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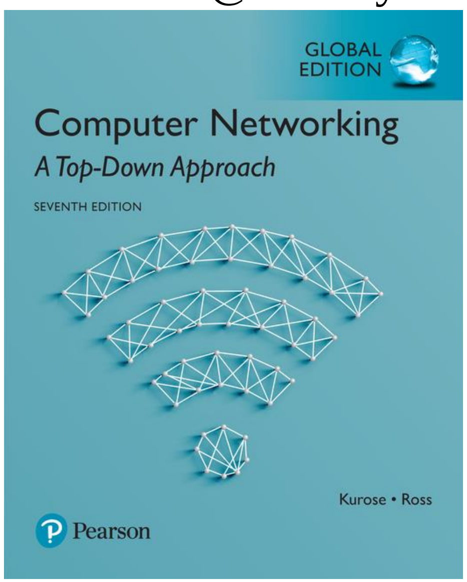
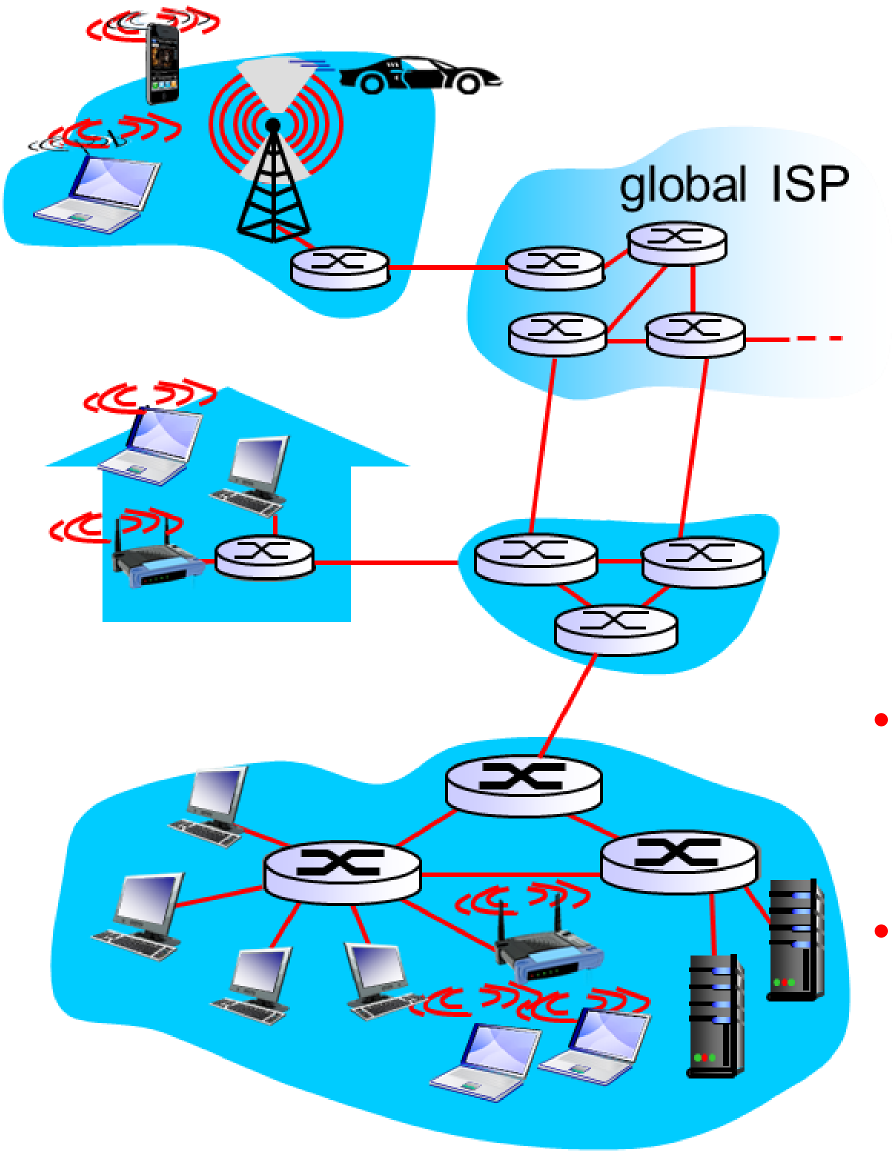


