Module 5

(MAC Sub Layer)

(Data Link Layer and Medium Access Sub Layer: Error Detection and Error Correction - Fundamentals, Block coding, Hamming Distance, CRC; Flow Control and Error control protocols - Stop and Wait, Go back – N ARQ, Selective Repeat ARQ, Sliding Window, Piggybacking, Random Access, Multiple access protocols -Pure ALOHA, Slotted ALOHA, CSMA/CD,CDMA/CA; Wired LAN, Wireless LANs, Connecting LANs and Virtual LANs)

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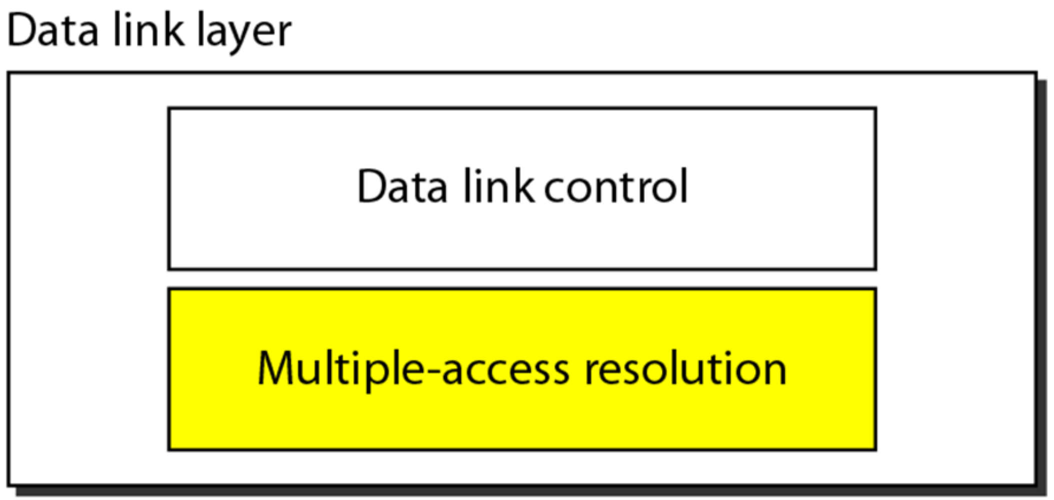
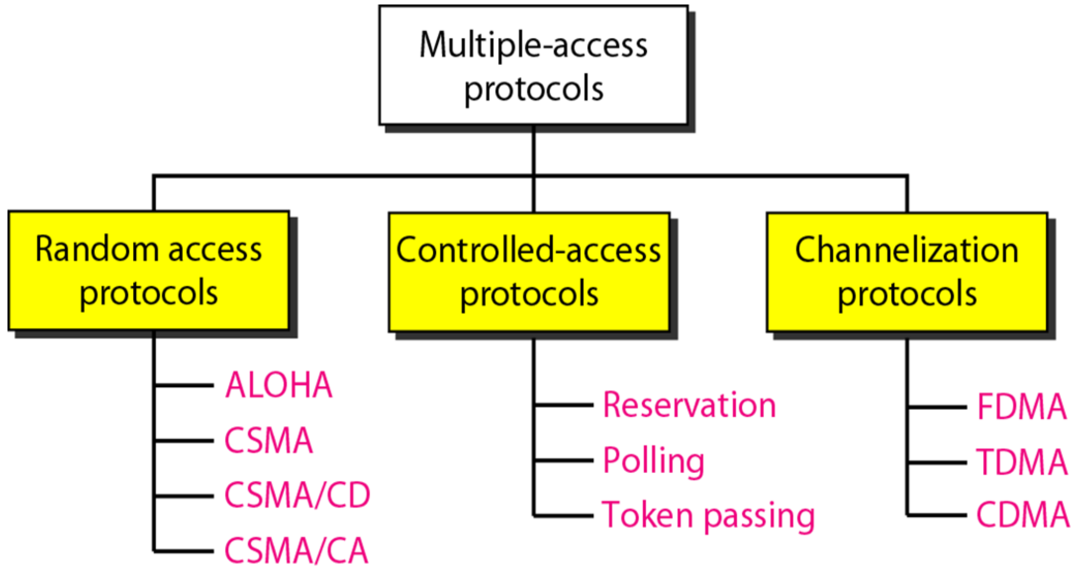
Media/Medium Access Control (MAC)

- Media/Medium Access Control (MAC) layer – lower sub-layer of the data link layer.
- Random Access or Contention Protocols
- Decides who should transmit and when
- No station is superior
- No station controls another
  - Permit/Deny to send data
- Any node may have data to transmit at any point of time
- Needs to avoid collision

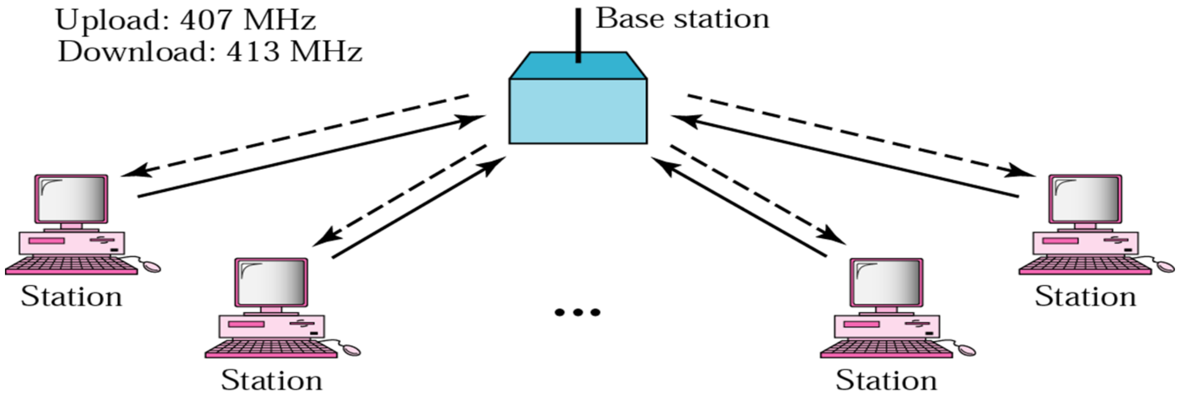




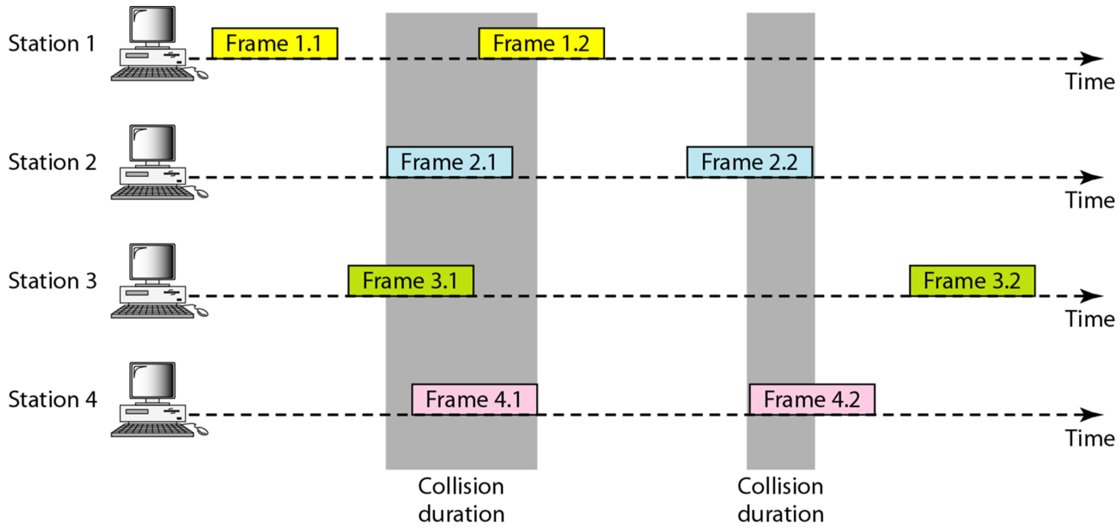
Taxonomy of Multiple Access Protocols

ALOHA

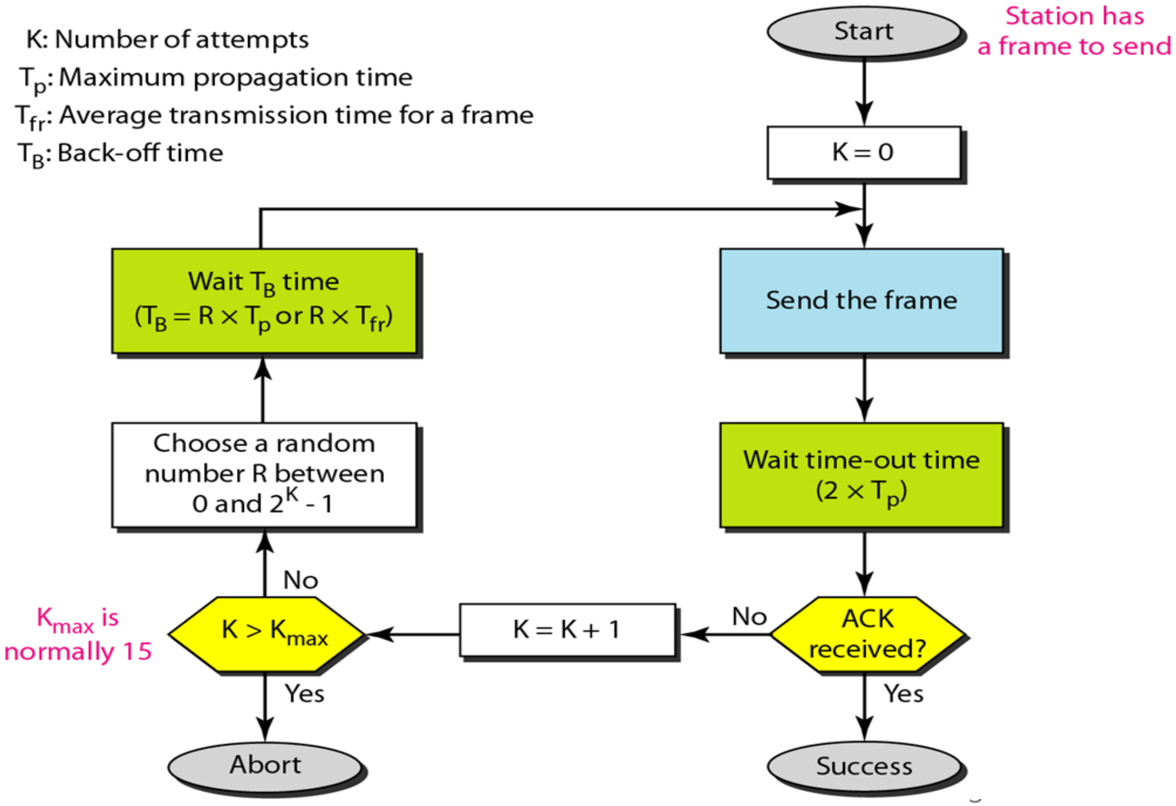
- Developed at the University of Hawaii, early 1970s
- Originally developed for radio (wireless) LAN, but can be extended for any shared medium
  - Transmission to and from a central station/base station
  - All other sources transmit using same frequency, central station uses another frequency



