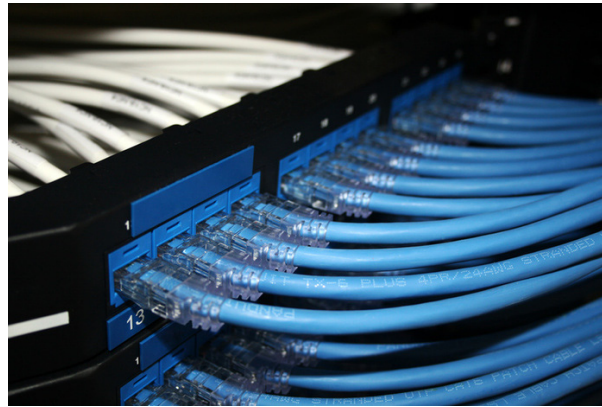


Data Center Ethernet



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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. Residential vs. Data Center Ethernet
2. Review of Ethernet Addresses, devices, speeds, algorithms
3. Enhancements to Spanning Tree Protocol
4. Virtual LANs
5. Data Center Bridging Extensions

Quiz: True or False?

Which of the following statements are generally true?

T F

- Ethernet is a local area network (Local \leq 2km)
- Token ring, Token Bus, and CSMA/CD are the three most common LAN access methods.
- Ethernet uses CSMA/CD.
- Ethernet bridges use spanning tree for packet forwarding.
- Ethernet frames are 1518 bytes.
- Ethernet does not provide any delay guarantees.
- Ethernet has no congestion control.
- Ethernet has strict priorities.

Residential vs. Data Center Ethernet

Residential	Data Center
<input type="checkbox"/> Distance: up to 200m	<input type="checkbox"/> No limit
<input type="checkbox"/> Scale: <ul style="list-style-type: none">➤ Few MAC addresses➤ 4096 VLANs	<input type="checkbox"/> Millions of MAC Addresses <input type="checkbox"/> Millions of VLANs Q-in-Q
<input type="checkbox"/> Protection: Spanning tree	<input type="checkbox"/> Rapid spanning tree, ... (Gives 1s, need 50ms)
<input type="checkbox"/> Path determined by spanning tree	<input type="checkbox"/> Traffic engineered path
<input type="checkbox"/> Simple service	<input type="checkbox"/> Service Level Agreement. Rate Control.
<input type="checkbox"/> Priority ⇒ Aggregate QoS	<input type="checkbox"/> Need per-flow/per-class QoS
<input type="checkbox"/> No performance/Error monitoring (OAM)	<input type="checkbox"/> Need performance/BER

IEEE 802 Address Format

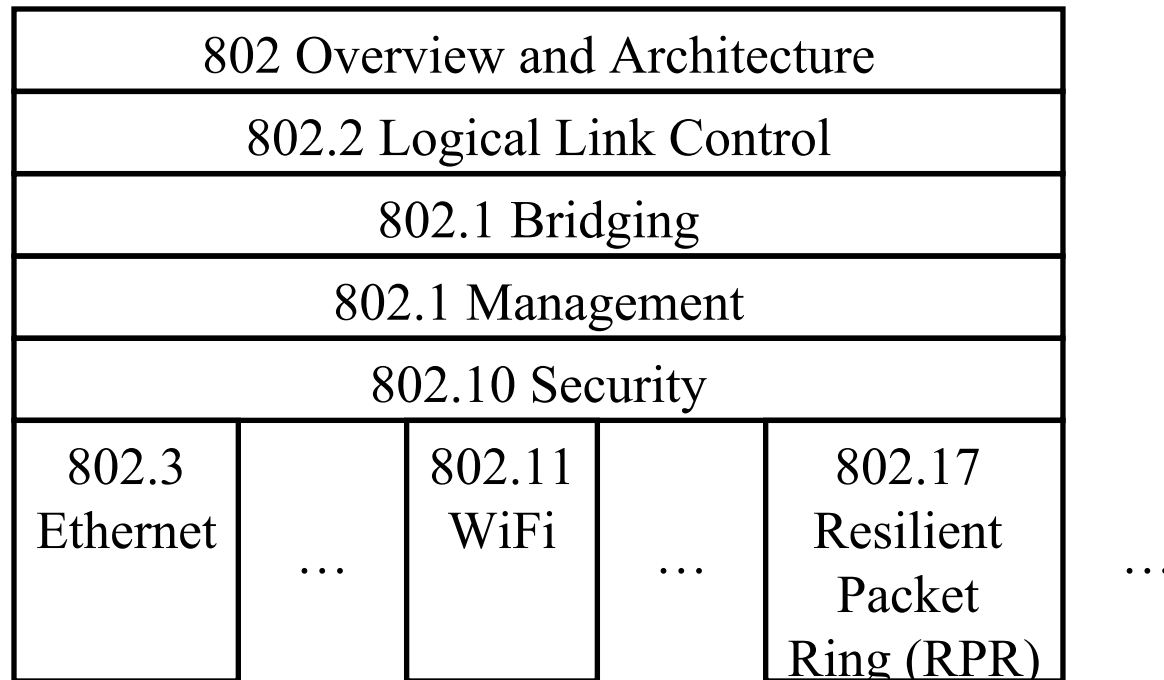
- 48-bit: 1000 0000 : 0000 0001 : 0100 0011
 : 0000 0000 : 1000 0000 : 0000 1100
 = 80:01:43:00:80:0C

Organizationally Unique Identifier (OUI)		24 bits assigned by OUI Owner
Individual/Group	Universal/Local	
1	1	22
		24

- Multicast = “To all bridges on this LAN”
- Broadcast = “To all stations” (Note: Local bit is set)
 = 111111...111 = FF:FF:FF:FF:FF:FF

IEEE Standards Numbering System

- IEEE 802.* and IEEE 802.1* standards (e.g., IEEE 802.1Q-2011) apply to all IEEE 802 technologies:
 - IEEE 802.3 Ethernet
 - IEEE 802.11 WiFi
 - IEEE 802.16 WiMAX



IEEE Standards Numbering (Cont)

- ❑ IEEE 802.3* standards apply only to Ethernet, e.g., IEEE802.3ba-2010
- ❑ Standards with all upper case letters are base standards
E.g., IEEE 802.1AB-2009
- ❑ Standards with lower case are additions/extensions/revisions.
Merged with the base standard in its next revision.
e.g., IEEE 802.1w-2001 was merged with IEEE 802.1D-2004
- ❑ Standards used to be numbered, sequentially, e.g., IEEE 802.1a, ..., 802.1z, 802.1aa, 802.1ab, ...
- ❑ Recently they started showing base standards in the additions, e.g., IEEE 802.1Qau-2010

