Lecture 10: Physical and Link Layers

Administrative

- Exams will be back by Monday
- Lab 4 is, um, a lot of work
- Real due date versus extension date

Topics Today

- Physical layer: chips versus bits
- Link layer
- Media access control (MAC)
- Ethernet
- MPLS

Protocol Layering

7	Application
6	Presentation
5	Session
4	Transport
3	Network
2	Link
1	Physical

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Physical Layer (Layer 1)

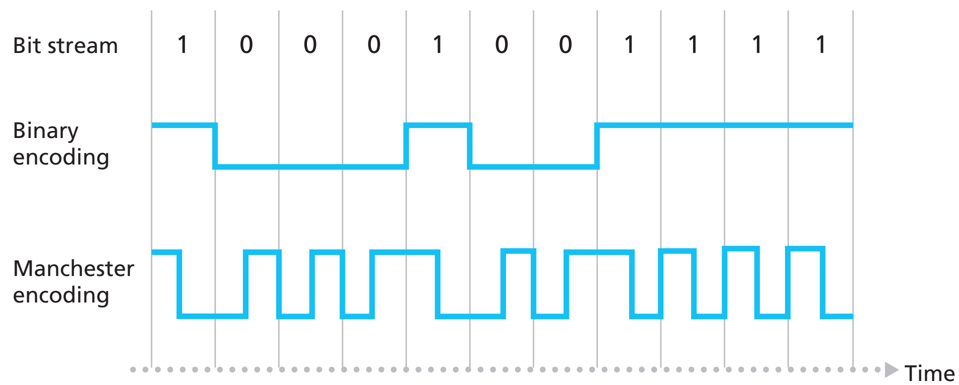
- **Responsible for specifying the physical medium**
  - Category 5 cable (Cat5): 8 wires, twisted pair, RJ45 jack
  - WiFi wireless: 2.4GHz
- **Responsible for specifying the signal**
  - 100BASE-T: 5-level pulse amplitude modulation (PAM-5)
  - 802.11b: Binary and quadrature phase shift keying (BPSK/QPSK)
- **Responsible for specifying the bits**
  - 100BASE-T: 4-to-6 bit-to-chip encoding, 3 chip symbols
  - 802.11b: Barker code (1-2Mbps), complementary code keying (5.5-11Mbps)

Specifying the signal

- **Chips versus bits**
  - Chips: data (in bits) at the physical layer
  - Bits: data above the physical layer
- **Physical layer states the analog signal/chip mapping**
  - On-off keying (OOK): voltage of 0 is 0, +V is 1
  - PAM-5: 000 is 0, 001 is +1, 010 is -1, 011 is -2, 100 is +2
  - Frequency shift keying (FSK)
  - Phase shift keying (PSK)
  - Don’t worry about this too much now: we’ll cover it in greater depth when we look at wireless

Manchester Encoding

- **Map a 0 bit to 01 in chips**
- **Map a 1 bit to 10 in chips**
  - E.g., 1100 → 10100101
  - E.g., 0110 → 01101001