ALOHA Network



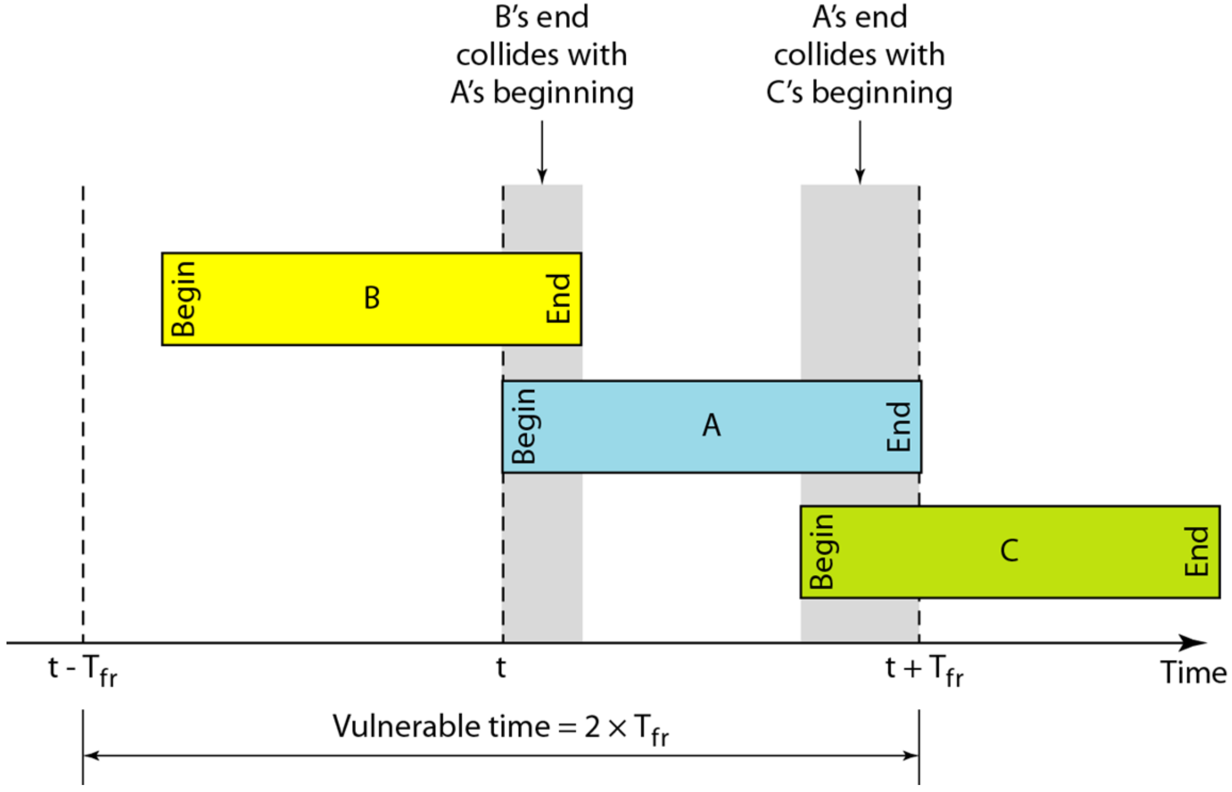
Frames in Pure ALOHA Network



Procedure for Pure ALOHA Protocol

ALOHA (Contd...)

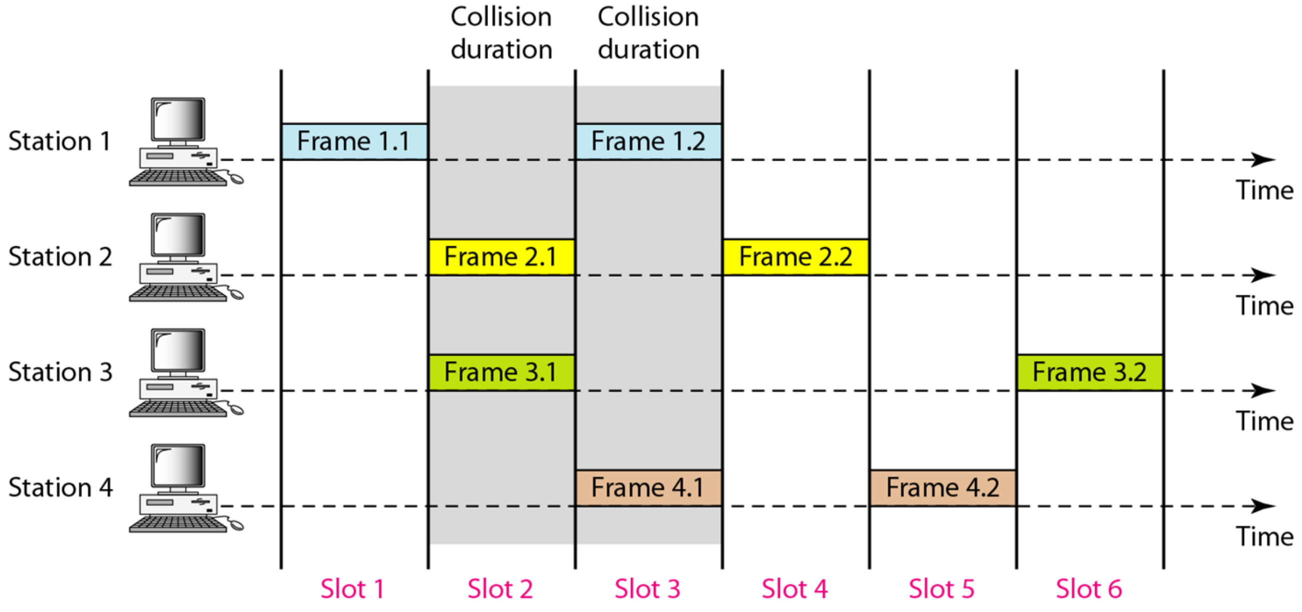
- Vulnerable time
  - Length of time in which there is a possibility of collision
  - All stations send fixed-length frames each requires T_{fr} seconds to transmit
  - Pure ALOHA vulnerable time = $2xT_{fr}$
- Throughput
  - The throughput for pure ALOHA is $S = G \times e^{-2G}$
  - The maximum throughput $S_{max} = 0.184$ when $G=0.5$
  - Max utilization 18.4% - very low for large nos. of users (stations) or for higher transmission rates



Vulnerable Time for Pure ALOHA Network

Slotted ALOHA

- Time on the channel divided into slots equal to frame transmission time
    - Needs a central clock to synchronize all stations
    - A station can start sending only at the beginning of a slot
- Reduces the number of collision than Pure ALOHA
    - Vulnerable period is halved compared to Pure ALOHA
    - Collision possible only if more than one stations become ready to transmit within the same slot



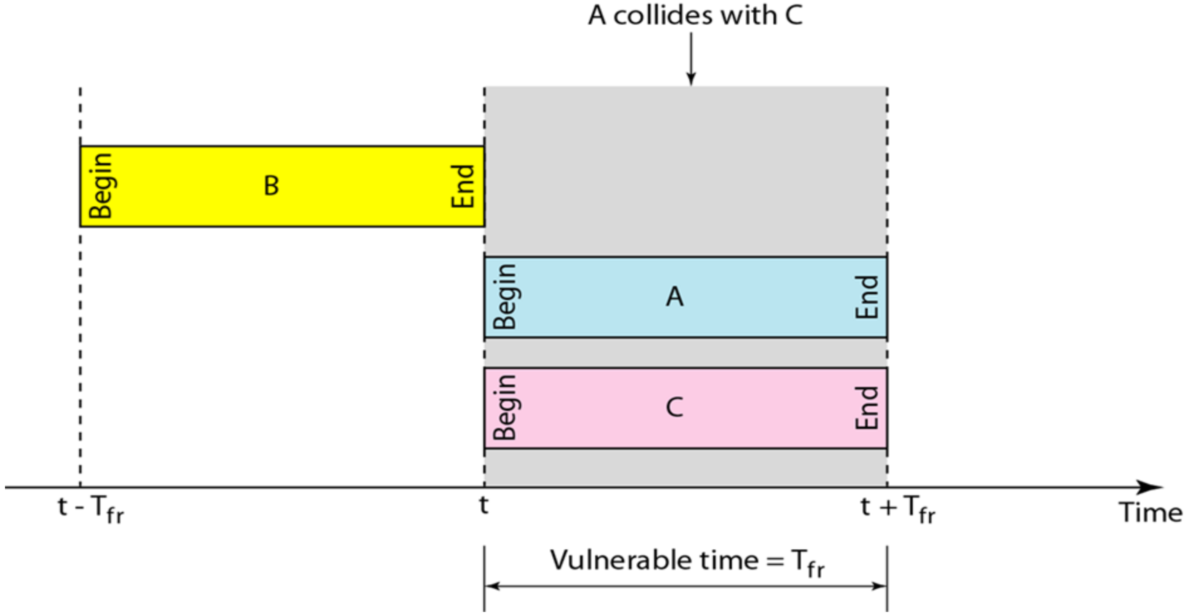
Frames in Slotted ALOHA Network

Slotted ALOHA (Contd…)

