2 Mbps, EBS=1MB, sends a 15 MB file at 30 Mbps.
What percent of packets will be dropped?
What percent will be marked?

Student Questions

Metro Ethernet OAM

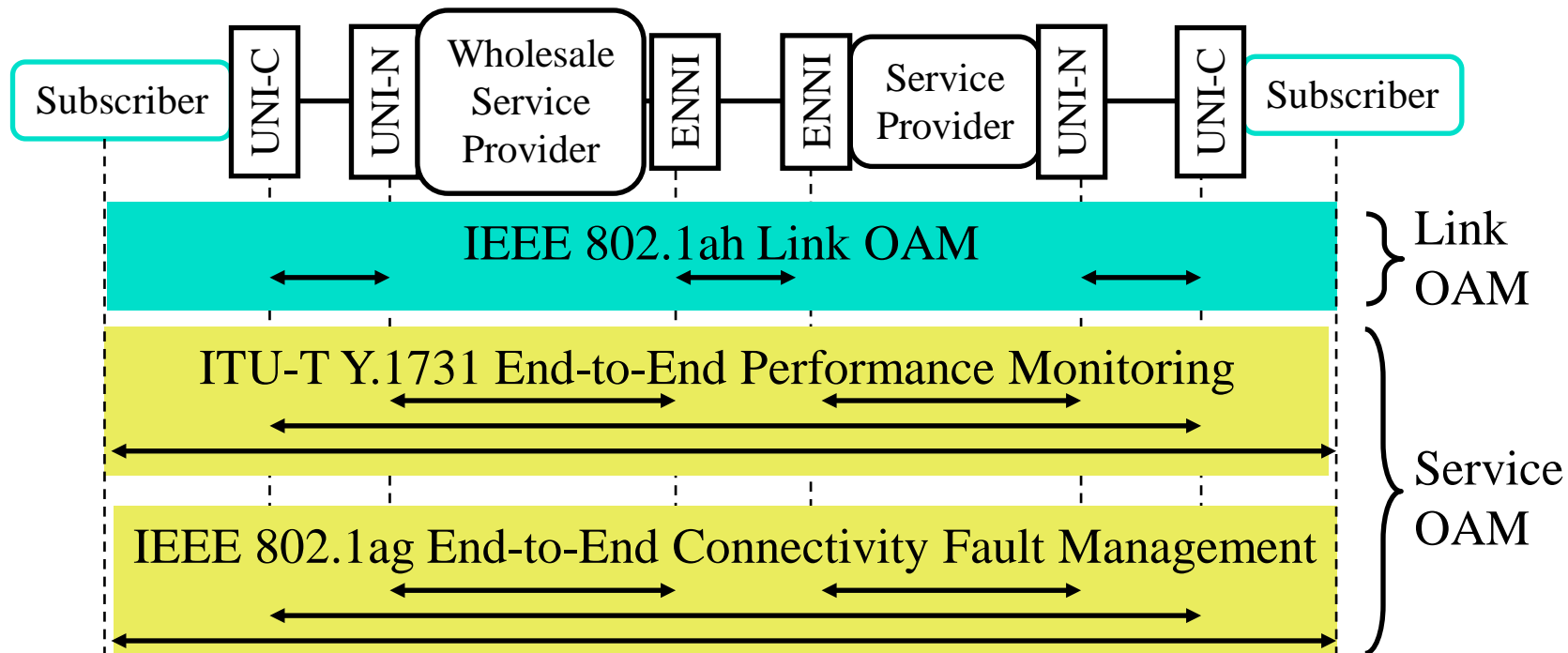
- ❑ Operation, Administration, and Maintenance (OAM)
- ❑ Defined in IEEE 802.1ag, IEEE 802.1ah, and ITU Y.1731
- ❑ Maintenance End Points (MEPs)
- ❑ Maintenance Intermediate Points (MIPs)
- ❑ Maintenance Entity Group (MEG): Level of Administration



Student Questions

Metro Ethernet OAM (Cont)