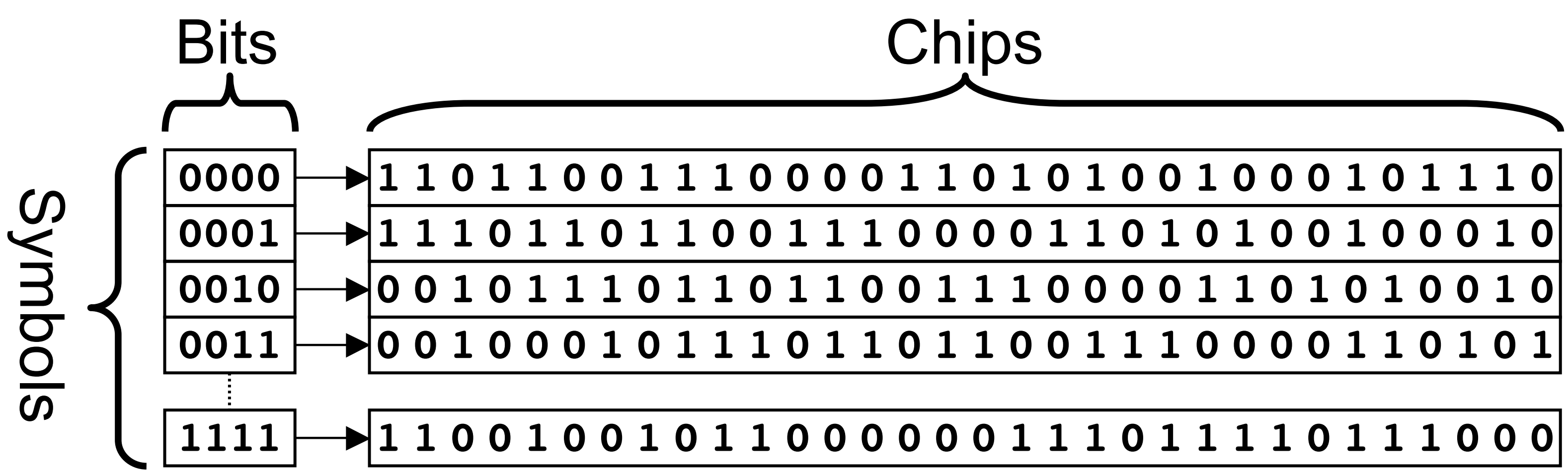


Encoding Motivations

- DC balancing (same number of 0s and 1s)
- Synchronization
- Can recover from some chip errors
- Can constrain analog signal patterns to make signal more robust
- Higher encoding → fewer bps, more robust
- Lower encoding → more bps, less robust

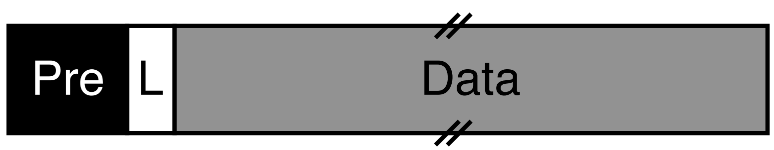
Physical Layer Encoding

- **Break bits up into *symbols*, encode symbols into chips**
- **Example: 802.15.4 uses a 32-to-4 chip-to-bit encoding**



Physical Layer Frames

- **Usually minimalist: "here's N bytes"**
  - Start symbol/preamble
  - Length field
  - Payload (link layer frame)

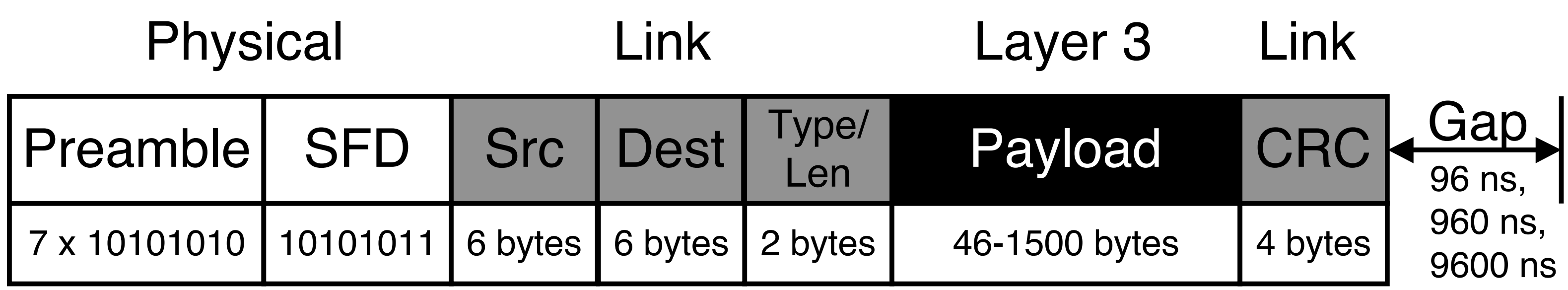


Link Layer Responsibilities

- **Single-hop addressing (e.g., Ethernet addresses)**
- **Media access control**
  - Link-layer congestion control
  - Collision detection/collision avoidance
- **Single-hop acknowledgements**

Ethernet: 802.3

- **Dominant wired LAN technology**
  - 10BASE5 (vampire taps)
  - 10BASE-T, 100BASE-TX, 1000BASE-T
- **Frame format:**



Ethernet Addressing

- **Each Ethernet card has a unique 48-bit ID**
  - Example: bramble
  - Example: market
- **24-bit organizationally unique identifier, 24-bit ID**
  - 0x000000-0x000009: Xerox
  - 0x0007e9: Intel (market.scs)
  - 0x001372: Dell (bramble09)
  - http://standards.ieee.org/regauth/oui/oui.txt