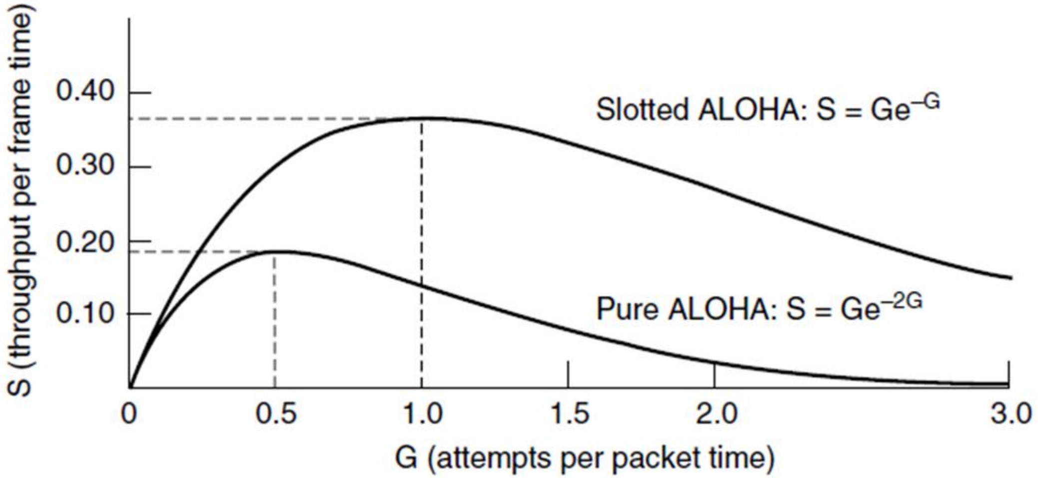
- Vulnerable time = T_{fr}

- Throughput
  - The throughput for slotted ALOHA is $S = G \times e^{-G}$
  - The maximum throughput $S_{max} = 0.368$ when $G = 1$

- One frame is generated during one frame transmission time
- 36.8% of these frames reach their destination successfully



Vulnerable Time for Slotted ALOHA Network

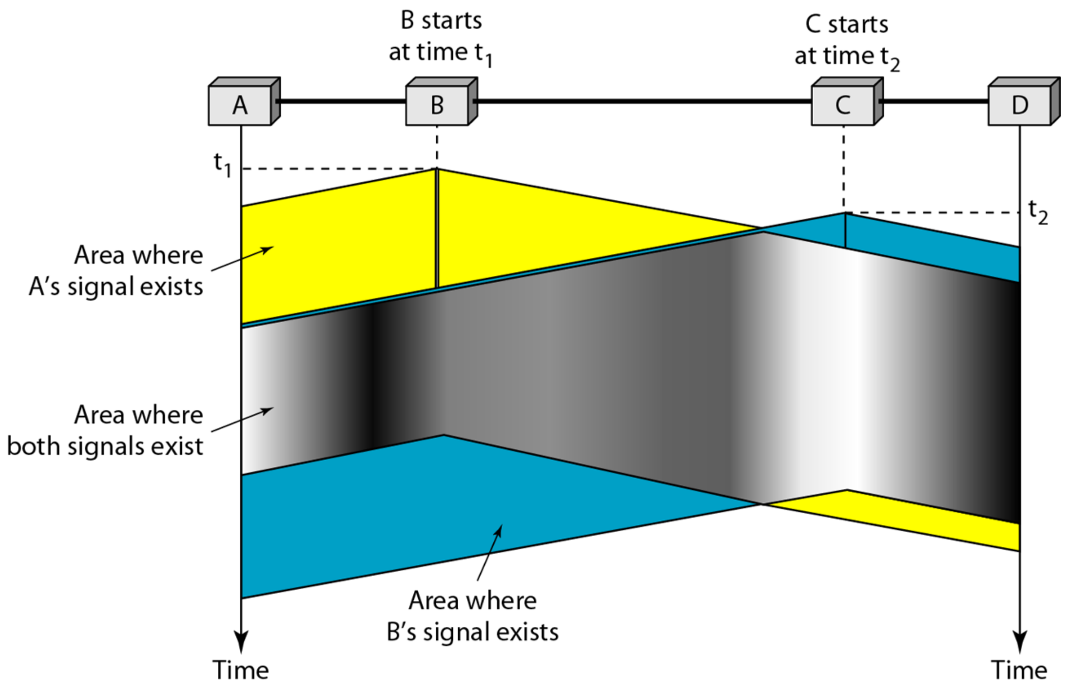


Throughput versus offered traffic for ALOHA systems.

Channel utilization of Pure ALOHA and slotted ALOHA

Carrier Sense Multiple Access (CSMA)

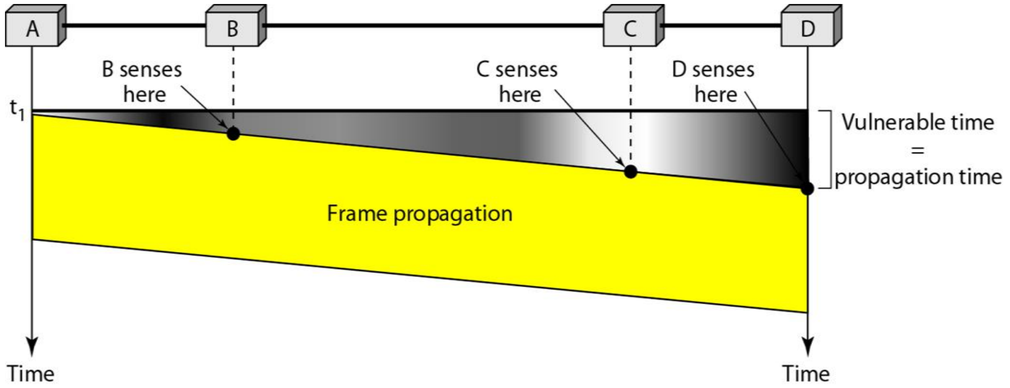
- Objective: reduce collision, improve throughput
- Whenever a station becomes ready to transmit a frame, it senses the medium (carrier sense)
- Principle: sense before transmit or listen before talk
- Stations wait for acknowledgements (ACK) from receivers before further transmissions
  - No ACK: sense medium
    - If idle, transmit, else wait
- Collision occurs due to propagation delay



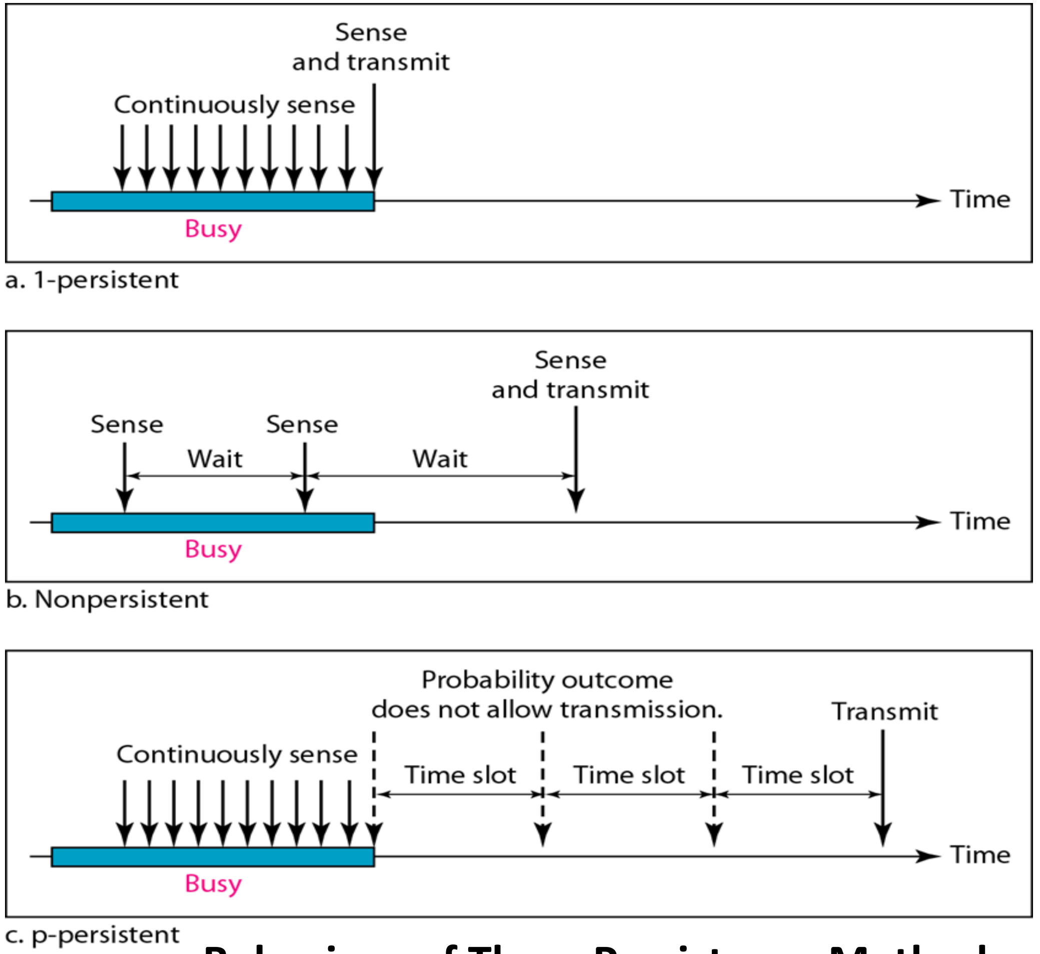
Space/Time Model of the Collision in CSMA

