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

Link Layer

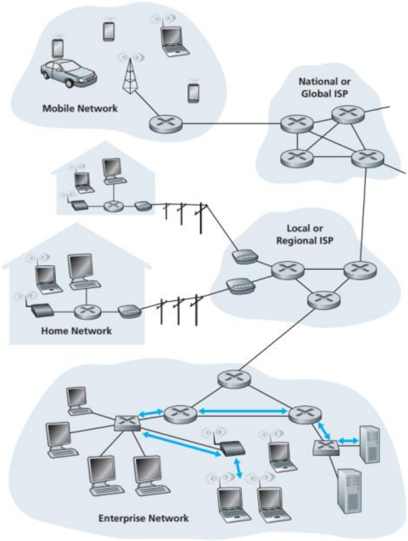
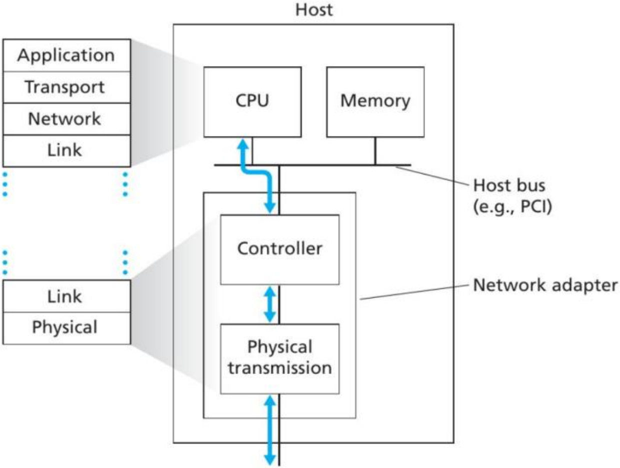


Figure 5.1 ♦ Six link-layer hops between wireless host and server

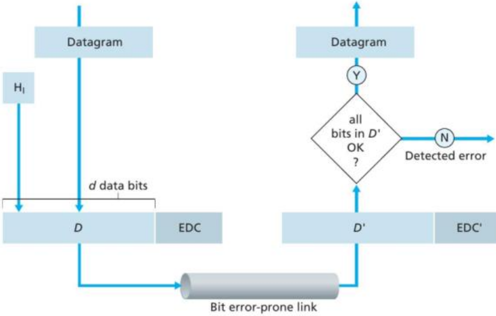
Where is the Link layer implemented



Link Layer Implementation

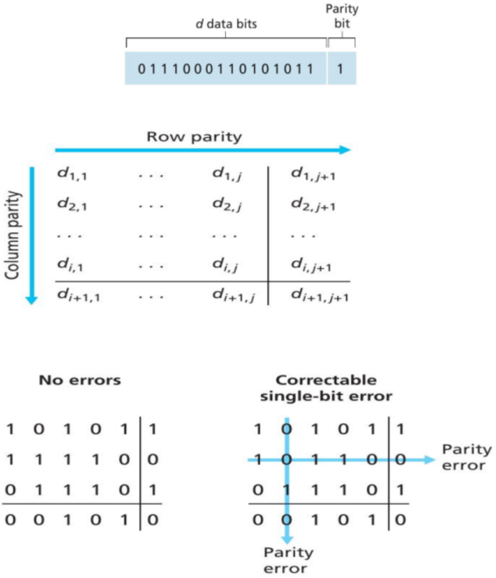
- Software components
  - receiving datagram from network layer
  - assembling link-layer addressing information
  - activating the controller hardware
- Hardware components
  - transfer frame from one adapter to another adapter
  - error detection and correction

Error Detection and Correction

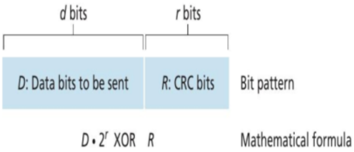


- EDC: error detection and correction bits
- Parity checks
- Checksumming methods
- Cyclic redundancy checks (CRC)

