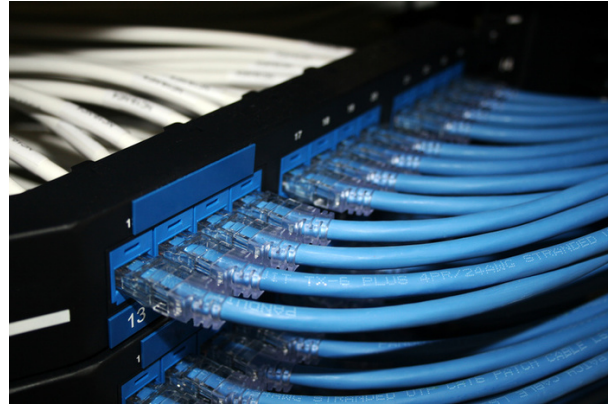


# Data Center Ethernet



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

<http://www.cse.wustl.edu/~jain/cse570-23/>

**Student Questions**



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

## Student Questions

## Quiz: True or False?

Which of the following statements is 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 trees for packet forwarding.
- Ethernet frames are 1518 bytes.
- Ethernet does not provide any delay guarantees.
- Ethernet has no congestion control.
- Ethernet has strict priorities.

## Student Questions

# 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"> <li>➤ Few MAC addresses</li> <li>➤ 4096 VLANs</li> </ul>	<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

## Student Questions

- Is the residential IP more trusted by the web server and less likely to be noticed and blocked?

*No. All residential IPs, when outside, are public IP addresses. They are from a block assigned to the carrier. You can not differentiate residential from non-residential IP addresses.*

---

# IEEE 802 Address Format

q 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

## Student Questions

- ❑ Can you explain the MAC emulation in more detail? Is that to "change" MAC addresses?

*The Ethernet chip allows the software to provide the MAC address instead of the burnt-in MAC.*

- ❑ Since there are only universal addresses, does the second bit always be 0 except for broadcast addresses?

*No. Local MACs are still in use, e.g., private group addresses.*

- ❑ Do companies that die out lose ownership of their OUI?

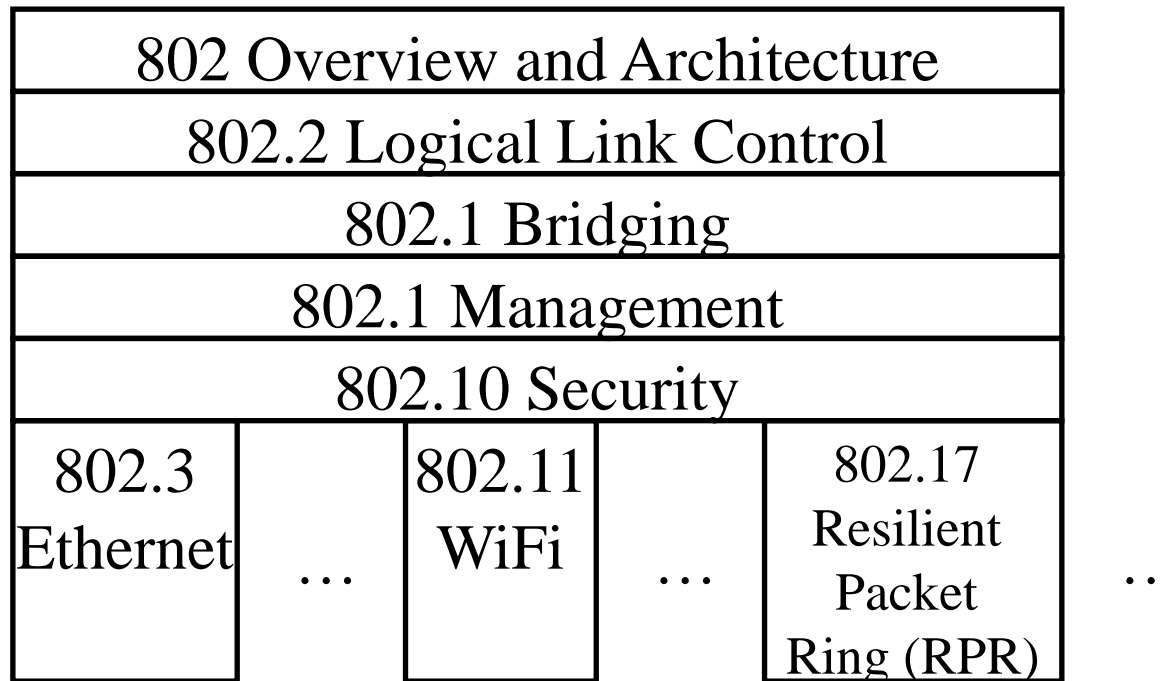
*Not really. Whoever buys the remainder usually gets those.*

- ❑ Is multicast just a more specific broadcast to a particular set of devices?

*Yes.*

# 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



## Student Questions

# 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 lowercase are additions/extensions/revisions.  
It is 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

## Student Questions

# Names, IDs, Locators



**Name:** John Smith

**ID:** 012-34-5678

**Locator:**

1234 Main Street

Big City, MO 12345

USA

❑ The locator changes as you move, and 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

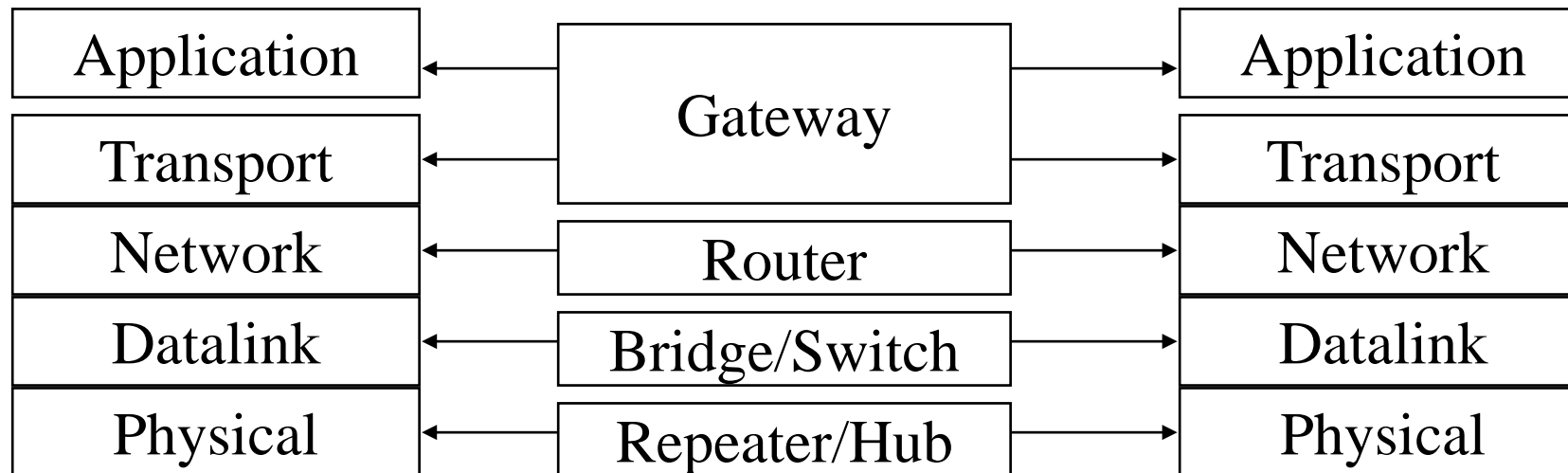
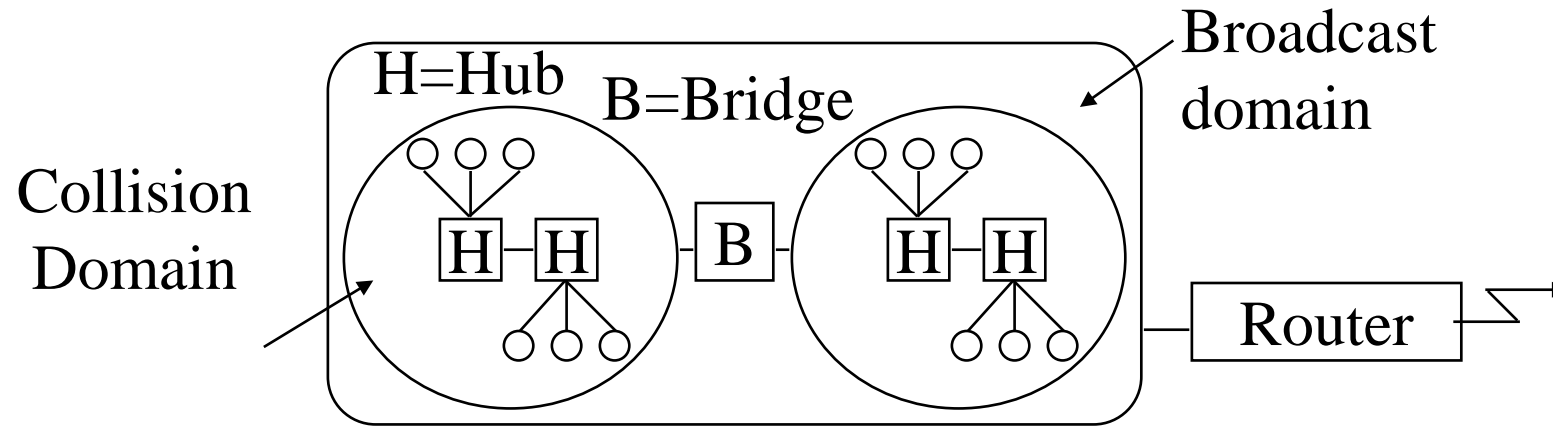
## Student Questions

- ❑ How does private browsing mode connect to the ID? Does it hide the ID but not the locator?

*Private mode hides ID, Locator, and Name.*



# Interconnection Devices



## Student Questions

- ❑ What is the difference between a switch and a router?

*The switch is an L2 device. The router is an L3 device. L2 devices do not look at L3-L7 headers. L3 devices do not have access to L1-L2 headers.*

- ❑ What is the thing connecting one hub to another hub in the same collision domain?