Carrier Sense Multiple Access (CSMA)

- Vulnerable time
  - Propagation time T_p
  - Collision results if a station sends a frame and any other station attempts to send at that time
  - If the first bit of the frame reaches the end of the medium – stations will refrain from sending
- What should stations do if the channel is idle/busy?
  - Persistence methods
    - 1-persistent
    - Non-persistent
    - p-persistent

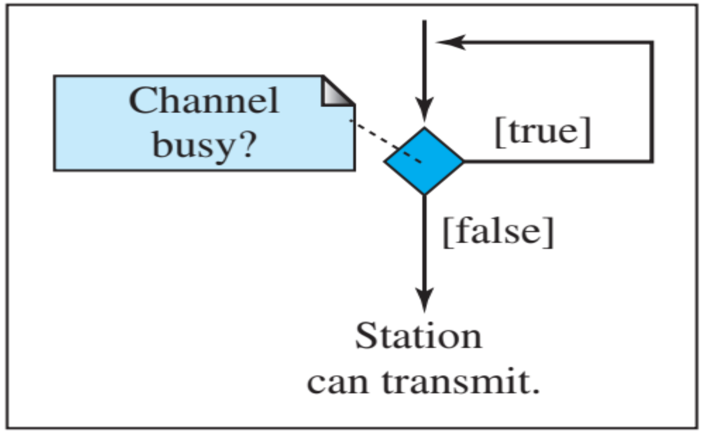


Vulnerable Time in CSMA

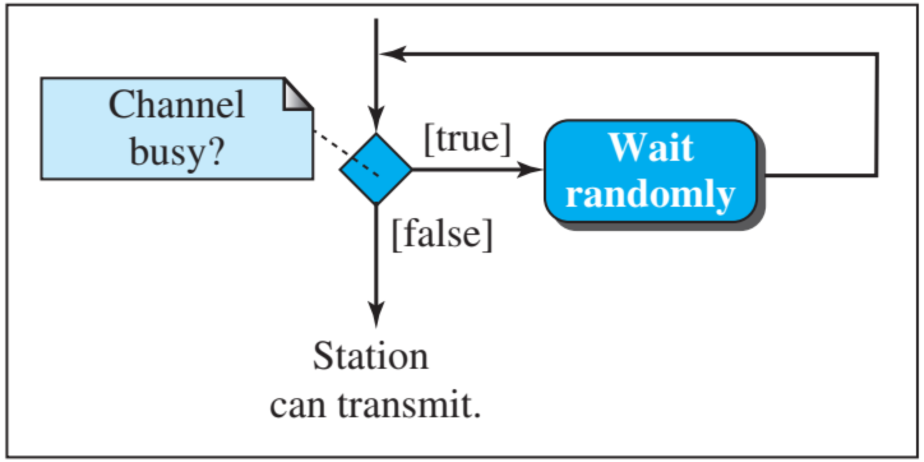


Behaviour of Three Persistence Methods

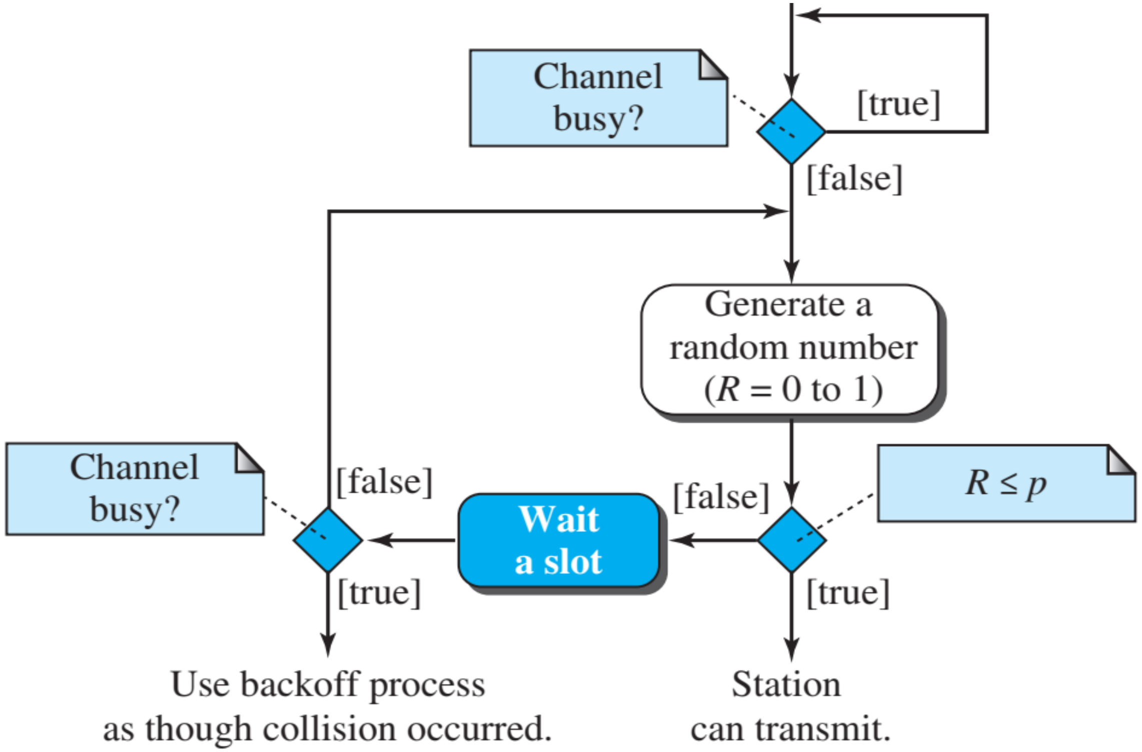
Carrier Sense Multiple Access (CSMA)



a. 1-Persistent



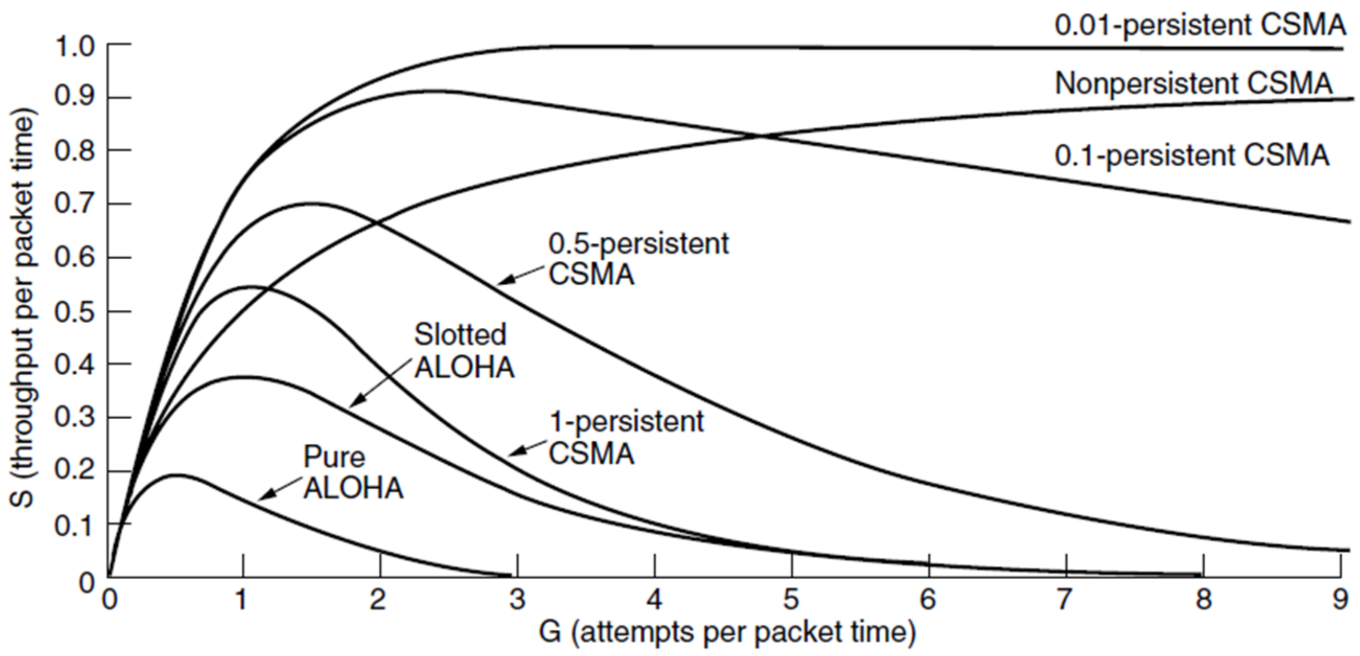
b. Nonpersistent



p-Persistent

Carrier Sense Multiple Access (CSMA)

- Evaluation
  - Low values of *p*
    - Lower chances of collision
    - Lower channel utilization
  - Higher values of *p*
    - Good channel utilization
    - Higher chances of collision
  - 1-persistent
    - Low load: good - prevents unnecessary wait without sensing medium
    - High load: higher chances of collision

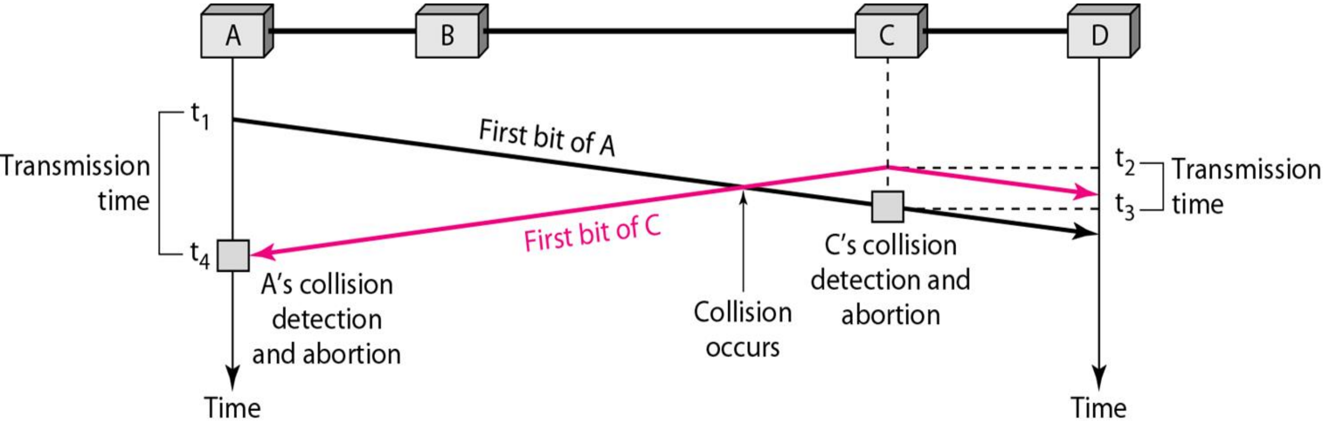


Comparison of the channel utilization versus load for various random access protocols.