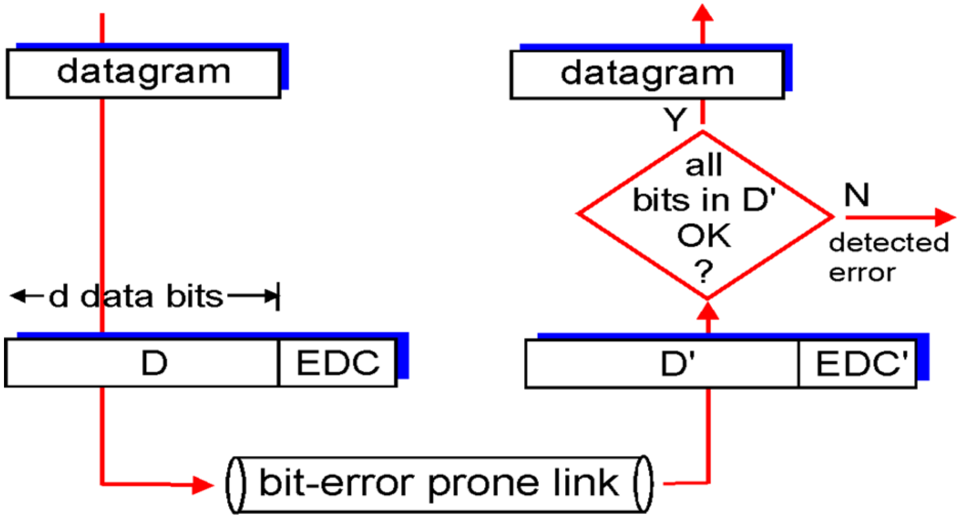
Computer Networking: A Top-down Approach, 7th edition.
Jim Kurose, Keith Ross
Pearson



- **Node**
  - Examples:
    - Host
    - Router
    - Switch
- **Link**
  - Communication channel that connect adjacent nodes
  - Examples:
    - Wired link
    - Wireless link
- **Frame**
  - Layer-2 packet
  - Encapsulate datagram
- **Data Link**
  - Provide communication channel between two neighbor nodes to transfer frame
  - Example: 802.11 (or WiFi)

- **Error Detection and Correction**
    - Error is caused by signal attenuation and noise
    - Receiver node detect error
        - Inform sender node to retransmit the frame, or
        - Correct the bit error
- **Medium Access Control (MAC)**
    - Coordinate which node transmit next
        - Why need MAC?
            - Many nodes share a link, if more than one node send at a time, collision happen!

- **EDC**
  - Error Detection and Correction bits (Redundancy)
- **D**
  - Data protected by error checking, including MAC header

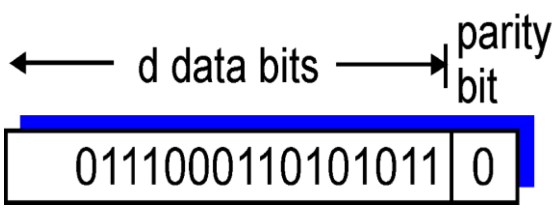


- Error detection not 100% reliable
  - May miss some errors
  - Larger EDC field provides better detection and correction

- Three technique
  - Parity check
  - Checksumming
  - Cyclic Redundancy Check (CRC)

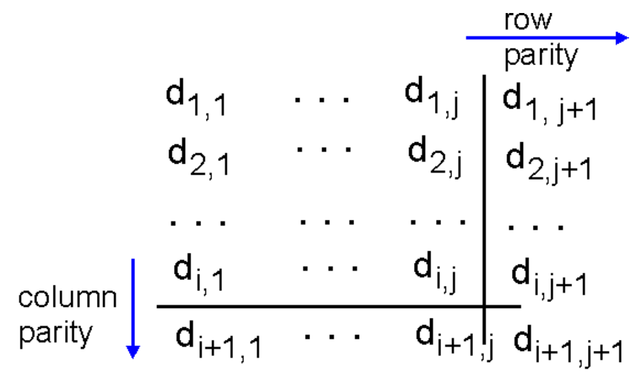
6.2 Parity Check

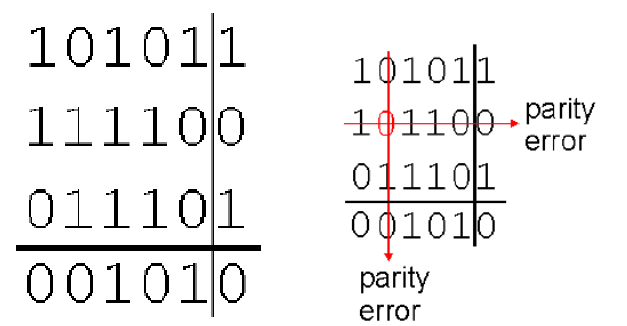
- **Single Bit Parity**
  - Detect single bit error
    - Data: *d* bits
    - Parity: 1 bit
  - Two types
    - Even parity
      - Total number of 1 in *d*+1 bits is even
    - Odd parity
      - Total number of 1 in *d*+1 bits is odd
      - E.g.:



  - Disadvantage
    - Cannot detect even number of bit error

- **Two-dimensional Parity**
  - Detect and *correct* single bit error
    - Data: *d* bits
      - Divided into *i* rows and *j* columns
    - Parity: *i* + *j* + 1 bits
      - Computed for each row and column
  - A single bit error cause errors to both row and column
    - Locate the bit error at the intersection of row and column