Names, IDs, Locators



Name: John Smith

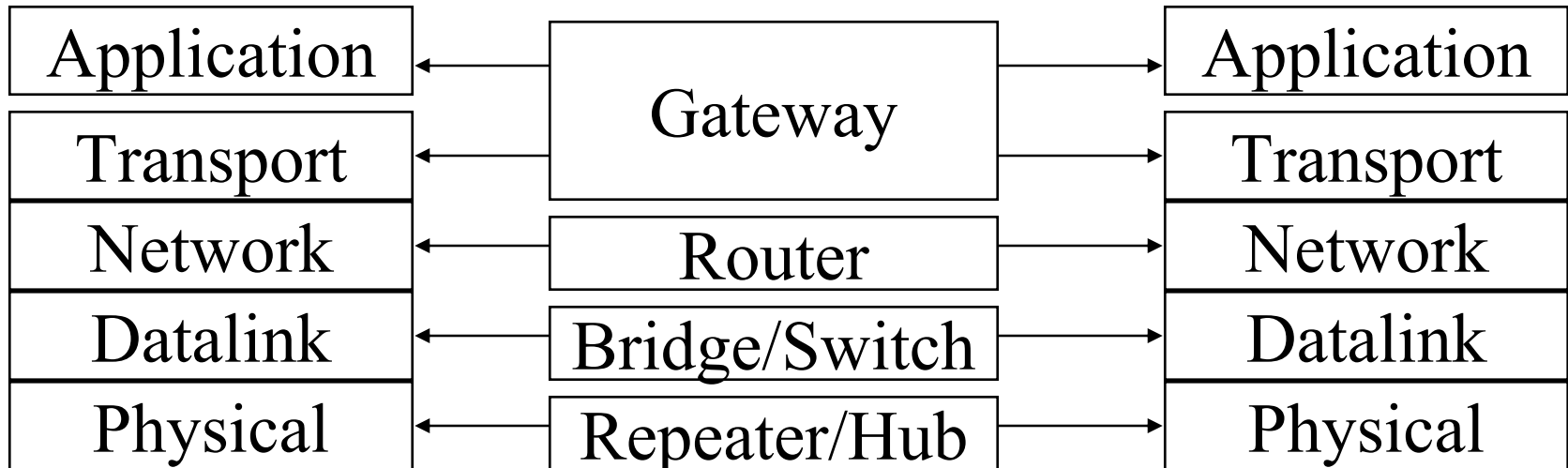
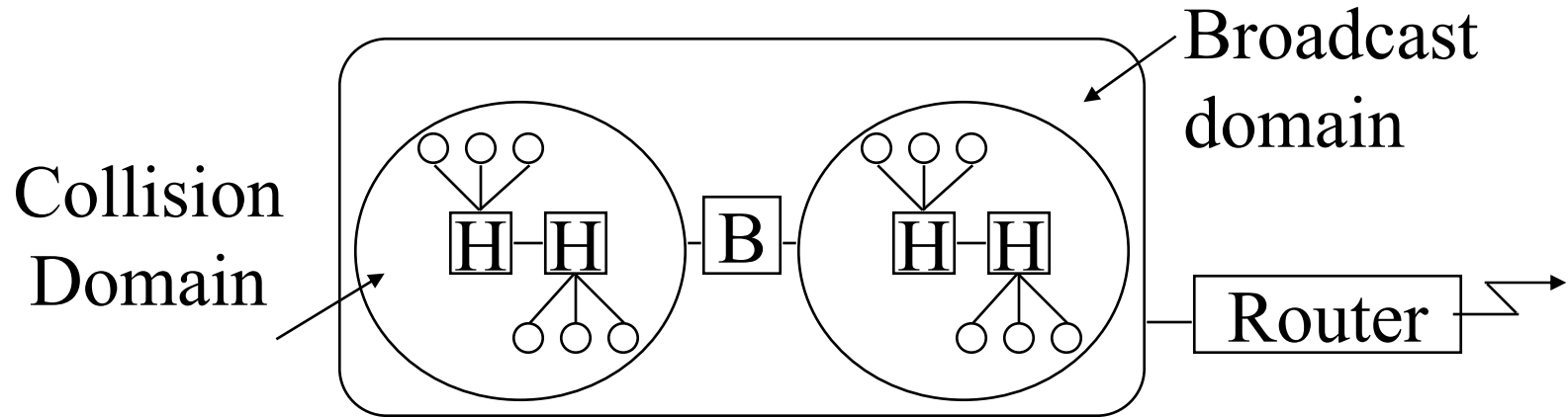
ID: 012-34-5678

Locator:

1234 Main Street
Big City, MO 12345
USA

- ❑ Locator changes as you move, ID and Names remain the same.
- ❑ **Examples:**
 - Names: Company names, DNS names (Microsoft.com)
 - IDs: Cell phone numbers, 800-numbers, Ethernet addresses, Skype ID, VOIP Phone number
 - Locators: Wired phone numbers, IP addresses

Interconnection Devices



Interconnection Devices (Cont)

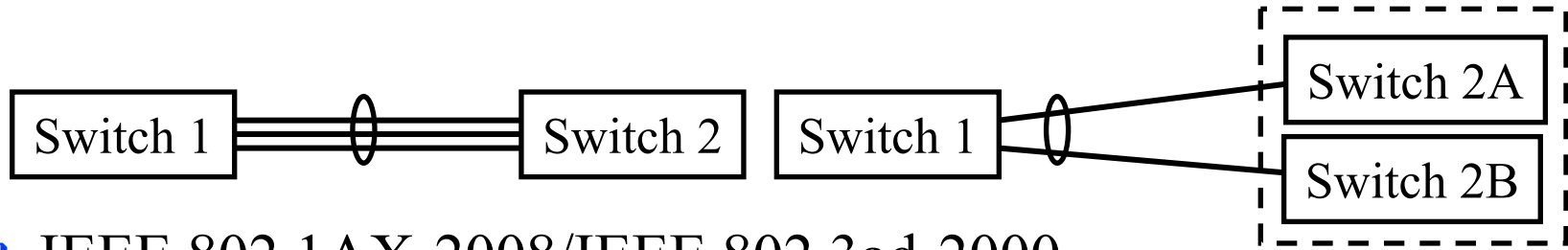
- ❑ **Repeater**: PHY device that restores data and collision signals
- ❑ **Hub**: Multiport repeater + fault detection and recovery
- ❑ **Bridge**: Datalink layer device connecting two or more collision domains. MAC multicasts are propagated throughout the LAN.
- ❑ **Router**: Network layer device. IP, IPX, AppleTalk.
Does not propagate MAC multicasts.
- ❑ **Switch**: Multiport bridge with parallel paths
- ❑ These are functions. Packaging varies.

Ethernet Speeds

- ❑ IEEE 802.3ba-2010 (40G/100G) standard
- ❑ 10Mbps, 100 Mbps, 1 Gbps versions have both CSMA/CD and Full-duplex versions
- ❑ No CSMA/CD in 10G and up
- ❑ No CSMA/CD in practice now even at home or at 10 Mbps
- ❑ 1 Gbps in residential, enterprise offices
- ❑ 1 Gbps in Data centers, moving to 10 Gbps and 40 Gbps
- ❑ 100G in some carrier core networks
100G is still more expensive than $10 \times 10G$
- ❑ Note: only decimal **bit** rates are used in networking
No cheating like binary byte values used in storage
 $1 \text{ Gbps} = 10^9 \text{ b/s}$, Buy 256 GB Disk = 238.4 GB storage

Ref: http://en.wikipedia.org/wiki/100_Gigabit_Ethernet

Link Aggregation Control Protocol (LACP)

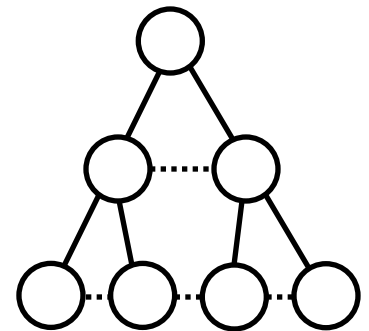
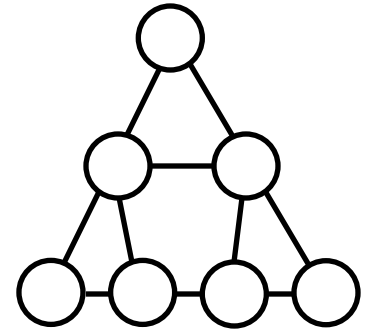


- ❑ IEEE 802.1AX-2008/IEEE 802.3ad-2000
- ❑ Allows several parallel links to be combined as one link
 $3 \times 1\text{Gbps} = 3\text{ Gbps}$
- ❑ Allows any speed links to be formed
- ❑ Allows fault tolerance
 \Rightarrow Combined Link remains connected even if one of the member links fails
- ❑ Several proprietary extensions. E.g., aggregate links to two switches which act as one switch.