*It is just another wire or link.*

- ❑ Is B in the graph represents a box that is a switch with different functions or just a Bridge?

*B=Bridge=Switch; H=Hub*

- ❖ How are collisions detected within a collision domain? Via Ethernet CSMA/CD? Do collision domains exist nowadays?

*Yes, collisions are detected by CSMA/CD. There are no collisions since there are only two nodes on each LAN link. But every chip still implements CSMA/CD.*

# 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.

## Student Questions

- ❑ How does the hub provide fault detection and recovery? I thought L4 provided this. *Hub cannot provide fault recovery. But they can detect L1 faults, such as a wire cut.*

- 
- ❑ On the slide before you said switches and bridges are the same thing but here they have two different definitions. So a switch is really an iteration of a bridge?

*Yes, bridges were initially two-port devices. Now, they are also multiport.*

- ❖ Why is error detection not 100% reliable?  
*Some errors cannot be detected.*

# Ethernet Speeds

- ❑ IEEE 802.3ba-2010 (40G/100G) Standard
- ❑ 10Mbps, 100 Mbps, and 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 10×10G
- ❑ Note: Only decimal **bit** rates are used in networking  
No cheating like binary byte values used in storage  
1 Gbps =  $10^9$  b/s, Buy 256 GB Disk = 238.4 GB storage

Ref: [http://en.wikipedia.org/wiki/100\\_Gigabit\\_Ethernet](http://en.wikipedia.org/wiki/100_Gigabit_Ethernet)

## Student Questions

- ❑ Is Ethernet speed decided by Ethernet switching throughput?

*No. Ethernet nominal speed is the bit rate on the wire. A 10 Gbps Ethernet link has 10 G bits per second on the wire.*

- ❑ What exactly is CSMA/CD?

*CSMA/CD = Carrier Sense Multiple Access with Collision Detection = Listen before you speak and stop if you hear someone else.*

- ❑ Will combining 10G with 100G have a bottleneck, making it slower *than 100G speed*?

*No. It is just 10X wiring.*

# Ethernet Speeds

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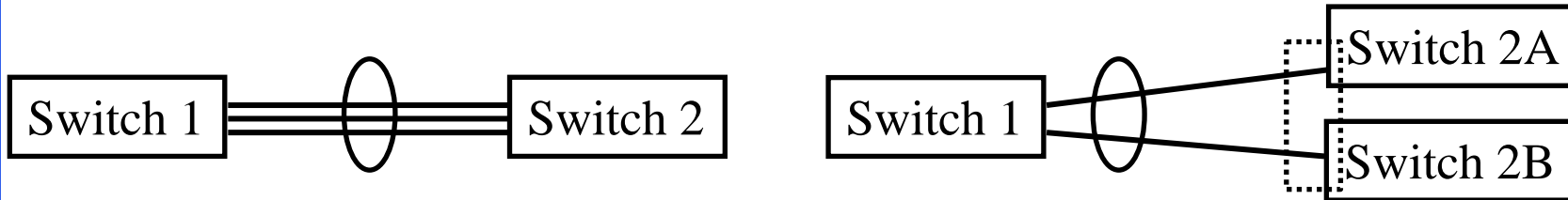
Ref: [http://en.wikipedia.org/wiki/100\\_Gigabit\\_Ethernet](http://en.wikipedia.org/wiki/100_Gigabit_Ethernet)

## Student Questions

- ❑ Could you remind me why switch can avoid CDMA/CD? I thought there might be some collisions within the switch.

*Switches use buffers and scheduled transfers inside. There are no collisions inside the switch.*

# 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  
⇒ The 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>

## Student Questions

- ❑ Are these essentially just redundant links between switches on the left side?

*They are not redundant links. They are parallel links. You send different packets on different links at the same time.*

- ❑ Links are aggregated using LACP, but switches are daisy-chained?

*There is no daisy-chaining. The figures have been redrawn to remove this confusion.*

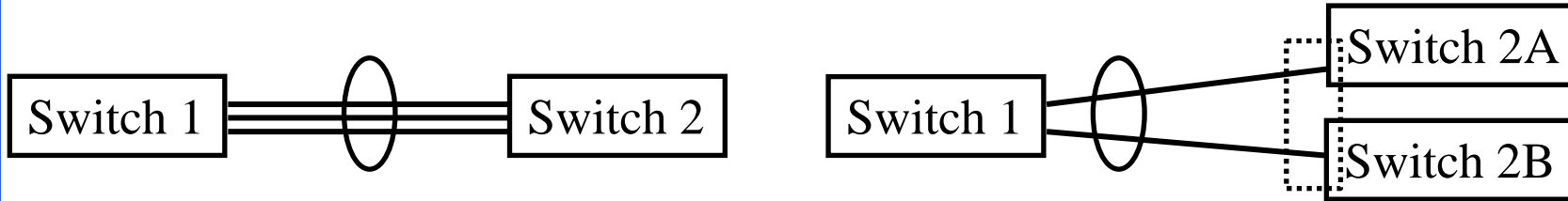
- ❑ When we use two links to two distinct switches (Switch 2A and 2B), do we send frames to both of them? or we use one of them, and the other one is actually on standby (like HA solutions or HSRP protocol)

*We send packets to just one. That's how we double the data rate. If we send to both, the data rate equals the minimum of the two.*

- ❑ Does LACP work for any link layer 2 protocol?

*It works only with IEEE 802 Protocols, e.g., Ethernet and Wi-Fi.*

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<http://www.enterasys.com/company/literature/datacenter-design-guide-wp.pdf>

## Student Questions

- ❑ Since it is difficult to see where you were pointing, is it switch one where LACP ensures packets are put back into order after coming from Switch 2A/B?

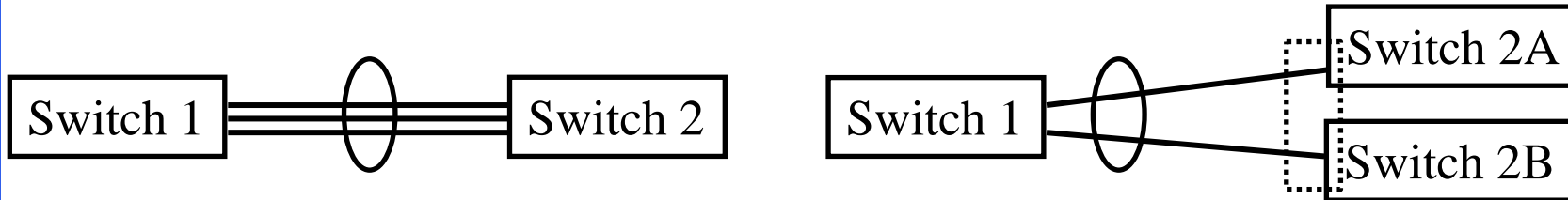
*The packets must be placed in order on every switch or virtual switch.*

- ❑ How often are switches failing that we are worried about redundancy? What causes them to fail?

*Banks/Sellers like Amazon could lose millions if there is a downtime.*

*Heat is the one reason why electronics fail.*

# Link Aggregation Control Protocol (LACP)



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## Student Questions

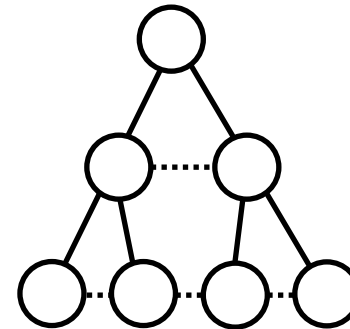
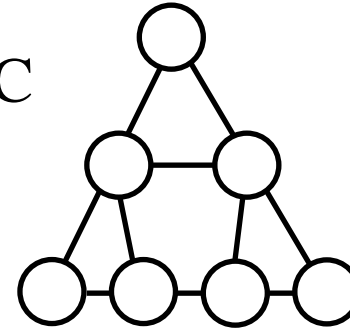
- ❖ How does LACP handle changes in the network topology? Is it just fault tolerance?

*If any component links break, the remaining links can be re-aggregated. This is for increasing the capacity of the link.*



# 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 discover 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.



## Student Questions

- ❑ In a spanning tree, the bridge with the lowest Bridge ID will become root, which means it will have the highest priority (lowest first 16-bit priority). Is there a particular reason for doing this? What does higher priority mean to the bridge (e.g., traffic through this bridge will have less chance of being blocked)?

*Root does not have any special privilege. It simply has to forward more traffic. Generally, you give the highest priority to your most potent bridge. The priority overrides the address.*

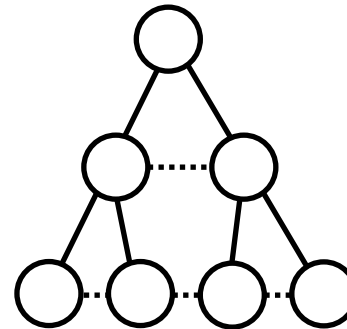
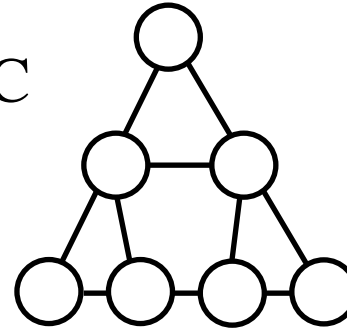
- ❑ Why form the original topology to a spanning tree? It seems some links are wasted, and the distance between some nodes is farther.