Parity Checks



Cyclic Redundancy Check (CRC)



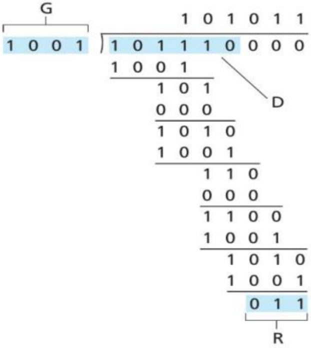
- Bit string can be viewed as a polynomial
- Sender and receiver agree on $r+1$ bit pattern known as generator G
- Most significant bit of G should be 1
- Given data D, sender will choose additional r bits, R and append them to D
- The resulting $d+r$ bit pattern should be divisible by G.
- CRC calculations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

CRC

- Find R such that there exists n that satisfies

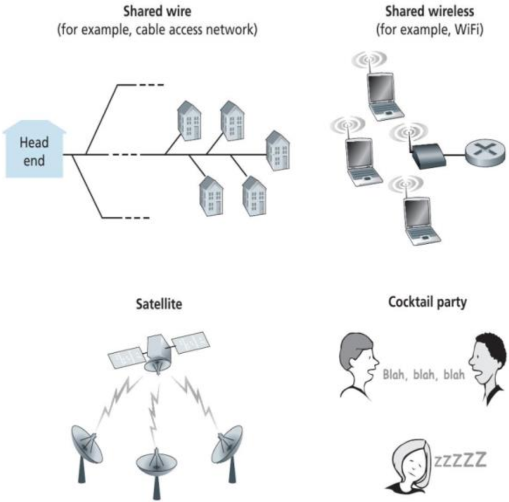
$$D.2^r \text{XOR } R = nG$$

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



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

Multiple Access Channels



Multiple Access Protocols

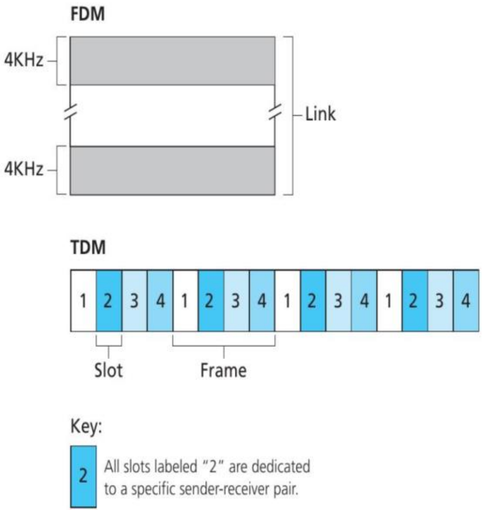
- If multiple nodes transmit frames at same time, packets collide!
- Channel partitioning protocols
  - TDM
  - FDM
- Random access protocols
  - Pure ALOHA
  - Slotted ALOHA
  - Carrier sense multiple access (CSMA), CSMA/CD
- Taking-turns Protocols
  - Polling protocol
  - Token-passing Protocol

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

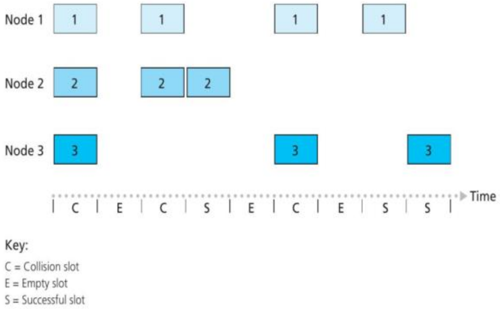
Model and assumptions

- 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

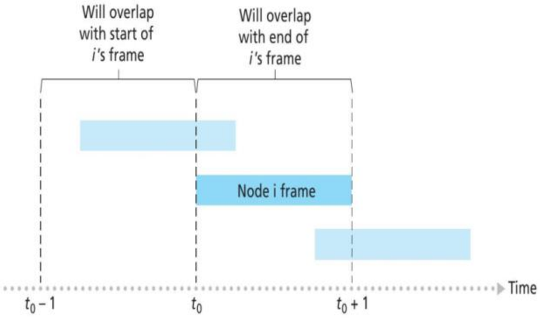
Efficiency of Slotted ALOHA

- Assume that each node always has a frame to send
- Probability that only one node (out of N) transmits
- $Np(1-p)^{N-1}$
- Efficiency $= Np(1-p)^{N-1}$
- Find p that maximizes efficiency, let it be p^*
- 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

