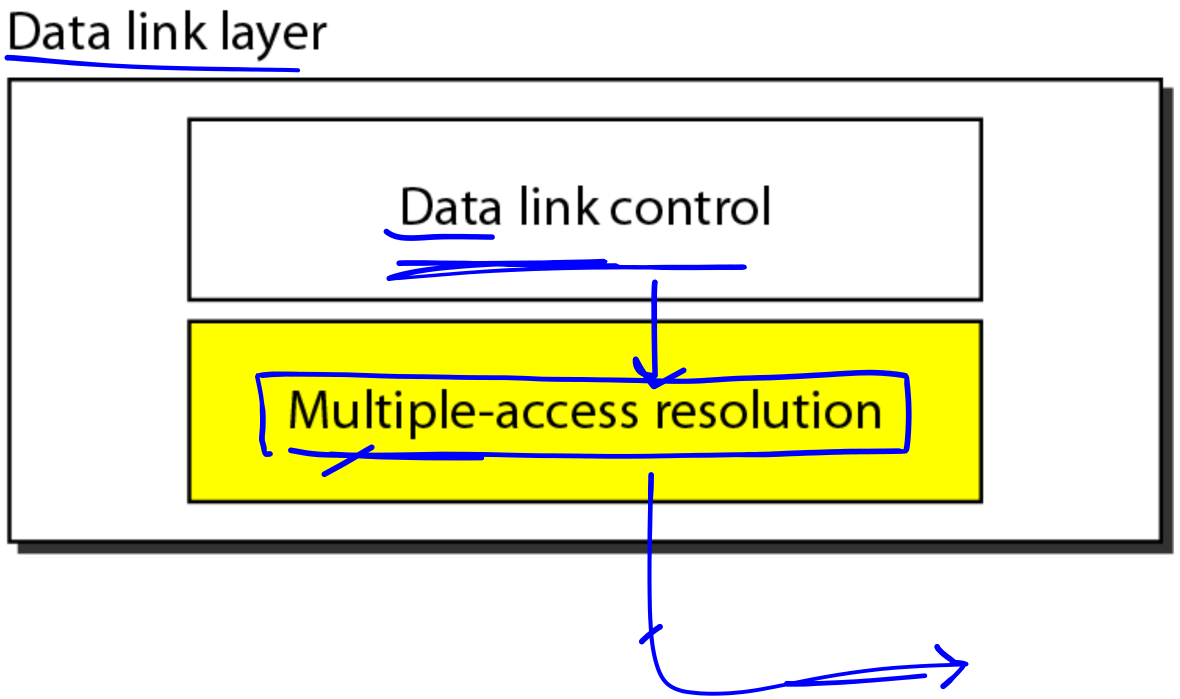
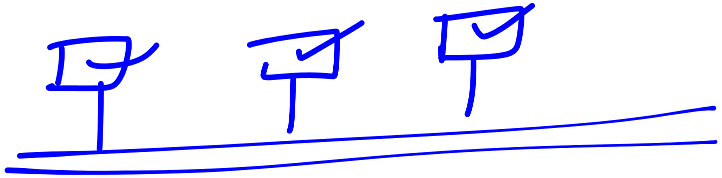
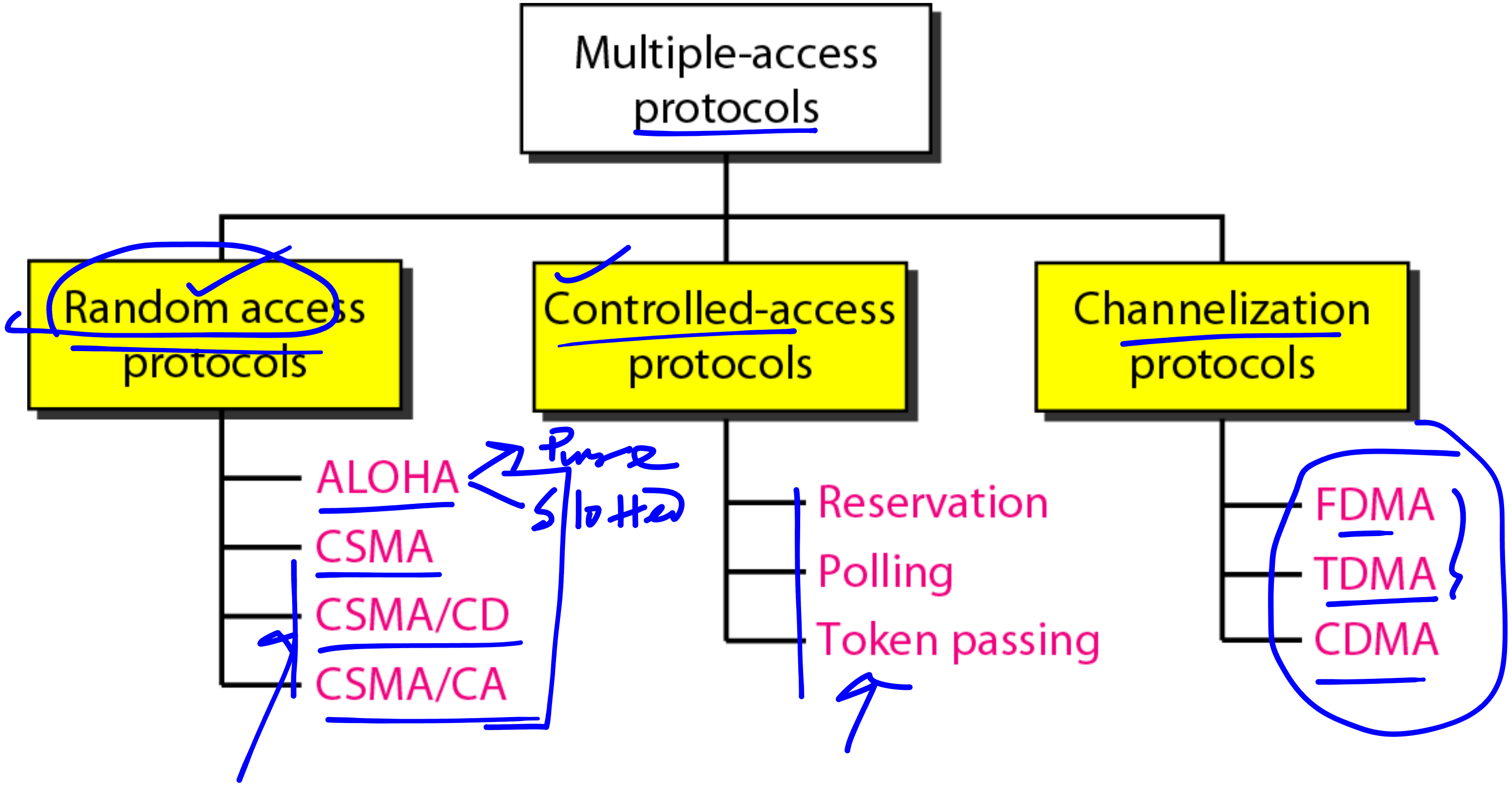
Media Access Control Protocols

Data link layer divided into two functionality-oriented sublayers



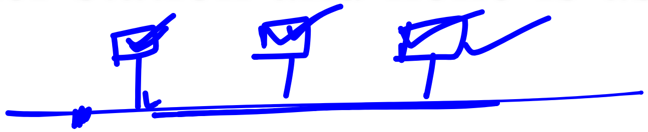
Taxonomy of multiple-access protocols discussed in this chapter





Random Access Protocols

- No station is superior to another station and none is assigned the control over another.



- No station permits, or does not permit, another station to send.
- At each instance, a station that has data to send uses a procedure defined by the protocol to make a decision on whether or not to send.
  - When can the station access the medium?
  - What can the station do if the medium is busy?
  - How can the station determine the success or failure of the transmission?
  - What can the station do if there is an access conflict?