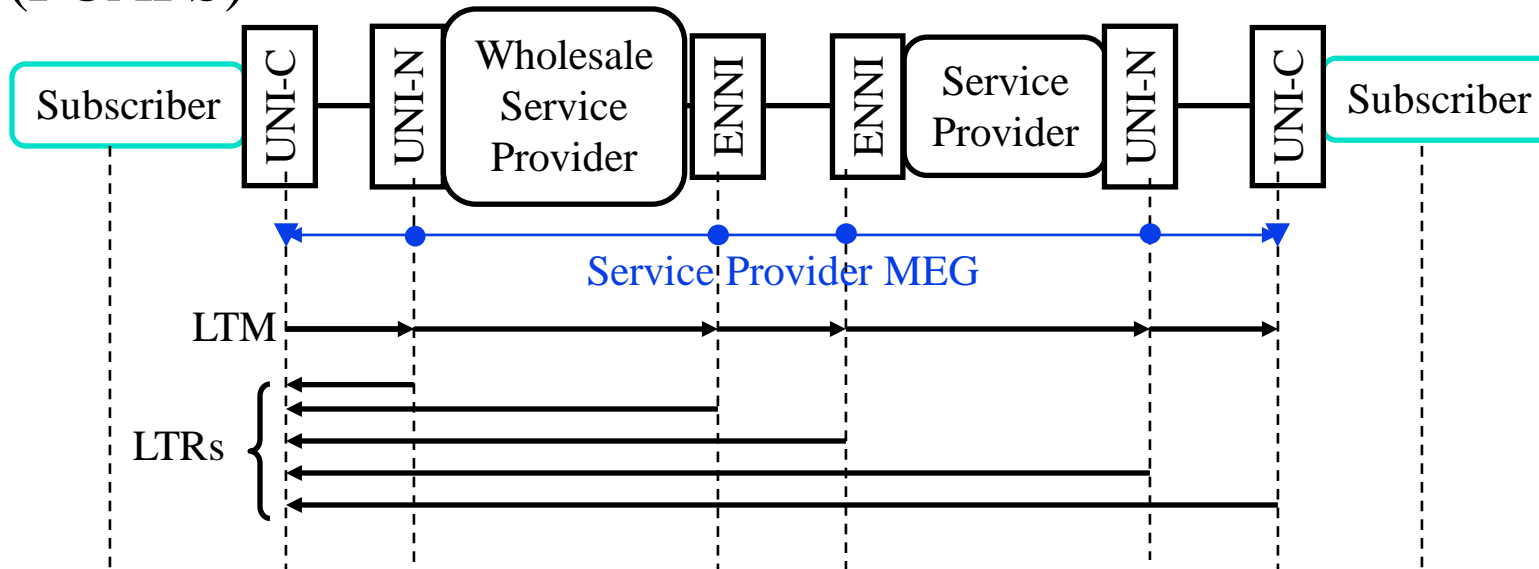
- ❑ Performance Monitoring: Measure throughput and latency
- ❑ Connectivity Fault Management: Monitor downtime
 - Service Fault Management
 - Link Fault Management



Student Questions

Metro Ethernet OAM Messages

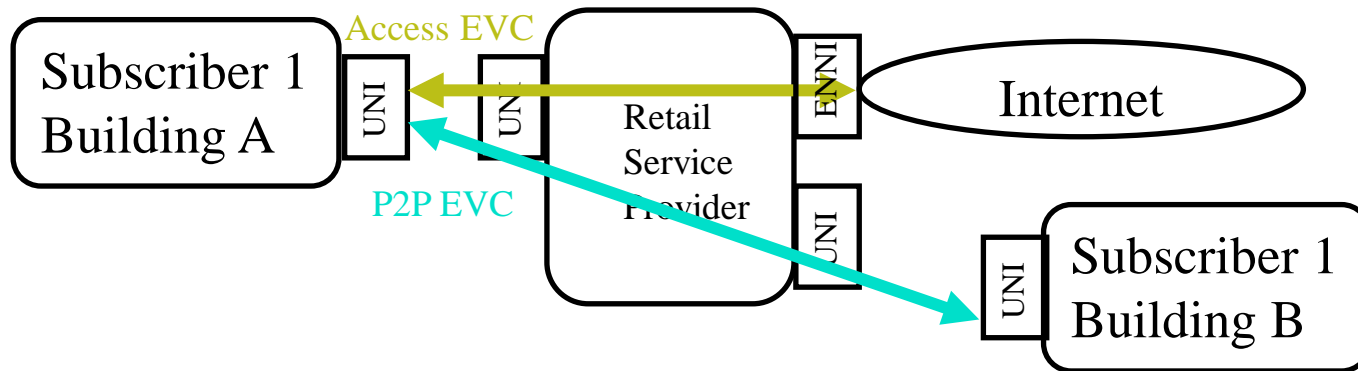
- ❑ Continuity Check Message (CCM) in both directions (Similar to IP Ping)
- ❑ Link Trace Message (LTM): Locates fault. Link Trace Response (LTR) is returned by each endpoint and intermediate point (similar to IP trace route)
- ❑ Fault, Configuration, Accounting, Performance, Security (FCAPS)