*Original topology is fixed and is done based on location and convenience. Spanning tree ensures that there are no loops.*



# Spanning Tree Algorithm

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## Student Questions

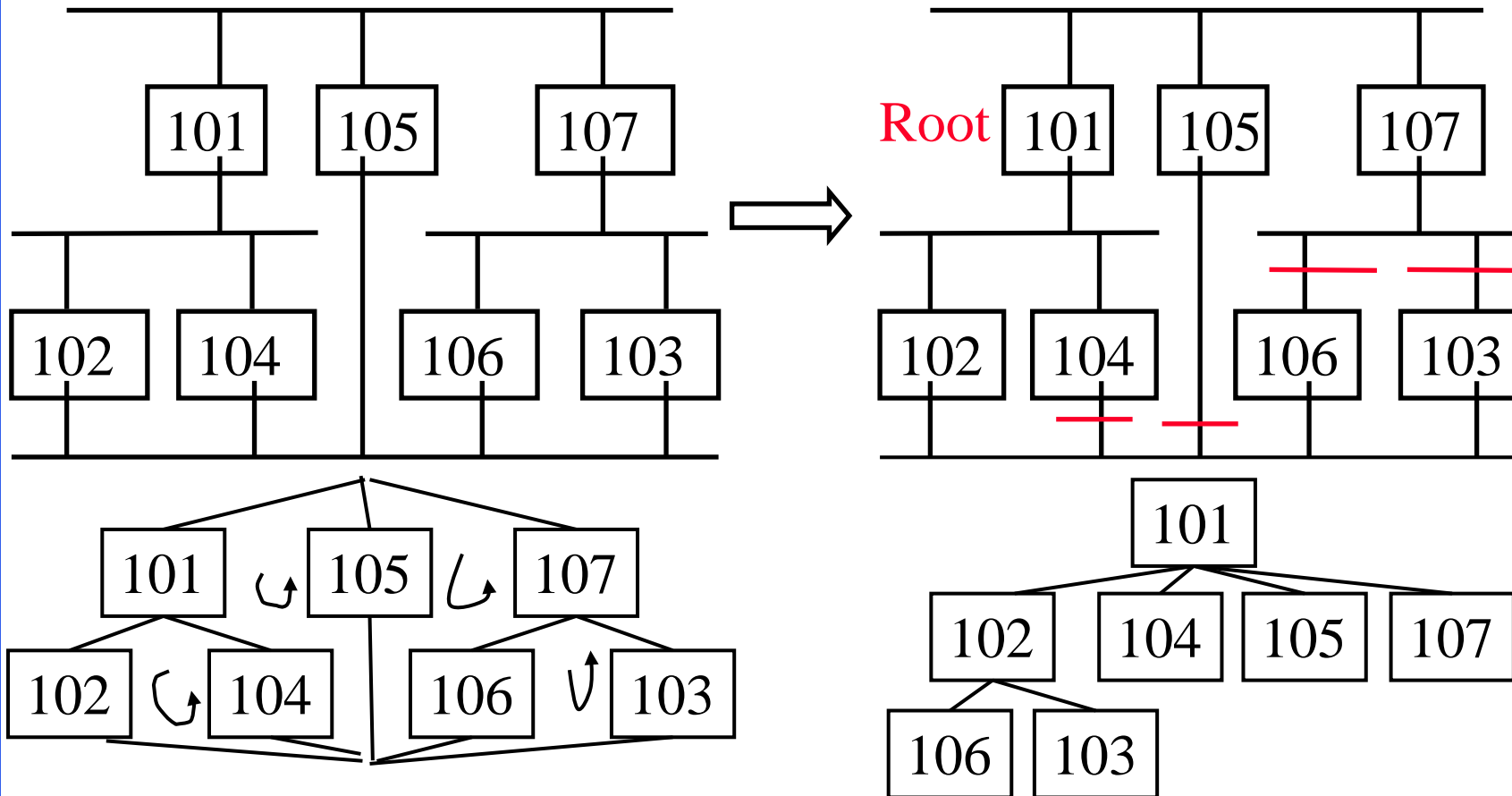
- ❑ Is there ever a problem where you must not go through the spanning tree? Maybe a “bridge” is broken? So the root would have to change? How often does the spanning tree algorithm update?

*Yes, when the bridges or links break, spanning tree algorithm is used.*

- ❑ Is Spanning Tree Algorithm implemented in the link layer, or in a distributed software running on each switch?

*It is more of a management protocol run to manage the topology after any link/device fails.*

# Spanning Tree Example



## Student Questions

- Should we kill the links between 102 and 104, 104 and 106, and 106 and 103? Can 107 be the root?

?

- Could you explain more about this example?

*Sure.*

- When there is an equal cost path to the root, how does STP decide which path to block?

*Randomly. Or by Equal cost multipath (hashing).*

- Could you please draw it as a tree and explain?

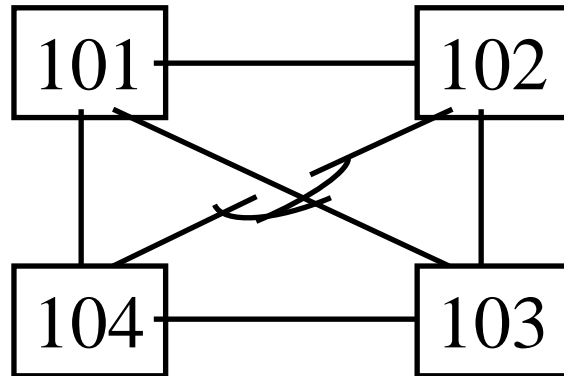
*Done.*

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

<https://support.huawei.com/enterprise/en/doc/EDOC1100092144>

# Homework 4

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



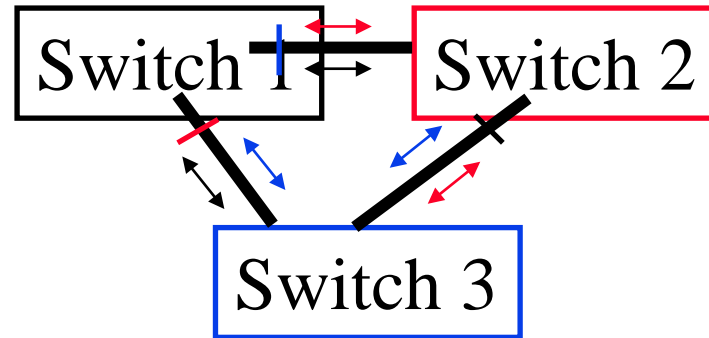
## Student Questions

# Enhancements to STP

- ❑ A topology change can result in a 1-minute 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.

## Student Questions

# 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 a forwarding state for some VLANs and a blocked state for others.

## Student Questions

- ❑ Are any new experimental algorithms used instead of Dijkstra's for building a routing table?

*Routing is an active research topic. BGP, for example, does not use Dijkstra's. IETF has nine working groups currently active on routing.*

- ❑ Are all VLAN groups connected by bridges?

*Logically yes. Now, running VLANs over long distances over IP is possible, as discussed in the next module.*

# IS-IS Protocol

- ❑ Intermediate System to Intermediate System (IS-IS) is a protocol for building routing tables. Link-State routing protocol  
⇒ Each node sends its connectivity (link state) information to all nodes in the network
- ❑ Each node then uses Dijkstra's algorithm 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 addresses
- ❑ OSPF is designed to run on top of IP  
IS-IS is general enough to be used on any transport  
⇒ Adopted by Ethernet

Ref: <http://en.wikipedia.org/wiki/IS-IS>

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<http://www.cse.wustl.edu/~jain/cse570-23/>

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## Student Questions

- ❑ Can IS-IS be used as a routing protocol for layer 3?

*Yes. And it is used in some networks.*

- ❑ Could you explain about OSPF?

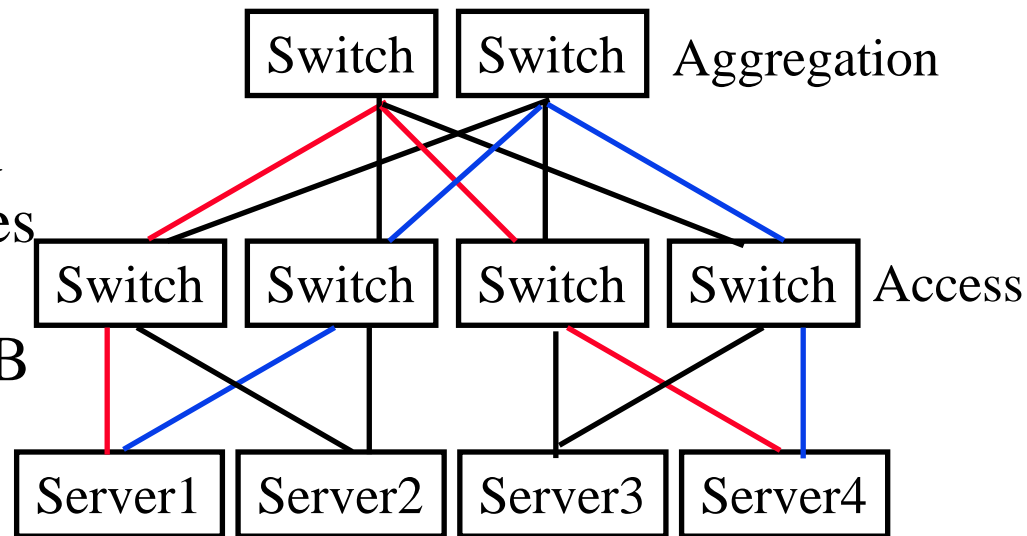
*Please see the CSE473 Class*

*Video:*

[https://www.cse.wustl.edu/~jain/cse473-23/i\\_5n1c.htm](https://www.cse.wustl.edu/~jain/cse473-23/i_5n1c.htm)

# Shortest Path Bridging

- ❑ IEEE 802.1aq-2012 (later incorporated in 802.1Q-2014)
- ❑ Allows all links to be used  
⇒ 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) is used to distribute the load



## Student Questions

- ❑ How does OSPF prevent Loops?  
*Using Dijkstra's algorithm.*
- ❑ Do we use the shortest path bridging in data centers

*Yes.*

- ❑ Is the shortest path always with the minimum number of hops, or can we consider other cost functions like congestion?

*You can specify any cost function, such as data rate, dollar cost, or hops.*

- ❑ I assume flow matching is expensive because we need TCAMs. Mainly, isn't it too expensive if we want to use shortest path bridging in data centers with many short flows?