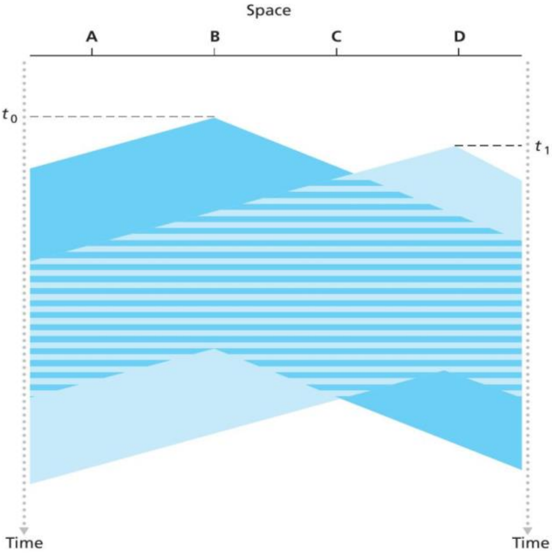


- Efficiency : $\frac{1}{2e}$

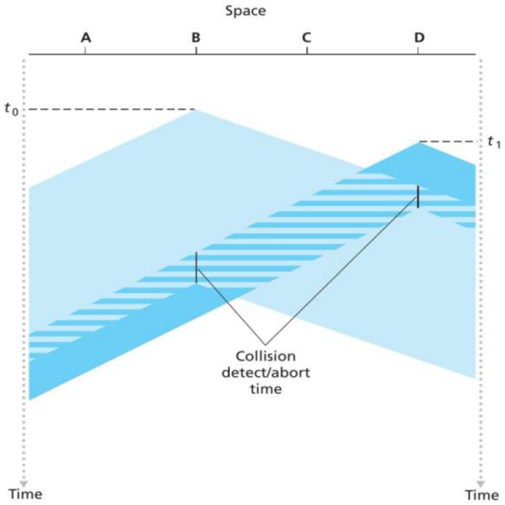
Carrier Sense Multiple Access

- 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

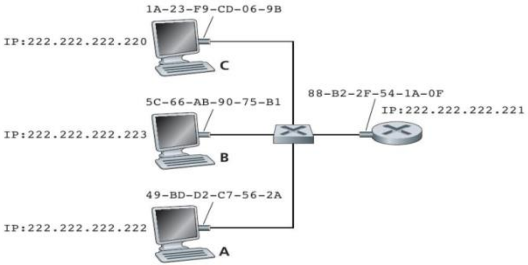


Taking-Turns Protocol

- 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

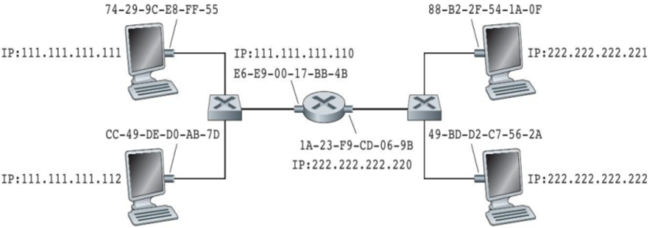
- Sending node has to provide it's link layer not only IP address of destination but also destination's MAC address
- How does the source node determines the MAC address of it's destination?
- Address Resolution Protocol (ARP)
- Analogous to DNS

