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/cse570-15/
Overview

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

\[ p \ p \ p ! \text{Ethernet is a local area network (Local \( \leq \) 2km)} \]

\[ p \ p \ p ! \text{Token ring, Token Bus, and CSMA/CD are the three most common LAN access methods.} \]

\[ p \ p \ p ! \text{Ethernet uses CSMA/CD.} \]

\[ p \ p \ p ! \text{Ethernet bridges use spanning tree for packet forwarding.} \]

\[ p \ p \ p ! \text{Ethernet frames are 1518 bytes.} \]

\[ p \ p \ p ! \text{Ethernet does not provide any delay guarantees.} \]

\[ p \ p \ p ! \text{Ethernet has no congestion control.} \]

\[ p \ p \ p ! \text{Ethernet has strict priorities.} \]
# Residential vs. Data Center Ethernet

<table>
<thead>
<tr>
<th>Residential</th>
<th>Data Center</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distance: up to 200m</td>
<td>No limit</td>
</tr>
<tr>
<td>Scale:</td>
<td>Millions of MAC Addresses</td>
</tr>
<tr>
<td>- Few MAC addresses</td>
<td>Millions of VLANs Q-in-Q</td>
</tr>
<tr>
<td>- 4096 VLANs</td>
<td>Rapid spanning tree, … (Gives 1s, need 50ms)</td>
</tr>
<tr>
<td>Protection: Spanning tree</td>
<td>Traffic engineered path</td>
</tr>
<tr>
<td>Path determined by spanning tree</td>
<td>Service Level Agreement. Rate Control.</td>
</tr>
<tr>
<td>Simple service</td>
<td>Need per-flow/per-class QoS</td>
</tr>
<tr>
<td>Priority</td>
<td>Need performance/BER</td>
</tr>
<tr>
<td>⇒ Aggregate QoS</td>
<td></td>
</tr>
<tr>
<td>No performance/Error monitoring (OAM)</td>
<td></td>
</tr>
</tbody>
</table>
IEEE 802 Address Format

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

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

<table>
<thead>
<tr>
<th>Organizationally Unique Identifier (OUI)</th>
<th>Individual/Group</th>
<th>Universal/Local</th>
<th>24 bits assigned by OUI Owner</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>1</td>
<td>22</td>
</tr>
<tr>
<td></td>
<td>24</td>
<td>24</td>
<td></td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>802 Overview and Architecture</th>
</tr>
</thead>
<tbody>
<tr>
<td>802.2 Logical Link Control</td>
</tr>
<tr>
<td>802.1 Bridging</td>
</tr>
<tr>
<td>802.1 Management</td>
</tr>
<tr>
<td>802.10 Security</td>
</tr>
<tr>
<td>802.3 Ethernet</td>
</tr>
<tr>
<td>802.11 WiFi</td>
</tr>
<tr>
<td>802.17 Resilient Packet Ring (RPR)</td>
</tr>
</tbody>
</table>

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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

LAN = Collision Domain

Extended LAN = Broadcast domain

Router

Application
Transport
Network
Datalink
Physical

Gateway
Router
Bridge/Switch
Repeater/Hub

Application
Transport
Network
Datalink
Physical
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 “extended LAN.”
- **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 10×10G
- 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

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
  \[\Rightarrow\text{Combined Link remains connected even if one of the member links fails}\]
- Several proprietary extensions. E.g., aggregate links to two switches which act as one switch.


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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.
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 ⇒ All TCP connections break
- Rapid Spanning Tree Protocol (RSTP) IEEE 802.1w-2001 incorporated in IEEE 802.1D-2004
- One tree for all VLANs ⇒ Common spanning tree
- Many trees ⇒ 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

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Shortest Path Bridging

- IEEE 802.1aq-2012
- 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) 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**

Users Switches Servers

- **Logical View**

Marketing LAN

Engineering LAN

Manufacturing LAN
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

<table>
<thead>
<tr>
<th>Switch Port</th>
<th>VLAN1</th>
<th>VLAN2</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>A2</td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>A3</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>B1</td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>B2</td>
<td>✓</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>VLAN1</th>
<th>VLAN2</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1B234565600</td>
<td>21B234565600</td>
</tr>
<tr>
<td>D34578923434</td>
<td>634578923434</td>
</tr>
<tr>
<td>1345678903333</td>
<td>8345678903333</td>
</tr>
<tr>
<td>3438473450555</td>
<td>9438473450555</td>
</tr>
<tr>
<td>4387434304343</td>
<td>5387434304343</td>
</tr>
<tr>
<td>4780357056135</td>
<td>6780357056135</td>
</tr>
<tr>
<td>4153953470641</td>
<td>9153953470641</td>
</tr>
<tr>
<td>3473436374133</td>
<td>0473436374133</td>
</tr>
<tr>
<td>3403847333412</td>
<td>8403847333412</td>
</tr>
<tr>
<td>3483434343143</td>
<td>8483434343143</td>
</tr>
<tr>
<td>4343134134234</td>
<td>0343134134234</td>
</tr>
</tbody>
</table>

- **VLAN1** = 23.45.6
- **VLAN2** = IPX

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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 ⇒ Standard Ethernet,
  1 ⇒ IBM Token Ring format (non-canonical or non-standard)
- CFI now replaced by Drop Eligibility Indicator (DEI)
- VLAN Identifier (12 bits ⇒ 4095 VLANs)
- Switches forward based on MAC address + VLAN ID
  Unknown addresses are flooded.