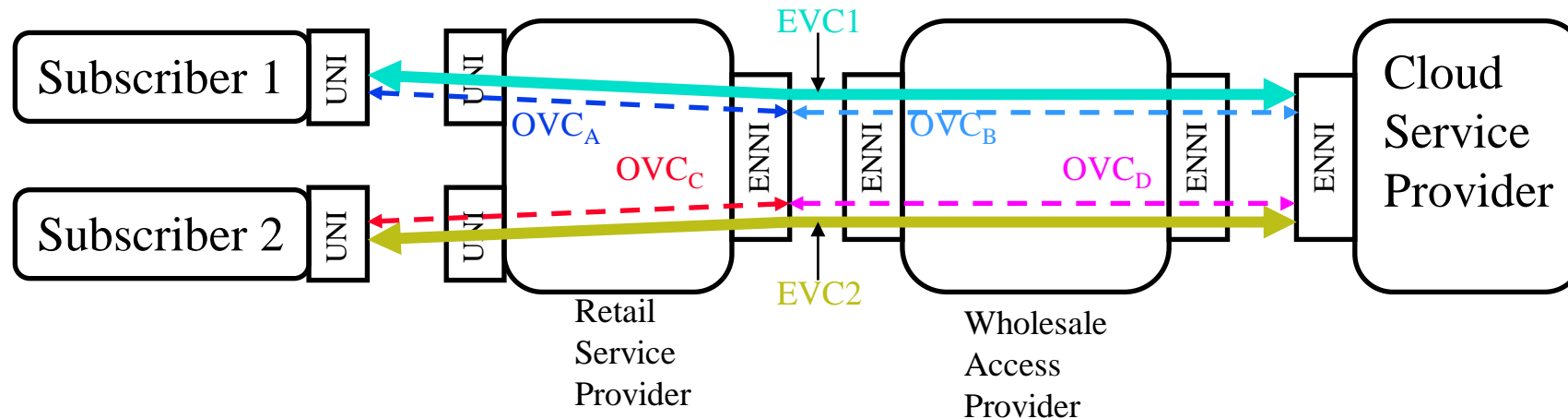
Student Questions

Metro Ethernet Use Cases

1. Head office to Satellite offices and/or Internet

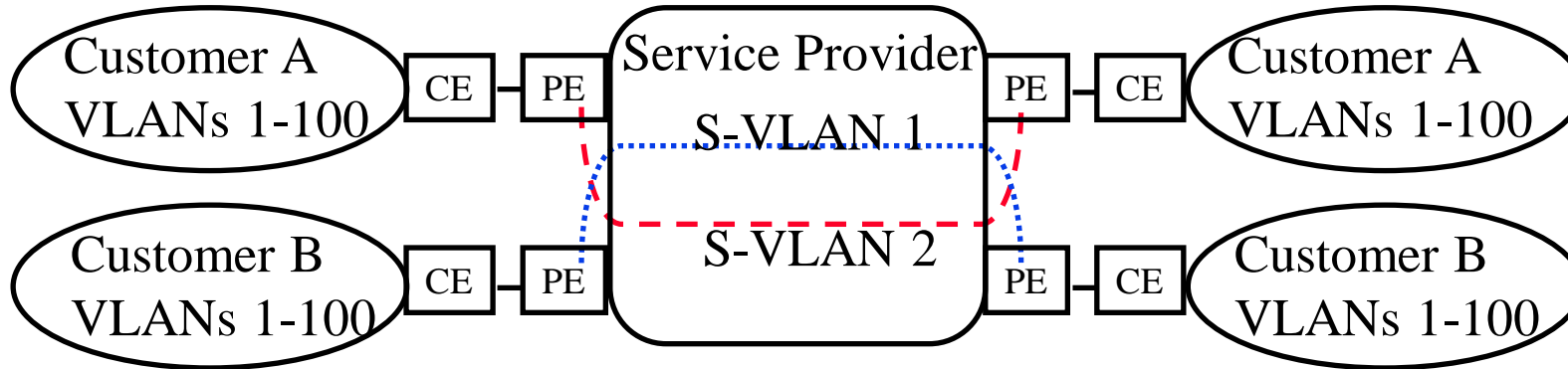


2. Customers to Cloud Service Provider



Student Questions

Ethernet Provider Bridge (PB)

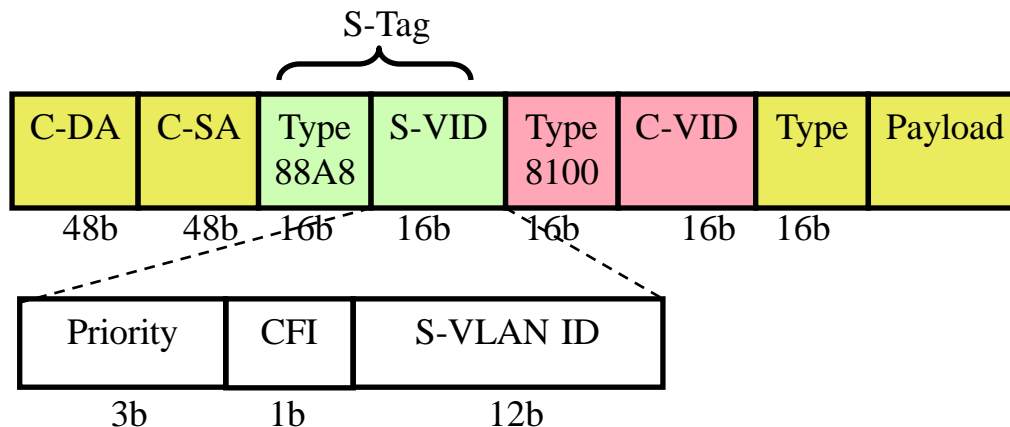


- ❑ IEEE 802.1ad-2005 incorporated in IEEE 802.1Q-2011
- ❑ Problem: Multiple customers may have the same VLAN ID. How do we keep them separate?
- ❑ Solutions:
 1. VLAN translation: Change customer VLANs to provider VLANs and back
 2. VLAN Encapsulation: Encapsulate customer frames