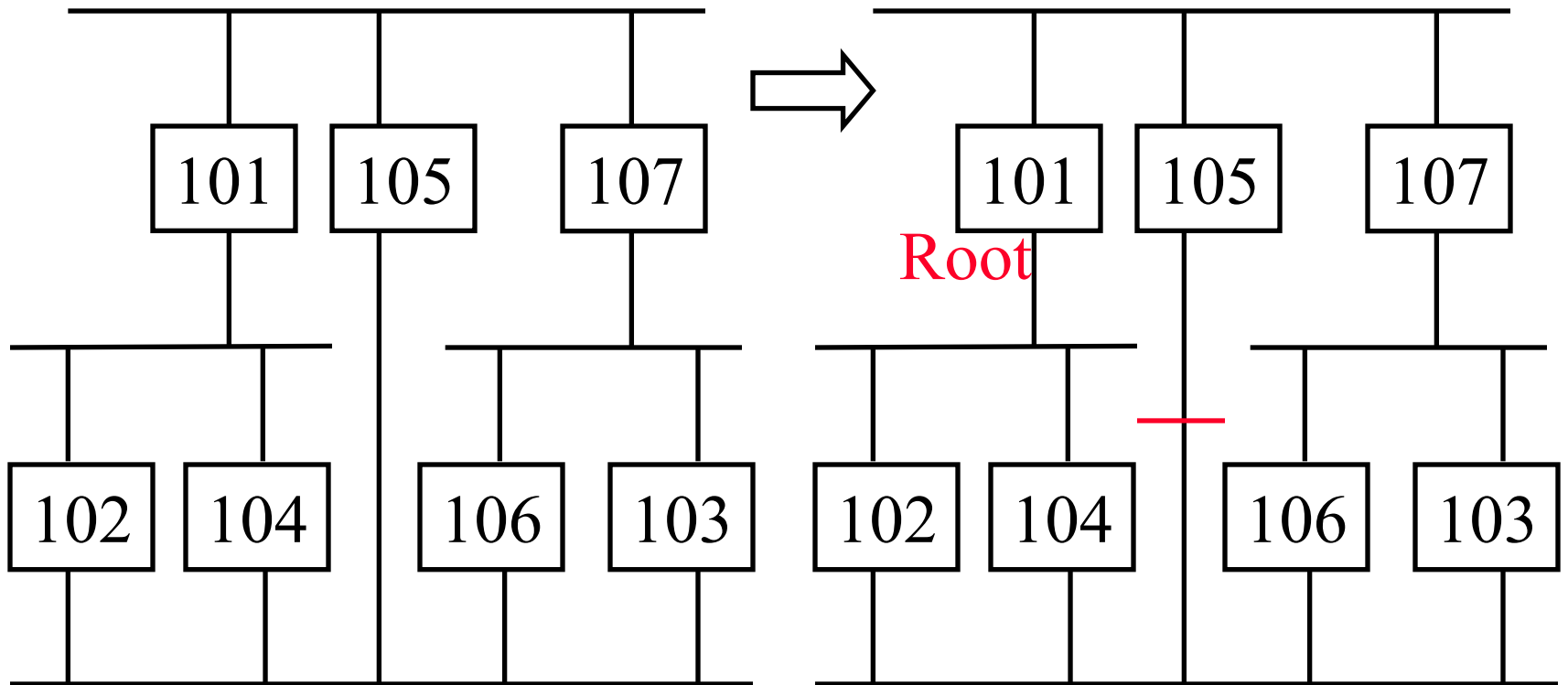
Ref: Enterasys, "Enterasys Design Center Networking – Connectivity and Topology Design Guide," 2013,
<http://www.enterasys.com/company/literature/datacenter-design-guide-wp.pdf>

Spanning Tree Algorithm

- ❑ Helps form a tree out of a mesh topology
- ❑ All bridges multicast to “All bridges”
 - My ID. 64-bit ID = 16-bit priority + 48-bit MAC address.
 - Root ID
 - My cost to root
- ❑ The bridges update their info using Dijkstra’s algorithm and rebroadcast
- ❑ Initially all bridges are roots but eventually converge to one root as they find out the lowest Bridge ID.
- ❑ On each LAN, the bridge with minimum cost to the root becomes the Designated bridge
- ❑ All ports of all non-designated bridges are blocked.



Spanning Tree Example



Ref: Cisco, "Understanding Spanning-Tree Protocol Topology Changes,"

http://www.cisco.com/en/US/tech/tk389/tk621/technologies_tech_note09186a0080094797.shtml

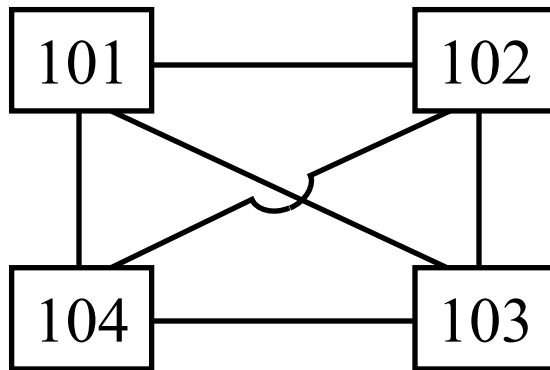
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Homework 4

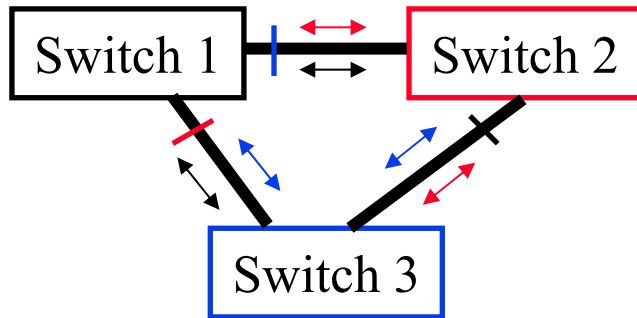
- Which links in the following diagram will be blocked by spanning tree? Justify your answer.



Enhancements to STP

- ❑ A topology change can result in 1 minute of traffic loss with STP \Rightarrow All TCP connections break
- ❑ Rapid Spanning Tree Protocol (RSTP)
IEEE 802.1w-2001 incorporated in IEEE 802.1D-2004
- ❑ One tree for all VLANs \Rightarrow Common spanning tree
- ❑ Many trees \Rightarrow Multiple spanning tree (MST) protocol
IEEE 802.1s-2002 incorporated in IEEE 802.1Q-2005
- ❑ One or more VLANs per tree.