*Flow matching is done by hashing the source and destination L2 or L3 addresses. Higher-layer switches can include higher-layer info, such as TCP port #. TCAMs are not used for this.*

Ref: [http://en.wikipedia.org/wiki/Shortest\\_Path\\_Bridging](http://en.wikipedia.org/wiki/Shortest_Path_Bridging)

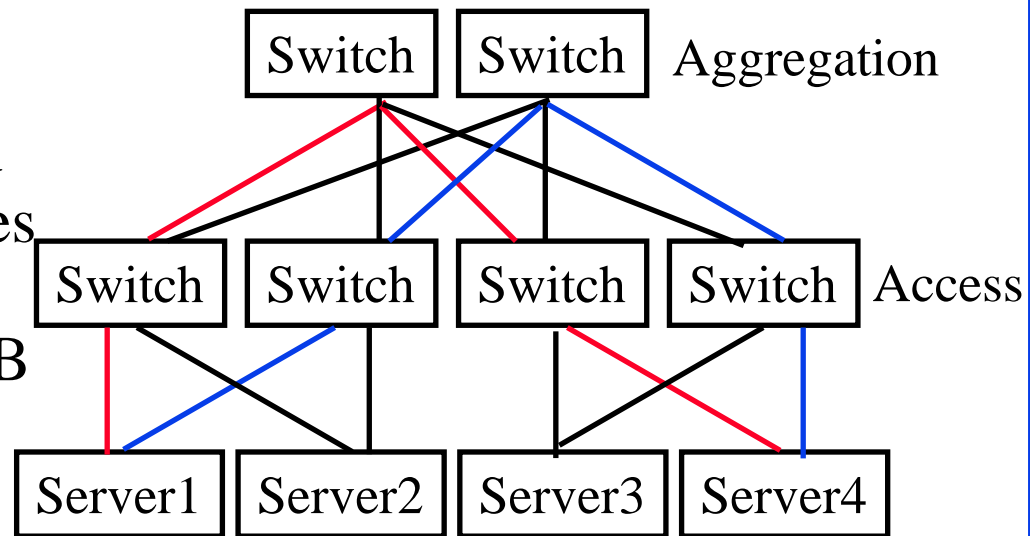
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## Student Questions

- ❑ Is there an optimal number of bridges?

*The number of bridges/switches depends on the # of connections and throughput required.*

Ref: [http://en.wikipedia.org/wiki/Shortest\\_Path\\_Bridging](http://en.wikipedia.org/wiki/Shortest_Path_Bridging)

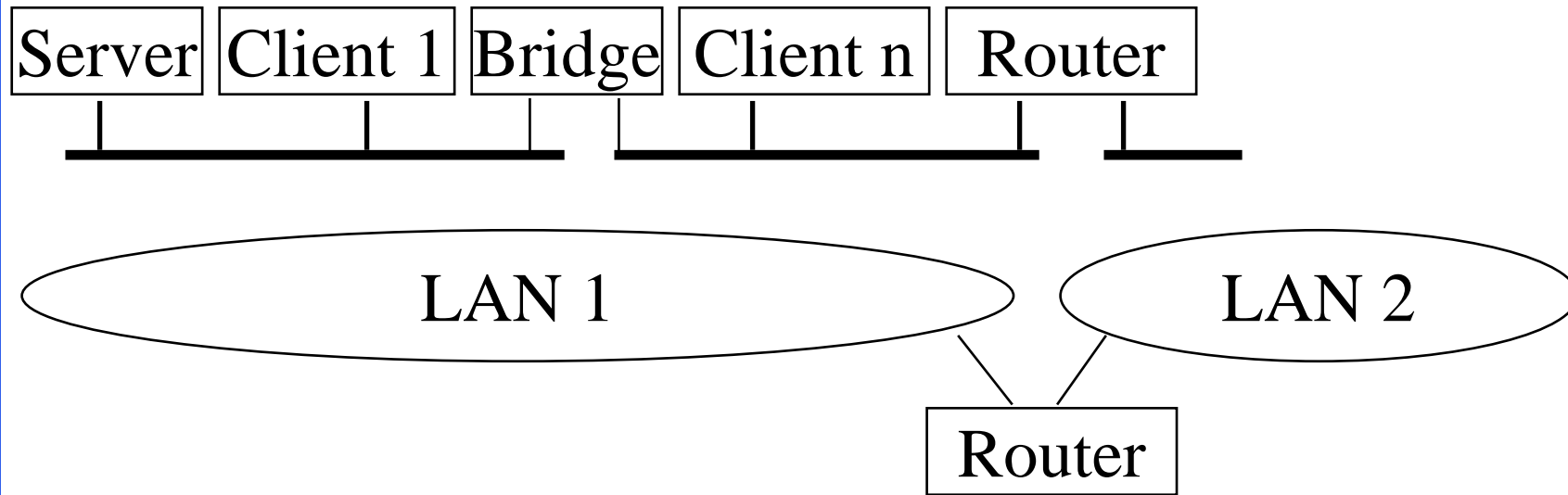
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# What is a LAN?

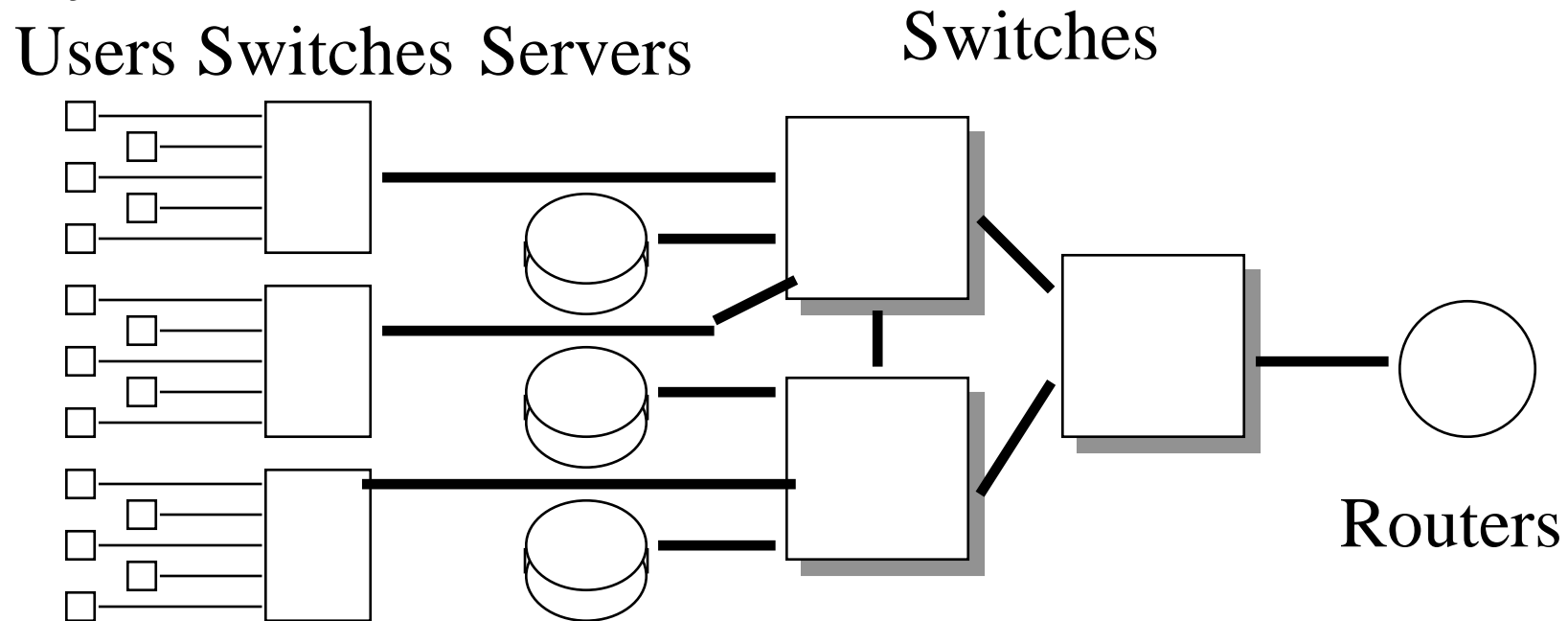


- ❑ LAN = Single broadcast domain = Subnet
- ❑ No routing between members of a LAN
- ❑ Routing required between LANs