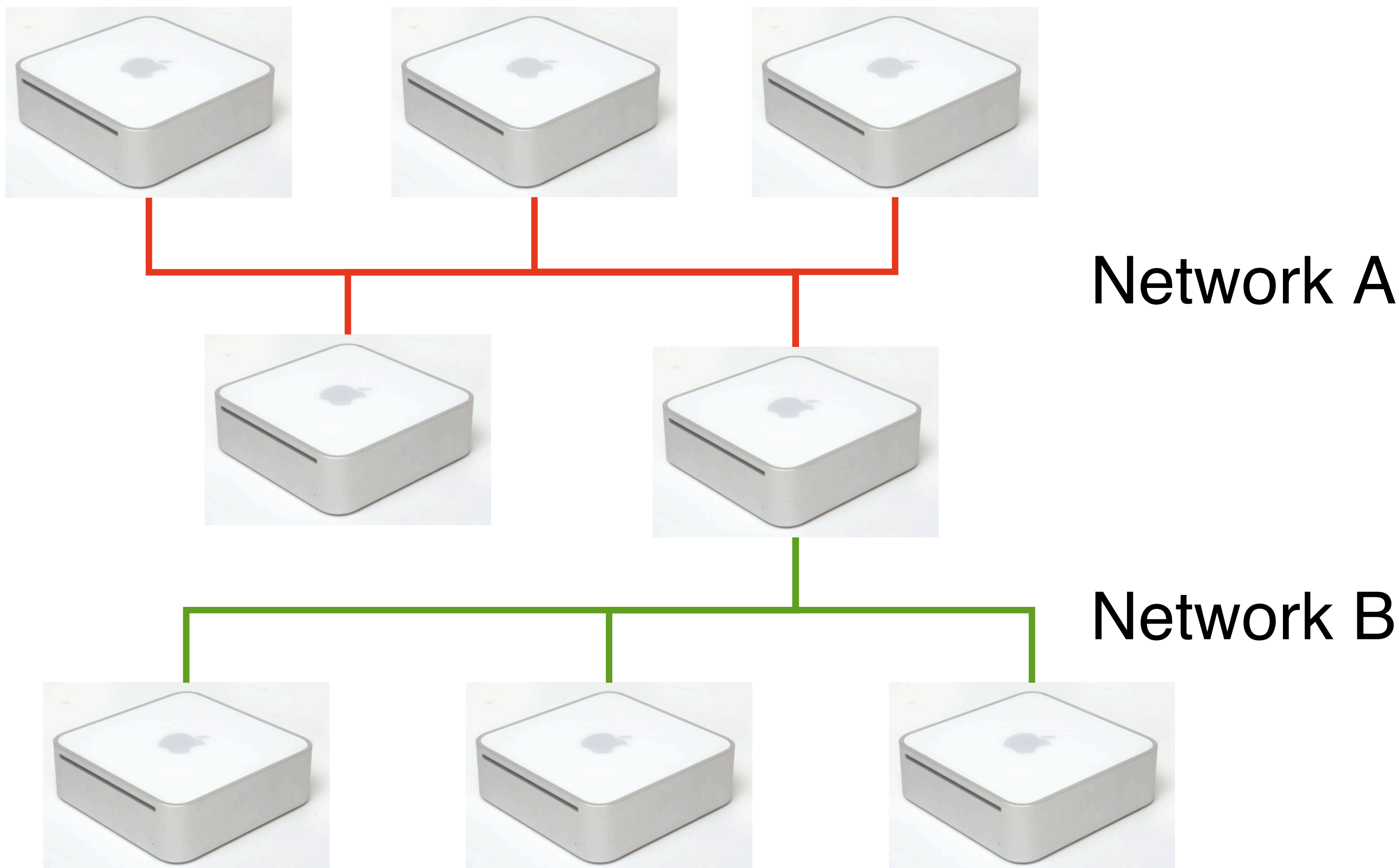
Media Access Control (MAC)

- **Link layer regulates access to a shared, physical medium**
- **If everyone talks at once, no-one hears anything**
- **Need to control when nodes send packets, to prevent collisions**
- **Variety of approaches**
  - **Time Division Multiple Access (TDMA)**
  - **Carrier Sense Multiple Access, Collision Detection (CSMA/CD)**
  - Carrier Sense Multiple Access, Collision Avoidance (CSMA/CA)
  - Request-to-send, clear-to-send (RTS/CTS)