MSTP (Multiple Spanning Tree)



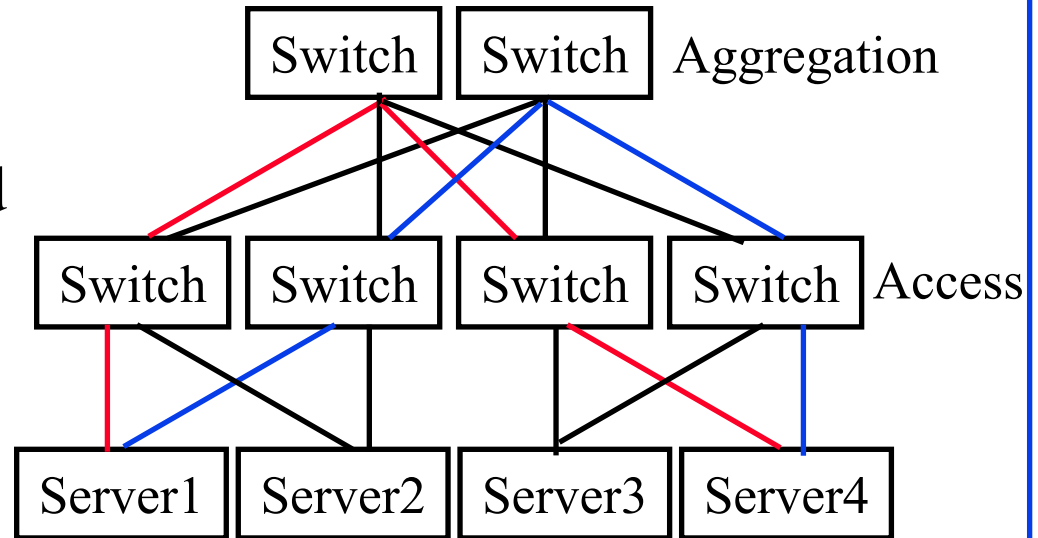
- ❑ MSTP (Multiple STP)
IEEE 802.1s-2002 incorporated in IEEE 802.1Q-2005
- ❑ Each tree serves a group of VLANs.
- ❑ A bridge port could be in forwarding state for some VLANs and blocked state for others.

IS-IS Protocol

- ❑ Intermediate System to Intermediate System (IS-IS) is a protocol to build routing tables. Link-State routing protocol => Each nodes sends its connectivity (link state) information to all nodes in the network
- ❑ Dijkstra's algorithm is then used by each node to build its routing table.
- ❑ Similar to OSPF (Open Shortest Path First).
- ❑ OSPF is designed for IPv4 and then extended for IPv6. IS-IS is general enough to be used with any type of addresses
- ❑ OSPF is designed to run on the top of IP IS-IS is general enough to be used on any transport
⇒ Adopted by Ethernet

Shortest Path Bridging

- ❑ IEEE 802.1aq-2012 (later incorporated in 802.1Q-2014)
- ❑ Allows all links to be used \Rightarrow Better CapEx
- ❑ IS-IS link state protocol (similar to OSPF) is used to build shortest path trees for each node to every other node within the SPB domain
- ❑ Equal-cost multi-path (ECMP) used to distribute load



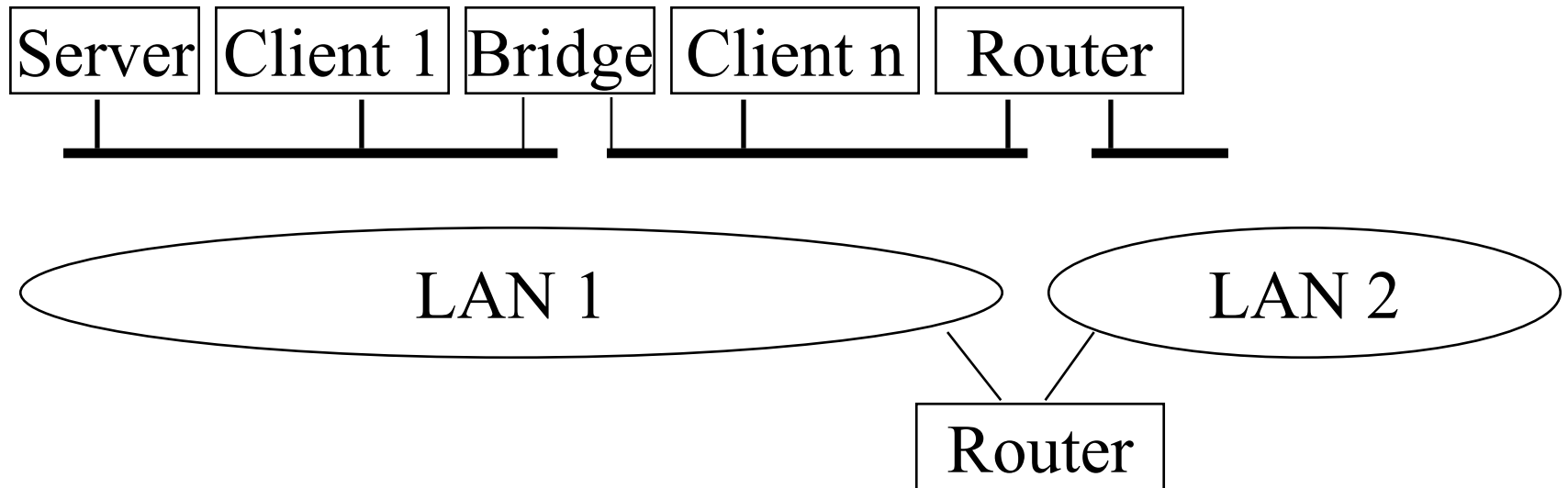
Ref: http://en.wikipedia.org/wiki/Shortest_Path_Bridging

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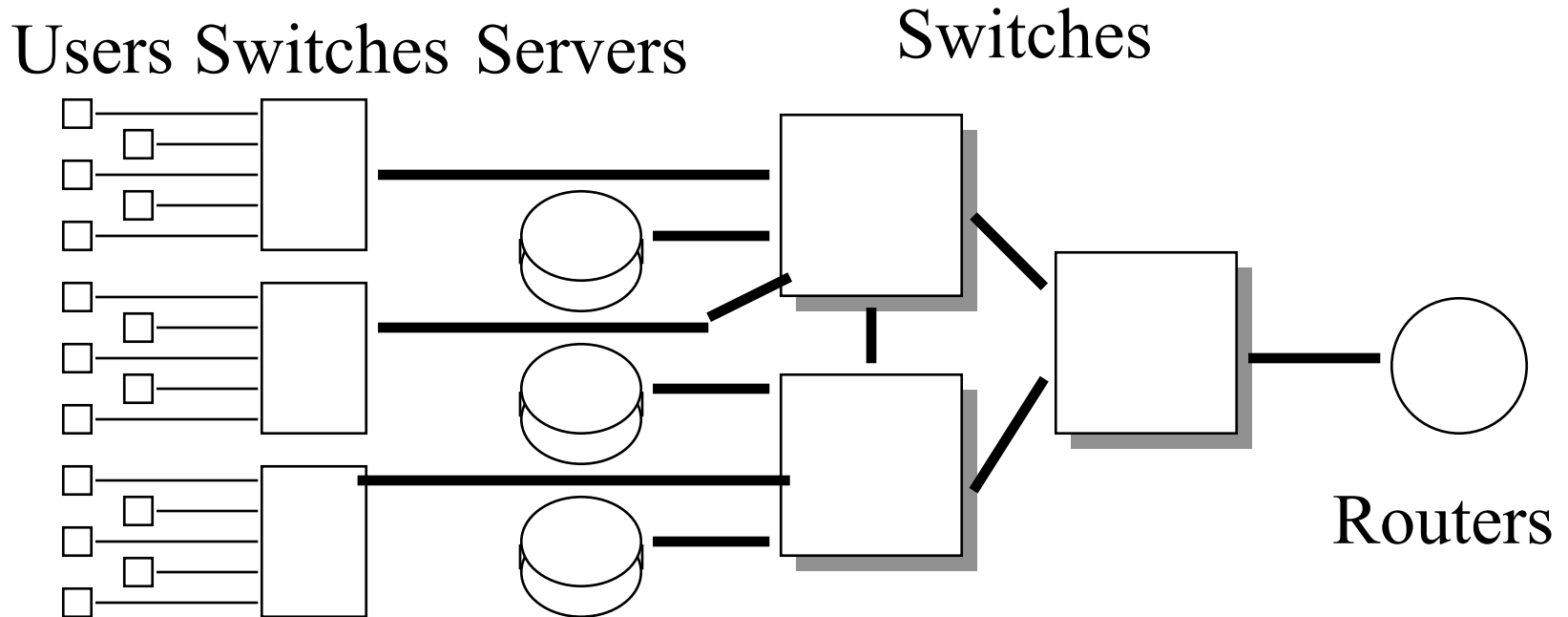
What is a LAN?