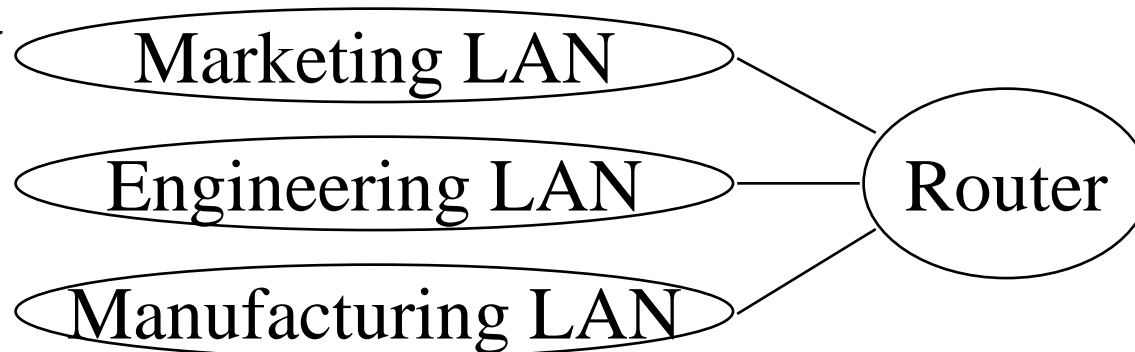
## Student Questions

# What is a Virtual LAN?

## Physical View



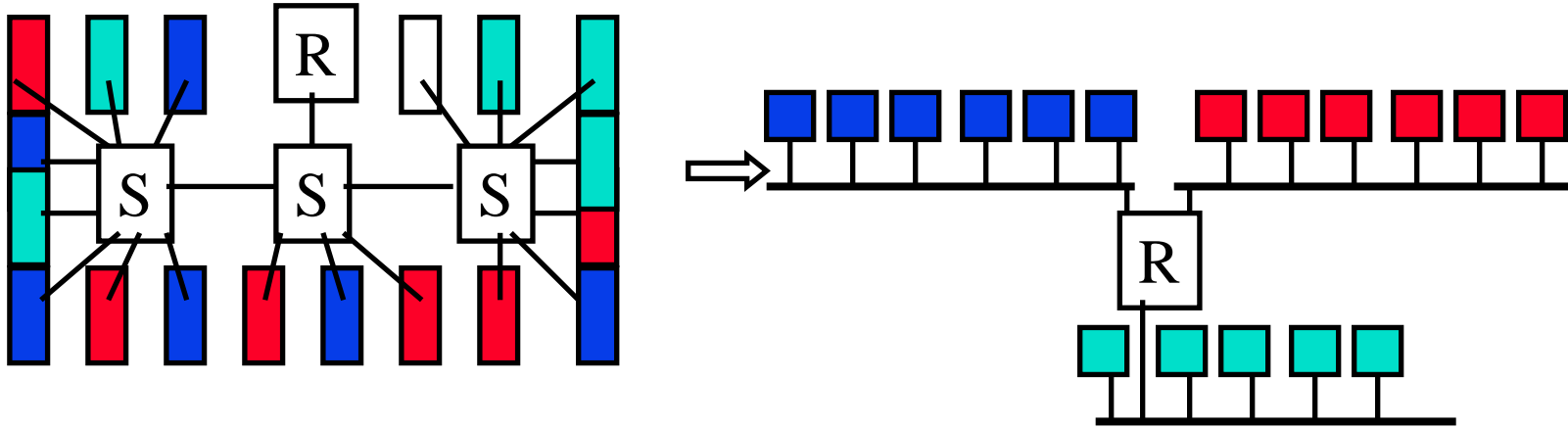
## Logical View



## Student Questions

- ❑ What are the disadvantages of VLANs?  
*Complexity in switches. ⇒ Many cheap switches may not have this feature.*

# Virtual LAN



## Student Questions

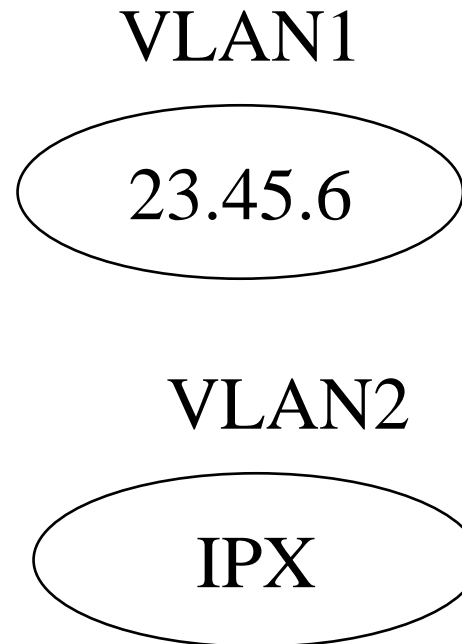
- ❑ Virtual LAN = Broadcasts and multicast goes only to the nodes in the virtual LAN
- ❑ LAN membership is defined by the network manager  $\Rightarrow$  Virtual

# Types of Virtual LANs

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

Switch Port	VLAN	
	1	2
A1	✓	
A2		✓
A3	✓	
B1		✓
B2	✓	

VLAN1	VLAN2
A1B234565600	21B234565600
D34578923434	634578923434
1345678903333	8345678903333
3438473450555	9438473450555
4387434304343	5387434304343
4780357056135	6780357056135
4153953470641	9153953470641
3473436374133	0473436374133
3403847333412	8403847333412
3483434343143	8483434343143
4343134134234	0343134134234



## Student Questions

- ❑ I imagine the device manages different types of VLANs at their corresponding layers. For example, a router takes care of layer-3 VLANs.

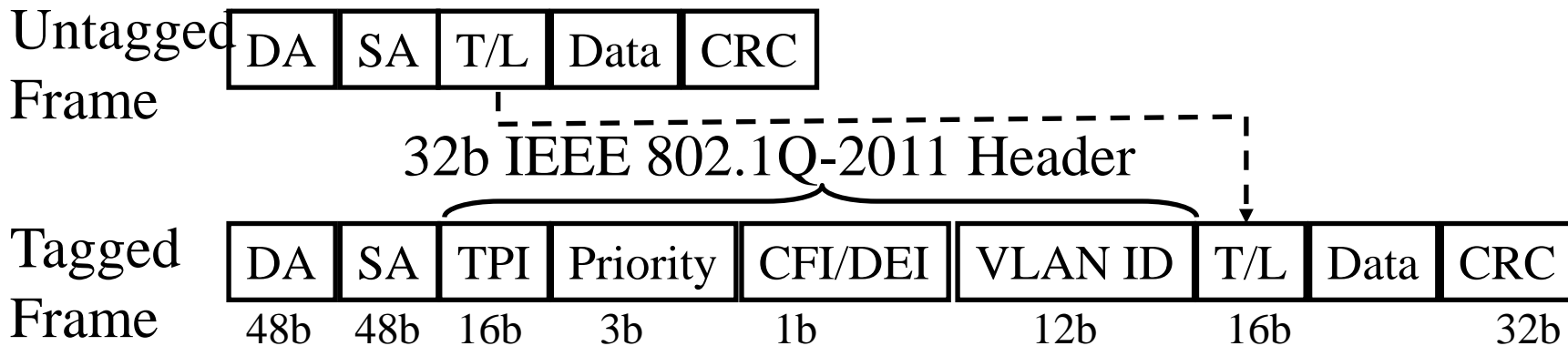
*For L3-VLANs, you need L3 information, and so only the L3 device can manage it. DHCP is an L3 device. It can take care of L2 and L3 VLANs. L1 VLANs are done manually or by L1 wiring automation.*

- ❑ After configuring VLAN, when a port belonging to a VLAN of the switch receives a broadcast frame, will all hosts belonging to the same VLAN receive the broadcast frame?

*Yes. VLAN==Shared broadcast*

# 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 is 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.



Ref: Canonical vs. noncanonical format, <https://www.ibm.com/docs/en/zos/2.2.0?topic=address-canonical-versus-noncanonical-format>

Ref: G. Santana, "Data Center Virtualization Fundamentals," Cisco Press, 2014, ISBN:1587143240

## Student Questions

- ❑ What are some reasons the DEI bit would be set?

*Nodes set DEI on packets that are not necessary. For example, in video coding, there are Keyframes (I), Forward predicted (P), and bi-directionally predicted frames (B) frames. B frames can be dropped under overload.*

# Link Layer Discovery Protocol (LLDP)

- ❑ IEEE 802.1AB-2009
- ❑ Neighbor discovery by periodic advertisements
- ❑ Every minute the 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](http://www.eetimes.com/document.asp?doc_id=1272069)

Ref: [http://en.wikipedia.org/wiki/Link\\_Layer\\_Discovery\\_Protocol](http://en.wikipedia.org/wiki/Link_Layer_Discovery_Protocol)

## Student Questions

- ❑ What is the purpose or need for designing LLDP?

*To find the neighbors so that network routing/forwarding can be done.*

- ❑ What uses are there for device discovery on the link layer?

*Which other devices are on this Ethernet?*

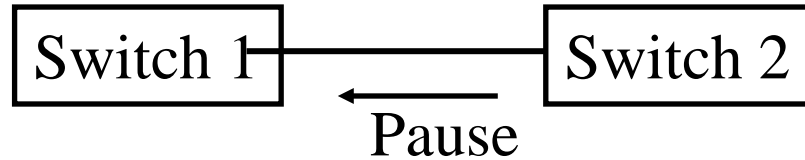
# Data Center Bridging

- ❑ 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>

## Student Questions

# 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 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](http://en.wikipedia.org/wiki/Ethernet_flow_control)

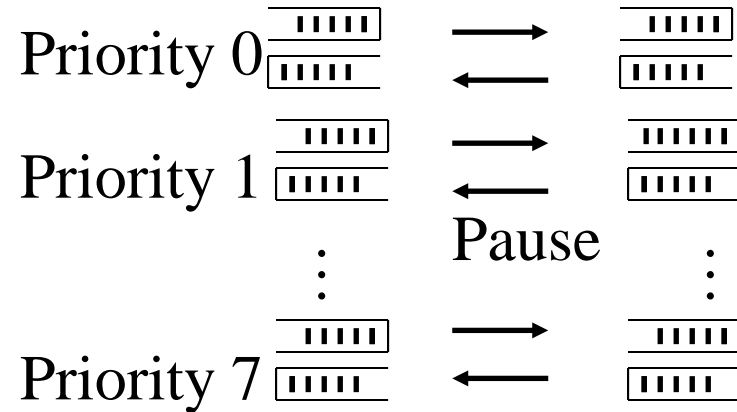
## Student Questions

- ❑ Other than TCP being a layer four protocol, what prevents the core concept of TCP control flow from being applied to Ethernet?