Student Questions

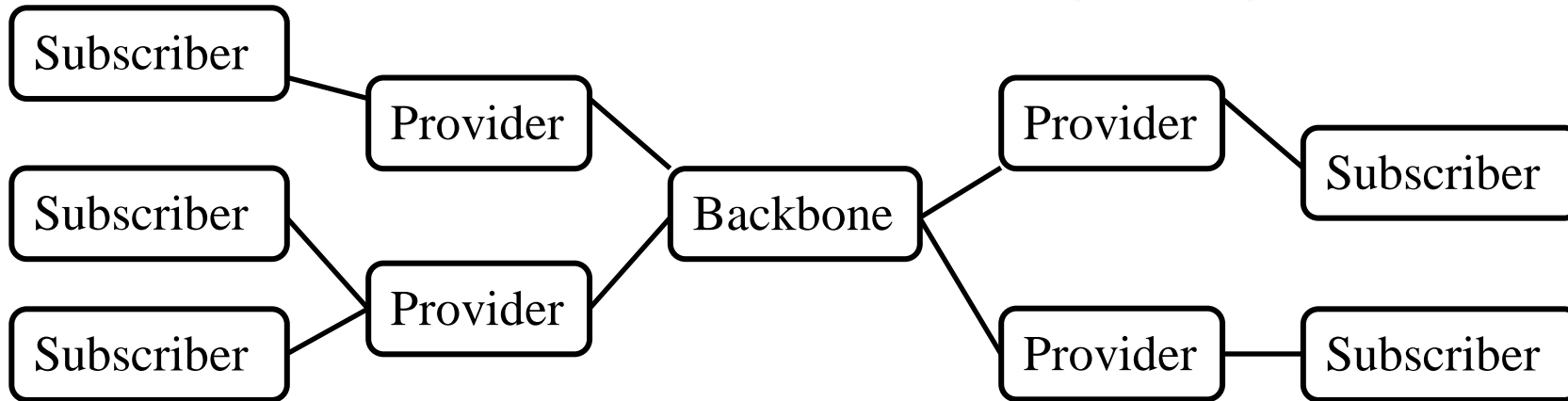
Provider Bridge (Cont)

- ❑ Q-in-Q Encapsulation: Provider inserts a service VLAN tag
VLAN translation Changes VLANs using a table
- ❑ Allows 4K customers to be serviced. Total 16M VLANs
- ❑ 8 Traffic Classes using Differentiated Services Code Points (DSCP) for Assured Forwarding



Student Questions

Provider Backbone Network (PBB)

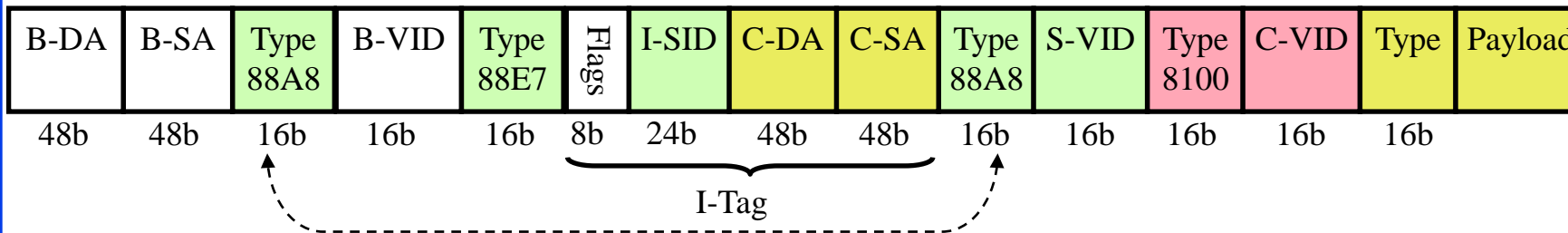
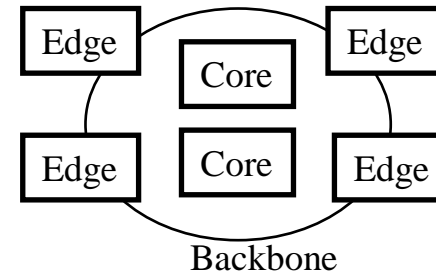


- ❑ Problem: The number of MAC addresses passing through backbone bridges is too large for all core bridges to remember. Broadcast and flooded (unknown address) frames give unwanted traffic and security issues.
- ❑ Solution: IEEE 802.1ah-2008 incorporated in 802.1Q-2011
- ❑ Add new source/destination MAC addresses pointing to the ingress backbone bridge and egress backbone bridge
⇒ Core bridges only know edge bridge addresses.

