Link Layer

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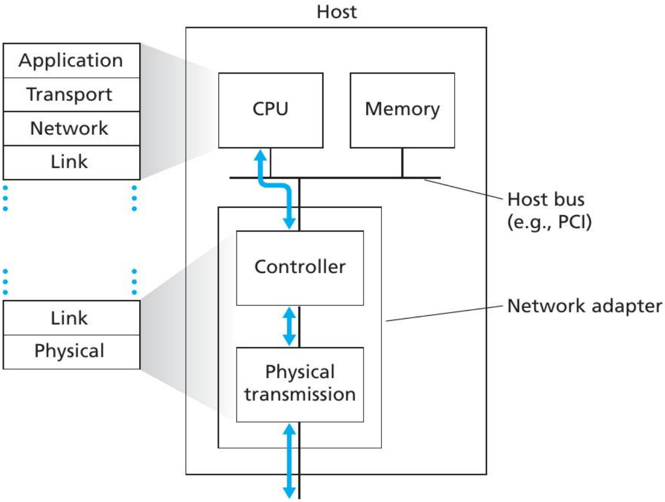
Link Layer

- Moves datagrams node-to-node
- Link layer protocols: Ethernet, IEEE 802.11 (Wirelss LAN/ Wifi), Token-ring, PPP
- Services
  - Framing
  - Link-access
  - Reliable-delivery
  - Flow Control
  - Error detection
  - Error correction
  - Half-duplex and Full-duplex

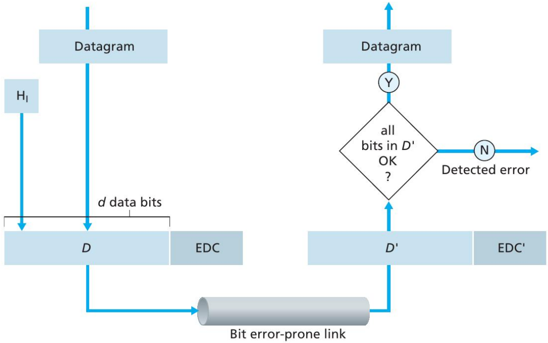
Where is the Link layer implemented



Link Layer Implementation

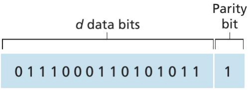
- Software components
  - receiving datagram from network layer
  - assembling link-layer addressing information
  - activating the controller hardware
- Hardware components
  - transfer frame from one adapter to another adapter
  - error detection and correction

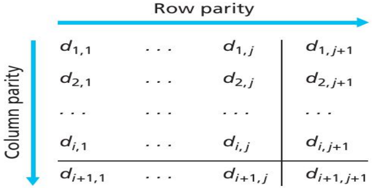
Error Detection and Correction

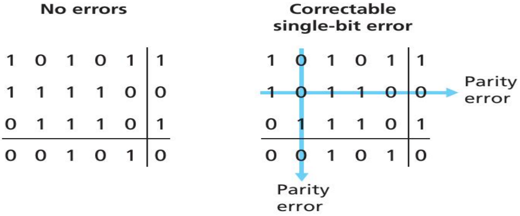


- EDC: error detection and correction bits
- Parity checks
- Checksumming methods
- Cyclic redundancy checks (CRC)

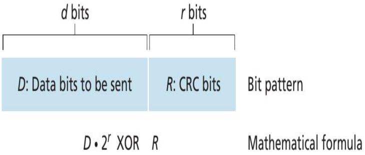
Parity Checks







Cyclic Redundancy Check (CRC)



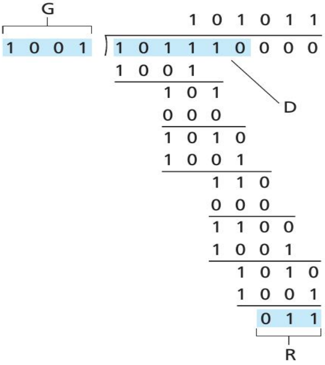
- Bit string can be viewed as a polynomial
- Sender and receiver agree on $r + 1$ bit pattern known as generator G
- Most significant bit of G should be 1
- Given data D, sender will choose additional r bits, R and append them to D
- The resulting $d + r$ bit pattern should be divisible by G.
- CRC calculations are done in modulo-2 arithmetic without carries and borrows (XOR operations)

CRC

- Find R such that there exists n that satisfies

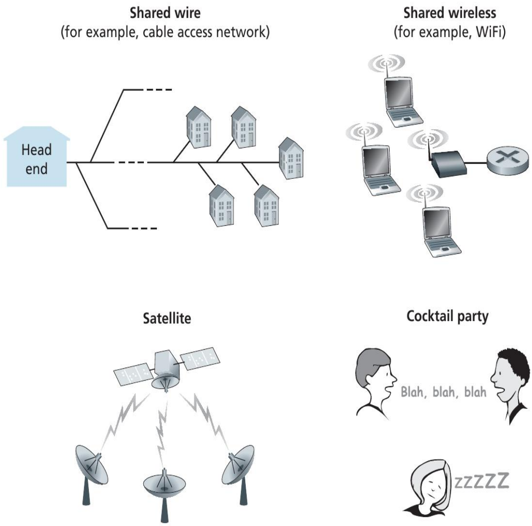
$$D.2^r \text{XOR } R = nG$$

- $R = \text{remainder } \frac{D.2^r}{G}$
- Example:



- International standards define 8-, 16-, 24-, 32-bit generators.