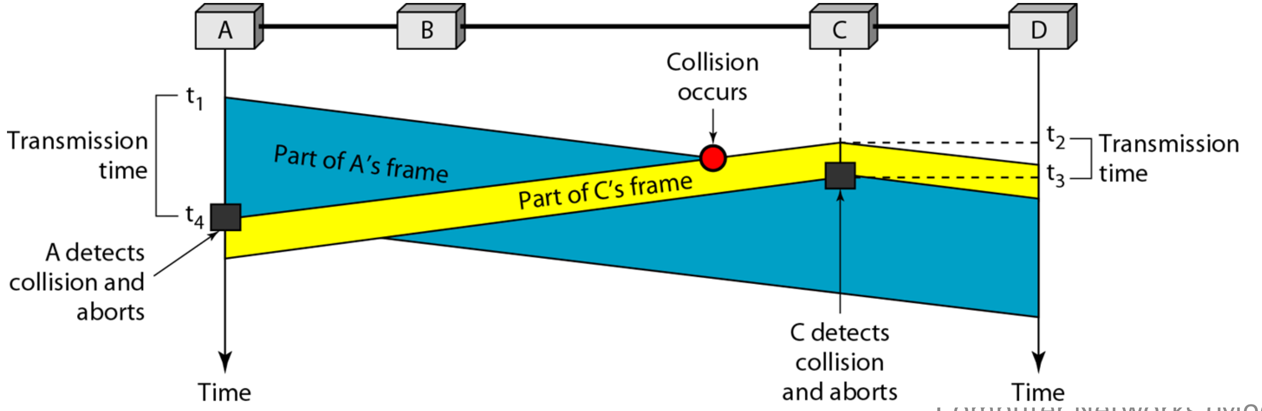
Throughput Vs. Offered Traffic for MAC Protocols

Carrier Sense Multiple Access with Collision Detection (CSMA/CD)

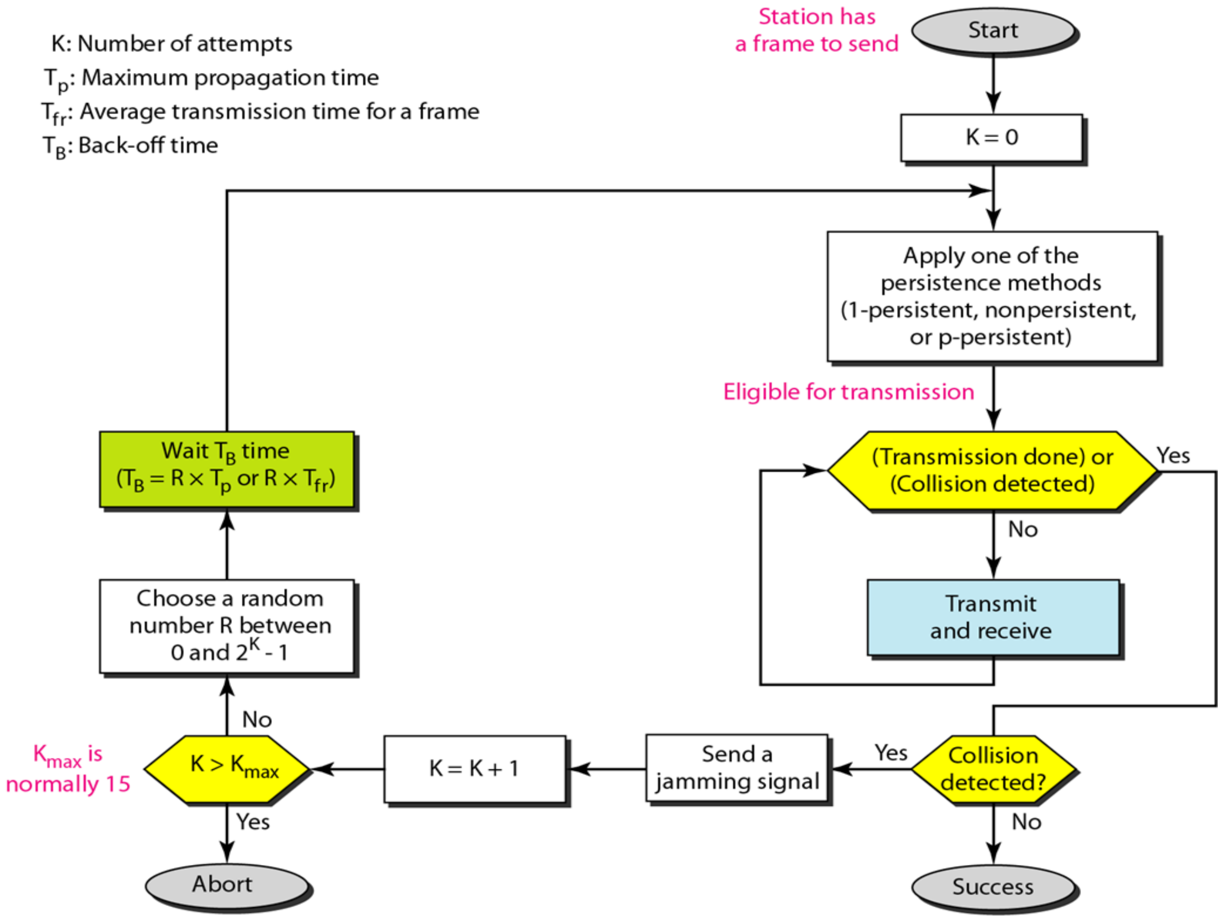
- Used in Ethernet LANs
- Three states: transmission, contention, idle
- Stations handle collision through monitoring
  - If collision is detected, station aborts transmission
  - Retransmits frame later



Collision of the First bit in CSMA/CD



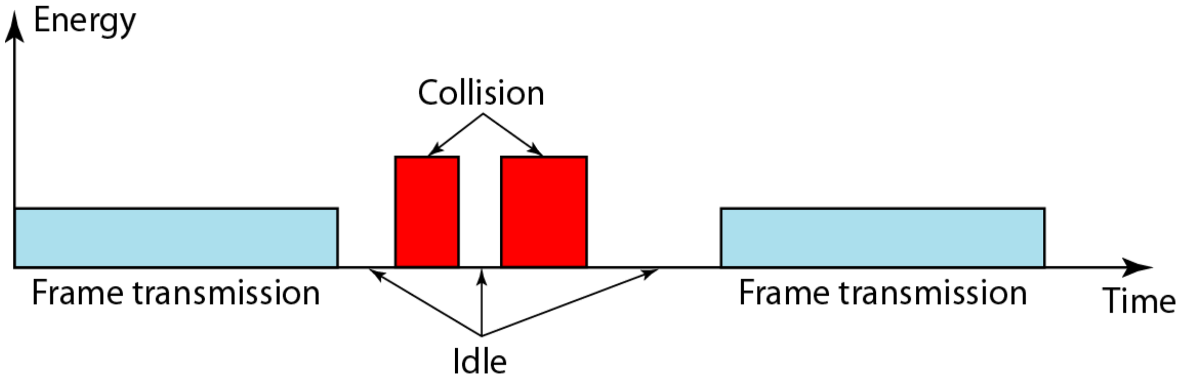
Collision and Abortion in CSMA/CD



Flow Diagram for the CSMA/CD

Carrier Sense Multiple Access with Collision Detection (CSMA/CD)

- Energy Level: three values
  - Zero, normal, abnormal
  - Sending stations needs to monitor the energy level to determine if the channel is idle, busy, or in collision mode.