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

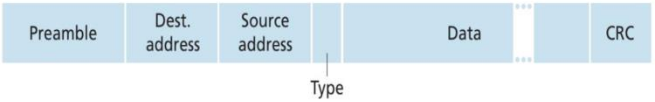
- Suppose node 222.222.222.220 wants to send a datagram to 222.222.222.222
- If ARP does not have an entry about the destination, it first constructs an ARP query packet.
- Query:
  - IP addresses of sender and receiver
  - sender's MAC address
  - Broadcast MAC address
- Encapsulated in a link-layer 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



- 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 $= \frac{1}{1+5d_{prop}/d_{trans}}$

Wireless Network

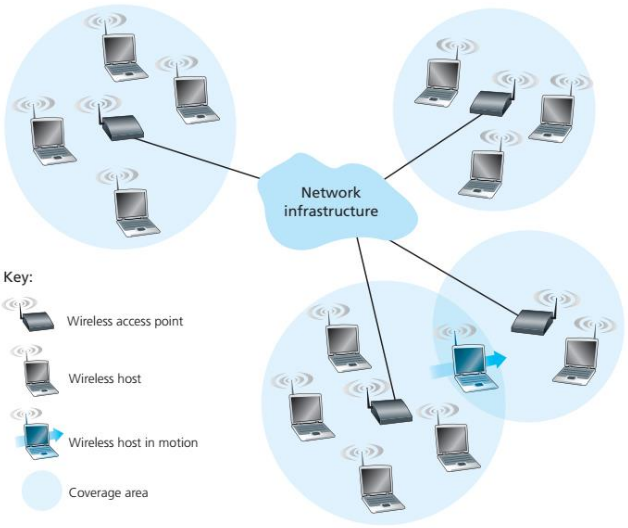


Figure 6.1 ♦ Elements of a wireless network

Wireless Network

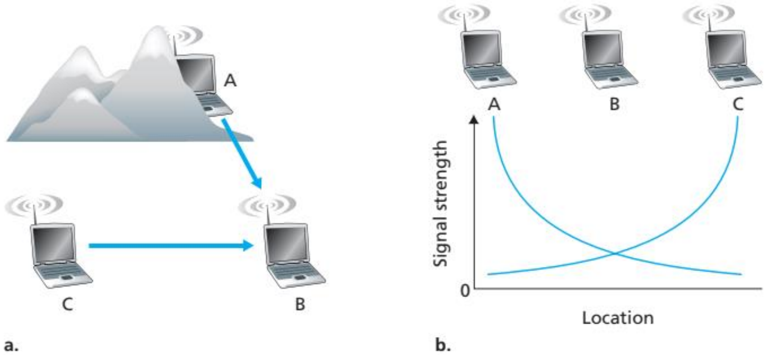


Figure 6.4 ♦ Hidden terminal problem caused by obstacle (a) and fading (b)

Wi-Fi

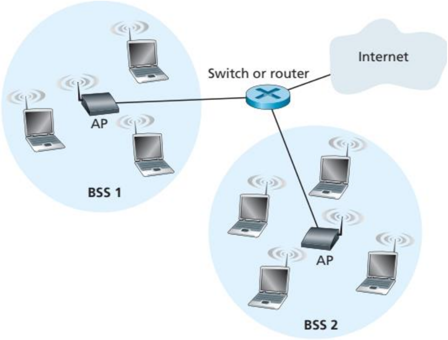
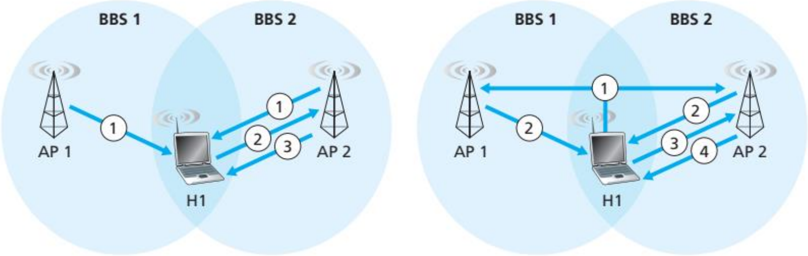