Student Questions

MAC-in-MAC Frame Format

- ❑ Backbone edge bridges (BEB) forward to other BEBs and learn customer MAC addresses
⇒ Backbone *core* bridges (BCB) do not learn customer MACs
- ❑ B-DA = Destination backbone bridge address
Determined by Customer Destination Address
- ❑ Backbone VLANs delimit the broadcast domains in the backbone



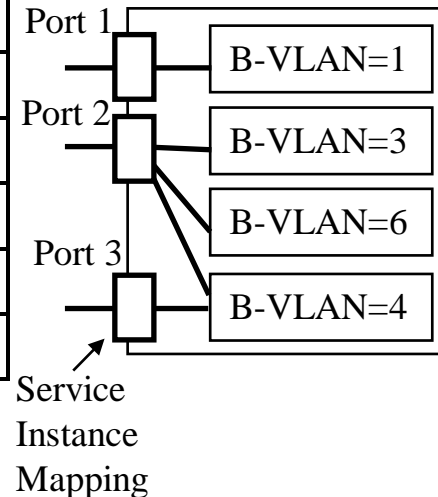
- ❑ Core switches forward based on Backbone Destination Bridge Address and Backbone-VLAN ID (60 bits)
Similar to 802.1ad Q-in-Q. Therefore, the same EtherType.

Student Questions

PBB Service Instance

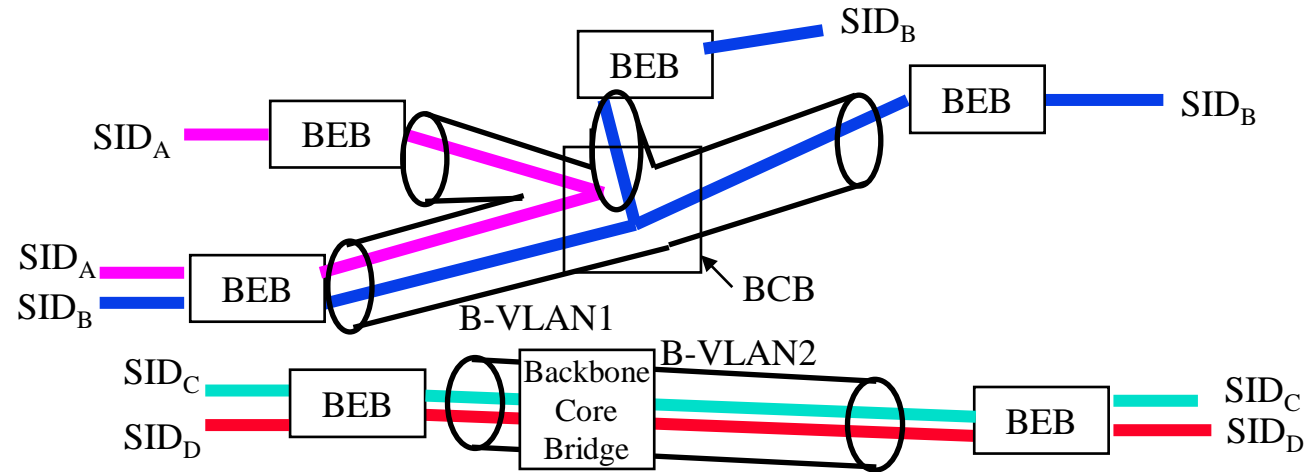
- ❑ 24-bit Service instance ID (I-SID) indicates a specific flow
 - All frames on a specific port, or
 - All frames on a specific port with a specific *service* VLAN or
 - All frames on a specific port with a specific service VLAN and a specific *customer* VLAN

SID	Definition	B-VLAN
1	Port 1	1
20	Port 2, S-VLAN=10	3
33	Port 2, S-VLAN=20	6
401	Port 2, S-VLAN=30, C-VLAN=100	4
502	Port 3, S-VLAN=40, C-VLAN=200	4



Student Questions

MAC-in-MAC (Cont)



- ❑ Each Backbone VLANs (B-VLAN) can carry multiple services
- ❑ 24-bit SID $\Rightarrow 2^{24}$ Service Instances in the backbone
- ❑ I-Tag format: I-Tag is not looked at in the core.
Includes C-DA+C-SA.
UCA=1 \Rightarrow Use customer addresses (used in CFM in the Edge)

Priority Code Point (I-PCP)	Drop Eligibility Indicator (I-DEI)	Use Customer Address (UCA)	Reserved 1	Reserved 2	Service Instance ID (I-SID)	Customer Destination Address (C-DA)	Customer Source Address (C-SA)
3b	1b	1b	1b	2b	24b	48b	48b

Student Questions

Connection Oriented Ethernet

- ❑ Connectionless: Path determined at forwarding
⇒ Varying QoS
- ❑ Connection Oriented: Path determined at provisioning
 - Path provisioned by management ⇒ Deterministic QoS
 - ❑ No spanning tree, No MAC address learning,
 - ❑ Frames forwarded based on VLAN Ids and Backbone bridge addresses
 - ❑ Path not determined by customer MAC addresses and other customer fields ⇒ More Secure
 - Reserved bandwidth per EVC
 - Pre-provisioned Protection path ⇒ Better availability