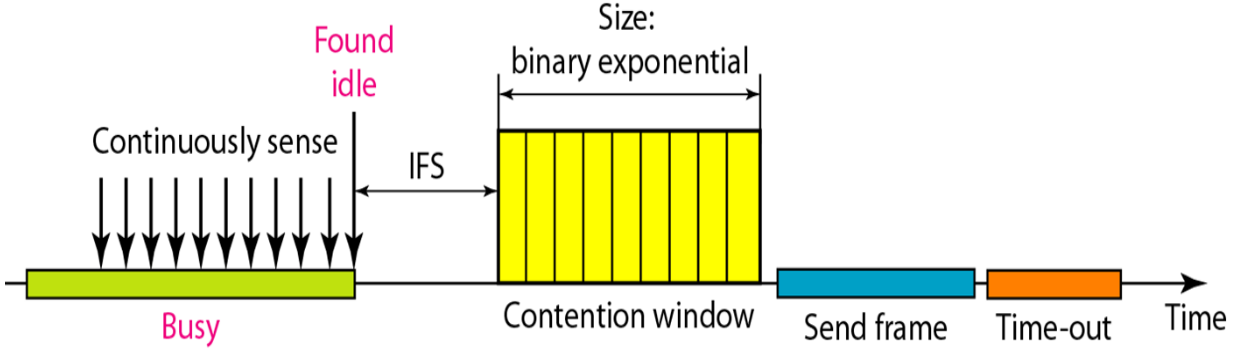


Energy Level during Transmission, Idleness, or Collision

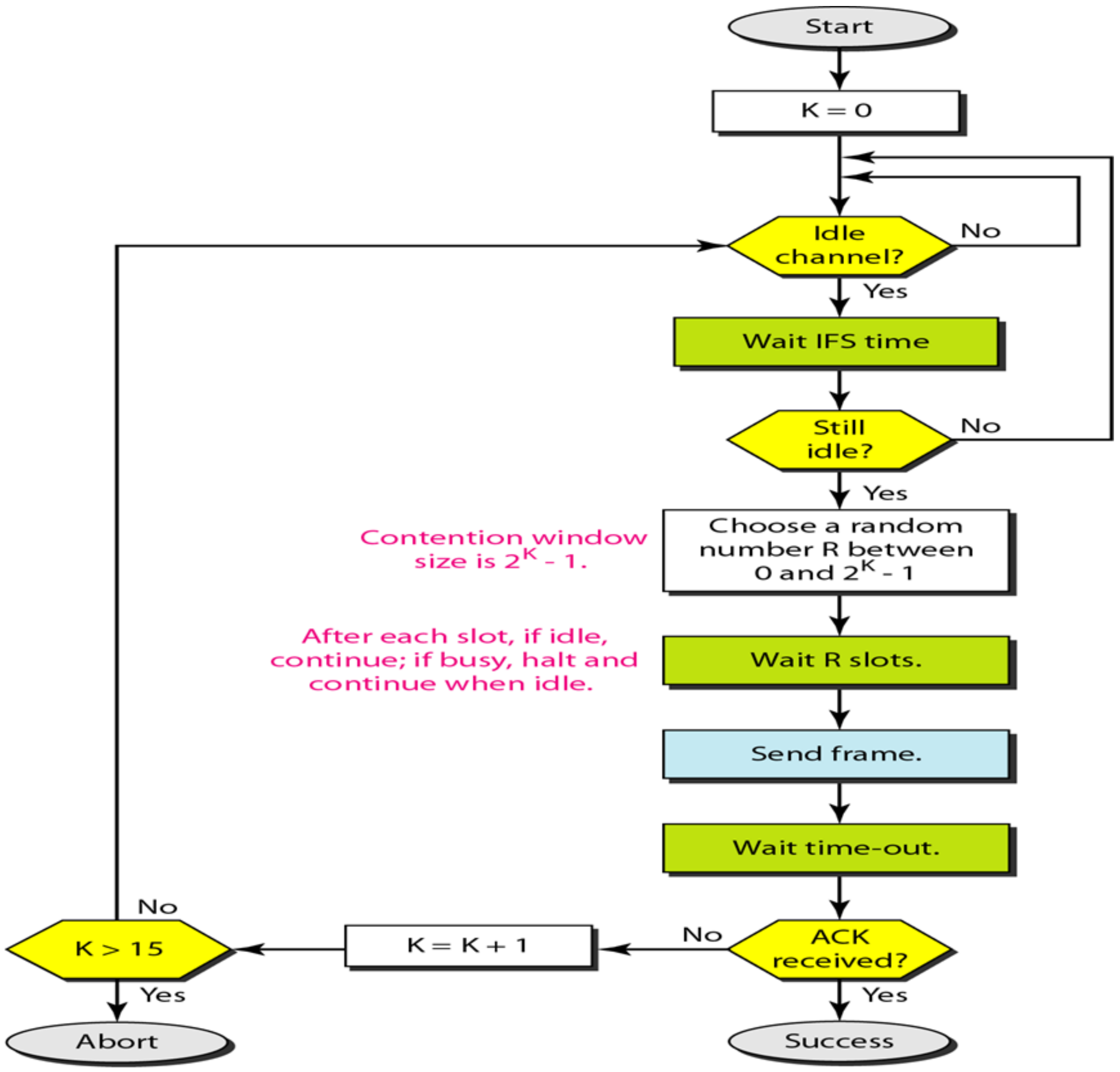
- Throughput: better than ALOHA
  - Depends on G and the persistence method; value of p in p-persistent
  - 1-persistent: max. throughput ~ 50% at $G = 1$.
  - Nonpersistent: max. throughput ~90%, G is in [3, 8].

Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA)

- Used for wireless networks
- Three strategies
  - Interframe space (IFS)
  - Contention window
  - Acknowledgements



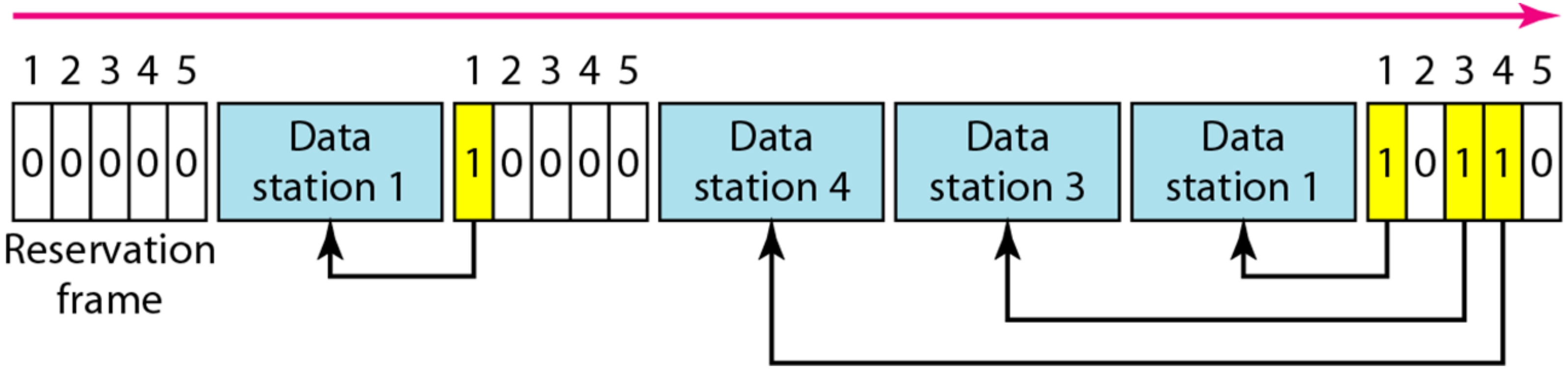
Timing in CSMA/CA



Flow Diagram for CSMA/CA

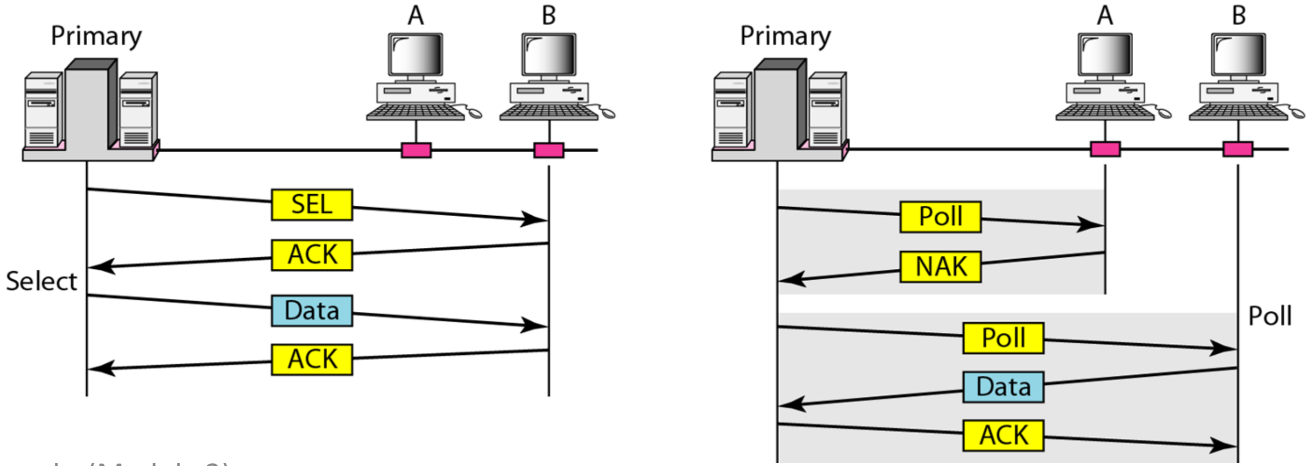
Controlled Access

- Stations consult one another to find which station has the right to send.
- A station cannot send unless it has been authorized by other stations.
- Three controlled access protocols: reservation, polling, token passing
- Reservation: *N* stations, *N* mini-slots; reservation frame precedes the data frames in each time interval



Reservation Frame Preceding Data Frames

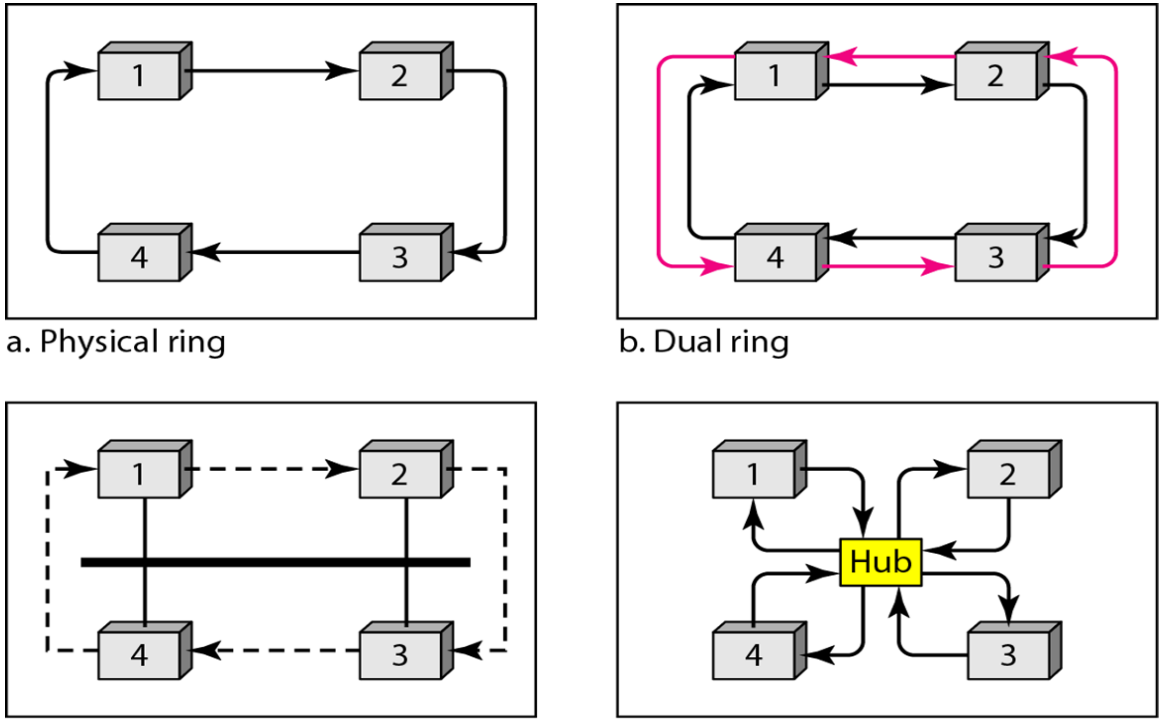
- Polling:
  - Primary station; secondary stations
  - Primary: controls the channel
  - Uses poll and select functions to prevent collisions