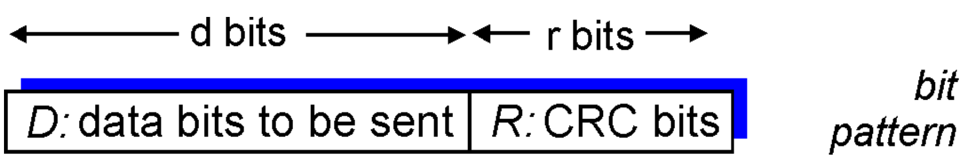
no errors

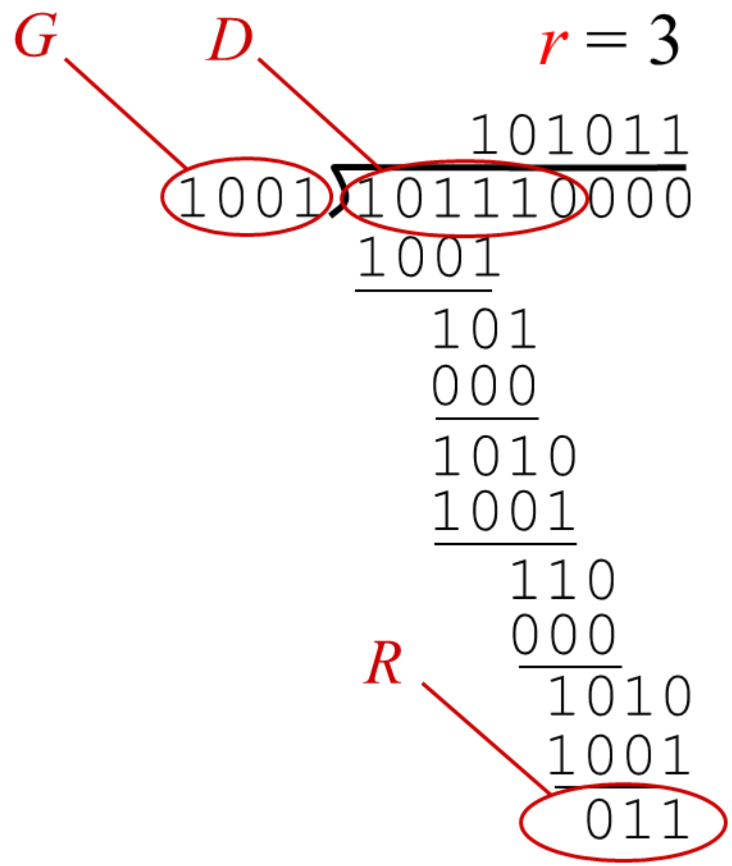
correctable single bit error

6.2 Cyclic Redundancy Check (CRC)

D	• Data bits to be sent • *d* bits
R	• CRC bits to be sent • *r* bits
G	• Most significant bit must be 1

D + *R*	• Must be exactly divisible by *G*
	  • So, no remainder
	  • If there is remainder, error detected!





- Example
  - D = 101110, d = 6, G = 1001, r = 3
  - The calculation show that, the 9 bits transmitted are 101110 011
  - Question:
    - Divide $D + R$ by G, what is the remainder? Do you think there is an error?

6.3 Multiple Access Links and Protocols

- Two Type of link
  - **Point-to-Point**
    - A sender transmit to a receiver
    - E.g.:
      - Between Ethernet switch and host
  - **Broadcast**
    - Multiple senders transmit in shared medium
      - A transmission can be received by other receivers
    - E.g.:
      - 802.11 wireless LAN

shared wire (e.g., cabled Ethernet)

shared RF (e.g., 802.11 WiFi)

humans at a cocktail party (shared air, acoustical)

- Broadcast
  - When more than one node transmit signal at the same time
    - Collision occur
- **Medium Access Control (MAC) protocol**
  - coordinate which node transmit next to prevent collision in broadcast

6.3 Multiple Access Links and Protocols

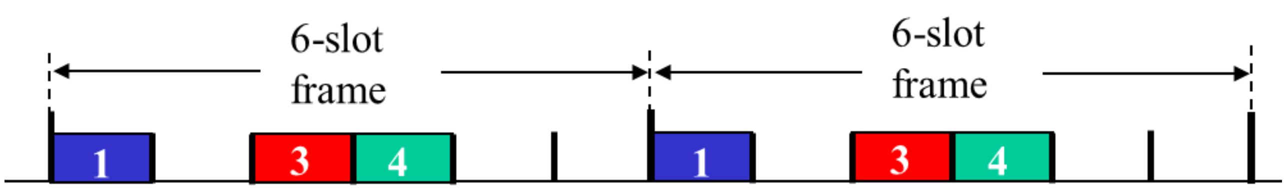
- Medium Access Control (MAC) Protocol
  - Three category
    - **Channel Partitioning Protocol**
      - Divide channel into smaller parts (E.g.: time slot, frequency), allocate the part to node
    - **Random Access Protocol**
      - Detect collision and recover from collision
    - **Taking-turn Protocol**
      - Nodes take turn to transmit