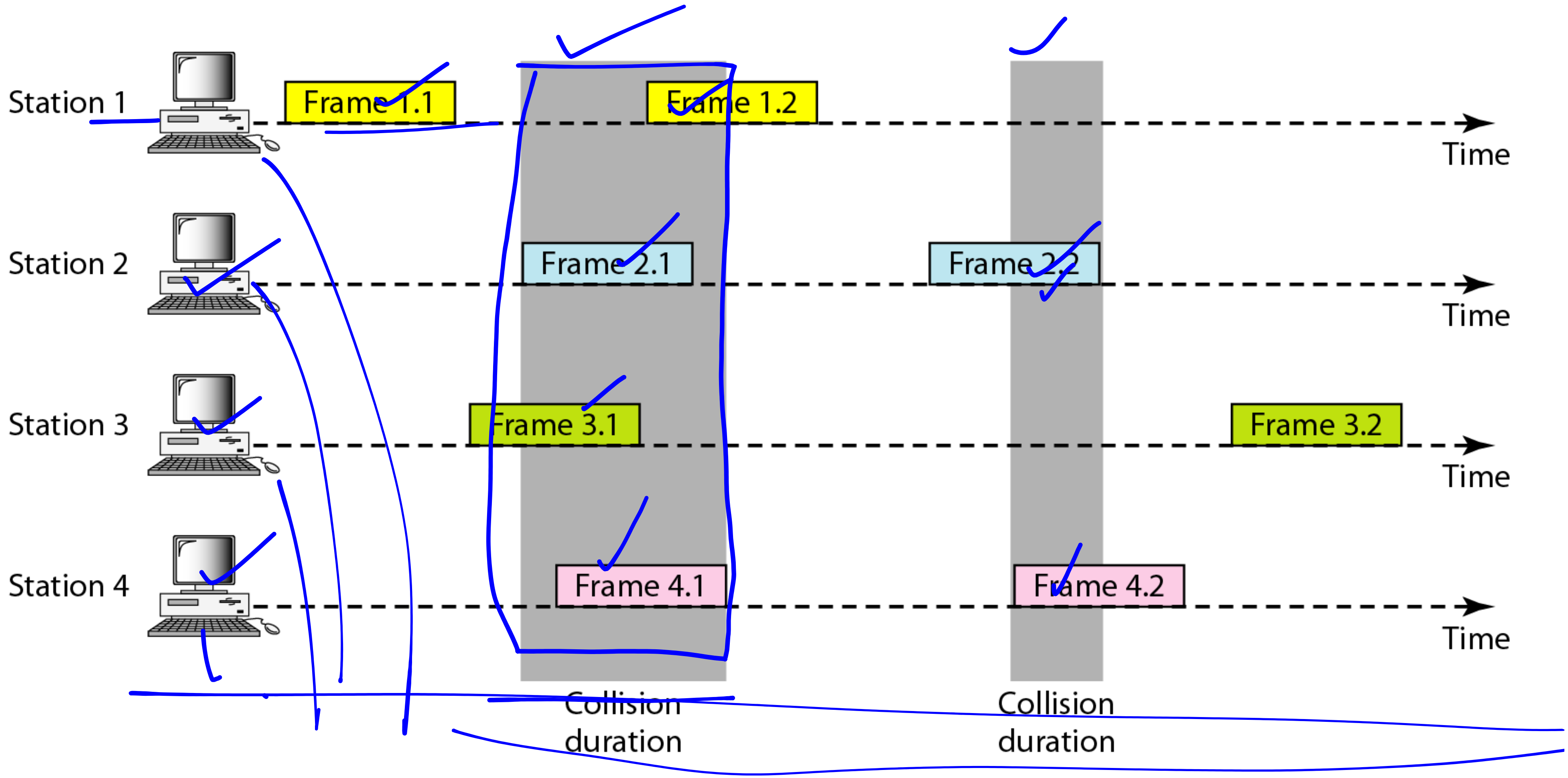
ALOHA

- Earliest random access method
  - Developed at the University of Hawaii in early 1970
- Designed for wireless LAN, but it can be used on any shared medium.
- Two types
  - Pure ALOHA
  - Slotted ALOHA

Pure ALOHA

- This is original ALOHA protocol
- This is simple and elegant protocol
- Each station sends a frame whenever it has a frame to send (multiple access)
  - But there is a possibility of collision between frames from different stations

Frames in a pure ALOHA network

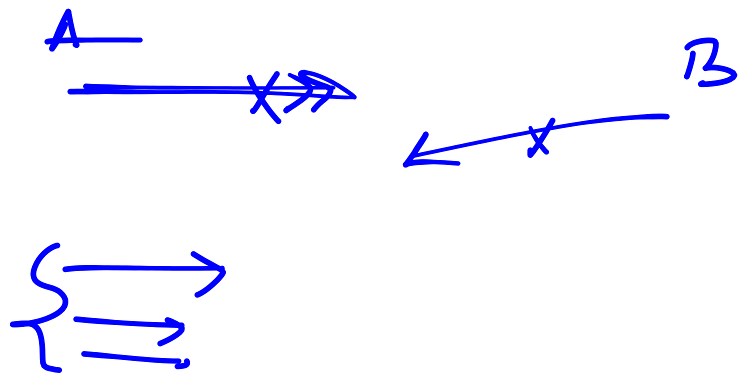


Pure ALOHA

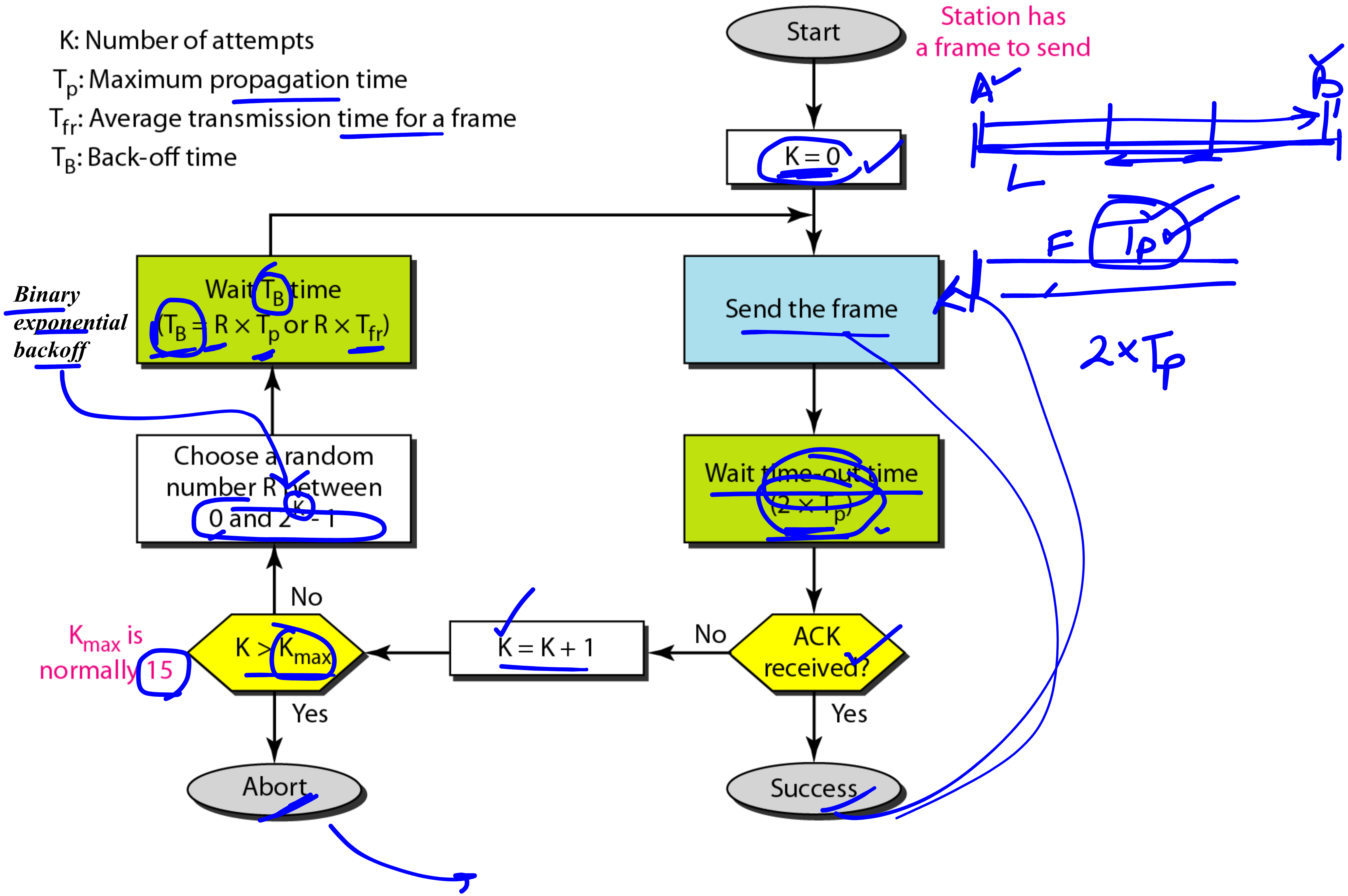
- This relies on acknowledgements from the receiver
  - When a station sends a frame, it expects the receiver to send an acknowledgement
  - If the acknowledgement does not arrive after a time-out period
    - Station assumes the packet has destroyed and resend further.
  - Resend of the packet is done not after time-out period
    - But after a *random amount of time* called *backoff time* T_B.

Pure ALOHA

- It has a second method to prevent congestion with retransmission
  - After a maximum number of retransmission attempts K_{max}, a station must give up and try later



Procedure for pure ALOHA protocol



Example

- ***The stations on a wireless ALOHA network are a maximum of 600 km apart. If we assume that signals propagate at 3×10^8 m/s, we find***

  $$T_p = (600 \times 10^5) / (3 \times 10^8) = 2 \text{ ms.}$$

- ***Now we can find the value of T_B for different values of K.***

$2^K - 1 =$

$T_B = R \times T_P$

a. For K = 1, the range is {0, 1}. The station needs to generate a random number with a value of 0 or 1.
   This means that T_B is either 0ms (0 × 2) or 2ms (1 × 2), based on the outcome of the random variable.