Select & Poll Functions in Polling Access Methods

Controlled Access

- Token passing:
  - Stations: organized in logical ring – *predecessor* and *successor*
  - Right to access passes as: *predecessor → current station → successor*
    - Circulation of a special packet : *token*
  - Stations have to wait until the token is received from the predecessor
  - All data sent – release token for the successor
  - Token management challenges: time limit of possession; continuous monitoring to ensure token has not been lost or destroyed; assign station priorities and control flow.

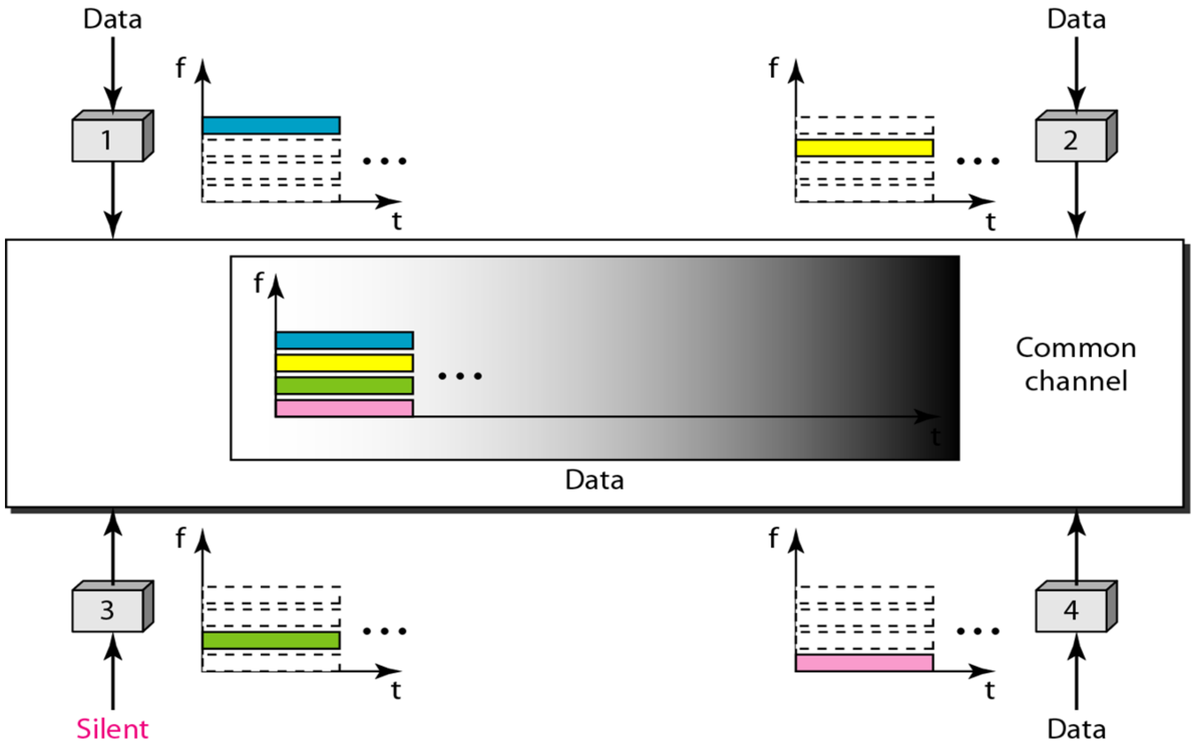


Logical Ring and Physical Topology in Token-passing Access Method

- Physical ring: system fails if one link fails
- Dual ring: uses auxiliary ring during link failure in the original ring (FDDI, CDDI)
- Bus ring: uses addresses of stations for forwarding token to successors (Token Bus LAN)
- Star ring: hub makes the ring; fault-tolerant; easy to add/remove stations in the ring (IBM's Token Ring LAN)

Channelization

- Available link bandwidth is shared in time, frequency, and code.
- Three protocols:
  - Frequency Division Multiple Access (FDMA)
  - Time Division Multiple Access (TDMA)
  - Code Division Multiple Access (CDMA)
- FDMA
  - Bandwidth of the common channel is divided into bands; separated by guard bands to prevent interference
  - Each band is reserved for a particular station

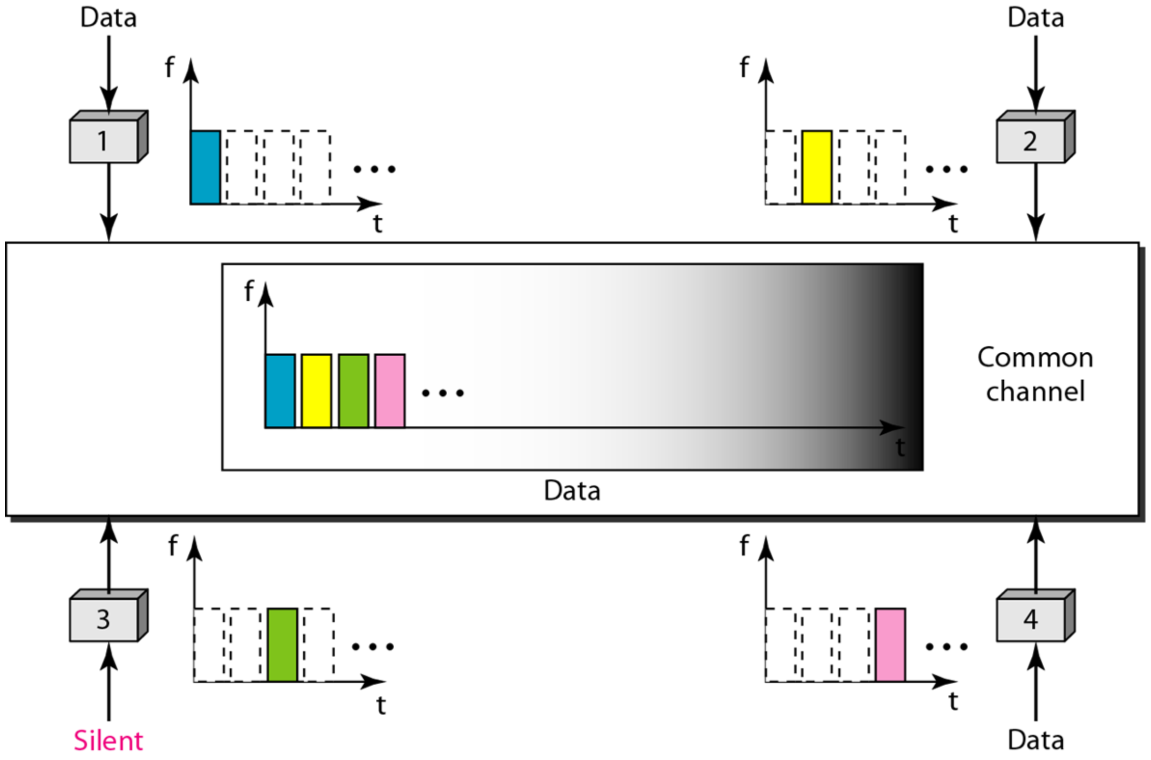


Frequency Division Multiple Access (FDMA)

- Different from physical layer technique – FDM (Frequency Division Multiplexing)

Channelization

- TDMA
  - Bandwidth of the common channel is time shared
  - Each station is allocated a time slot during which it can send data
  - Need to know the beginning and location of slot
    - Synchronization overhead due to propagation delay
    - Insert guard times
    - Synchronization bits at the beginning of each slot
  - Different from physical layer technique – TDM (Time Division Multiplexing)



Time Division Multiple Access (TDMA)

Channelization

- CDMA
  - Based on coding theory
  - Chips: sequence of numbers (code) assigned to each station
  - Properties of chip sequence
    - Each sequence is made of *N* elements, where *N* is the number of stations.
    - Scalar multiplication
    - Inner product
    - Inner product of two different sequences results in 0
    - Adding two sequences – element-wise addition generating another sequence.
  - Chip generation done using Walsh table

C_1 = [+1 +1 +1 +1] C_2 = [+1 -1 +1 -1] C_3 = [+1 +1 -1 -1] C_4 = [+1 -1 -1 +1]