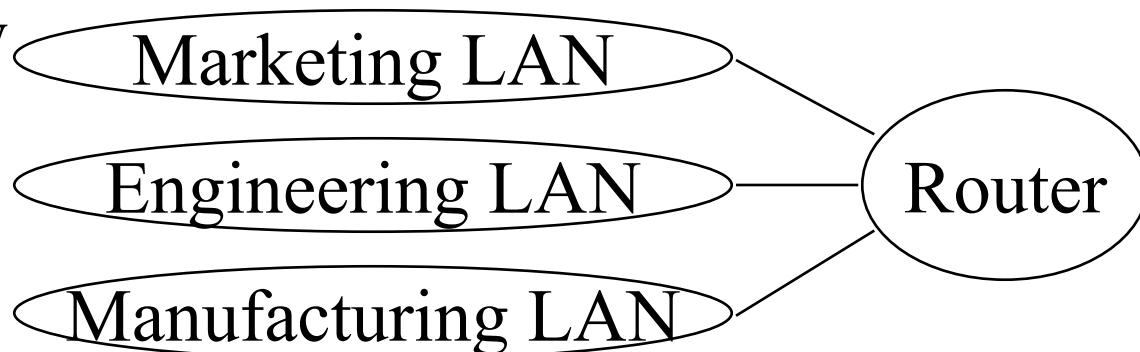
- ❑ LAN = Single broadcast domain = Subnet
- ❑ No routing between members of a LAN
- ❑ Routing required between LANs

What is a Virtual LAN

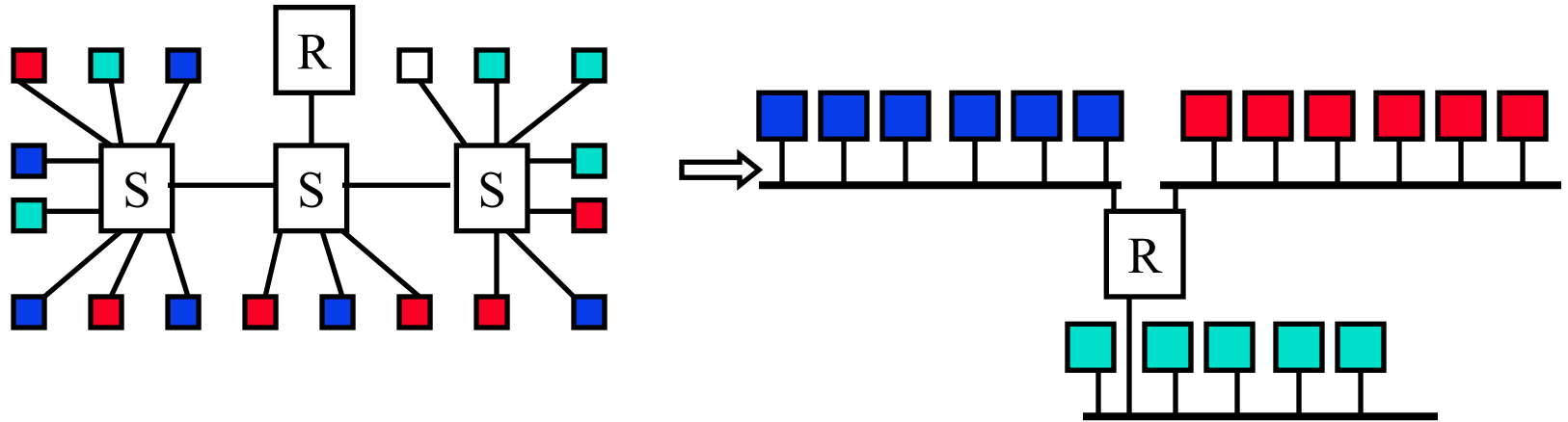
Physical View



Logical View



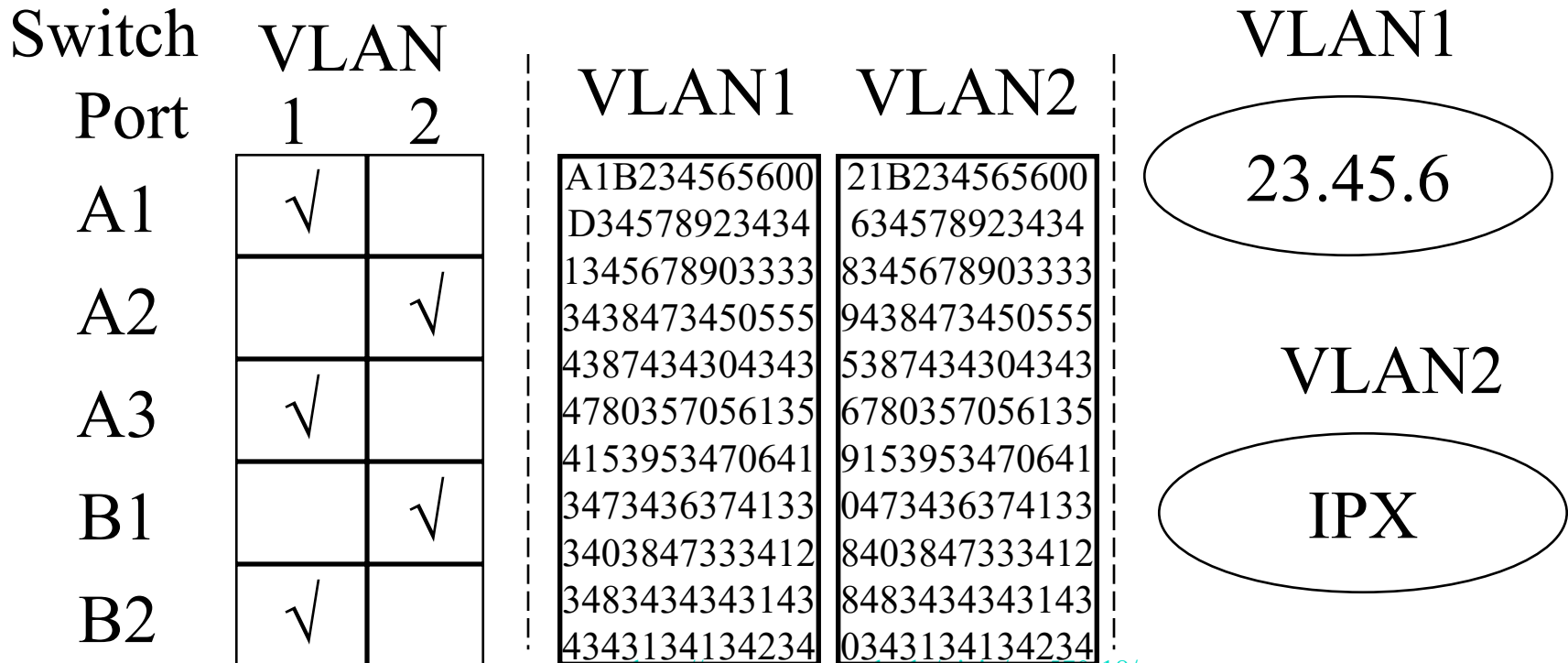
Virtual LAN



- ❑ Virtual LAN = Broadcasts and multicast goes only to the nodes in the virtual LAN
- ❑ LAN membership defined by the network manager
⇒ Virtual

Types of Virtual LANs

- ❑ Layer-1 VLAN = Group of Physical ports
- ❑ Layer-2 VLAN = Group of MAC addresses
- ❑ Layer-3 VLAN = IP subnet



IEEE 802.1Q-2011 Tag

- ❑ Tag Protocol Identifier (TPI)
- ❑ Priority Code Point (PCP): 3 bits = 8 priorities 0..7 (High)
- ❑ Canonical Format Indicator (CFI): 0 \Rightarrow Standard Ethernet, 1 \Rightarrow IBM Token Ring format (non-canonical or non-standard)
- ❑ CFI now replaced by Drop Eligibility Indicator (DEI)
- ❑ VLAN Identifier (12 bits \Rightarrow 4095 VLANs)
- ❑ Switches forward based on MAC address + VLAN ID
Unknown addresses are flooded.