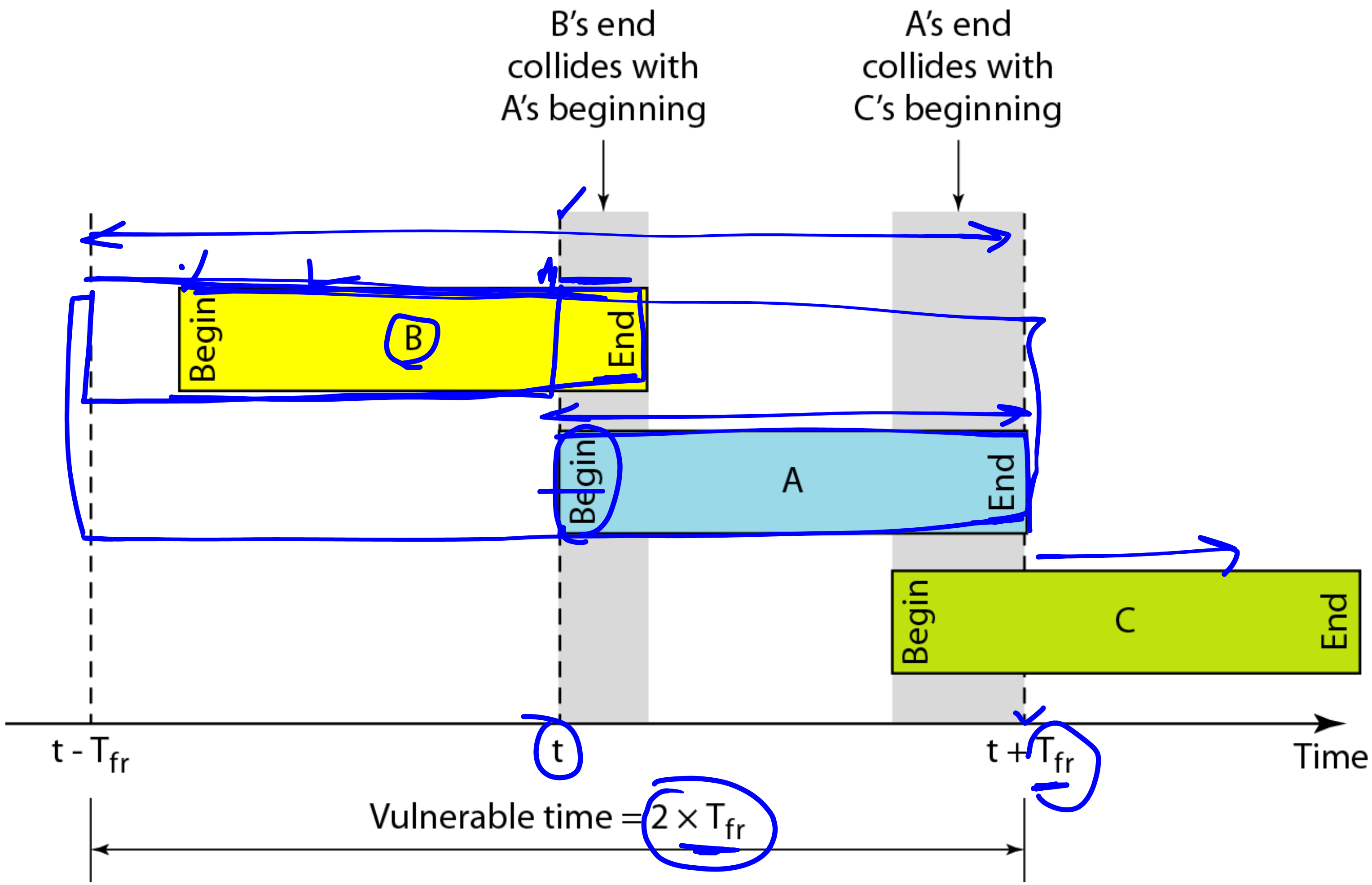
b. For K = 2, the range is {0, 1, 2, 3}. This means that T_B can be 0, 2, 4, or 6ms, based on the outcome of the random variable.

Example (continued)

c. For K = 3, the range is {0, 1, 2, 3, 4, 5, 6, 7}. This means that T_B can be 0, 2, 4, . . . , 14ms, based on the outcome of the random variable.

d. We need to mention that if K > 10, it is normally set to 10.

Vulnerable time for pure ALOHA protocol



Example

L

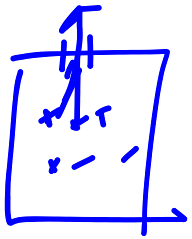
A pure ALOHA network transmits 200-bit frames on a shared channel of 200 kbps. What is the requirement to make this frame collision-free?

T_f

Solution

- Average frame transmission time T_{fr} is 200 bits/200 kbps or 1 ms.
- The vulnerable time is 2×1 ms = 2 ms.
- This means no station should send later than 1ms before this station starts transmission and no station should start sending during the one 1-ms period that this station is sending.

ALOHA



T_{fr}

Note

- The throughput or successful transmission for pure ALOHA is $\boxed{S = G \times e^{-2G}}$
  - G is the average number of frames generated by the system during one frame transmission.
- The maximum throughput $S_{max} = 0.184$ when G=(1/2)

100

18.4%

Example

A pure ALOHA network transmits 200-bit frames on a shared channel of 200 Kbps. What is the throughput if the system (all stations together) produces
a. 1000 frames per second b. 500 frames per second
c. 250 frames per second.

1×10^{-3} s

Solution

L B

The frame transmission time is 200 bits/200Kbps or 1 ms.

G

a. If the system creates 1000 frames per second, this is 1 frame per millisecond. The load is 1. In this case $S = G \times e^{-2G}$ or $S = 0.135$ (13.5 percent).

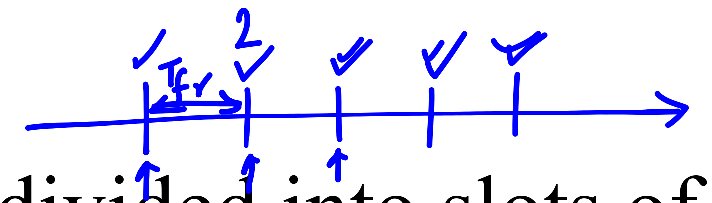
This means that the throughput is $1000 \times 0.135 = 135$ frames. Only 135 frames out of 1000 will probably survive.

Example (continued)

b. If the system creates 500 frames per second, this is (1/2) frame per millisecond. The load is (1/2). In this case $S = G \times e^{-2G}$ or $S = 0.184$ (18.4 percent). This means that the throughput is $500 \times 0.184 = 92$ and that only 92 frames out of 500 will probably survive. Note that this is the maximum throughput case, percentagewise.

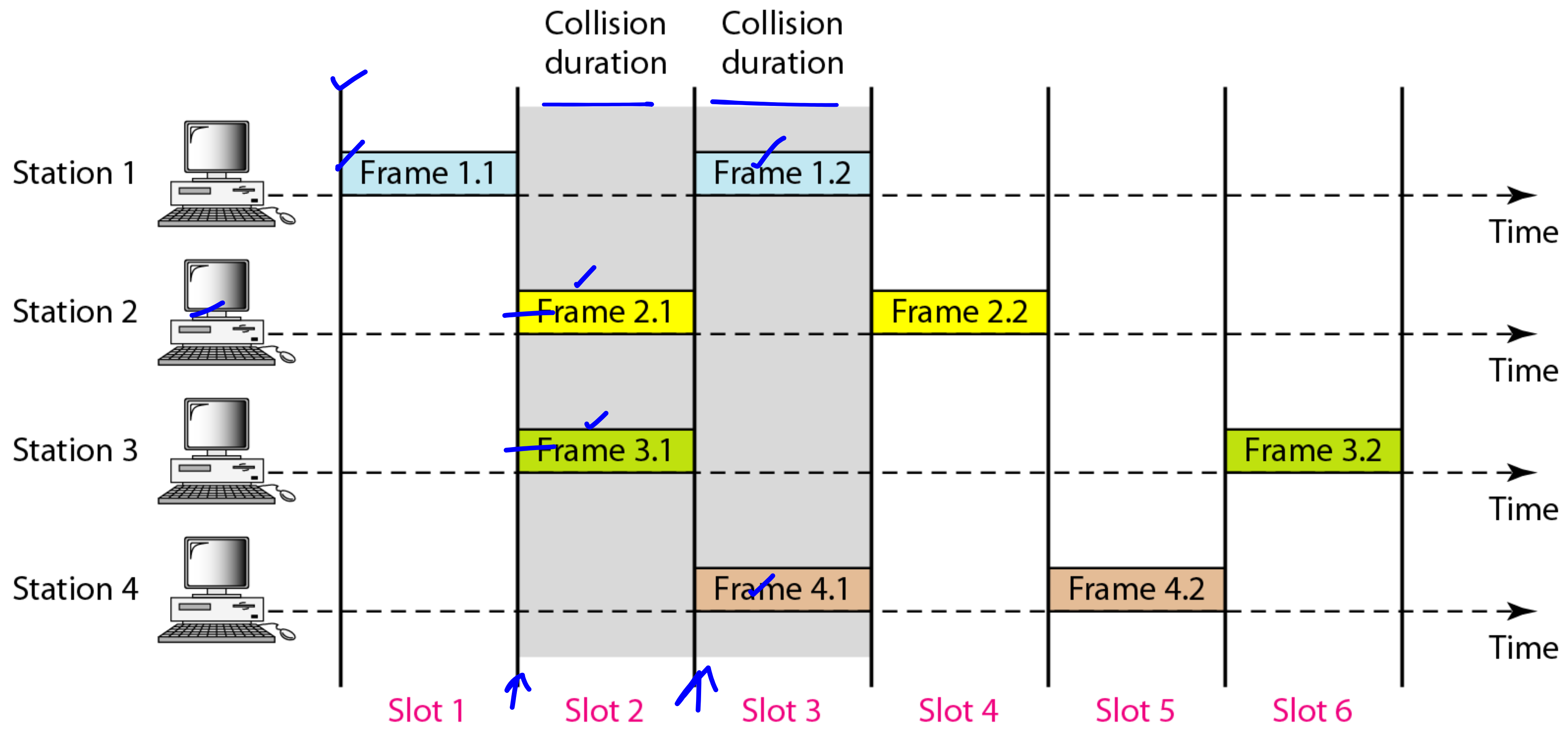
c. If the system creates 250 frames per second, this is (1/4) frame per millisecond. The load is (1/4). In this case $S = G \times e^{-2G}$ or $S = 0.152$ (15.2 percent). This means that the throughput is $250 \times 0.152 = 38$. Only 38 frames out of 250 will probably survive.