*Speed and cost. Datalink devices are supposed to be cheap, fast, and, therefore, simple.*



# Priority-based Flow Control (PFC)



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

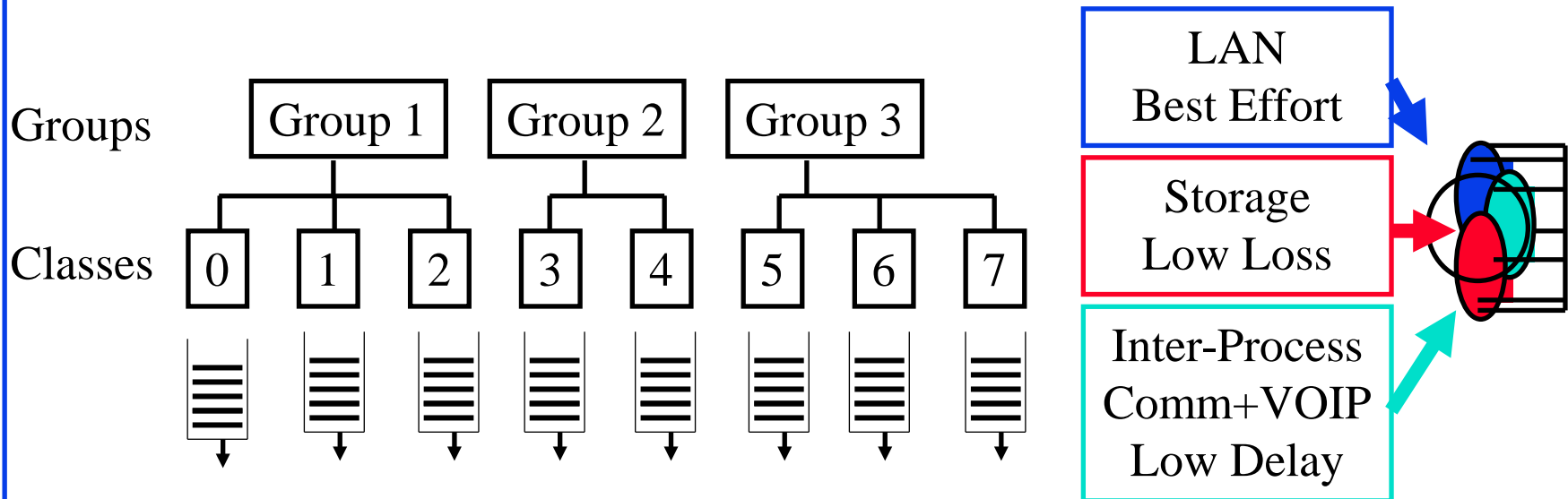
## Student Questions

- ❑ Are there guidelines to which types of messages can be assigned to which priorities?  
*Applications and network managers decide and then program their devices accordingly.*

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](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 into eight classes (not priorities)
- ❑ The classes are grouped.
- ❑ The standard requires min 3 groups: 1 with PFC (Storage with low loss), 1 W/O PFC (LAN), 1 with Strict Priority (Inter-process communication and VOIP with low latency)

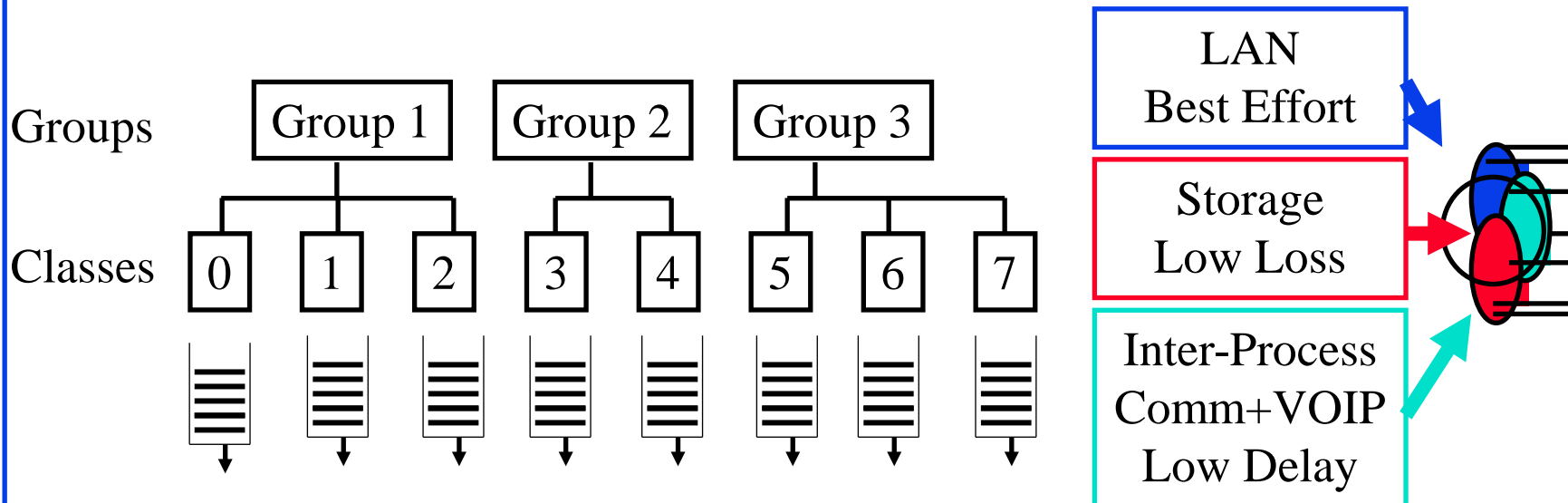


## Student Questions

- ❑ Is the reservation end-to-end? Or do we have to manually reserve and define each group on each switch along the path? Can it be used with RSVP?  
*Here, all reservations are L2. So, on one extended LAN only. That extended LAN can have many L2 switches in between.*
- ❑ Priority flow control is called Class-based Flow Control; how are classes related to priorities? What is the main difference between PFC and strict priority?  
*Priority creates an orderly queue. Classes do not necessarily have an order.*
- ❑ So, in a word, ETS was invented to guarantee the minimum bandwidth required to ensure the normal operation of each network.  
*For real-time video services*

# Enhanced Transmission Selection

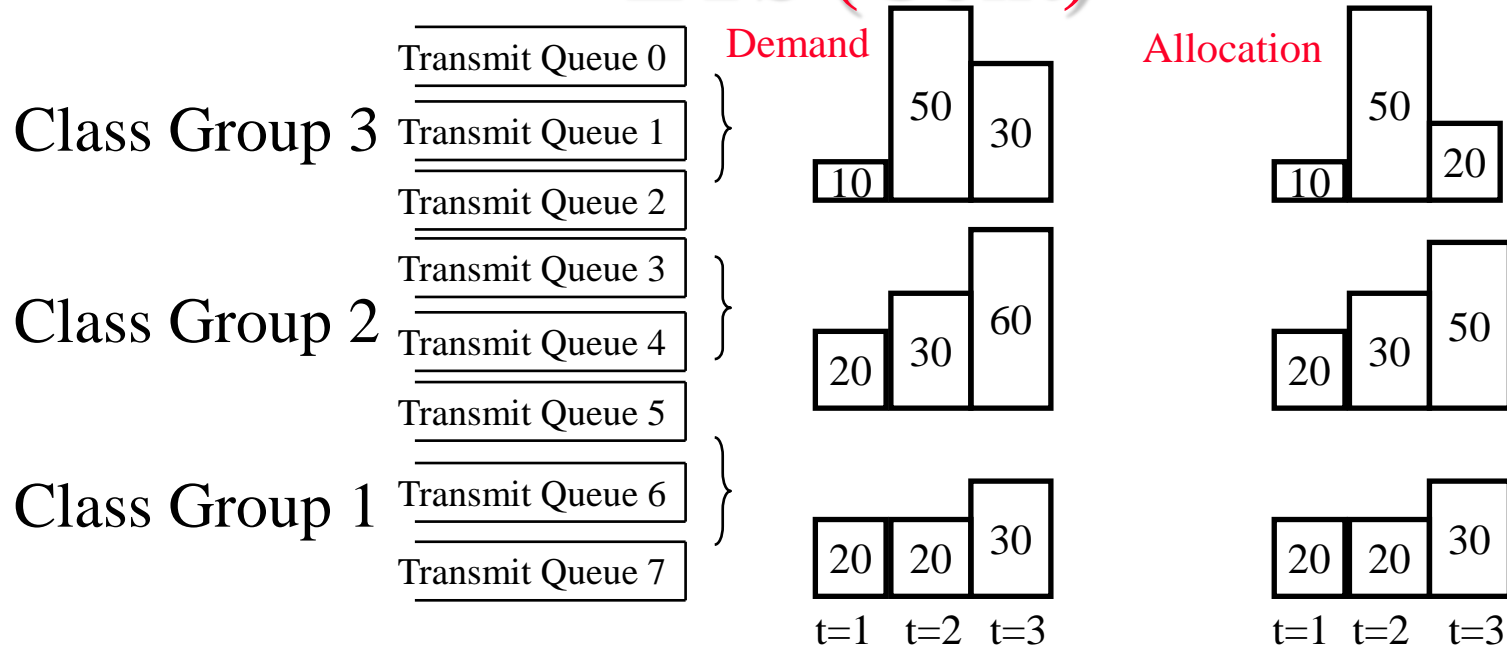
- ❑ IEEE 802.1Qaz-2011
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- ❑ Traffic is divided into eight classes (not priorities)
- ❑ The classes are grouped.
- ❑ The standard requires min 3 groups: 1 with PFC (Storage with low loss), 1 W/O PFC (LAN), 1 with Strict Priority (Inter-process communication and VOIP with low latency)



## Student Questions

- ❑ How does ETS interact with IEEE 802.1p priority tagging? What happens when the bandwidth is exceeded?  
*802.1p is older. ETS is a new replacement. Strict priorities of 802.1p are not considered good. They starve lower priority flows. So now classes are used in place of priority.*
- ❖ Groups are representative of the data loss tolerance, correct? Could you explain again what the classes within the groups represent?  
*Both groups and class are arbitrary. Using groups for loss tolerance and classes for throughput would be one example.*