- Medium Access Control (MAC) Protocol
  - Three category
    - **Channel Partitioning Protocol**
      - Two type
        - **Time-Division Multiplexing (TDM)**
        - **Frequency-Division Multiplexing (FDM)**
    - **Random Access Protocol**
      - Three type
        - **Slotted ALOHA**
        - **Carrier Sense multiple Access (CSMA)**
        - **CSMA with Collision Detection (CSMA/CD)**
          - Used by Ethernet
    - **Taking-turn Protocol**
      - Two type
        - **Polling protocol**
        - **Token-passing protocol**

6.3 Channel Partitioning Protocols: Time-Division Multiplexing (TDM)

- Time-Division Multiplexing (TDM)
  - Time is divided into **Time Frame**
    - Frame is divided into **Time Slot**
      - Assign each time slot to one of the *N* nodes for transmission
      - Unused slot is wasted
  - Node
    - Access to time slot in round
    - E.g.:
      - 6 nodes
      - Node 1, 3, 4 transmit

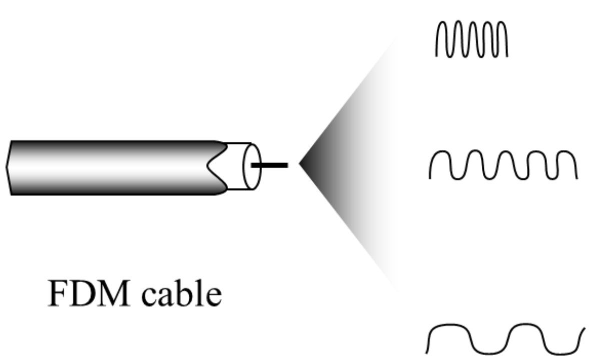
- Advantage
  - Reduce collision
  - Fair
    - Let channel bandwidth is *R* bps, number of time slots is *N*
    - Each node get *R*/*N* bps
- Disadvantage
  - Unused slot is wasted, and cannot be used by other nodes
  - Node must wait for its allocated time slot to transmit
  - All nodes must be time synchronized

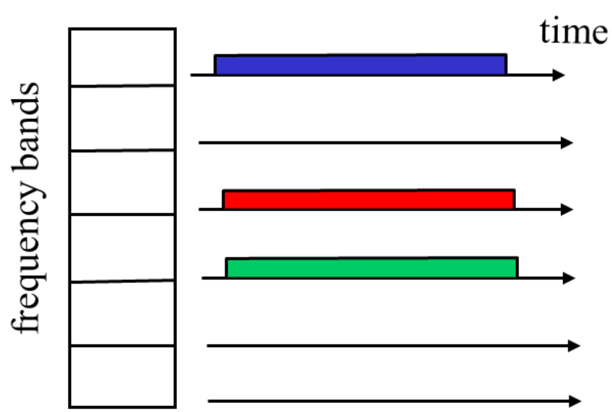


6.3 Channel Partitioning Protocols: Frequency-Division Multiplexing (FDM)

- Frequency-Division Multiplexing (FDM)
  - Channel bandwidth is *R* bps is divided into different **bands**
    - Each band has bandwidth *R*/*N* bps
    - Assign each band to one of the *N* nodes for transmission
    - Unused band is wasted
  - Node
    - Access to an allocated band
    - E.g.:
      - 6 nodes
      - Node 1, 3, 4 transmit

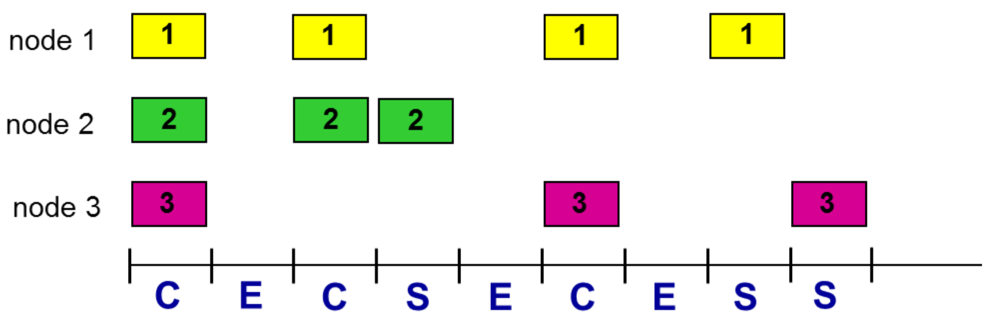
- Advantage
  - Reduce collision
  - Fair
    - Let channel bandwidth is *R* bps, number of bands is *N*
    - Each node get *R*/*N* bps
- Disadvantage
  - Unused band is wasted, and cannot be used by other nodes
  - Node cannot transmit more than *R*/*N* bps