Slotted ALOHA



- In this case the time is divided into slots of T_{fr} seconds.
- Force the station to send only at the beginning of time slot.
- If a station misses the moment, it must wait until the beginning of the net time slot
- Still there is a possibility of collision
  - When more than one station try to send at the beginning of the slot

Frames in a slotted ALOHA network



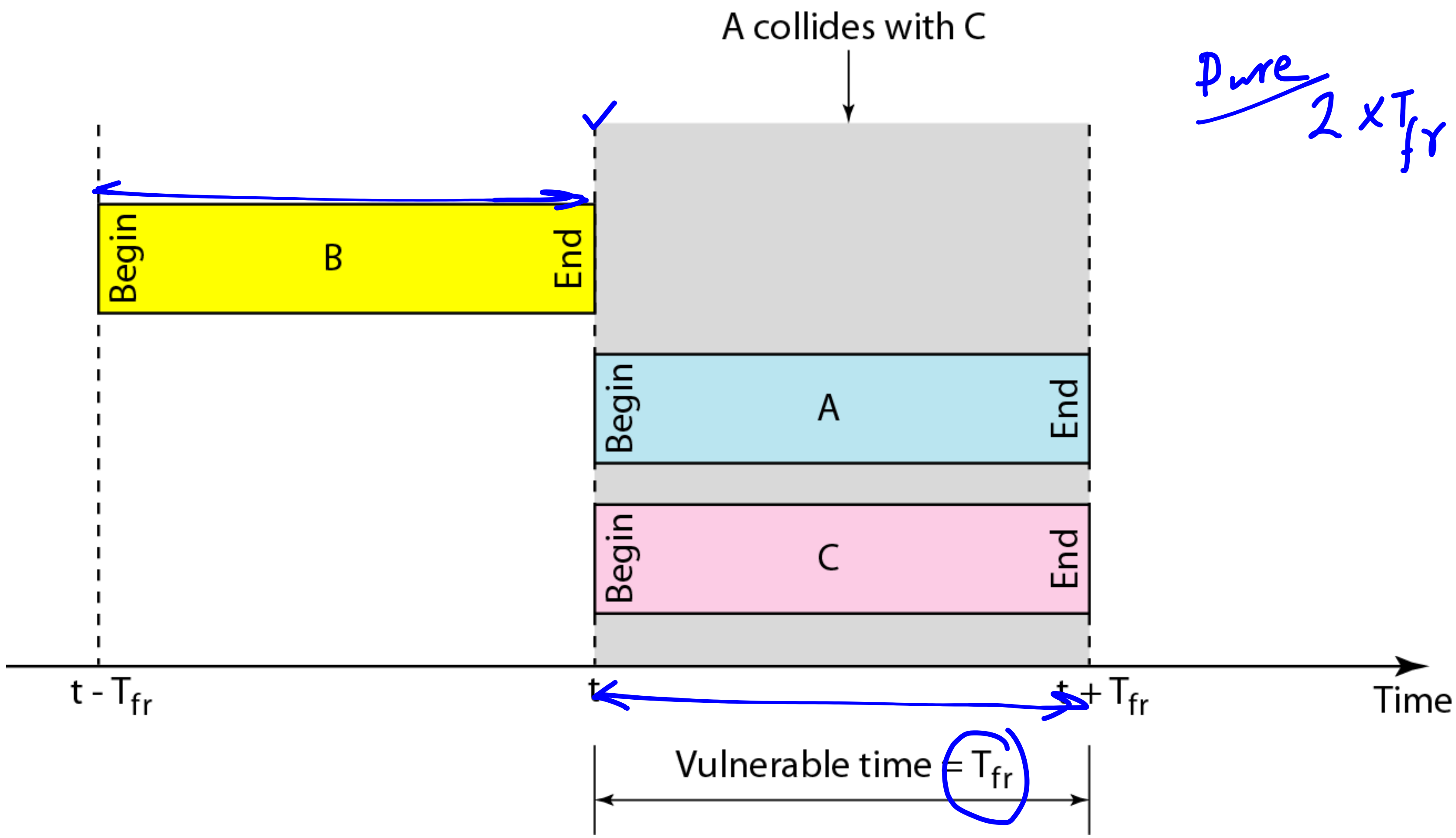
Pure $S = G \times e^{-2G}$

Note

- **The throughput for slotted ALOHA is $S = G \times e^{-G}$**

- **The maximum throughput $S_{max} = 0.368$ when G = 1.**

Vulnerable time for slotted ALOHA protocol



Example

- **A slotted ALOHA network transmits 200-bit frames on a shared channel of 200 Kbps.**
- **What is the throughput if the system (all stations together) produces**

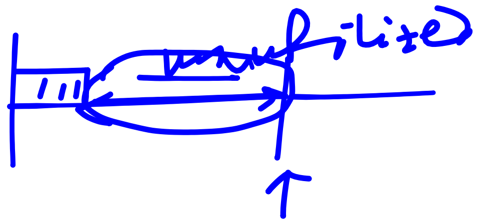
a. 1000 frames per second   b. 500 frames per second

c. 250 frames per second.

Solution

The frame transmission time is 200bits/200 Kbps or 1 ms.

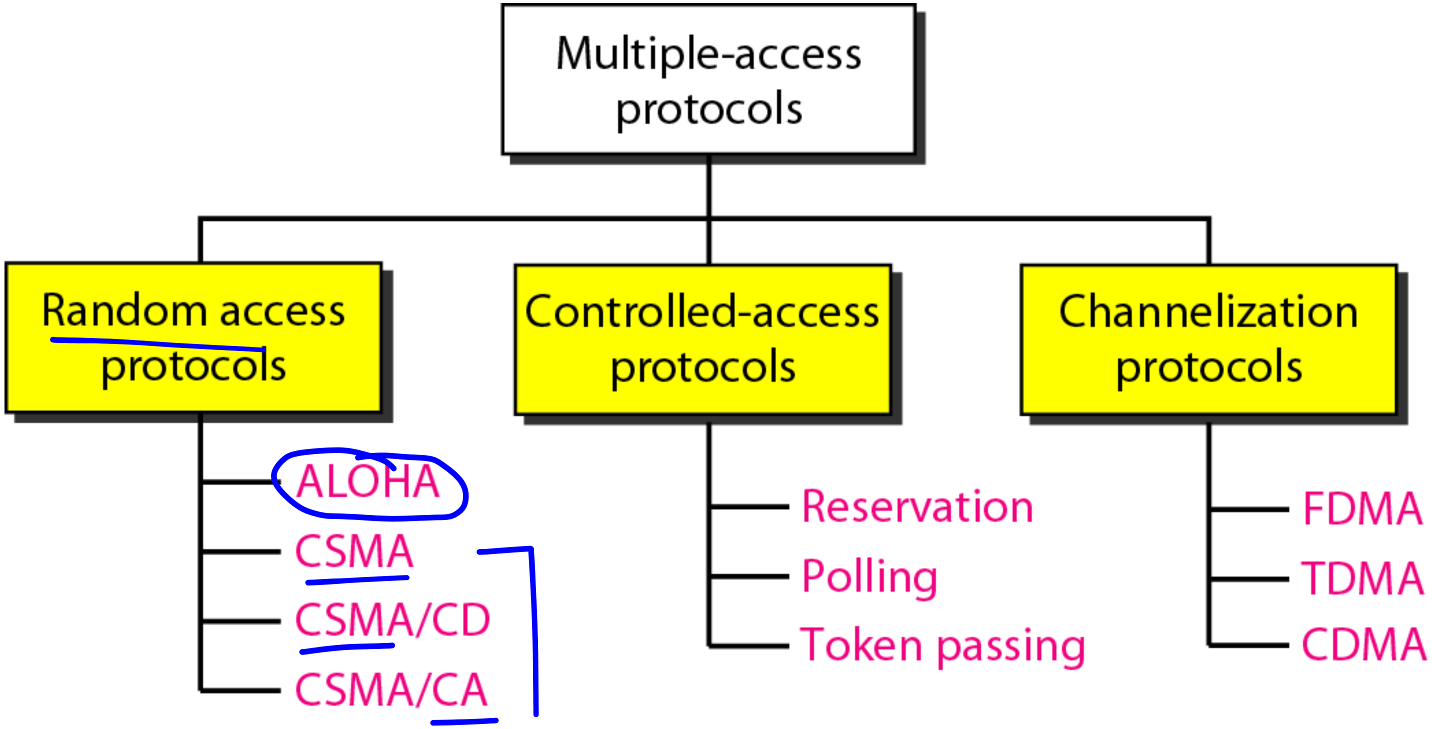
a. If the system creates 1000 frames per second, this is 1 frame per millisecond. The load is 1. In this case $S = G \times e^{-G}$ or S = 0.368 (36.8 percent). This means that the throughput is 1000 × 0.0368 = 368 frames. Only 386 frames out of 1000 will probably survive.