Untagged
Frame



32b IEEE 802.1Q-2011 Header

Tagged
Frame



Ref: Canonical vs. MSB Addresses, <http://support.lexmark.com/index?page=content&id=HO1299>
Ref: G. Santana, "Data Center Virtualization Fundamentals," Cisco Press, 2014, ISBN:1587143240
Washington University in St. Louis <http://www.cse.wustl.edu/~jain/cse570-18/>

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Link Layer Discovery Protocol (LLDP)

- ❑ IEEE 802.1AB-2009
- ❑ Neighbor discovery by periodic advertisements
- ❑ Every minute a LLC frame is sent on every port to neighbors
- ❑ LLDP frame contains information in the form of Type-Length-Value (TLV)
- ❑ Types: My Chassis ID, My Port ID, Time-to-live, Port description (Manufacturer, product name, version), Administratively assigned system name, capabilities, MAC address, IP Address, Power-via-MDI, Link aggregation, maximum frame size, ...



Ref: M. Srinivasan, "Tutorial on LLDP," http://www.eetimes.com/document.asp?doc_id=1272069

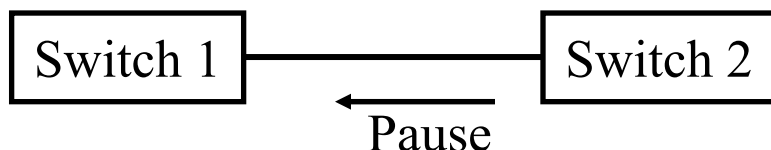
Ref: http://en.wikipedia.org/wiki/Link_Layer_Discovery_Protocol

Data Center Bridging

- ❑ Goal: To enable storage traffic over Ethernet
- ❑ Four Standards:
 - Priority-based Flow Control (IEEE 802.1Qbb-2011)
 - Enhanced Transmission Selection (IEEE 802.1Qaz-2011)
 - Congestion Control (IEEE 802.1Qau-2010)
 - Data Center Bridging Exchange (IEEE 802.1Qaz-2011)
- ❑ All of these are now incorporated in IEEE 802.1Q-2014

Ref: M. Hagen, "Data Center Bridging Tutorial," <http://www.iol.unh.edu/services/testing/dcb/training/DCB-Tutorial.pdf>

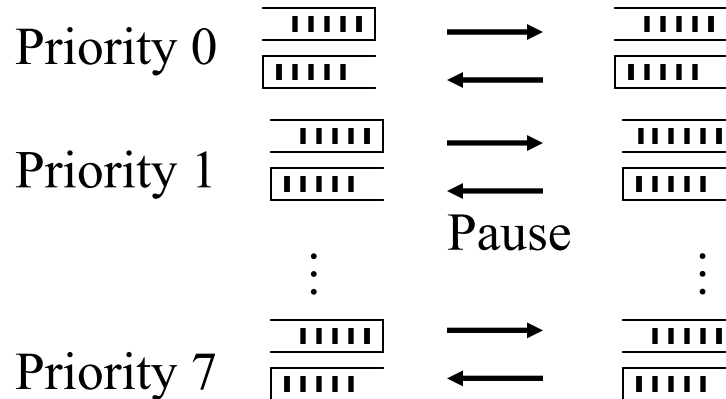
Ethernet Flow Control: Pause Frame



- ❑ Defined in IEEE 802.3x-1997. A form of on-off flow control.
- ❑ A receiving switch can stop the adjoining sending switch by sending a “Pause” frame.
Stops the sender from sending any further information for a time specified in the pause frame.
- ❑ The frame is addressed to a standard (well-known) multicast address. This address is acted upon but not forwarded.
- ❑ Stops all traffic. Causes congestion backup.

Ref: http://en.wikipedia.org/wiki/Ethernet_flow_control

Priority-based Flow Control (PFC)



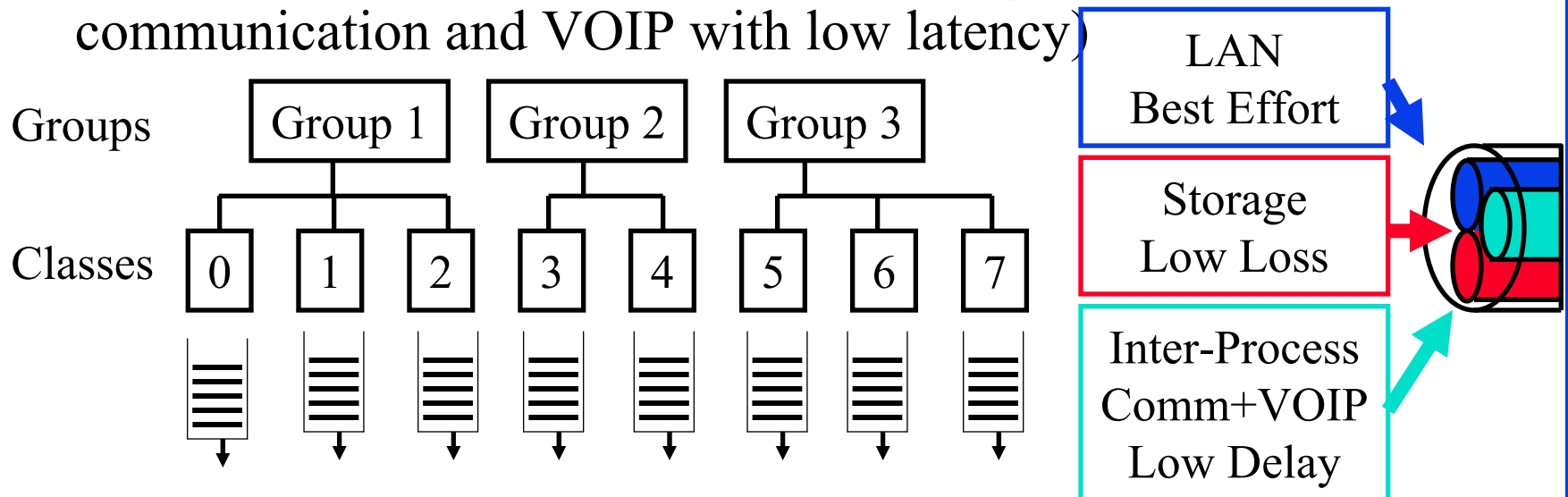
- ❑ IEEE 802.1Qbb-2011
- ❑ IEEE 802.1Qbb-2011 allows any single priority to be stopped. Others keep sending