6.3 Random Access Protocols: Slotted ALOHA

- Slotted ALOHA
  - Time is divided into **Time Frame**
    - Frame is divided into **Time Slot**
      - *NEVER* assign each time slot to one of the *N* nodes for transmission
      - Node access to time slot randomly
        - If collision, retransmit again with probability *p*
      - Unused slot is wasted
  - Node
    - Access to time slot in round
    - E.g.: 3 nodes
      - C = collision, E = wasted, S = successful transmission
      - For successful transmission, only one node can transmit in a time slot



- Advantage
  - Node need NOT wait for its allocated time slot to transmit
    - Can transmit at full rate *R* bps
  - Reduce collision
    - If collision, retransmit again with probability *p*
  - Fair
    - If collision, retransmit again with a fair probability *p*
- Disadvantage
  - Unused slot is wasted
  - All nodes must be time synchronized

6.3 Random Access Protocols: Slotted ALOHA

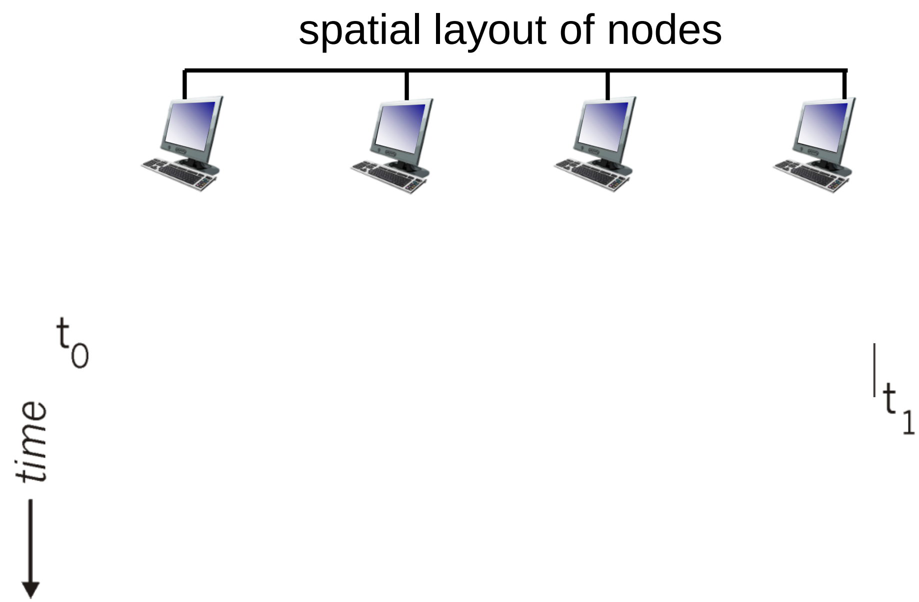
- Slotted ALOHA
  - Efficiency
    - Long-run percentage of time slots with successful transmissions
    - Assumption
      - Many nodes want to transmit at all time
    - What is the efficiency of Slotted ALOHA?
      - Number of nodes, N
      - Probability that a node transmit in a time slot, p
      - Probability that a node do NOT transmit in a time slot, $1-p$
        - Probability that N-1 nodes do NOT transmit in a time slot, $(1-p)^{N-1}$
      - Probability of a node's successful transmission, $p(1-p)^{N-1}$
      - Efficiency

        = Probability of N nodes' successful transmission

        $= Np(1-p)^{N-1}$

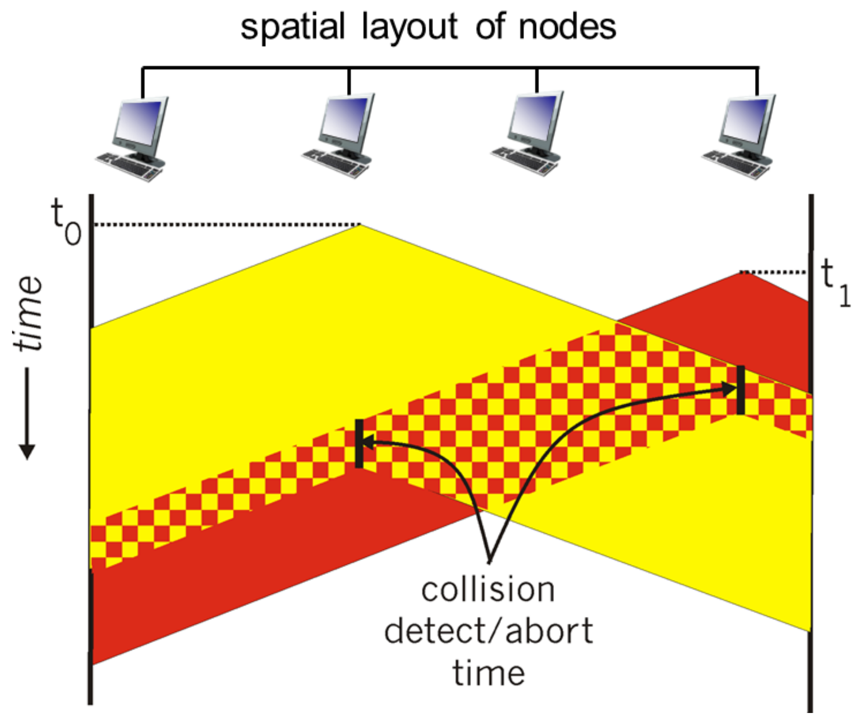
6.3 Random Access Protocols: Carrier Sense Multiple Access (CSMA)