Example (continued)

b. If the system creates 500 frames per second, this is (1/2) frame per millisecond. The load is (1/2). In this case $S = G \times e^{-G}$ or $S = 0.303$ (30.3 percent). This means that the throughput is $500 \times 0.0303 = 151$. Only 151 frames out of 500 will probably survive.

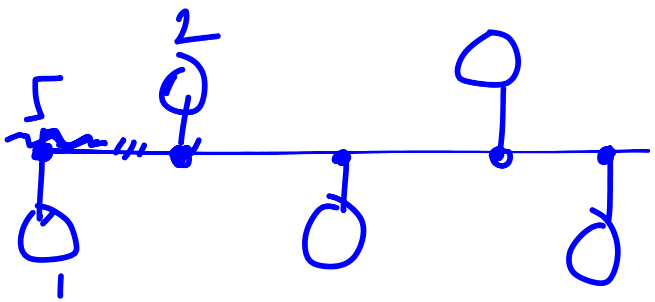
c. If the system creates 250 frames per second, this is (1/4) frame per millisecond. The load is (1/4). In this case $S = G \times e^{-G}$ or $S = 0.195$ (19.5 percent). This means that the throughput is $250 \times 0.195 = 49$. Only 49 frames out of 250 will probably survive.



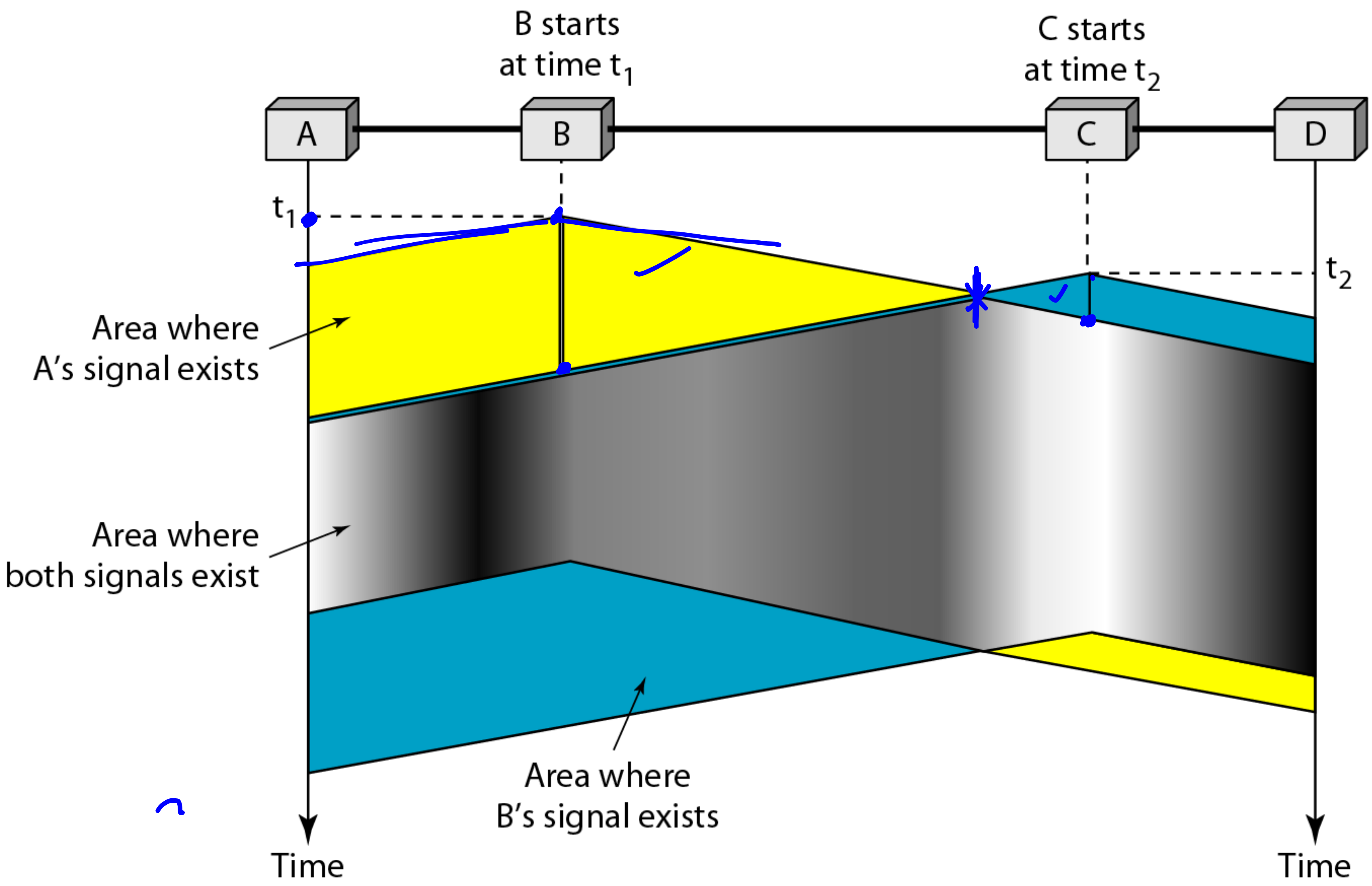
Multiple-access protocols
Random access protocols
ALOHA
CSMA
CSMA/CD
CSMA/CA
Controlled-access protocols
Reservation
Polling
Token passing
Channelization protocols
FDMA
TDMA
CDMA

Carrier Sense Multiple Access (CSMA)