Multiple Access Channels



Multiple Access Protocols

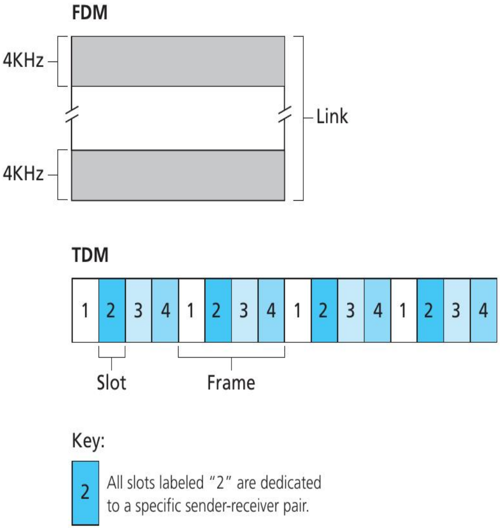
- If multiple nodes transmit frames at same time, packets collide!
- Channel partitioning protocols
  - TDM
  - FDM
- Random access protocols
  - Pure ALOHA
  - Slotted ALOHA
  - Carrier sense multiple access (CSMA), CSMA/CD
- Taking-turns Protocols
  - Polling protocol
  - Token-passing Protocol

Multiple Access Protocols

Desirable characteristics of MAC protocols on a broadcast channel of rate R bps:

- When only one node is has frames to send, that node should have throughput of R bps
- When M nodes have frames to send, each node should have throughput of R/M bps
- Protocol is decentralized
- Protocol is simple and inexpensive to implement.

Channel Partitioning Protocol



Drawbacks of TDM and FDM

- When only one node is active, it gets throughput of R/N bps.
- Node has to wait for its turn!
- Code division multiple access (CDMA)

Slotted ALOHA

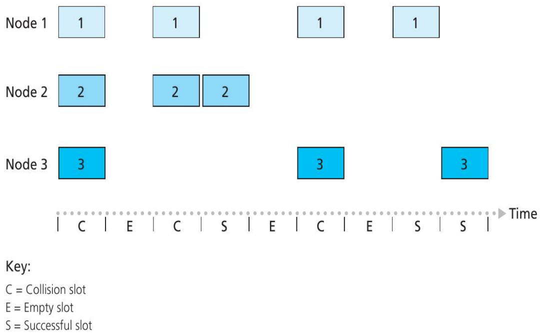
Model and assumptions

- All frame consists of exactly L bits
- Time is divided into slots of size L/R seconds
- Nodes start to transmit frames only at the beginning of slots
- Nodes are synchronized
- If two or more frames collide in a slot, then all nodes can detect the collision before the slot ends

Slotted ALOHA

- When a node has fresh frame to send, it waits for beginning of the next slot and transmits the frame in the slot
- If there is no collision, the node has successfully transmitted the packet and no need to retransmit
- If there is a collision, the node detects it before end of the slot. The node retransmits the frame in each subsequent slot with probability p until the frame is transmitted without a collision

Slotted ALOHA: Drawbacks



- Collisions
- Empty spaces
- Efficiency: fraction of successful slots

Efficiency of Slotted ALOHA

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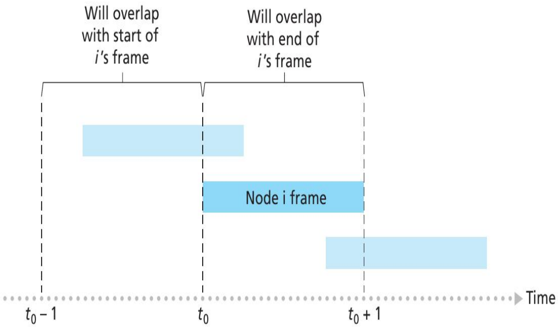
- As $N \to \infty$, Efficiency $\to \frac{1}{e}$
- Only 37% of slots are used for successful transmission! a similar analysis show that 37% slots are empty and remaining slots have collisions.

Pure ALOHA

- Unslotted time axis
- Transmit a frame as soon as it arrives
- If there is a collision, node retransmits the frame immediately with probability p. Otherwise, wait for frame transmission time.
- After this wait, it then retransmits the frame with probability p or waits for another frame time with probability $1 - p$.