Figure 6.7 ♦ IEEE 802.11 LAN architecture

An IEEE 802.11 ad hoc network

Wi-Fi

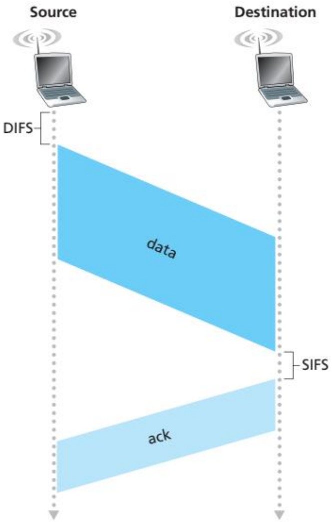


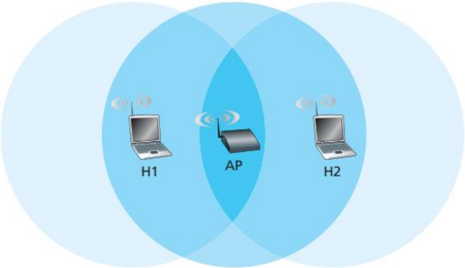
a. **Passive scanning**
1. Beacon frames sent from APs
2. Association Request frame sent: H1 to selected AP
3. Association Response frame sent: Selected AP to H1

a. **Active scanning**
1. Probe Request frame broadcast from H1
2. Probes Response frame sent from APs
3. Association Request frame sent: H1 to selected AP
4. Association Response frame sent: Selected AP to H1

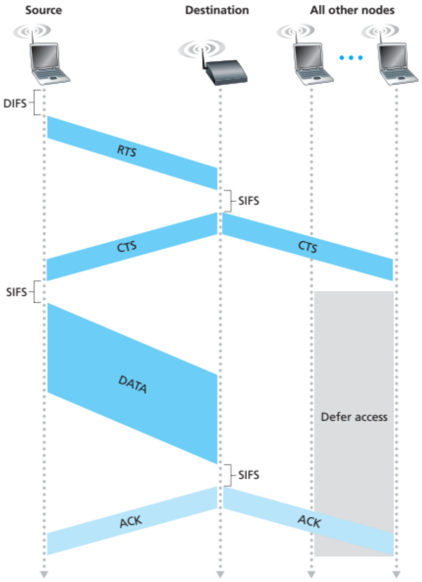
Figure 6.9 ♦ Active and passive scanning for access points

Wi-Fi





Wi-Fi



Source
Destination
All other nodes
DIFS
RTS
SIFS
CTS
CTS
SIFS
DATA
Defer access
SIFS
ACK
ACK

P3. Suppose the information portion of a packet (*D* in Figure 5.3) contains 10 bytes consisting of the 8-bit unsigned binary ASCII representation of string "Networking." Compute the Internet checksum for this data.

P5. Consider the 7-bit generator, G=10011, and suppose that D has the value 1010101010. What is the value of R?

Tutorial_Link_Layer

P8. In Section 5.3, we provided an outline of the derivation of the efficiency of slotted ALOHA. In this problem we'll complete the derivation.

a. Recall that when there are N active nodes, the efficiency of slotted ALOHA is $Np(1-p)^{N-1}$. Find the value of p that maximizes this expression.

b. Using the value of p found in (a), find the efficiency of slotted ALOHA by letting N approach infinity. *Hint*: $(1 - 1/N)^N$ approaches $1/e$ as N approaches infinity.

Tutorial_Link_Layer

P17. Recall that with the CSMA/CD protocol, the adapter waits $K \cdot 512$ bit times after a collision, where K is drawn randomly. For $K = 100$, how long does the adapter wait until returning to Step 2 for a 10 Mbps broadcast channel? For a 100 Mbps broadcast channel?