Ref: J. L. White, "Technical Overview of Data Center Networks," SNIA, 2013,

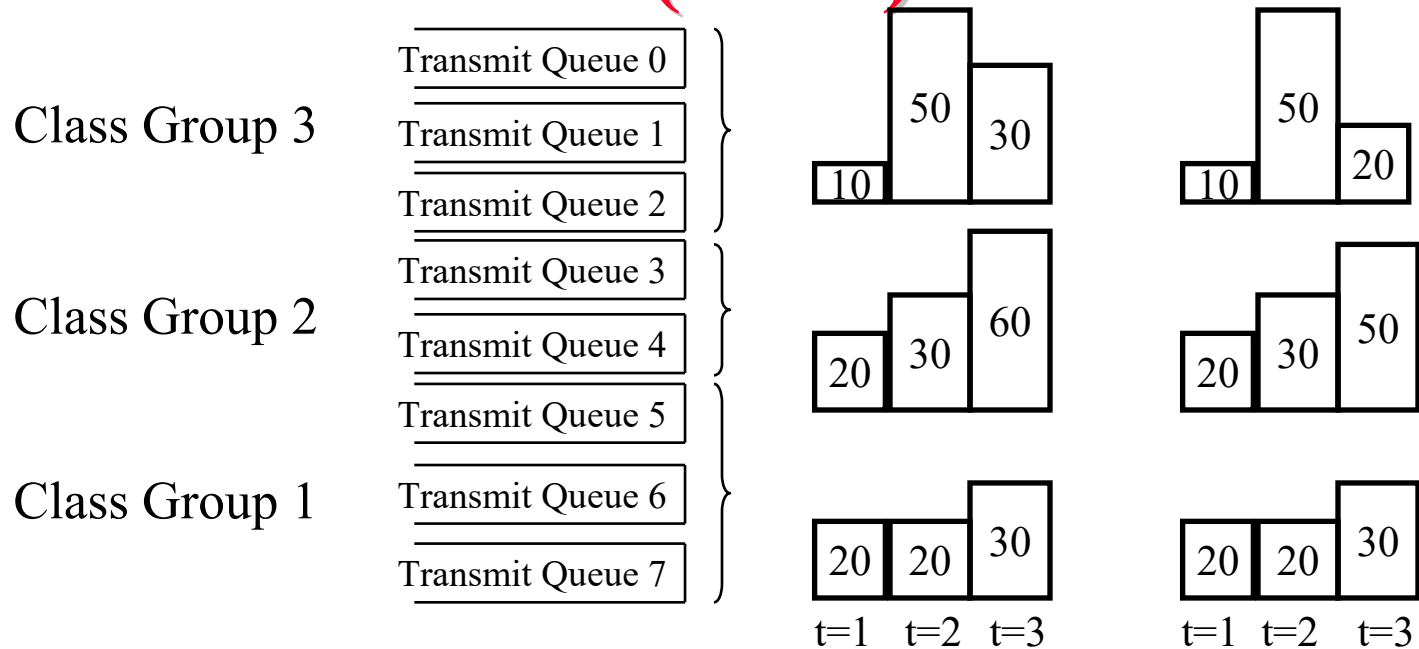
http://www.snia.org/sites/default/education/tutorials/2012/fall/networking/JosephWhite_Technical%20Overview%20of%20Data%20Center%20Networks.pdf

Enhanced Transmission Selection

- ❑ IEEE 802.1Qaz-2011
- ❑ Goal: Guarantee bandwidth for applications sharing a link
- ❑ Traffic is divided in to 8 classes (not priorities)
- ❑ The classes are grouped.
- ❑ Standard requires min 3 groups: 1 with PFC (Storage with low loss), 1 W/O PFC (LAN), 1 Strict Priority (Inter-process communication and VOIP with low latency)



ETS (Cont)



- ❑ Bandwidth allocated per class group in 1% increment but 10% precision ($\pm 10\%$ error).
- ❑ Max 75% allocated \Rightarrow Min 25% best effort
- ❑ Fairness within a group
- ❑ All unused bandwidth is available to all classes wanting more bandwidth. Allocation algorithm **not** defined.
- ❑ Example: Group 1=20%, Group 2=30%

A ETS Fairness Example

- ❑ **Max-Min Fairness:** Giving more to any one should not require decreasing to someone with less allocation (Help the poorest first)
- ❑ **Example:** In a 3-class group bridge, Groups 1 and 2 have a minimum guaranteed bandwidth of 20% and 30%, respectively.
In a particular time slot, the traffic demands for group 1, 2, and 3 are 30%, 60%, 30%, respectively. How much should each group get?
- ❑ Iteration 1: Group 1 = 20, Group 2 = 30,
Unallocated = 50, Unsatisfied groups = 3
Fair allocation of unallocated bandwidth = $50/3$ per group
- ❑ Iteration 2: Group 1 = $20+10$ (can't use more), Group 2 = $30+50/3$,
Group 3 = $50/3$
Total Used = $280/3$, Unallocated = $20/3$, Unsatisfied groups = 2,
Fair share of unallocated bandwidth = $10/3$ per group
- ❑ Iteration 3: Group 1 = 30, Group 2 = $30+50/3+10/3$,
Group 3 = $50/3+10/3$
Total Used = 100, Unallocated = 0 \Rightarrow Done.

Tabular Method for Max-Min Fairness

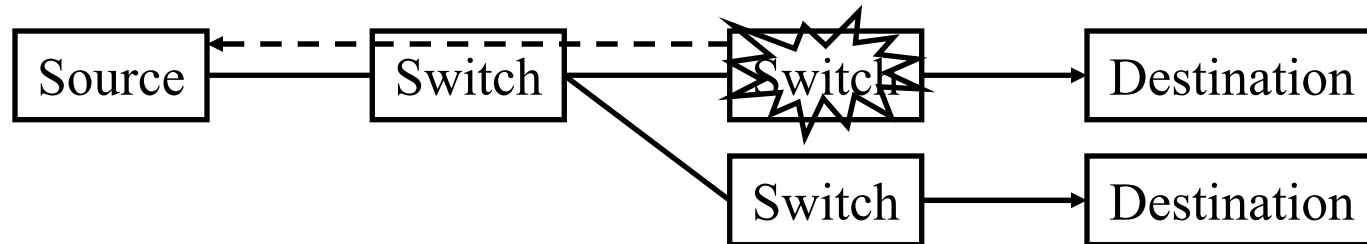
Iteration		1	2	3	Total	Unused	# Unsatisfied
	Demand	30	60	30	120		
1	Guaranteed Allocation	20	30	0	50	50	
	Total Used	20	30	0	50	50	3
2	Additional Allocation	16.7	16.7	16.7			
	Total Used	30	46.7	16.7	93.3	6.7	2
3	Additional Allocation	0	3.3	3.3			
	Total Used	30	50	20	100	0	2

- ❑ Iterations end when either unused capacity or # of unsatisfied groups is zero.

Homework 4B

- What would be max-min allocation for a 4 group system in which group 1 through 3 are guaranteed 10%, 20%, and 30% respectively. The demands on a 100 Gbps system are 1 Gbps, 4Gbps, and 35 Gbps, and 70 Gbps.

Quantized Congestion Notification (QCN)

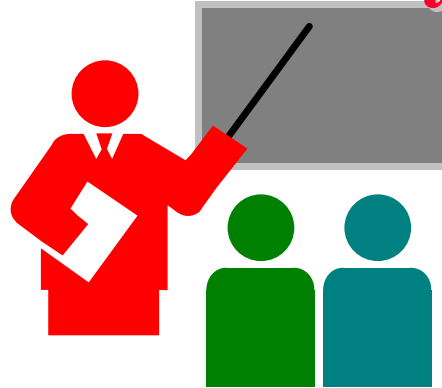


- ❑ IEEE 802.1Qau-2010 Dynamic Congestion Notification
- ❑ A source quench message is sent by the congested switch direct to the source. The source reduces its rate for that flow.
- ❑ Sources need to keep per-flow states and control mechanisms
- ❑ Easy for switch manufacturers but complex for hosts.
Implemented in switches but not in hosts \Rightarrow Not effective.
- ❑ The source may be a router in a subnet and not the real source
 \Rightarrow Router will drop the traffic. QCN does not help in this case.