# ETS (Cont)

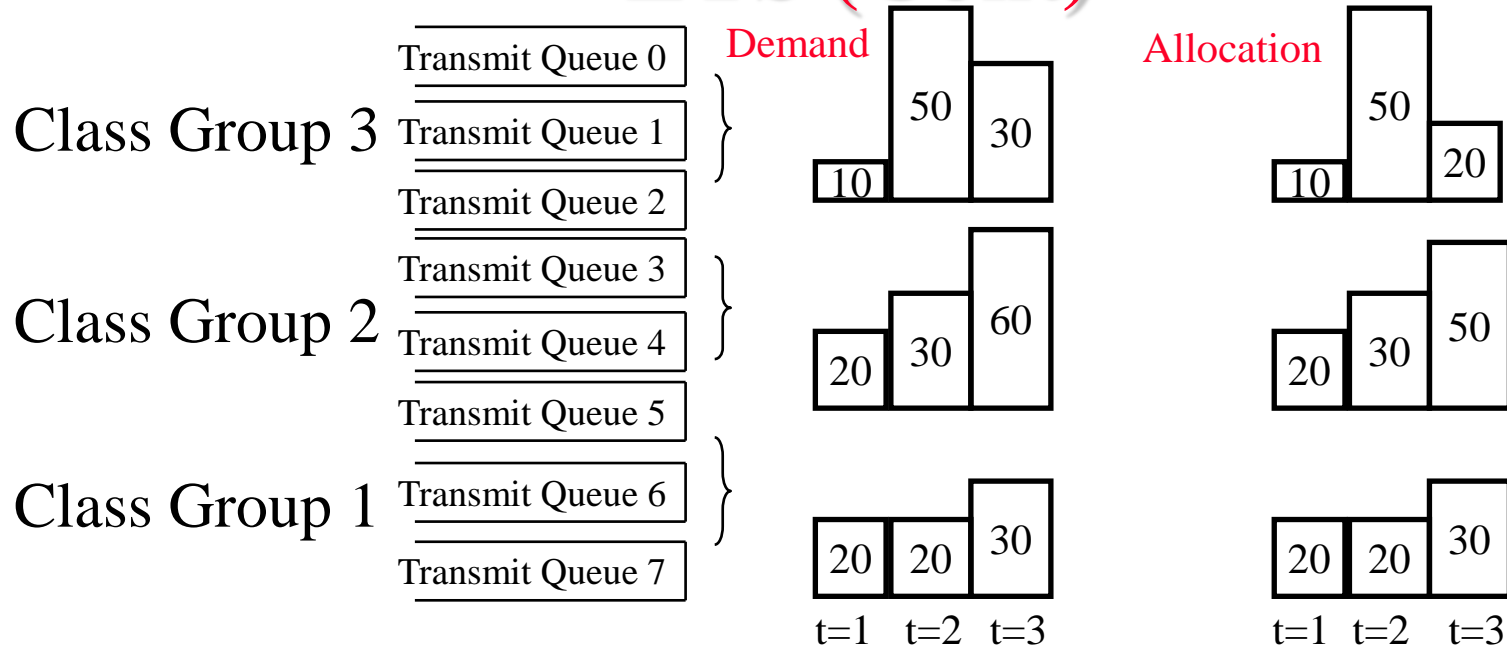


- Bandwidth allocated per class group in 1% increment but 10% precision ( $\pm 10\%$  error).
- Max 75% allocated  $\Rightarrow$  Min 25% best effort
- Fairness within a group
- All unused bandwidth is available to all classes wanting more bandwidth. The allocation algorithm is **not** defined.
- Example: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

## Student Questions

- Is the left demand and the proper allocation? Is it supposed to coordinate with the numbers on slide 31?  
*Yes, Yes!*
- What do the six different figures on the top right represent?  
*Top=Group 2, Middle-Group 2, Bottom=Group 1  
Left=Demand, Right=Allocation*
- In this slide, we defined max-min fairness as an allocation algorithm for ETS, but in slide 29, we say, "allocation algorithm is not defined."  
*The standard does not require any particular algorithm. Companies can choose their own most, like max-min fairness.*
- Does 10% precision imply a minimum 10% allocation? Otherwise, the allocation would be negative.  
*Precision is related to how accurately you measure it.  
1 Mbps  $\approx$  1.2 Mbps, 1.1 Mbps, 1.001 Mbps*

# ETS (Cont)



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

## Student Questions

- ❑ Would the classes contain the flows? One flow in class 1, one in class 2, etc.

*Network managers and applications decide what classes to use for each flow. ETS does not do flow-level inspection or forwarding.*

# A ETS Fairness Example

- ❑ **Max-Min Fairness:** Giving more to anyone 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 groups 1, 2, and 3 are 30%, 60%, and 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,  
A 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.

## Student Questions

- ❑ Could you please explain the example again?

*Sure.*

- ❑ Does the max-min fairness, to some extent, avoid network congestion? For example, an ill-behaved flow of large data packets will only affect itself rather than other flows.

*Congestion: Load > Capacity*

*Fairness: Equal distribution of capacity*

- ❑ If the guaranteed bandwidth exceeds the expected demand for one group, should we reallocate the extra bandwidth to the rest groups or keep it?

*Yes, if actual demand < Guaranteed.*

- ❑ How expensive is it to perform bandwidth allocation adjustment for the groups? How often is it performed on a network (e.g., checking the demanded bandwidth and doing the fairness calculation)?

*Vendor specific. I am still trying to figure it out. But once per second would be reasonable on a Gbps link. It would depend upon the cost of the link.*

# A ETS Fairness Example

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- ❑ **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.

## Student Questions

- ❑ In iteration 2, why the total used is  $280/3$  and unallocated is  $20/3$ ?  
 $Used = 20 + 10 + 30 + (50/3) + (50/3) = 280/3$   
 $Unallocated = Left\ over = 100 - (280/3) = 20/3$
- ❑ Is it possible that the total bandwidth demand exceeds 100 percent?  
*Yes. Two users each could send 100%  $\rightarrow$  Load = 200%*

---

- ❑ Does the Max-Min Fairness maximize the bottleneck of the transmission?  
*Bottleneck applies to equipment. Fairness applies to traffic and flows. Max-Min maximizes the throughput of the flow with the minimum throughput. That flow cannot be called a "Bottleneck."*
- ❑ Is the Max-Min Fairness the most commonly used?

*Yes.*



# A ETS Fairness Example

- ❑ **Max-Min Fairness:** Giving more to anyone 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.  
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A 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.

## Student Questions

- ❑ Is there a protocol if the groups collectively ask for more than 100% minimum bandwidth?  
*Yes, ETS is designed precisely for such situations. The total bandwidth required in the example is more than 100%.*



# 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 unused capacity or # of unsatisfied groups is zero.

## Student Questions

- So the satisfaction is based on the demand, not based on providing the minimum guaranteed BW?

*Satisfaction = Allocated/Demand*

- In the test, do we have to use fractions instead of floating points?

*You can use either.*

- How do you define "poorest"? In this example (30,60,30), why not work on satisfying the most significant number of groups first? Ignoring 60 and satisfying 30 and 30 first?

*Poor = Low demand*

- If the demand exceeds the guaranteed, can we reallocate the unused BW?

*Yes, particularly if others need it. Also, there are "best effort" customers whose guarantee is zero.*

- Is the demand for each group dynamic? For example, after iteration 3, the demand of groups 1, 2, and 3 changes to 10, 10, 10. Will the bandwidth assigned to each group be decreased?

*Yes. It is dynamic. We have to reallocate every few seconds.*

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

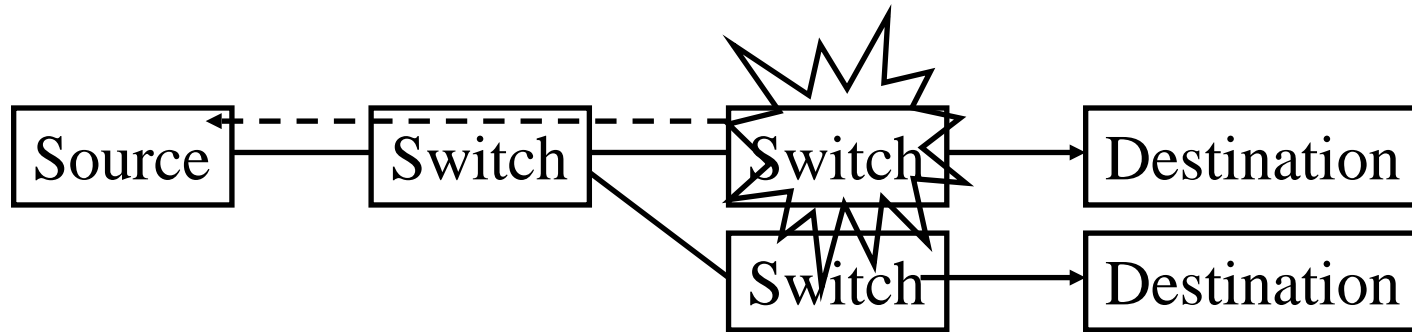
## Student Questions

## Homework 4B

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

### Student Questions

# Quantized Congestion Notification (QCN)



- ❑ IEEE 802.1Qau-2010 Dynamic Congestion Notification
- ❑ A source quench message is sent by the congested switch directly 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  
 $\Rightarrow$  The router will drop the traffic. QCN does not help.

## Student Questions

- ❑ So, we use the AIMD instead of QCN?  
*AIMD is an algorithm for systems with no explicit rate feedback. QCN simply provides source-quench feedback, which can be used with AIMD.*
- ❑ In the video, we could not see the slide for QCN. Could you explain it again?

# 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

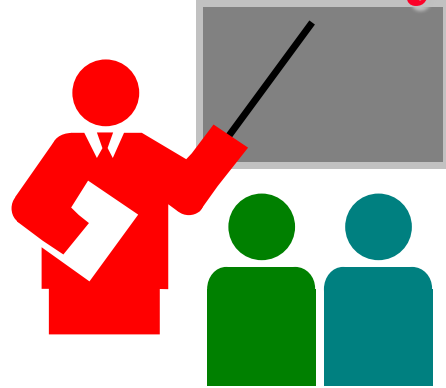
## Student Questions

- ❑ What aspects does DCBX extend based on DCB?