- Carrier Sense Multiple Access (CSMA)
  - Sense channel before transmission
    - If channel is sensed idle
      - Transmit frame
    - If channel is sensed busy
      - Defer transmission
  - Collision can still occur
    - Propagation delay cause two nodes unable to hear each other immediately
    - Longer propagation delay cause more collision
    - At t_0, a node transmit. At t_1, the signal has not arrive a second node yet due to propagation delay. The second node transmit. Collision occur
  - Disadvantage
    - No collision detection. Continue transmission even collision occur

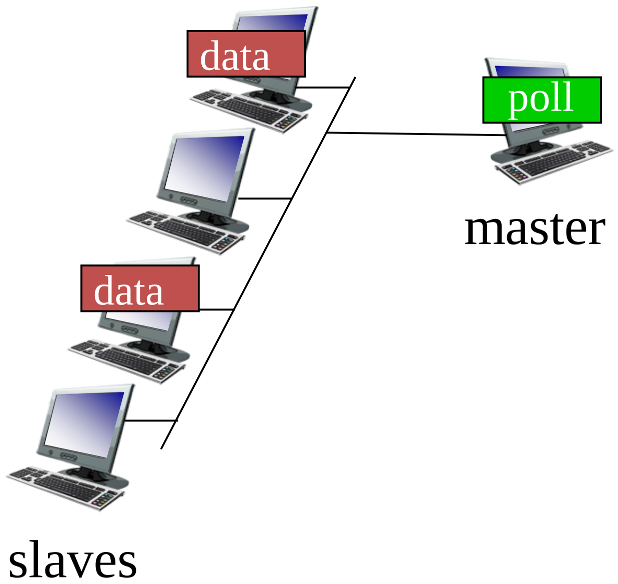


6.3 Random Access Protocols: Carrier Sense Multiple Access with Collision Detection (CSMA/CD)

- Carrier Sense Multiple Access with Collision Detection (CSMA/CD)
  - Sense channel before and *during* transmission
    - If channel is sensed idle, transmit frame
    - If channel is sensed busy, defer transmission
    - During transmission, if collision is detected, stop transmission immediately
  - If collision, retransmit again after a random delay
    - Use **binary exponential backoff** to determine random delay
      - After n^{th} collision, choose K at random from $\{0,1,2, \ldots, 2^n-1\}$.
        - Maximum $n = 10$
      - Wait K time slot and retransmit
      - Longer backoff delay with more collision
      - First collision: $K \in \{0,1\}$
      - Second collision: $K \in \{0,1,2,3\}$
      - Third collision: $K \in \{0,1,2,3,4,5,6,7\}$
      - Ten collision or more: $K \in \{0,1, \ldots, 1023\}$

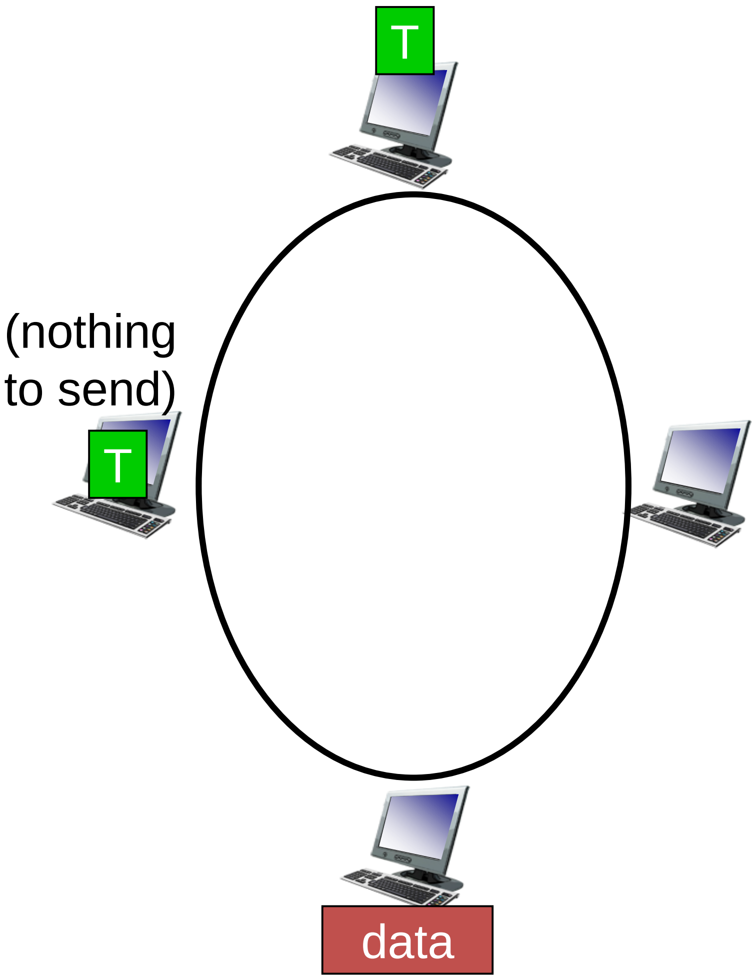


- Polling Protocol
  - Master node poll slave nodes in round-robin manner
    - Slave node transmit packet when polled
  - Disadvantage
    - Polling overhead
    - Latency
      - Must poll slaves without packet for transmission
    - Single point of failure (master fail)