MAC Goals

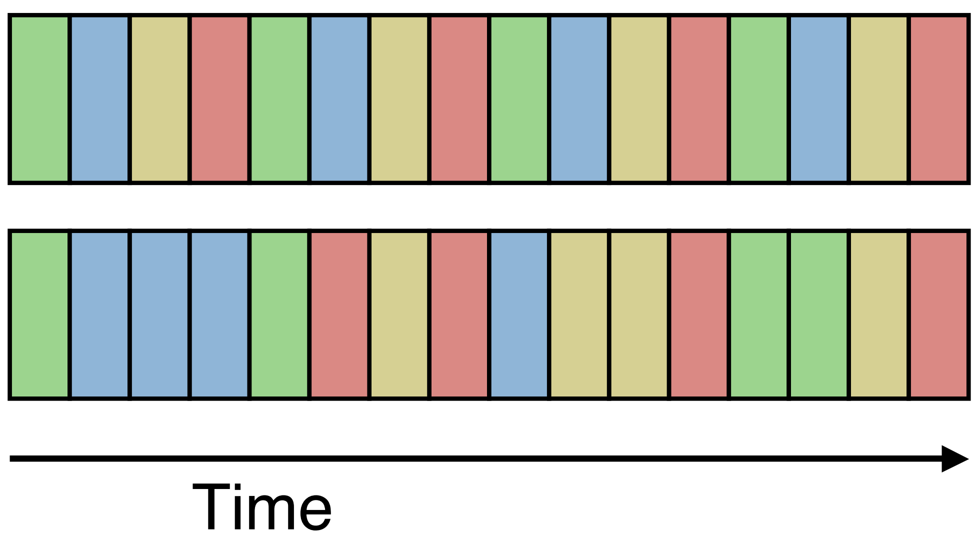
- Be able to use all of the link capacity
- One node can get 100%
- Multiple nodes can each get a share, don't collide

Conceptual Model of Wired Media Access



TDMA

- Divide time into slots, each device is allowed to transmit in some number of slots
- No collisions, when everyone transmits, link is fully utilized
- Single node cannot use all of the capacity ($\frac{1}{n}$)



