Carrier Ethernet

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

http://www.cse.wustl.edu/~jain/cse570-18/

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

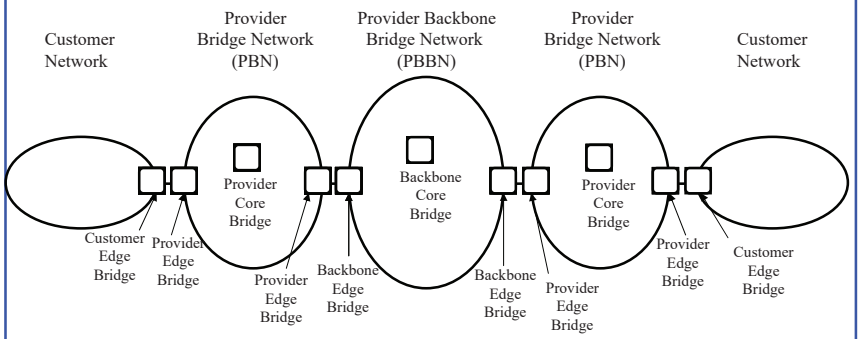
Note: Although these technologies were originally developed for carriers, they are now used inside multi-tenant data centers (clouds)

Enterprise vs. Carrier Ethernet

Enterprise	Carrier
Distance: up to 2km	Up to 100 km
Scale:	
➢ Few K MAC addresses	Millions of MAC Addresses
➢ 4096 VLANs	Millions of VLANs Q-in-Q
Protection: Spanning tree	Rapid spanning tree (Gives 1s, need 50ms)
Path determined by spanning tree	Traffic engineered path
Simple service	SLA
Priority ⇒ Aggregate QoS	Need per-flow QoS
No performance/Error monitoring (OAM)	Need performance/BER

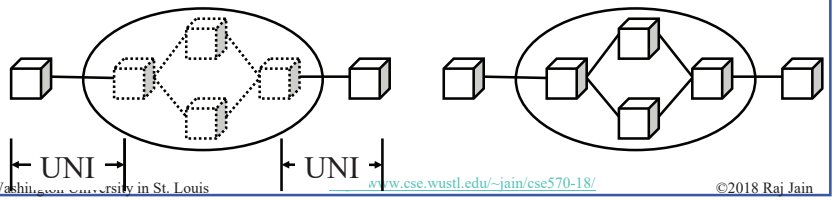
Carriers vs. Enterprise

Network Hierarchy



Issue: UNI vs Peer-to-Peer Signaling

- Two Business Models:
  - Carrier: Overlay or cloud
    - Network is a black-box
    - User-to-network interface (UNI) to create/destroy light paths (in OIF)
  - Enterprise: Peer-to-Peer
    - Complete exchange of information



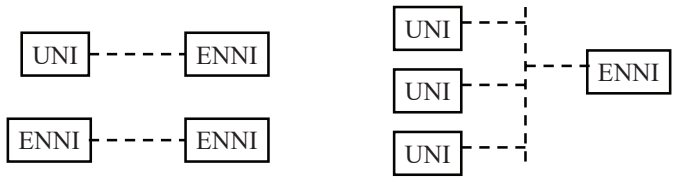
UNI vs. ENNI

- **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 customer's 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

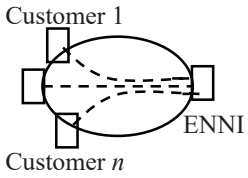
Operator Virtual Connection (OVC)

- 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.



Metro Access Ethernet Private Line

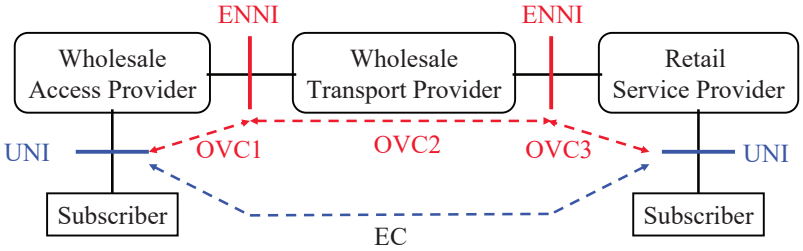
- **Access Ethernet Private Line (Access-EPL)**:
  - Port-based service for Internet access
    Like the service at your home.
  - Ends at your access provider, where many other Access-EPLs may end
  - Access provider has only one interface
    Shared by many Access-EPLs ⇒Different from p2p EPL.