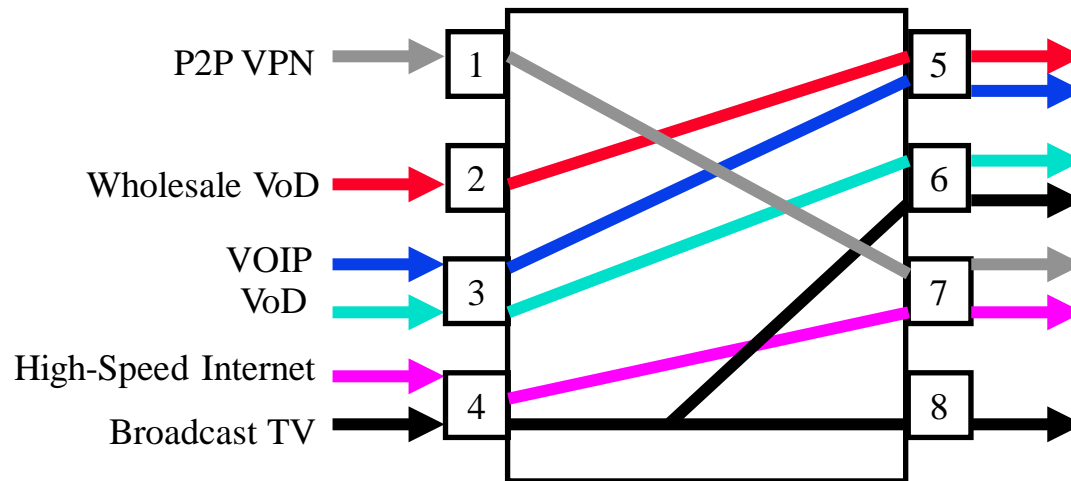


Student Questions

VLAN Cross-Connect

- ❑ Cross-connect \Rightarrow Circuit oriented
- ❑ Connection-oriented Ethernet with Q-in-Q
- ❑ Forward frames based on VLAN ID and Input port
 \Rightarrow No MAC Learning

Input Port	VLAN ID	Output Port
1	200	7
2	201	5
3	20	5
3	21	6
4	100	7
4	101	8



Student Questions

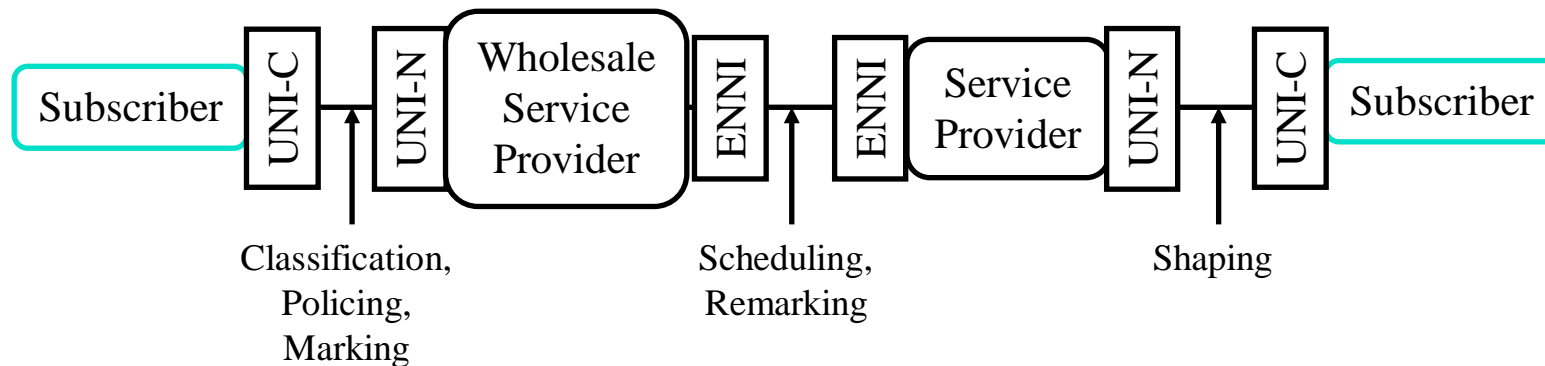
PBB-TE

- ❑ Provider Backbone Bridges with Traffic Engineering (PBB-TE)
- ❑ IEEE 802.1Qay-2009 incorporated in 802.1Q-2011
- ❑ Provides connection-oriented P2P (*E-Line*) Ethernet service
- ❑ For PBB-TE traffic VLANs:
 - Turn off MAC learning
 - Discard frames with unknown addresses and broadcasts.
⇒ No flooding
 - Disable Spanning Tree Protocol.
 - Add protection path switching for each direction of the trunk
- ❑ Switch forwarding tables are administratively populated using management
- ❑ Same frame format as MAC-in-MAC. No change.