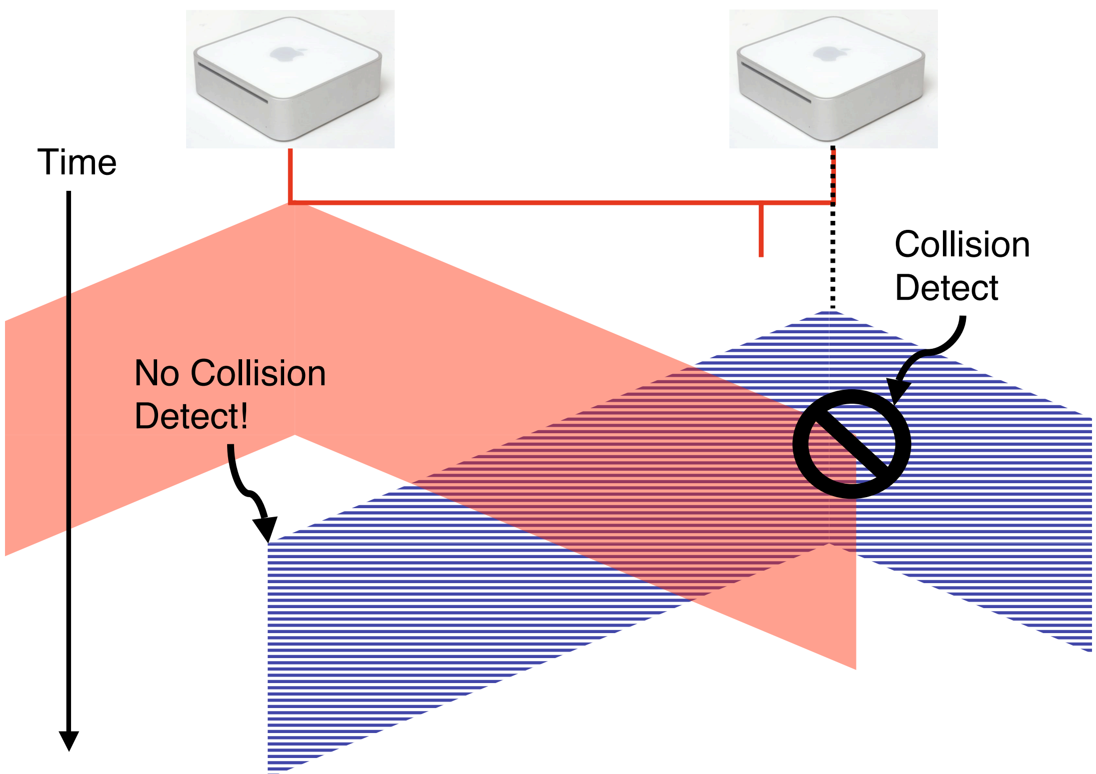
CSMA

- **Node senses the channel for activity**
- **Transmits if it thinks the channel is idle**
- **CSMA/CD: can detect if there is a collision, and back off**
  - Randomized
  - Grows exponentially on consecutive collisions C
  - $rand(0, 2^C) \cdot 512$ bit times
  - Drop when C grows large (in practice)

Collision Detect

- **Collision detection constrains maximum wire length and minimum frame length**
- **At least one node must detect a collision**
- **Hypothetical: propagation time is zero**
  - Can there be collisions?
  - RX/TX turnaround time

Violating Timing Constraints



Ethernet Efficiency

- **One node can use full link capacity**
- **Assuming RX/TX turnaround time of zero**
  - As $n \rightarrow \inf$, use = $\frac{1}{1+5t_{prop}/t_{trans}}$
  - If $t_{prop} \rightarrow 0$, efficiency approaches 1
  - If $t_{trans} \rightarrow \inf$, efficiency approaches 1
  - if $t_{prop} = t_{trans}$, efficiency approaches 16%.

Ethernet Capture Effect

- Exponential backoff leads to self-adaptive use of channel
- When a node succeeds, it transmits the next packet immediately
- Result: bursts of packets from single nodes

Ethernet Speeds

- **Network diameter limits:**
  - 10Mbps: 2800m
  - 100Mbps: 205m
  - Gigabit: 205m!
- **Gigabit Ethernet**
  - Uses more of the CAT5 wires (125 MHz · 8 signals)
  - Pad with dummy data (signal extension) for CD (512 bytes vs. bits)

Hubs vs. Switches

- Hub: connects multiple ethernet segments to act like a single segment (shared collision domain, physical layer connectivity)
- Switch: store and forward between segments (single collision domains, link layer connectivity)
- 10Gbps Ethernet is not a shared medium
- Very little Ethernet today is shared: collision detection never triggered (duplex, separate RX and TX wires)

Congestion Interaction

- Congestion can occur at layer 2 (collisions, high utilization)
- Congestion control can occur at layer 2 (backoff)
- Congestion can occur at layer 3 (packet drops)
- Congestion control can occur at layer 4 (rate adaptation)
- Interactions are non-trivial

ARP and DHCP, revisited

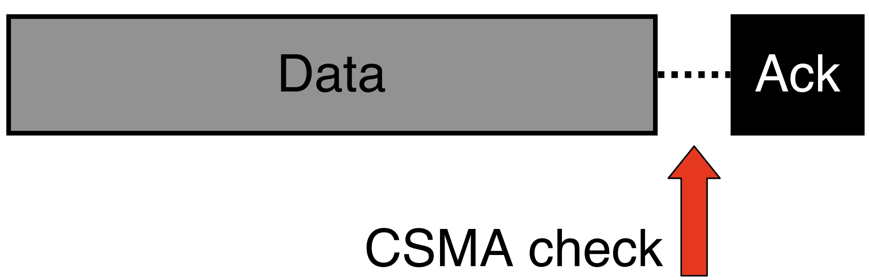
- **Lecture 3: DHCP allows a node to dynamically obtain an IP address, netmask, and gateway**
- **Lecture 3: Address Resolution Protocol maps IP addresses to link address**
- **Common exchange:**
  - Broadcast DHCP discover
  - Receive gateway IP address IP_G, local address IP_A
  - ARP gateway address IP_G (announcing self), receive $Ether_G$
  - Send packet to IP_B using $Ether_G$ as next hop
- **What if node is on the subnet?**

Layer 2 Acknowledgements

- **Common in wireless (more on this in lecture 12)**
- **If layer 2 successfully receives a frame, it immediately sends an ACK**
- **Assumes** $T_{prop} << T_{trans}$
- **Hypothetical situation:**
  - Let's say a router won't send an ACK if it drops the packet
  - Let's say a router will keep on retrying a packet until it is ACKed
  - Do we still need end-to-end ACKs?