E-Access

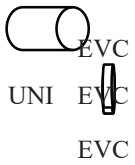
End-to-End Metro Ethernet Connection

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



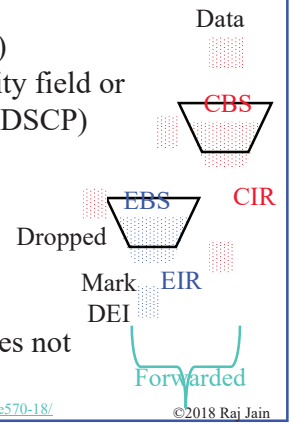
Ethernet Virtual Connections (EVCs)

- **Port-based ECs**: Forwarding not based on VLANs.
  Frames delivered to remote UNI/ENNI for P2P or
  Based on 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 ⇒ No OCs



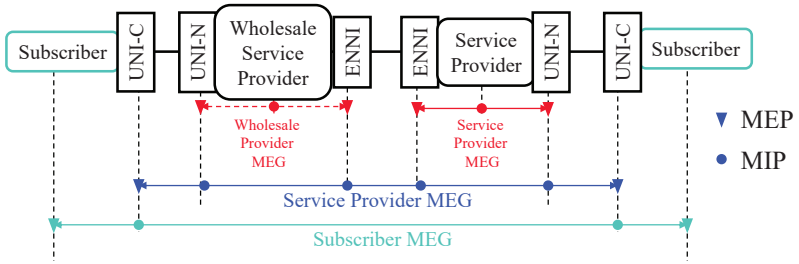
Metro Ethernet Service Attributes

- Bandwidth Profiles: Limits on data dates
  - 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)
- Rate specified by 5 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)



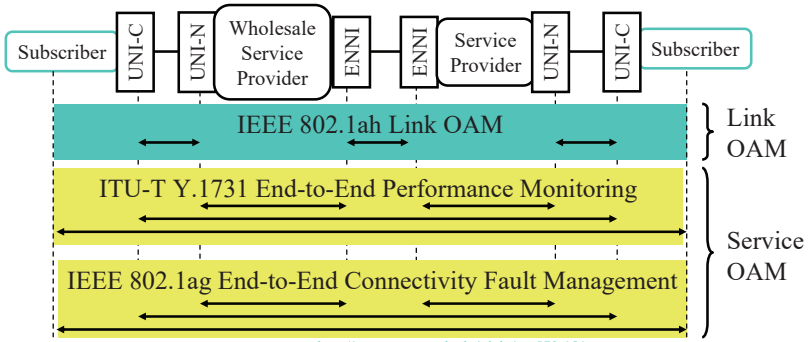
Metro Ethernet OAM

- 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



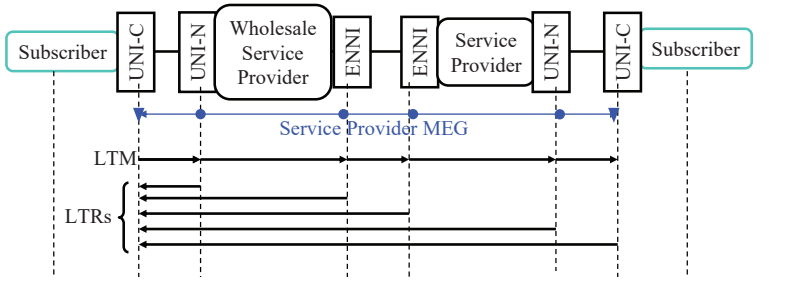
Metro Ethernet OAM (Cont)