Student Questions

PBB-TE QoS

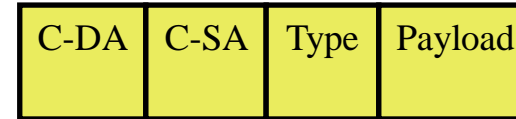
- ❑ Guarantees QoS \Rightarrow No need for MPLS or SONET/SDH
- ❑ UNI traffic is classified by Port, Service VLAN ID, Customer VLAN ID, priority, Unicast/Multicast
- ❑ UNI ports are *policed* \Rightarrow Excess traffic is dropped
No policing at NNI ports. Only remarking, if necessary.
- ❑ Traffic may be marked and remarked at both UNI and NNI



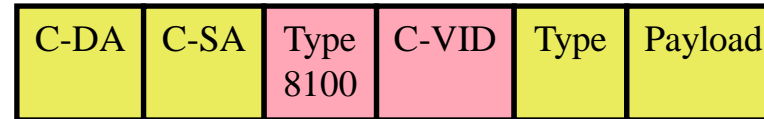
Student Questions

Ethernet Tagged Frame Format Evolution

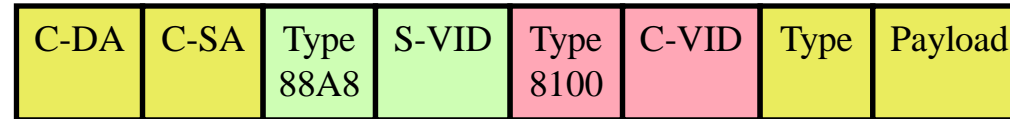
- Original Ethernet



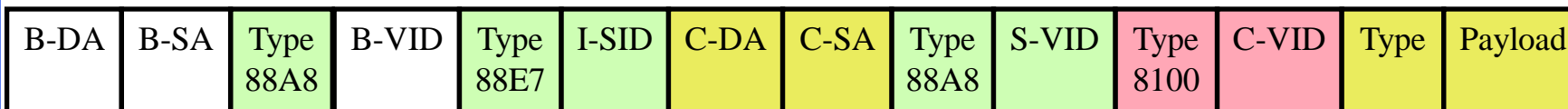
- IEEE 802.1Q VLAN



- IEEE 802.1ad PB



- IEEE 802.1ah PBB or 802.1Qay PBB-TE



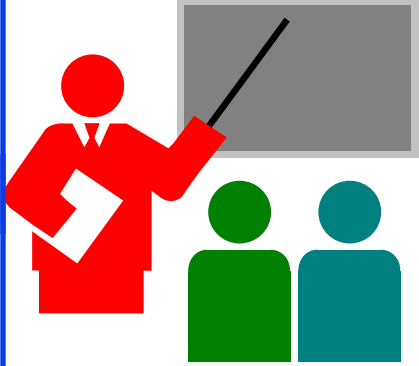
Tag Type	Value
Customer VLAN	8100
Service VLAN or Backbone VLAN	88A8
Backbone Service Instance	88E7

Student Questions

Comparison of Technologies

	Basic Ethernet	MPLS	PB	PBB-TE
Resilience	No	Protection Fast Reroute	SPB/LAG	Protection Fast Reroute
Security	No	Circuit Based	VLAN	Circuit Based
Multicast	Yes	Inefficient	Yes	No. P2P only
QoS	Priority	Diffserve	Diffserve+ Guaranteed	Diffserve+ Guaranteed
Legacy Services	No	Yes (PWE3)	No	No
Traffic Engineering	No	Yes	No	Yes
Scalability	Limited	Complex	Q-in-Q	Q-in-Q+ Mac-in-MAC
Cost	Low	High	Medium	Medium
OAM	No	Some	Yes	Yes

Student Questions



Summary

1. Carriers use User-to-Network Interface (UNI) signaling rather than peer-to-peer signaling
2. Metro Ethernet allows E-Line, E-Access, E-Tree, and E-LAN services
3. Q-in-Q allows service providers to carry customer VLAN tags in their Ethernet Frames
4. MAC-in-MAC extension allows very large Ethernet networks spanning over several backbone carriers
5. PBB-TE extension allows connection-oriented Ethernet with QoS guarantees and protection

Student Questions

Reading List

- ❑ Fujitsu, “Carrier Ethernet Essentials,”
<http://www.fujitsu.com/downloads/TEL/fnc/whitepapers/CarrierEthernetEssentials.pdf>
- ❑ R. Santitoro, “Metro Ethernet Services – A Technical Overview,” The Metro Ethernet Forum, 2003, V2.7,
<https://www.tacs.eu/Analyses/Ethernet/metro-ethernet-services.pdf>

Student Questions

References

- ❑ G. Santana, “Datacenter Virtualization Fundamentals,” Cisco Press, 2014, ISBN: 1587143240 (Safari Book)
- ❑ H. Saboowala, M. Abid, S. Modali, "Designing Networks and Services for the Cloud: Delivering business-grade cloud applications and services," Cisco Press 2013, ISBN:1587142945 (Safari Book)