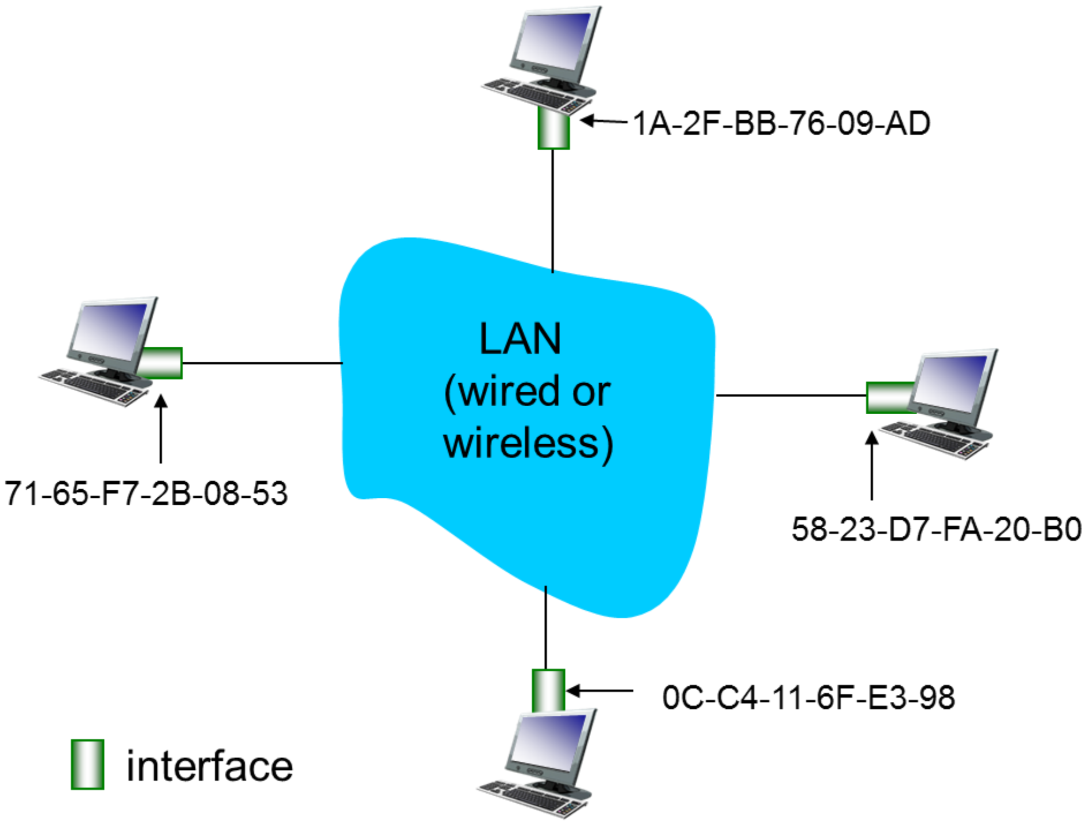
6.3 Taking-Turn Protocols: Token-passing Protocol

- Token-passing protocol
  - Pass token from one node to the another sequentially
  - Disadvantage
    - Token overhead
    - Latency
      - Must pass token to node without packet for transmission
    - Single point of failure
      - Token is lost
      - Node forgot to release token
      - Node that hold the token is not working