Chip Sequence

$$2 \bullet [+1\ +1\ -1\ -1] = [+2\ +2\ -2\ -2]$$

Scalar multiplication

$$[+1\ +1\ -1\ -1] \bullet [+1\ +1\ -1\ -1] = 1 + 1 + 1 + 1 = 4$$

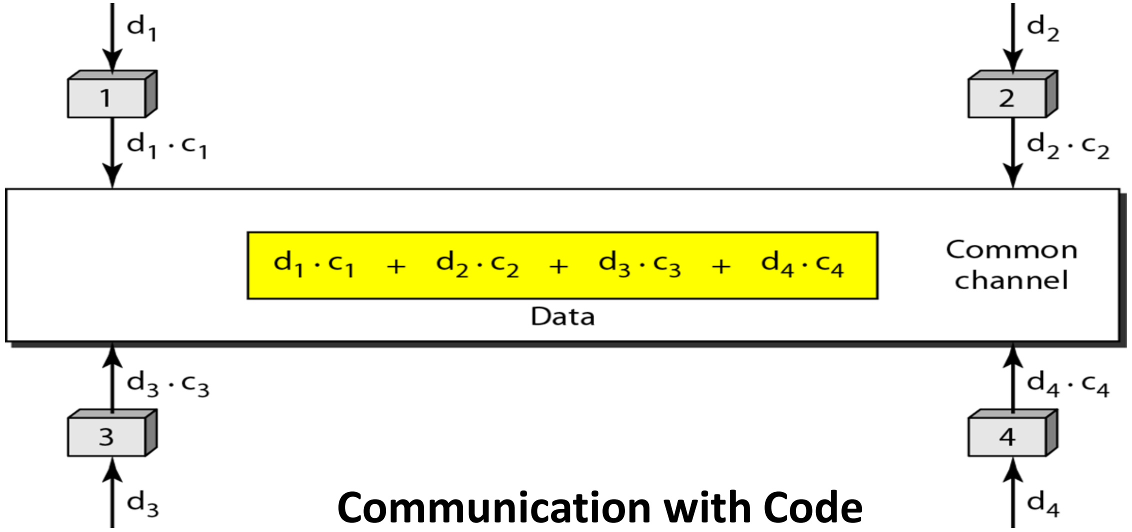
Inner Product

$$[+1\ +1\ -1\ -1] \bullet [+1\ +1\ +1\ +1] = 1 + 1 - 1 - 1 = 0$$

Inner Product of Two Different Sequences

$$[+1\ +1\ -1\ -1] + [+1\ +1\ +1\ +1] = [+2\ +2\ 0\ 0]$$

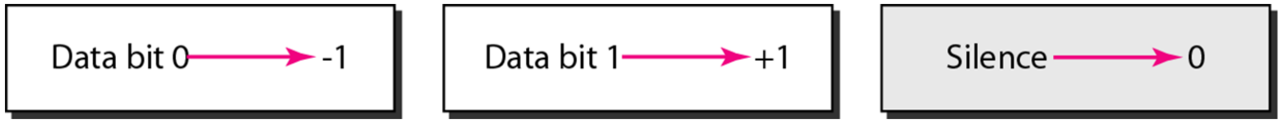
Addition of Two Sequences



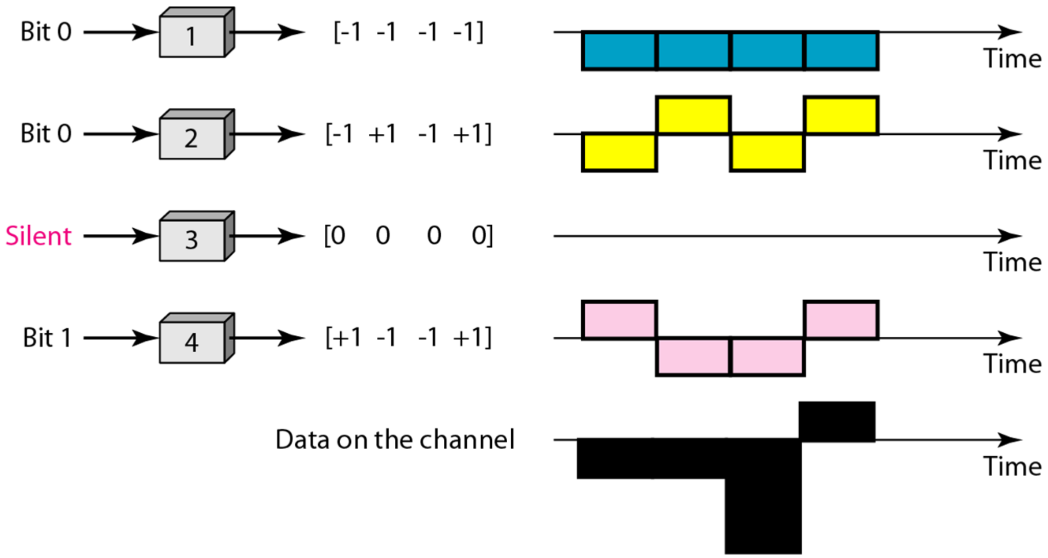
Communication with Code

$$\text{data} = (d_1 \cdot c_1 + d_2 \cdot c_2 + d_3 \cdot c_3 + d_4 \cdot c_4) \cdot c_1$$
$$= d_1 \cdot c_1 \cdot c_1 + d_2 \cdot c_2 \cdot c_1 + d_3 \cdot c_3 \cdot c_1 + d_4 \cdot c_4 \cdot c_1 = 4 \times d_1$$

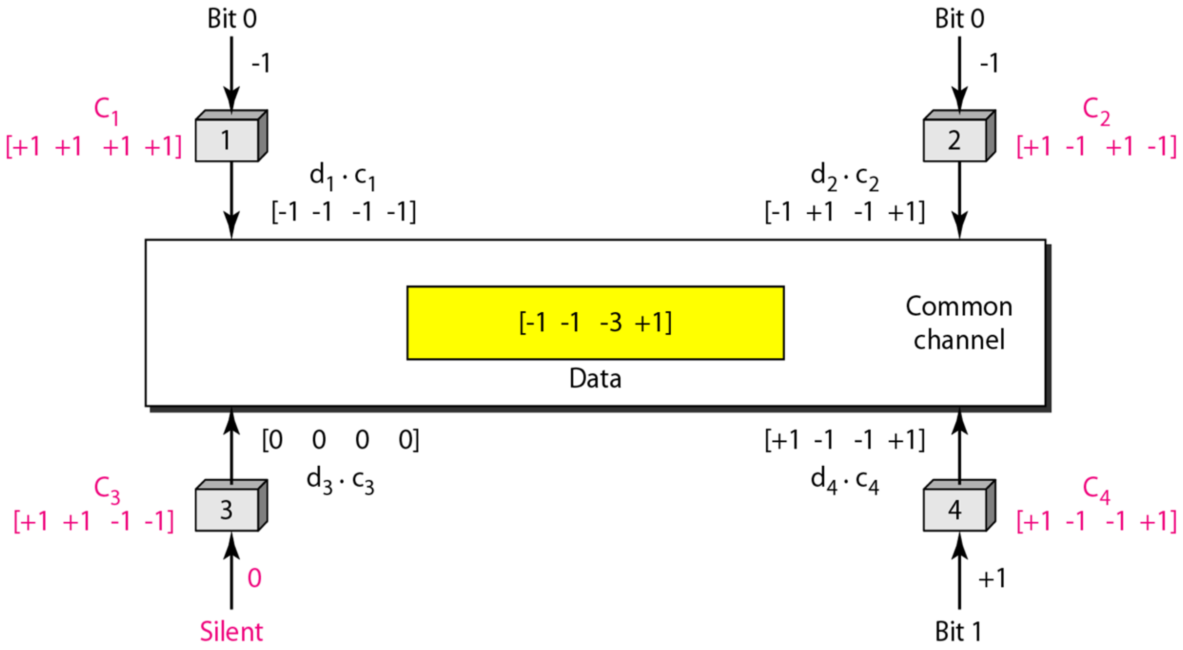
Channelization



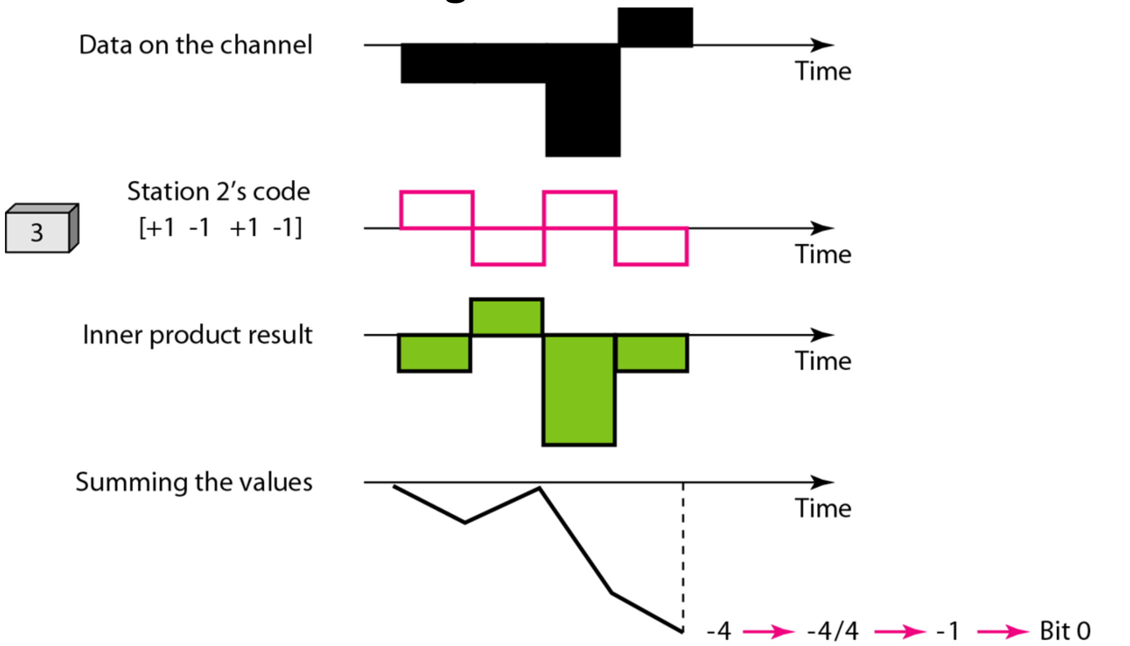
Data Representation in CDMA



Digital Signal Created by Four Stations in CDMA



Sharing Channel in CDMA



Decoding of Composite Signals for one Station in CDMA