*It defines a protocol for the exchange of parameters.*

---

# 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 packet loss by enhanced transmission selection and Priority-based flow control

## Student Questions

# 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

## Student Questions

# 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

## Student Questions



# 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

## Student Questions

# List of Acronyms (Cont)

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

## Student Questions

# Reading List

- ❑ G. Santana, “Data Center Virtualization Fundamentals,” Cisco Press, 2014, ISBN:1587143240
- ❑ Enterasys, “Enterasys Design Center Networking - Connectivity and Topology Design Guide,” 2013,  
<http://www.enterasys.com/company/literature/datacenter-design-guide-wp.pdf>
- ❑ Ref: Huawei, “Understanding Spanning-Tree Protocol Topology Changes,”  
<https://support.huawei.com/enterprise/en/doc/EDOC1100092144>
- ❑ Cisco, Understanding Rapid Spanning Tree Protocol (802.1w),  
[http://www.cisco.com/en/US/tech/tk389/tk621/technologies\\_white\\_paper09186a0080094cfa.shtml](http://www.cisco.com/en/US/tech/tk389/tk621/technologies_white_paper09186a0080094cfa.shtml)
- ❑ Canonical vs. noncanonical format,  
<https://www.ibm.com/docs/en/zos/2.2.0?topic=address-canonical-versus-noncanonical-format>

## Student Questions

# 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](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>

## Student Questions

# Wikipedia Links

- ❑ [http://en.wikipedia.org/wiki/10-gigabit\\_Ethernet](http://en.wikipedia.org/wiki/10-gigabit_Ethernet)
- ❑ [http://en.wikipedia.org/wiki/100\\_Gigabit\\_Ethernet](http://en.wikipedia.org/wiki/100_Gigabit_Ethernet)
- ❑ [http://en.wikipedia.org/wiki/Data\\_center](http://en.wikipedia.org/wiki/Data_center)
- ❑ [http://en.wikipedia.org/wiki/Data\\_center\\_bridging](http://en.wikipedia.org/wiki/Data_center_bridging)
- ❑ [http://en.wikipedia.org/wiki/Data\\_link\\_layer](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_flow_control)
- ❑ [http://en.wikipedia.org/wiki/Ethernet\\_frame](http://en.wikipedia.org/wiki/Ethernet_frame)
- ❑ [http://en.wikipedia.org/wiki/Ethernet\\_physical\\_layer](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/Fast_Ethernet)
- ❑ [http://en.wikipedia.org/wiki/Gigabit\\_Ethernet](http://en.wikipedia.org/wiki/Gigabit_Ethernet)

## Student Questions

# Wikipedia Links (Cont)

- ❑ [http://en.wikipedia.org/wiki/IEEE\\_802.1aq](http://en.wikipedia.org/wiki/IEEE_802.1aq)
- ❑ [http://en.wikipedia.org/wiki/IEEE\\_802.1D](http://en.wikipedia.org/wiki/IEEE_802.1D)
- ❑ [http://en.wikipedia.org/wiki/IEEE\\_802.1Q](http://en.wikipedia.org/wiki/IEEE_802.1Q)
- ❑ [http://en.wikipedia.org/wiki/IEEE\\_802.3](http://en.wikipedia.org/wiki/IEEE_802.3)
- ❑ [http://en.wikipedia.org/wiki/IEEE\\_P802.1p](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)
- ❑ [http://en.wikipedia.org/wiki/Link\\_Aggregation\\_Control\\_Protocol](http://en.wikipedia.org/wiki/Link_Aggregation_Control_Protocol)
- ❑ [http://en.wikipedia.org/wiki/Link\\_layer](http://en.wikipedia.org/wiki/Link_layer)
- ❑ [http://en.wikipedia.org/wiki/Link\\_Layer\\_Discovery\\_Protocol](http://en.wikipedia.org/wiki/Link_Layer_Discovery_Protocol)
- ❑ [http://en.wikipedia.org/wiki/Logical\\_link\\_control](http://en.wikipedia.org/wiki/Logical_link_control)
- ❑ [http://en.wikipedia.org/wiki/MAC\\_address](http://en.wikipedia.org/wiki/MAC_address)
- ❑ <http://en.wikipedia.org/wiki/MC-LAG>

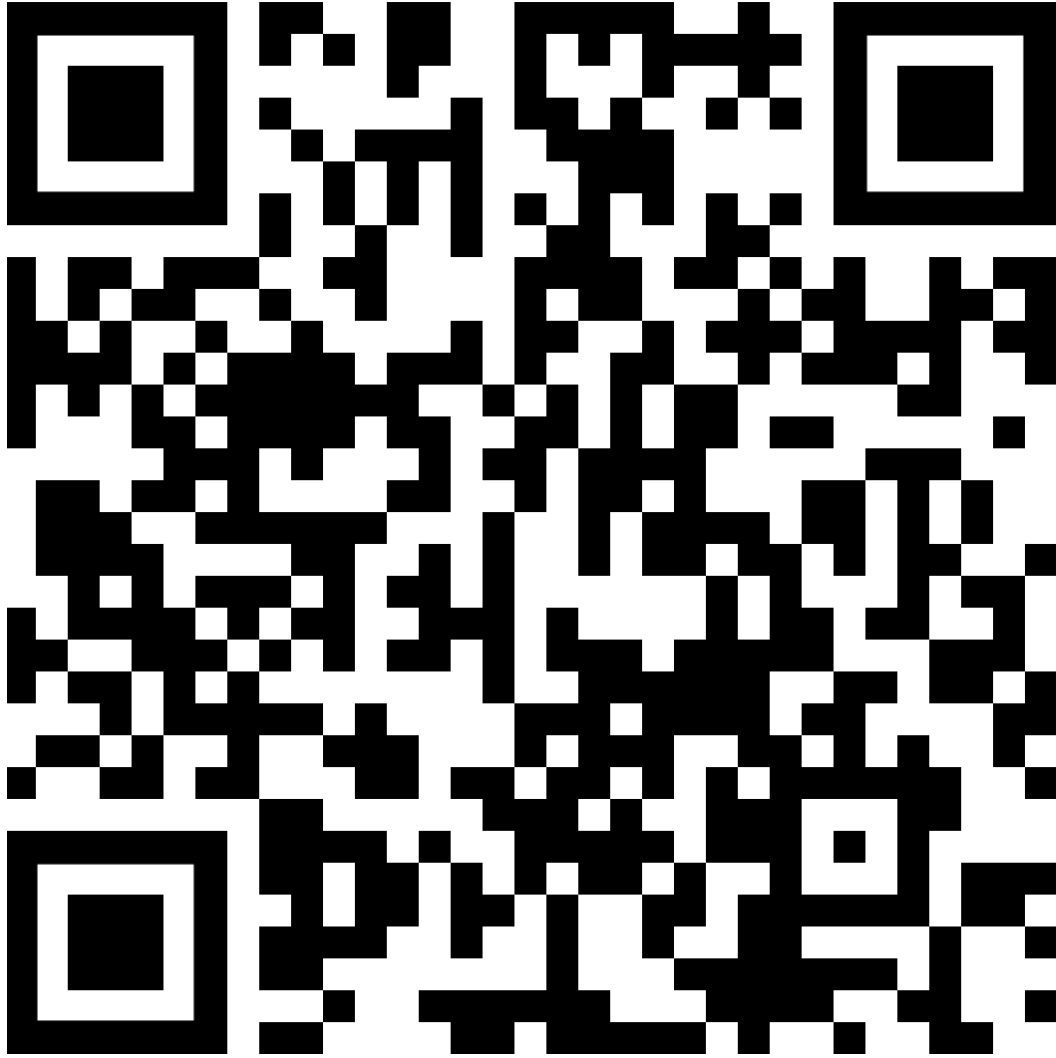
## Student Questions

# Wikipedia Links (Cont)

- ❑ [http://en.wikipedia.org/wiki/Media\\_Independent\\_Interface](http://en.wikipedia.org/wiki/Media_Independent_Interface)
- ❑ [http://en.wikipedia.org/wiki/Minimum\\_spanning\\_tree](http://en.wikipedia.org/wiki/Minimum_spanning_tree)
- ❑ [http://en.wikipedia.org/wiki/Network\\_switch](http://en.wikipedia.org/wiki/Network_switch)
- ❑ [http://en.wikipedia.org/wiki/Organizationally\\_unique\\_identifier](http://en.wikipedia.org/wiki/Organizationally_unique_identifier)
- ❑ [http://en.wikipedia.org/wiki/Port\\_Aggregation\\_Protocol](http://en.wikipedia.org/wiki/Port_Aggregation_Protocol)
- ❑ [http://en.wikipedia.org/wiki/Priority-based\\_flow\\_control](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/Shortest_Path_Bridging)
- ❑ [http://en.wikipedia.org/wiki/Spanning\\_tree](http://en.wikipedia.org/wiki/Spanning_tree)
- ❑ [http://en.wikipedia.org/wiki/Spanning\\_Tree\\_Protocol](http://en.wikipedia.org/wiki/Spanning_Tree_Protocol)
- ❑ [http://en.wikipedia.org/wiki/Subnetwork\\_Access\\_Protocol](http://en.wikipedia.org/wiki/Subnetwork_Access_Protocol)
- ❑ [http://en.wikipedia.org/wiki/Virtual\\_LAN](http://en.wikipedia.org/wiki/Virtual_LAN)

## Student Questions

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Raj Jain

<http://rajjain.com>

[http://www.cse.wustl.edu/~jain/cse570-23/m\\_04dce.htm](http://www.cse.wustl.edu/~jain/cse570-23/m_04dce.htm)

## Student Questions

- Slides on the min-max fairness tabular method and QCN are missing.  
*If a slide takes less than 5 seconds, it does not appear in the video.*
- When explaining calculation, it's unclear in the video because we cannot see which part of the ppt is being pointed while speaking. Is it possible to do an illustration from a blank paper?

*Good feedback for the future.*

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## Related Modules



CSE567M: Computer Systems Analysis (Spring 2013),

[https://www.youtube.com/playlist?list=PLjGG94etKypJEKjNAa1n\\_1X0bWWNyZcof](https://www.youtube.com/playlist?list=PLjGG94etKypJEKjNAa1n_1X0bWWNyZcof)

CSE473S: Introduction to Computer Networks (Fall 2011),

[https://www.youtube.com/playlist?list=PLjGG94etKypJWOSPMh8Azcgy5e\\_10TiDw](https://www.youtube.com/playlist?list=PLjGG94etKypJWOSPMh8Azcgy5e_10TiDw)



Wireless and Mobile Networking (Spring 2016),

[https://www.youtube.com/playlist?list=PLjGG94etKypKeb0nzyN9tSs\\_HCd5c4wXF](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/channel/UCN4-5wzNP9-ruOzQMs-8NUw>

## Student Questions