Pure ALOHA

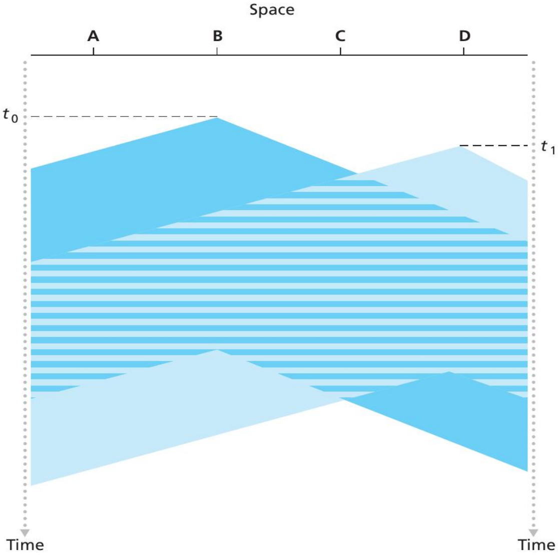


- Efficiency : $\frac{1}{2e}$

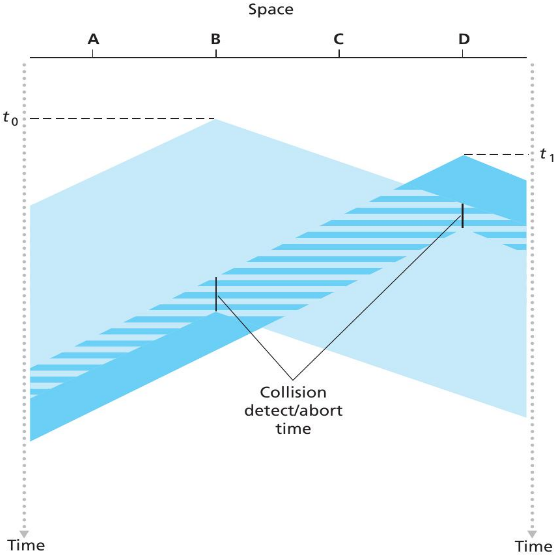
Carrier Sense Multiple Access

- Listen before speaking: carrier sensing
- If channel is busy, nodes 'backs off' a random amount of time and then senses again.
- If the channel is idle, node transmits the frame
- collision detection: If someone else begins talking at the same time, stop talking

CSMA



CSMA/CD

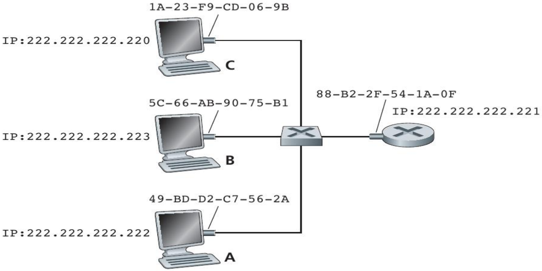


Taking-Turns Protocol

- Polling Protocol
  - Master node polls each of the nodes in a round-robin fashion
  - Polling delay
  - Master node may fail!
- Token-passing Protocol
  - A special-purpose frame known as a token is exchanged among the nodes
  - A node with token can transmit a maximum number of frames and send the token to next node
  - A node holds token only if it has frames to transmit
  - Very efficient.

Link-Layer Addressing

- Are IP addresses really unique?
- Node's adapter has a link-layer address
- Also known as LAN address or Physical address or MAC address
- MAC address
  - Managed by IEEE
  - Flat structure
  - Broadcast address : FF-FF-FF-FF-FF-FF



Address Resolution Protocol

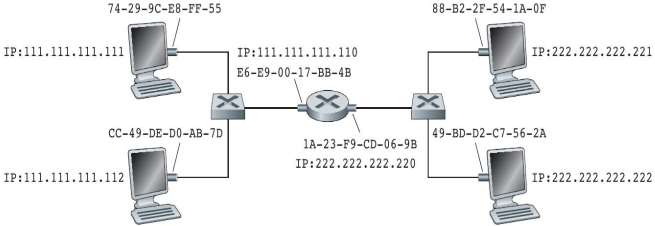
- Sending node has to provide it's link layer not only IP address of destination but also destination's MAC address
- How does the source node determines the MAC address of it's destination?
- Address Resolution Protocol (ARP)
- Analogous to DNS

IP Address	MAC Address	TTL
222.222.222.221	88-B2-2F-54-1A-0F	13:45:00
222.222.222.223	5C-66-AB-90-75-B1	13:52:00