Ack Effect on CSMA

- Layer 2 acks require two channel checks
- Want to make sure we don't check between packet and ACK



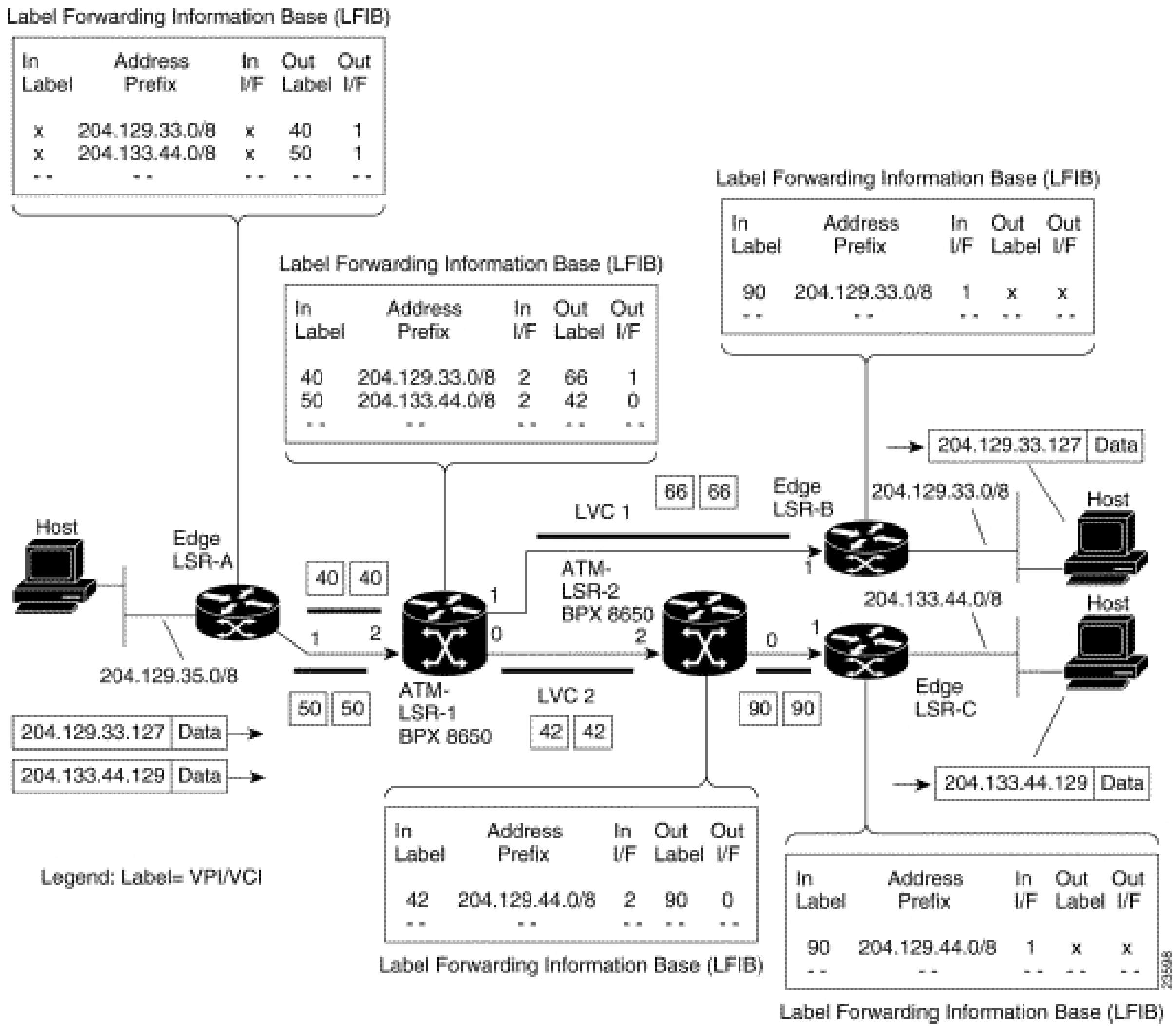
MPLS

- **Multiprotocol Label Switching**
- **Sits between layer 2 and 3 ("layer 2.5")**
- **Prepend a "label" to frame**
- **Switch in terms of label, rather than destination address**
  - Two packets to the same destination can take different paths
  - Separating addressing from forwarding enables traffic engineering
  - Label changes from input to output

MLPS Architecture

- **Label Edge Router (LER)**
- **Label Switch Router (LSR)**
- **Label Distribution Protocol (LDP)**
- **Label Forwarding Information Base (LFIB)**

Example MPLS (from Cisco)



Where Layer 2 is Going