DCBX

- ❑ Data Center Bridging eXchange, IEEE 802.1Qaz-2011
- ❑ Uses LLDP to negotiate quality metrics and capabilities for Priority-based Flow Control, Enhanced Transmission Selection, and Quantized Congestion Notification
- ❑ New TLV's
 - Priority group definition
 - Group bandwidth allocation
 - PFC enablement per priority
 - QCN enablement
 - DCB protocol profiles
 - FCoE and iSCSI profiles

Summary



1. Ethernet's use of IDs as addresses makes it very easy to move systems in the data center \Rightarrow Keep traffic on the same Ethernet
2. Spanning tree is wasteful of resources and slow.
Ethernet now uses shortest path bridging (similar to OSPF)
3. VLANs allow different non-trusting entities to share an Ethernet network
4. Data center bridging extensions reduce the packet loss by enhanced transmission selection and Priority-based flow control

List of Acronyms

- ❑ BER Bit Error Rate
- ❑ BPDU Bridge Protocol Data Unit
- ❑ CD Collision Detection
- ❑ CFI Canonical Format Indicator
- ❑ CRC Cyclic Redundancy Check
- ❑ CSMA Carrier Sense Multiple Access with Collision Detection
- ❑ DA Destination Address
- ❑ DCB Data Center Bridging
- ❑ DCBX Data Center Bridging eXtension
- ❑ DEI Drop Eligibility Indicator
- ❑ DNS Domain Name System
- ❑ ECMP Equal-cost multi-path
- ❑ ETS Enhanced Transmission Selection
- ❑ GB Giga Byte

List of Acronyms (Cont)

- ❑ ID Identifier
- ❑ IP Internet Protocol
- ❑ IEEE Institution of Electrical and Electronics Engineers
- ❑ IS-IS Intermediate System to Intermediate System
- ❑ iSCSI Internet Small Computer System Interface
- ❑ LACP Link Aggregation Control Protocol
- ❑ LAN Local Area Network
- ❑ LLC Logical Link Control
- ❑ LLDP Link Layer Discovery Protocol
- ❑ MAC Media Access Control
- ❑ MDI Medium Dependent Interface
- ❑ MSB Most significant byte first
- ❑ MST Multiple Spanning Tree
- ❑ MSTP Multiple Spanning Tree Protocol
- ❑ OAM Operations, Administration, and Management

List of Acronyms (Cont)

- ❑ OSPF Open Shortest Path First
- ❑ OUI Organizationally Unique Identifier
- ❑ PCP Priority Code Point
- ❑ PFC Priority-based Flow Control
- ❑ PHY Physical layer
- ❑ QCN Quantized Congestion Notification
- ❑ QoS Quality of Service
- ❑ RSTP Rapid Spanning Tree Protocol
- ❑ SA Source Address
- ❑ SNIA Storage Networking Industries Association
- ❑ SPB Shortest Path Bridging
- ❑ STP Spanning Tree Protocol
- ❑ TCP Transmission Control Protocol
- ❑ TLV Type-Length-Value
- ❑ TPI Tag Protocol Identifier
- ❑ VLAN Virtual Local Area Network
- ❑ VM Virtual machine

List of Acronyms (Cont)

- ❑ VOIP Voice over IP
- ❑ WAN Wide Area Network
- ❑ WiFi Wireless Fidelity
- ❑ WiMAX Wireless Interoperability for Microwave Access

Reading List

- ❑ G. Santana, “Data Center Virtualization Fundamentals,” Cisco Press, 2014, ISBN:1587143240
- ❑ Enterasys, “Enterasys Design Center Networking - Connectivity and Topology Design Guide,” 2013,
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- ❑ Cisco, “Understanding Spanning-Tree Protocol Topology Changes,”
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- ❑ Cisco, Understanding Rapid Spanning Tree Protocol (802.1w),
http://www.cisco.com/en/US/tech/tk389/tk621/technologies_white_paper09186a0080094cfa.shtml
- ❑ Canonical vs. MSB Addresses,
<http://support.lexmark.com/index?page=3Dcontent&id=3DHO1299>

Reading List (Cont)

- ❑ M. Hagen, “Data Center Bridging Tutorial,”
<http://www.iol.unh.edu/services/testing/dcb/training/DCB-Tutorial.pdf>
- ❑ J. L. White, “Technical Overview of Data Center Networks,” SNIA, 2013,
http://www.snia.org/sites/default/education/tutorials/2012/fall/networking/JosephWhite_Technical%20Overview%20of%20Data%20Center%20Networks.pdf
- ❑ I. Pepelnjak, “DCB Congestion Notification (802.1Qau),”
<http://blog.ipSPACE.net/2010/11/data-center-bridging-dcb-congestion.html>

Wikipedia Links

- ❑ http://en.wikipedia.org/wiki/10-gigabit_Ethernet
- ❑ http://en.wikipedia.org/wiki/100_Gigabit_Ethernet
- ❑ http://en.wikipedia.org/wiki/Data_center
- ❑ http://en.wikipedia.org/wiki/Data_center_bridging
- ❑ http://en.wikipedia.org/wiki/Data_link_layer
- ❑ <http://en.wikipedia.org/wiki/EtherChannel>
- ❑ <http://en.wikipedia.org/wiki/Ethernet>
- ❑ http://en.wikipedia.org/wiki/Ethernet_flow_control
- ❑ http://en.wikipedia.org/wiki/Ethernet_frame
- ❑ http://en.wikipedia.org/wiki/Ethernet_physical_layer
- ❑ <http://en.wikipedia.org/wiki/EtherType>
- ❑ http://en.wikipedia.org/wiki/Fast_Ethernet
- ❑ http://en.wikipedia.org/wiki/Gigabit_Ethernet

Wikipedia Links (Cont)

- ❑ http://en.wikipedia.org/wiki/IEEE_802.1aq
- ❑ http://en.wikipedia.org/wiki/IEEE_802.1D
- ❑ http://en.wikipedia.org/wiki/IEEE_802.1Q
- ❑ http://en.wikipedia.org/wiki/IEEE_802.3
- ❑ http://en.wikipedia.org/wiki/IEEE_P802.1p
- ❑ <http://en.wikipedia.org/wiki/IS-IS>
- ❑ http://en.wikipedia.org/wiki/Link_Aggregation
- ❑ http://en.wikipedia.org/wiki/Link_Aggregation_Control_Protocol
- ❑ http://en.wikipedia.org/wiki/Link_layer
- ❑ http://en.wikipedia.org/wiki/Link_Layer_Discovery_Protocol
- ❑ http://en.wikipedia.org/wiki/Logical_link_control
- ❑ http://en.wikipedia.org/wiki/MAC_address
- ❑ <http://en.wikipedia.org/wiki/MC-LAG>

Wikipedia Links (Cont)

- ❑ http://en.wikipedia.org/wiki/Media_Independent_Interface
- ❑ http://en.wikipedia.org/wiki/Minimum_spanning_tree
- ❑ http://en.wikipedia.org/wiki/Network_switch
- ❑ http://en.wikipedia.org/wiki/Organizationally_unique_identifier
- ❑ http://en.wikipedia.org/wiki/Port_Aggregation_Protocol
- ❑ http://en.wikipedia.org/wiki/Priority-based_flow_control
- ❑ <http://en.wikipedia.org/wiki/RSTP>
- ❑ http://en.wikipedia.org/wiki/Shortest_Path_Bridging
- ❑ http://en.wikipedia.org/wiki/Spanning_tree
- ❑ http://en.wikipedia.org/wiki/Spanning_Tree_Protocol
- ❑ http://en.wikipedia.org/wiki/Subnetwork_Access_Protocol
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