ARP

- Suppose node 222.222.222.220 wants to send a datagram to 222.222.222.222
- If ARP does not have an entry about the destination, it first constructs an ARP query packet.
- Query:
  - IP addresses of sender and receiver
  - sender's MAC address
  - Broadcast MAC address
- Encapsulated in a link-layer frame and sent in to the subnet
- Each node checks to see if its IP address matches with the destination address
- The one node with a match sends a ARP response packet with desired mapping

Sending a Datagram Off the Subnet



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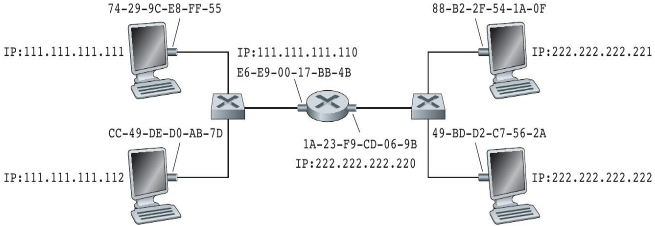

- Destination MAC address should be that of router's MAC on subnet 1

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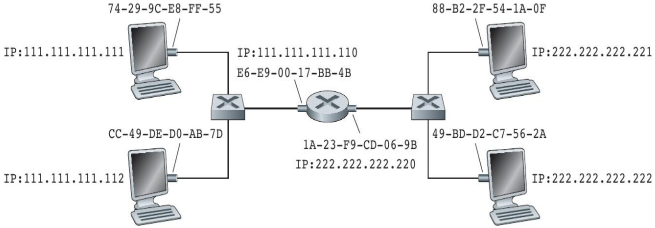

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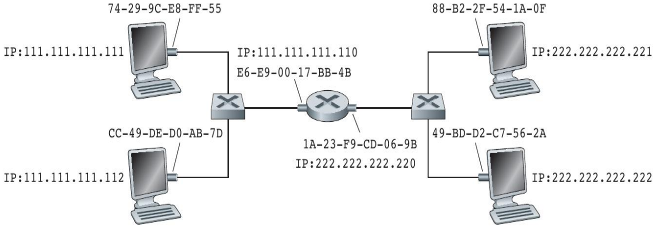
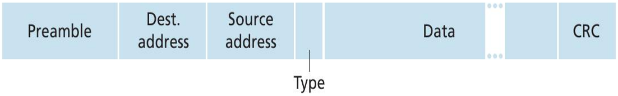


- Destination MAC address should be that of router's MAC on subnet 1
- The router determines the correct interface based on destination IP address
- After processing, router encapsulates the datagram in a frame with destination MAC address.

Ethernet



- Popular wired LAN technology
- Data field: minimum length is 46 bytes and maximum length is 1500 bytes
- Type field: specifies the protocol at network layer
- Preamble:
  - 8-bytes
  - first byte has value 10101010
  - last byte has value 10101011
  - to synchronize the clocks

Ethernet's MAC Protocol: CSMA/CD

- The adapter takes datagram from network layer and prepares Ethernet frame and keeps in adapter's buffer
- If the channel is idle for 96 bit times, it starts to transmit the frame
- If the channel is busy, it waits until it senses no signal energy plus 96 bit times and then starts to transmit the frame
- If the adapter transmits the entire frame without detecting collision, the adapter is finished with the frame
- If the adapter detects a collision, it stops transmitting its frame and instead transmits a 48-bit jam signal

Ethernet's MAC Protocol: CSMA/CD

- After transmitting the jam signal, the adapter enters an exponential backoff phase.
- Exponential Backoff: After experiencing nth collision in a row for a frame, the adapter chooses a value for K at random from $\{0, 1, 2, \ldots, 2^m - 1\}$ for $m = \min(n, 10)$. The adapter then waits $K.512$ bit times and then returns to step 2.
- d_{prop} is maximum time it takes signal energy to propagate between any two adapters
- d_{trans} is the time to transmit a maximum size Ethernet frame.
- Efficiency $= \frac{1}{1+5d_{prop}/d_{trans}}$

PPP: Point-to Point Protocol

- Requirements of PPP:
  - packet framing
  - multiple network layer protocols
  - multiple types of links
  - error detection
- Frame: flag, address, and control bits are always fixed.

Flag	Address		Control			Flag
01111110	11111111	00000011	Protocol	Data	FCS	01111110
1 byte	1 byte	1 byte	1 or 2 byte	Variable	2 or 4 byte	

PPP frame Format

Byte Stuffing

- flag bits indicate the beginning and ending of a frame
- What if the flag bit pattern occurs in the data?
- PPP defines a control escape byte 01111101
- If a flag bit pattern occurs in the data, PPP precedes that instance with control escape byte
- If control escape byte to occur in the data, PPP precedes that with control escape byte.
- This process is known as byte stuffing.

Link-layer Switch

- Forwarding: Switch function that determines an interface to which a frame should be directed

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- Details on Link-layer switches (Section 5.6) are left for self study.