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



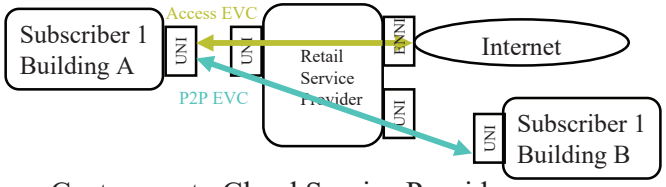
Metro Ethernet OAM Messages

- 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 end point and intermediate point (similar to IP trace route)

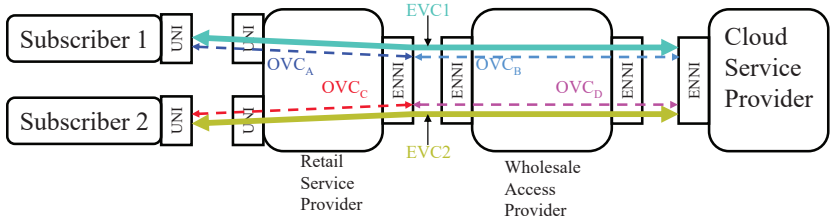


Metro Ethernet Use Cases

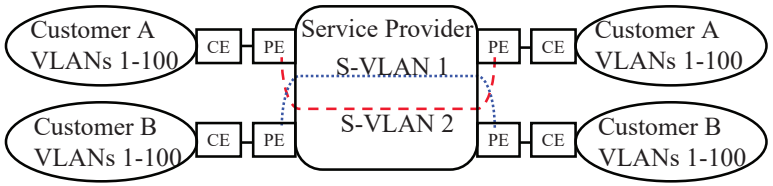
1. Head office to Satellite offices and/or Internet



2. Customers to Cloud Service Provider



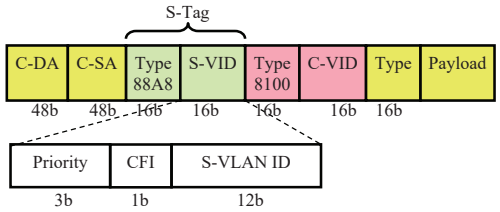
Ethernet Provider Bridge (PB)



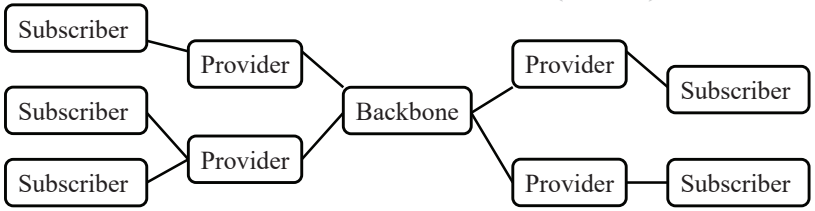
- IEEE 802.1ad-2005 incorporated in IEEE 802.1Q-2011
- Problem: Multiple customers may have the same VLAN ID. How to keep them separate?
- Solutions:
  1. VLAN translation: Change customer VLANs to provider VLANs and back
  2. VLAN Encapsulation: Encapsulate customer frames

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



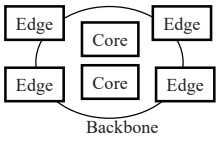
Provider Backbone Network (PBB)

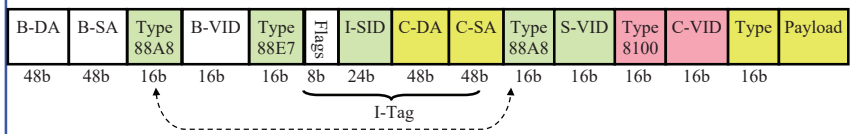


- Problem: Number of MAC addresses passing through backbone bridges is too large for all core bridge to remember Broadcast and flooded (unknown address) frames give unwanted traffic and security issues
- Solution: IEEE 802.1ah-2008 now in 802.1Q-2011
- Add new source/destination MAC addresses pointing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

MAC-in-MAC Frame Format

- Backbone edge bridges (BEB) forward to other BEB's 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



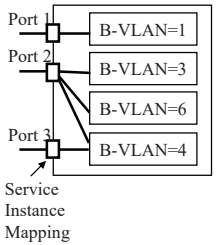


- Core switches forward based on Backbone Destination Bridge Address and Backbone-VLAN ID (60 bits)
  Similar to 802.1ad Q-in-Q. Therefore, same EtherType.