Student Questions

Wikipedia Links

- ❑ http://en.wikipedia.org/wiki/Carrier_Ethernet
- ❑ http://en.wikipedia.org/wiki/Connection-oriented_Ethernet
- ❑ http://en.wikipedia.org/wiki/Ethernet_Private_Line
- ❑ http://en.wikipedia.org/wiki/Ethernet_Virtual_Private_Line
- ❑ http://en.wikipedia.org/wiki/IEEE_802.1ad
- ❑ http://en.wikipedia.org/wiki/IEEE_802.1ag
- ❑ http://en.wikipedia.org/wiki/IEEE_802.1ah-2008
- ❑ http://en.wikipedia.org/wiki/Metro_Ethernet
- ❑ http://en.wikipedia.org/wiki/Metro_Ethernet_Forum
- ❑ http://en.wikipedia.org/wiki/Network-to-network_interface
- ❑ http://en.wikipedia.org/wiki/Operations,_administration_and_management
- ❑ http://en.wikipedia.org/wiki/Provider_Backbone_Bridge_Traffic_Engineering
- ❑ http://en.wikipedia.org/wiki/Traffic_policing
- ❑ http://en.wikipedia.org/wiki/Traffic_shaping
- ❑ http://en.wikipedia.org/wiki/User%E2%80%93network_interface
- ❑ http://en.wikipedia.org/wiki/Virtual_Private_LAN_Service

Student Questions

Acronyms

❑ B-VID	Backbone VLAN Identifier
❑ BER	Bit Error Rate
❑ C-VID	Customer VLAN Identifier
❑ CBS	Committed Burst Size
❑ CCM	Continuity Check Message
❑ CE	Customer Edge
❑ CFI	Canonical Form Indicator
❑ CFM	Connectivity Fault Management
❑ CIR	Committed Information Rate
❑ CM	Color Mode
❑ CoS	Class of Service
❑ DA	Destination Address
❑ DEI	Drop Eligibility Indicator
❑ DSCP	Differentiated Services Code Points
❑ EBS	Excess Burst Size
❑ EC	Ethernet Connection

Student Questions

Acronyms (Cont)

- ❑ EIR Excess Information rate
- ❑ ENNI External Network to Network Interface
- ❑ EPL Ethernet Private Line
- ❑ EVC Ethernet Virtual Connection
- ❑ EVP-Access Ethernet Virtual Private Access
- ❑ EVP-LAN Ethernet Virtual Private Local Area Network
- ❑ EVP-Line Ethernet Virtual Private Line
- ❑ EVP-Tree Ethernet Virtual Private Tree
- ❑ EVPL Ethernet Virtual Private Line
- ❑ I-SID Instance Service ID
- ❑ ID Identifier
- ❑ IEEE Institution of Electrical and Electronic Engineers
- ❑ IETF Internet Engineering Task Force
- ❑ IP Internet Protocols
- ❑ ITU International Telecommunications Union

Student Questions

Acronyms (Cont)

- ❑ LAN Local Area Network
- ❑ LTM Link Trace Message
- ❑ LTR Link Trace Response
- ❑ MAC Media Access Control
- ❑ MEG Maintenance Entity Group
- ❑ MEP Maintenance End Points
- ❑ MIP Maintenance Intermediate Points
- ❑ MP Multi-Point
- ❑ MPLS Multi-Protocol Label Switching
- ❑ NNI Network-to-Network Interface
- ❑ OAM Operation, Administration and Maintenance
- ❑ OC Optical Carrier
- ❑ OIF Optical Interoperability Forum
- ❑ OVC Operator Virtual Connection

Student Questions

Acronyms (Cont)

- ❑ PB Provider Bridge
- ❑ PBB-TE Provider Backbone Bridge with Traffic Engineering
- ❑ PBB Provider Backbone Bridge
- ❑ PBBE Provider BackBone Edge
- ❑ PBBN Provider Backbone Network
- ❑ PBEB Provider backbone edge bridges
- ❑ PBN Provider Bridging network
- ❑ PBX Private Branch Exchange
- ❑ PCP Priority Code Point
- ❑ PDH Plesiochronous Digital Hierarchy
- ❑ PE Provider Edge
- ❑ PW Pseudo-Wire
- ❑ PWE3 Pseudo-Wire Emulation Edge-to-Edge
- ❑ QoS Quality of Service
- ❑ S-VID Service (Provider) VLAN ID
- ❑ SA Source Address
- ❑ SDH Synchronous Digital Hierarchy

Student Questions

Acronyms (Cont)

- ❑ SID Service Identifier
- ❑ SLA Service Level Agreement
- ❑ SONET Synchronous optical network
- ❑ TE Traffic Engineering
- ❑ TV Television
- ❑ UCA Use Customer Address (flag)
- ❑ UNI User to Network Interface
- ❑ VID VLAN Identifier
- ❑ VLAN Virtual Local Area Network
- ❑ VoD Video on Demand
- ❑ VoIP Voice over IP
- ❑ VPN Virtual Private Network

Student Questions

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<http://rajjain.com>

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http://www.cse.wustl.edu/~jain/cse5700-25/m_06cee.htm

Related Modules



CSE567M: Computer Systems Analysis (Spring 2013),

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

CSE473S: Introduction to Computer Networks (Fall 2011),

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Video Podcasts of Prof. Raj Jain's Lectures,

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

Student Questions