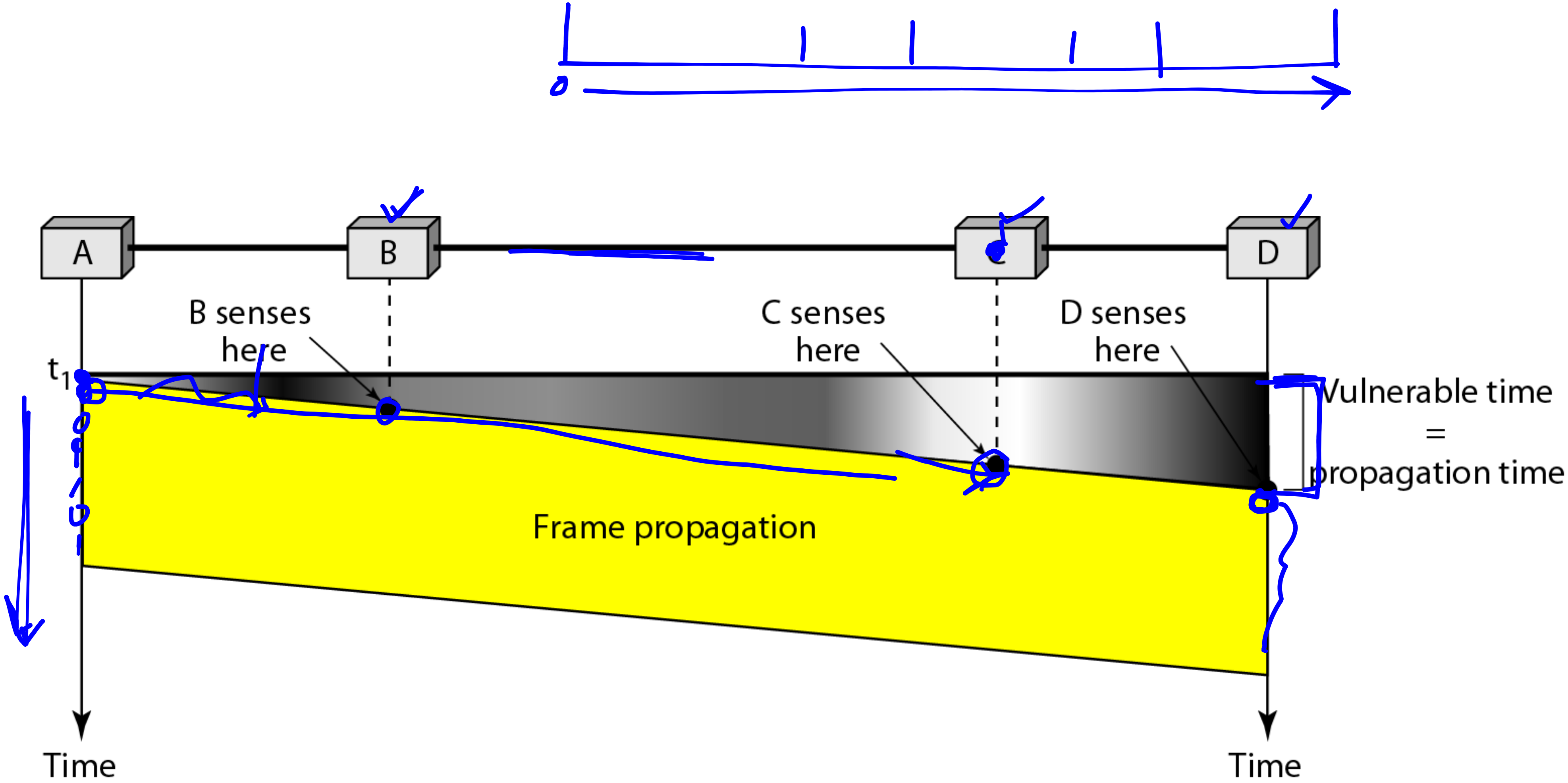
- CSMA requires that each station first listen to the medium (or check the state of the medium) before sending.
  - Basic idea is *"sense before transmit"* or *"listen before talk"*
- This mechanism reduces the possibility of collision but can not eliminate



Space/time model of the collision in CSMA



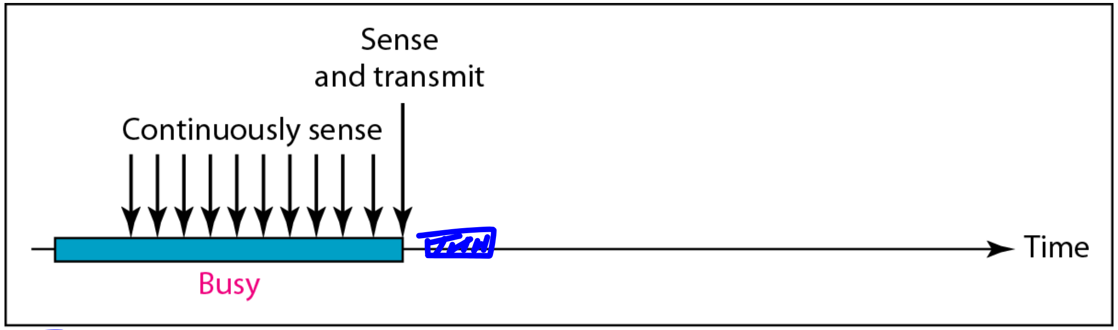
Vulnerable time in CSMA



Persistence Method

- What should a station do if the channel is busy?
- What should a station do if the channel is idle?
- Three methods have been designed
  - 1-persistent
  - Nonpersistent
  - p-persistent

Behavior of three persistence methods

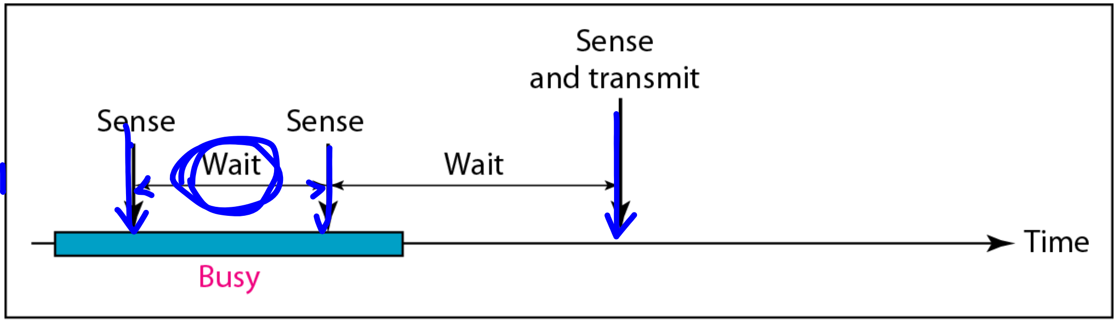


a. 1-persistent

Idle **→** ***sends the frame immediately.***

2^k-1

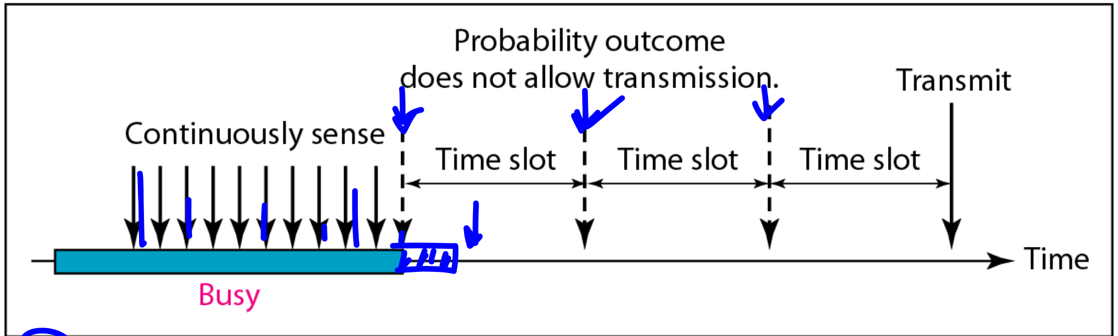
0



b. Nonpersistent

Busy **→** ***wait random time***

Idle **→** ***sends immediately***

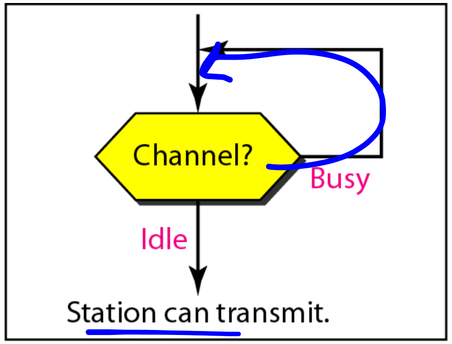


c. p-persistent

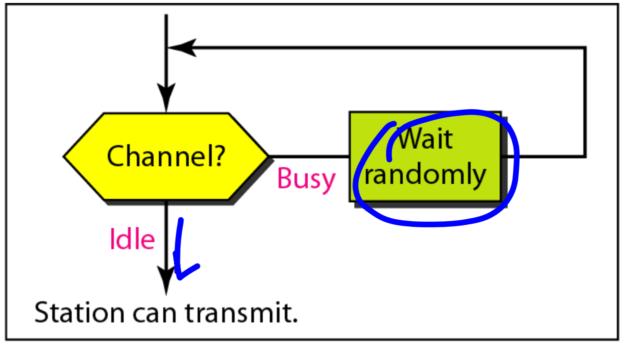
Idle **→** ***With probability p***

- ***if the channel has time slot equal to or greater than propagation time transmit***
- ***Else with probability (1-p)*** ***wait for the beginning of the next time slot***

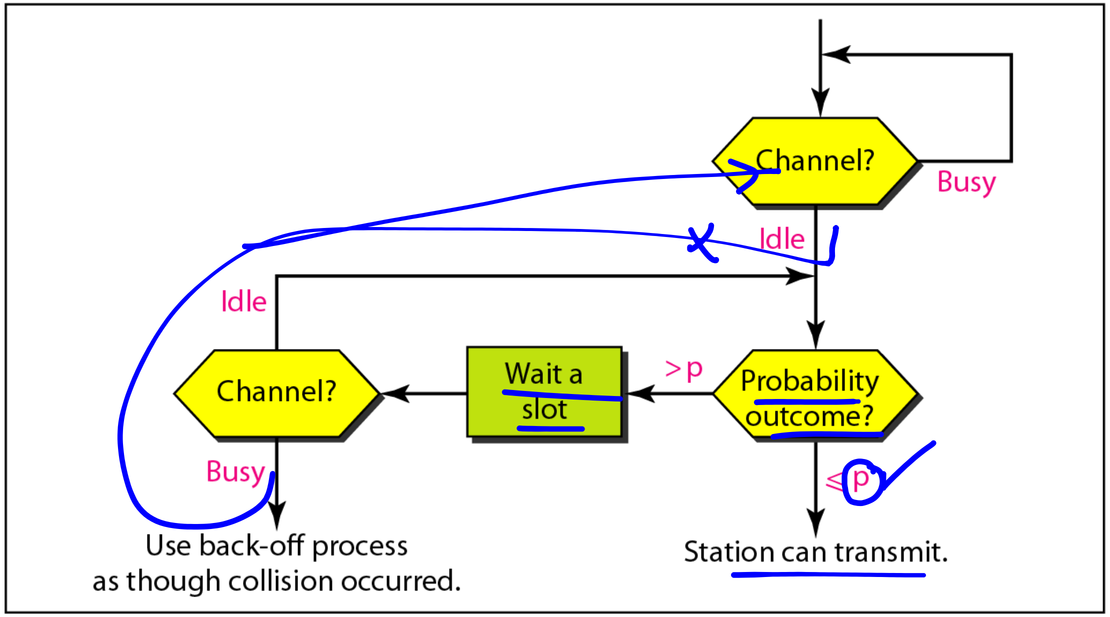
Flow diagram for three persistence methods