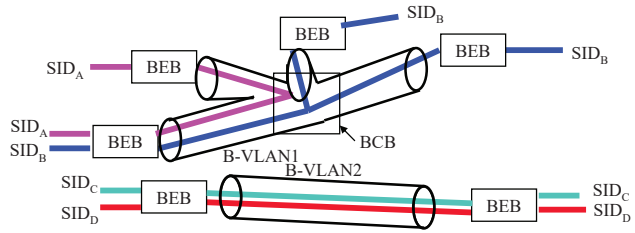
PBB Service Instance

- 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



MAC-in-MAC (Cont)



- Each Backbone VLANs (B-VLAN) can carry multiple services
- 24-bit SID ⇒ 2^{24} Service Instances in the backbone
- I-Tag format: I-Tag not looked at in the core.
  Includes C-DA+C-SA.
  UCA=1 ⇒ 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

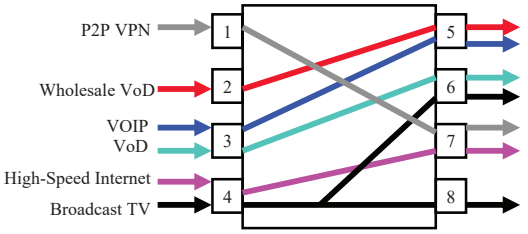
Connection Oriented Ethernet

- 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 bridges addresses
    - Path not determined by customer MAC addresses and other customer fields ⇒ More Secure
  - Reserved bandwidth per EVC
  - Pre-provisioned Protection path ⇒ Better availability

VLAN Cross-Connect

- Cross-connect ⇒ Circuit oriented
- Connection Oriented Ethernet with Q-in-Q
- Forward frames based on VLAN ID and Input port
  ⇒ 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

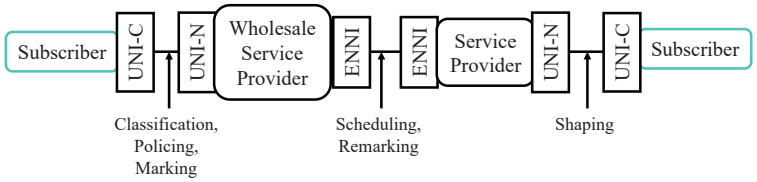


PBB-TE

- Provider Backbone Bridges with Traffic Engineering (PBB-TE)
- IEEE 802.1Qay-2009 now 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 address 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 with MAC-in-MAC. No change.

PBB-TE QoS

- Guarantees QoS ⇒ 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* ⇒ Excess traffic is dropped
  No policing at NNI ports. Only remarking, if necessary.
- Traffic may be marked and remarked at both UNI and NNI



Ethernet Tagged Frame Format Evolution

- Original Ethernet

C-DA	C-SA	Type	Payload

- IEEE 802.1Q VLAN

C-DA	C-SA	Type 8100	C-VID	Type	Payload

- IEEE 802.1ad PB

C-DA	C-SA	Type 88A8	S-VID	Type 8100	C-VID	Type	Payload

- IEEE 802.1ah PBB or 802.1Qay PBB-TE

B-DA	B-SA	Type 88A8	B-VID	Type 88E7	I-SID	C-DA	C-SA	Type 88A8	S-VID	Type 8100	C-VID	Type	Payload

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

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

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

Reading List

- Fujitsu, "Carrier Ethernet Essentials," http://www.fujitsu.com/downloads/TEL/fnc/whitepapers/CarrierEthernetEssentials.pdf (must read)
- 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)

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

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

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

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

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

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

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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

Wireless and Mobile Networking (Spring 2016),
https://www.youtube.com/playlist?list=PLjGG94etKypKeb0nzyN9tSs_HCd5c4wXF

CSE571S: Network Security (Fall 2011),
https://www.youtube.com/playlist?list=PLjGG94etKypKvzfVtutHcPFJXumyyg93u

Video Podcasts of Prof. Raj Jain's Lectures,
https://www.youtube.com/user/ProfRajJain/playlists