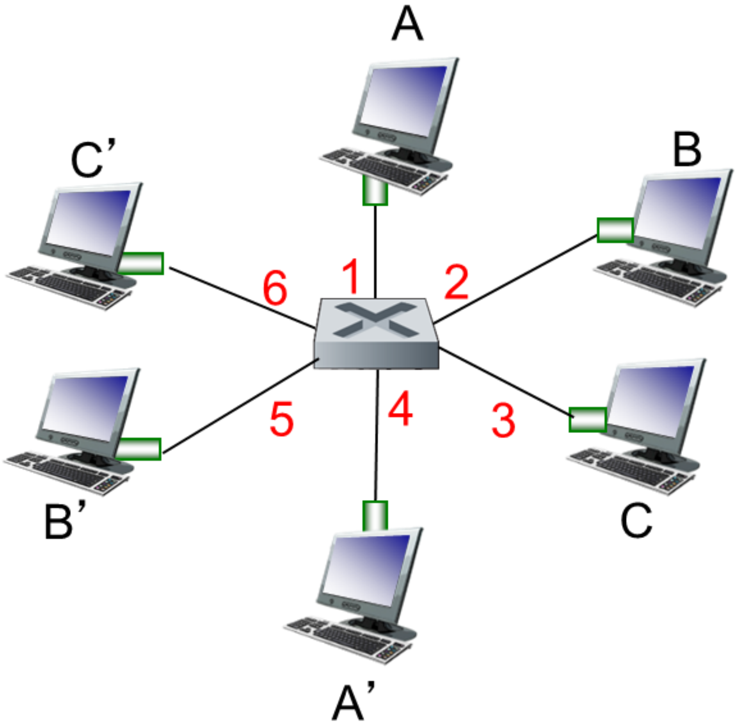
6.4 Link-layer Addressing

- IP Address
  - 32 bits
  - Network layer address for interface used for forwarding datagram
  - Example
    - FF.FF.FF.FF (or 255.255.255.255)
- MAC Address
  - 48 bits
  - Link layer address for interface used for forwarding frame
  - Example
    - FF.FF.FF.FF.FF.FF (or 255.255.255.255.255.255)
    - Each interface has unique MAC address



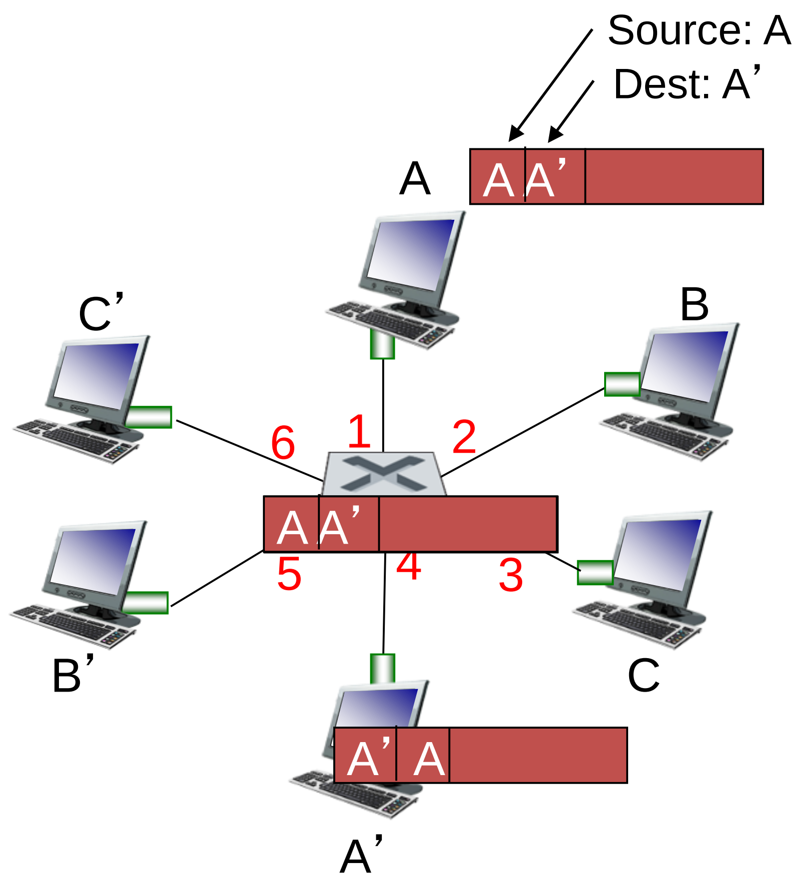
6.4 Link-layer Switches

- Use CSMA/CD
- Services
  - Store-and-Forward frame
    - Read incoming frame's MAC address
    - Store frame
    - Get MAC address of outgoing interface
    - Forward frame to one or more outgoing links
      - A-to-A' and B-to-B' can transmit simultaneously, without collisions
  - Transparent
    - Host is not aware of switches
  - Self-learning (or plug-and-play)
    - Switches do not need to be configured



switch with six interfaces (1,2,3,4,5,6)

- Self-learning
  - Switch learn which host can be reached through which interface
  - When frame is received, switch learn MAC address of sender's incoming interface
  - Records the following in switch table
    - MAC address of sender's incoming interface
    - Interface
  - If switch does not know the interface for the destination's MAC address
    - Flood the frame
    - Destination respond
      - When frame is received, switch learn MAC address of destination's incoming interface



MAC addr	interface	TTL
A *A'*	*1* *4*	*60* *60*

switch table (initially empty)

6.4 Link-layer Switches
Comparison of Switches and Routers

- Both are store-and-forward:
  - Router
    - Network-layer device
      - Examine network-layer header
  - Switch
    - Link-layer device
      - Examine link-layer headers
- Both have forwarding tables
  - Router
    - Compute table using
      - Routing algorithm
      - IP address
  - Switch
    - Learn forwarding table using
      - Flood
      - Self-learning
      - MAC address