a. 1-persistent

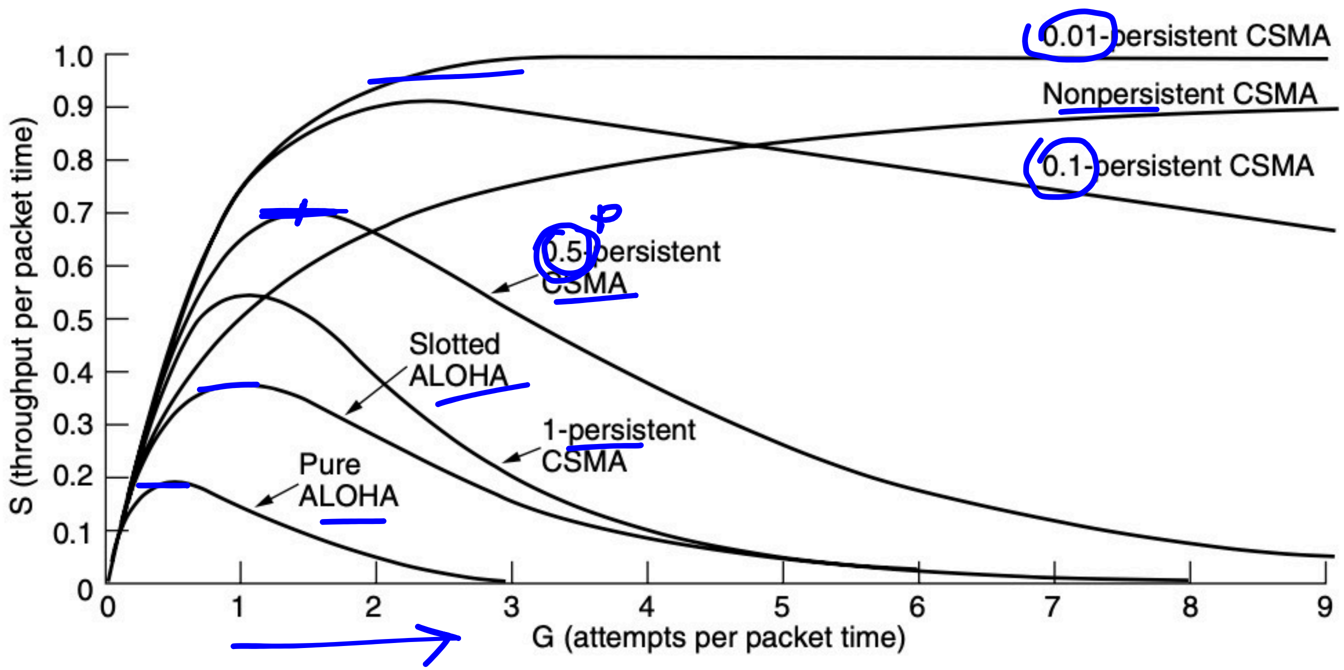


b. Nonpersistent



c. p-persistent

Comparison of throughputs for different CSMAs



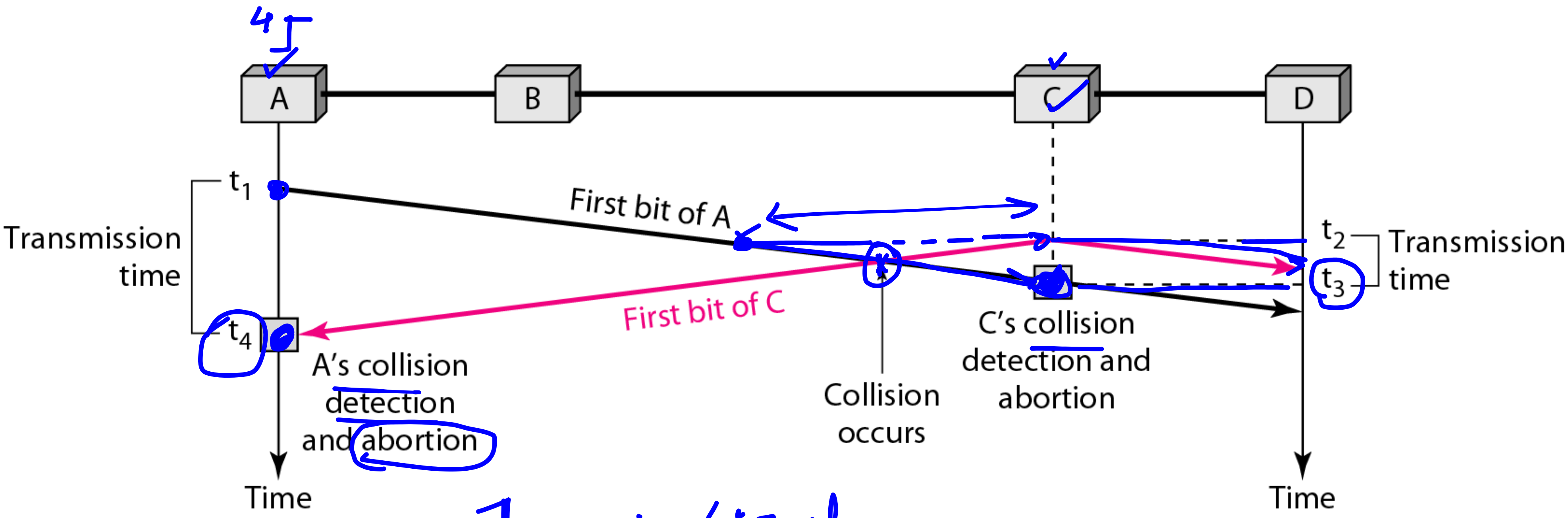
Courtesy: Tanenbaum and Wetherall Book

CSMA/CD

- CSMA does not specify the method after collision
  - CSMA/CD advocates how to handle the collision