Untagged Frame

<table>
<thead>
<tr>
<th>DA</th>
<th>SA</th>
<th>T/L</th>
<th>Data</th>
<th>CRC</th>
</tr>
</thead>
</table>

32b IEEE 802.1Q-2011 Header

Tagged Frame

<table>
<thead>
<tr>
<th>DA</th>
<th>SA</th>
<th>TPI</th>
<th>Priority</th>
<th>CFI/DEI</th>
<th>VLAN ID</th>
<th>T/L</th>
<th>Data</th>
<th>CRC</th>
</tr>
</thead>
<tbody>
<tr>
<td>48b</td>
<td>48b</td>
<td>16b</td>
<td>3b</td>
<td>1b</td>
<td>12b</td>
<td>16b</td>
<td>32b</td>
<td></td>
</tr>
</tbody>
</table>
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: 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)

Ref: M. Hagen, “Data Center Bridging Tutorial,” [http://www.iol.unh.edu/services/testing/dcb/training/DCB-Tutorial.pdf](http://www.iol.unh.edu/services/testing/dcb/training/DCB-Tutorial.pdf)

Ethernet Flow Control: Pause Frame

- 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.

Priority-based Flow Control (PFC)

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


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Enhanced Transmission Selection

- IEEE 802.1Qaz-2011
- Goal: Guarantee bandwidth for applications sharing a link
- Traffic is divided into 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 (±10% error).
- Max 75% allocated ⇒ 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%, 50%, 50%, 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 ⇒ Done.
**Tabular Method for Max-Min Fairness**

<table>
<thead>
<tr>
<th>Iteration</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>Total</th>
<th>Unused</th>
<th># Unsatisfied</th>
</tr>
</thead>
<tbody>
<tr>
<td>Demand</td>
<td>30</td>
<td>60</td>
<td>30</td>
<td>120</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>1</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Guaranteed Allocation</td>
<td>20</td>
<td>30</td>
<td>0</td>
<td>50</td>
<td>50</td>
<td></td>
</tr>
<tr>
<td>Total Used</td>
<td>20</td>
<td>30</td>
<td>0</td>
<td>50</td>
<td>50</td>
<td>3</td>
</tr>
<tr>
<td><strong>2</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Additional Allocation</td>
<td>16.7</td>
<td>16.7</td>
<td>16.7</td>
<td>50</td>
<td>50</td>
<td>3</td>
</tr>
<tr>
<td>Total Used</td>
<td>30</td>
<td>46.7</td>
<td>16.7</td>
<td>93.3</td>
<td>6.7</td>
<td>2</td>
</tr>
<tr>
<td><strong>3</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Additional Allocation</td>
<td>0</td>
<td>3.3</td>
<td>3.3</td>
<td>100</td>
<td>0</td>
<td>2</td>
</tr>
</tbody>
</table>

- Iterations end when either unused capacity or # of unsatisfied groups is zero.
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 ⇒ Not effective.
- The source may be a router in a subnet and not the real source ⇒ Router will drop the traffic. QCN does not help in this case.

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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 ⇒ 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
<table>
<thead>
<tr>
<th>Acronym</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>OSPF</td>
<td>Open Shortest Path First</td>
</tr>
<tr>
<td>OUI</td>
<td>Organizationally Unique Identifier</td>
</tr>
<tr>
<td>PCP</td>
<td>Priority Code Point</td>
</tr>
<tr>
<td>PFC</td>
<td>Priority-based Flow Control</td>
</tr>
<tr>
<td>PHY</td>
<td>Physical layer</td>
</tr>
<tr>
<td>QCN</td>
<td>Quantized Congestion Notification</td>
</tr>
<tr>
<td>QoS</td>
<td>Quality of Service</td>
</tr>
<tr>
<td>RSTP</td>
<td>Rapid Spanning Tree Protocol</td>
</tr>
<tr>
<td>SA</td>
<td>Source Address</td>
</tr>
<tr>
<td>SNIA</td>
<td>Storage Networking Industries Association</td>
</tr>
<tr>
<td>SPB</td>
<td>Shortest Path Bridging</td>
</tr>
<tr>
<td>STP</td>
<td>Spanning Tree Protocol</td>
</tr>
<tr>
<td>TCP</td>
<td>Transmission Control Protocol</td>
</tr>
<tr>
<td>TLV</td>
<td>Type-Length-Value</td>
</tr>
<tr>
<td>TPI</td>
<td>Tag Protocol Identifier</td>
</tr>
<tr>
<td>VLAN</td>
<td>Virtual Local Area Network</td>
</tr>
<tr>
<td>VM</td>
<td>Virtual machine</td>
</tr>
</tbody>
</table>
List of Acronyms (Cont)

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

- Canonical vs. MSB Addresses, [http://support.lexmark.com/index?page=3Dcontent&id=3DHO1299&locale=3Den&userlocale=3DEN_US](http://support.lexmark.com/index?page=3Dcontent&id=3DHO1299&locale=3Den&userlocale=3DEN_US)
M. Srinivasan, “Tutorial on LLDP,”

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M. Hagen, “Data Center Bridging Tutorial,”
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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),”
Wikipedia Links

- http://en.wikipedia.org/wiki/EtherType
Wikipedia Links (Cont)

- [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/Logical_link_control](http://en.wikipedia.org/wiki/Logical_link_control)
Wikipedia Links (Cont)

- http://en.wikipedia.org/wiki/Media_Independent_Interface
- http://en.wikipedia.org/wiki/Port_Aggregation_Protocol