Collision of the first bit in CSMA/CD

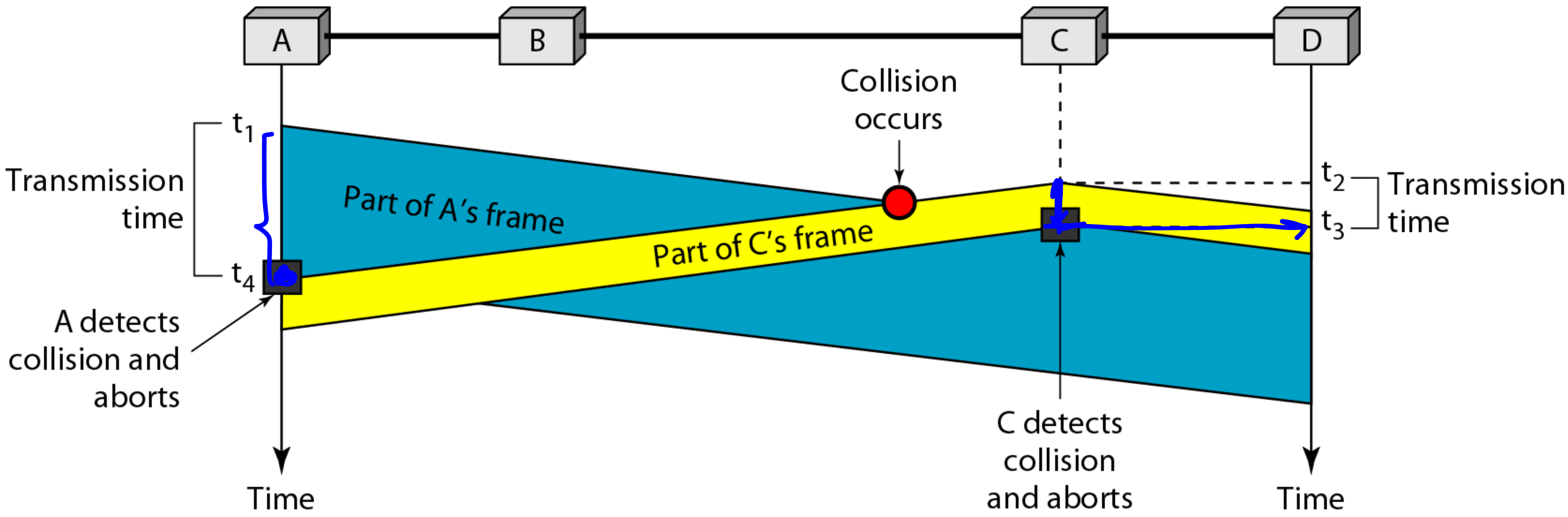
4.5/5



Jamming signal

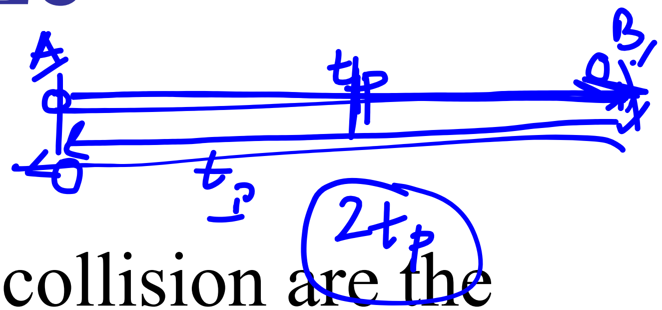
48-bits

Collision and abortion in CSMA/CD



Minimum frame size

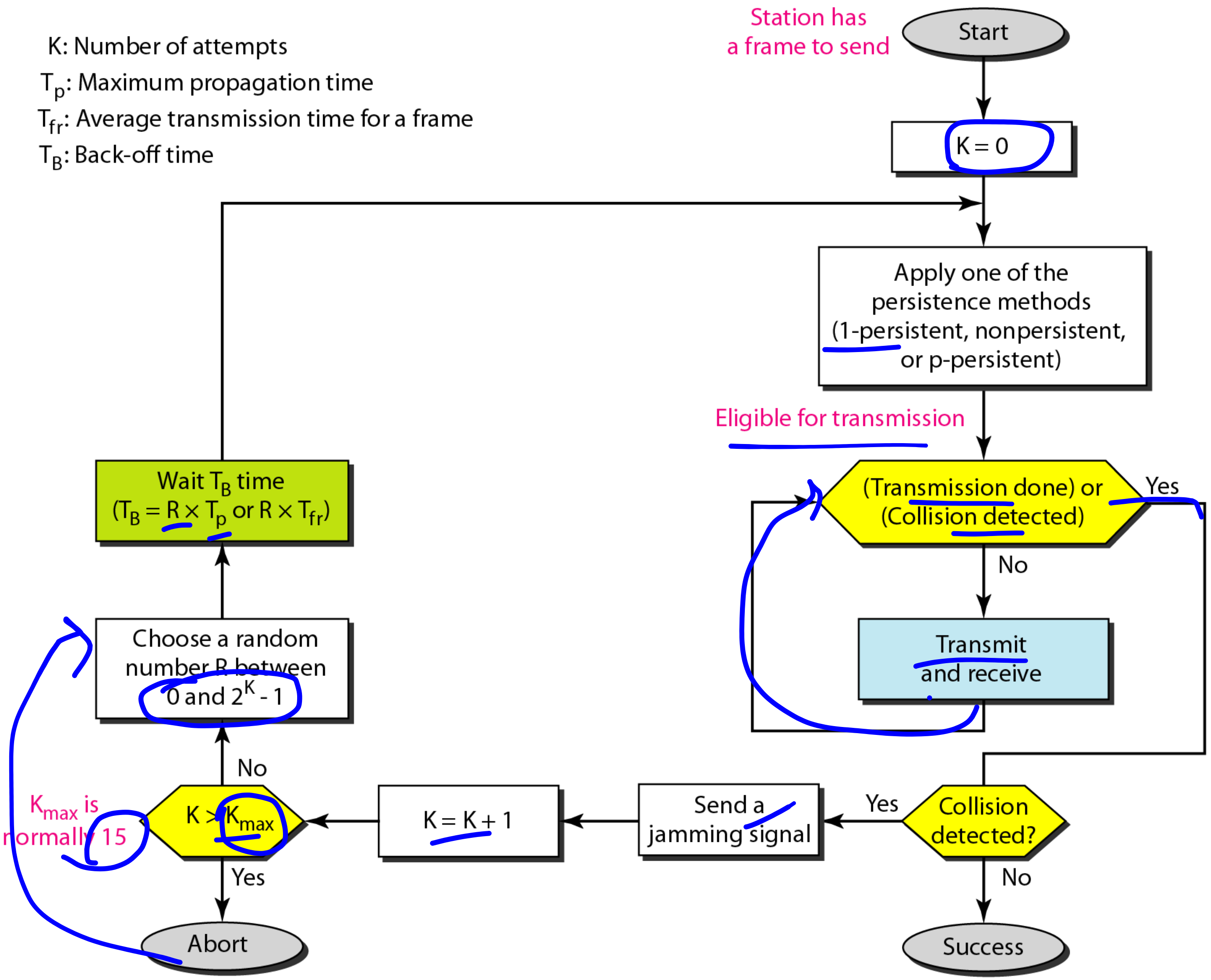
- Assume the worst case:



  - Two stations involved in a collision are the maximum distance apart
  - The signal from the first takes time T_p to reach the second
  - The effect of the collision takes another T_p to reach the first
  - So the minimum time required to transmit the data to detect the collision is $2T_p$
    - Hence, *minimum size of the frame is $2T_p$*

Flow diagram for the CSMA/CD

1, P, D



Example

A network using CSMA/CD has a bandwidth of 10 Mbps. If the maximum propagation time (including the delays in the devices and ignoring the time needed to send a jamming signal, as we see later) is 25.6 μs, what is the minimum size of the frame?

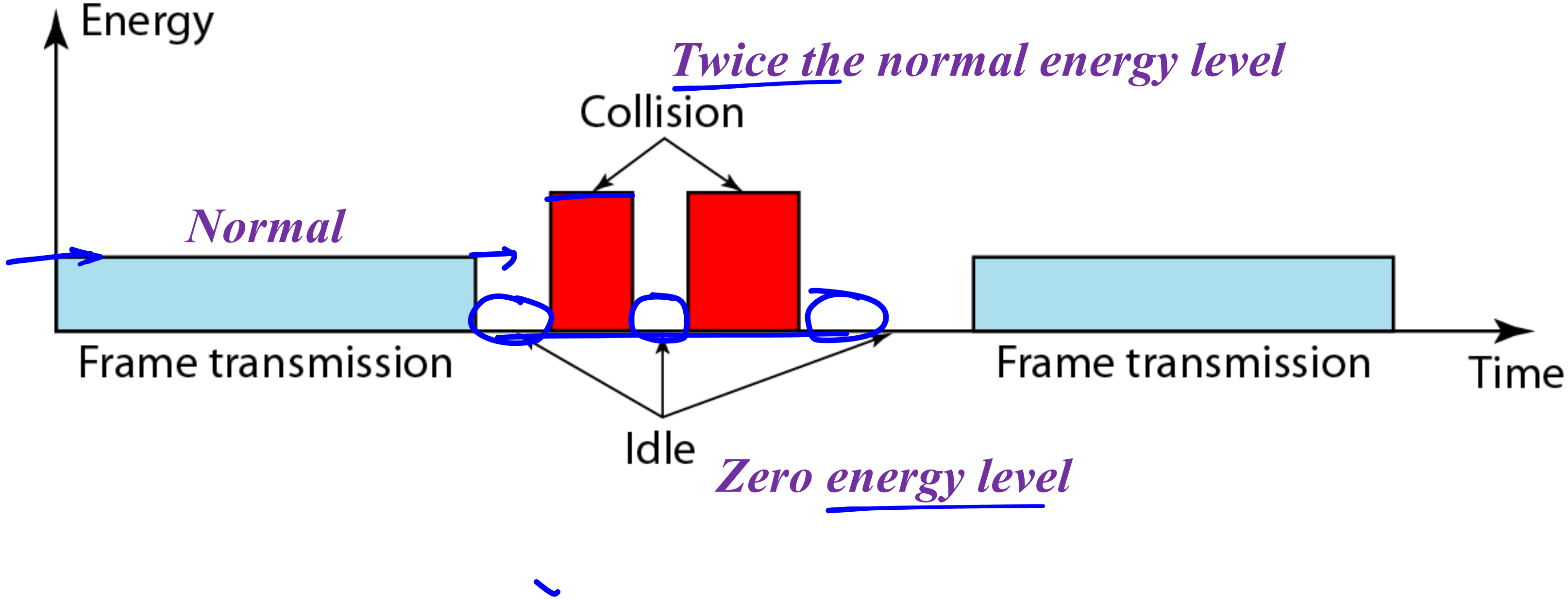
Solution

- The frame transmission time is $T_{fr} = 2 \times T_p = 51.2\ \mu s$.

$\frac{L}{B} = T_{fr}$

- This means, in the worst case, a station needs to transmit for a period of 51.2 μs to detect the collision
- The minimum size of the frame is 10 Mbps × 51.2 μs = 512 bits or 64 bytes.
- This is actually the minimum size of the frame for Standard Ethernet.

Energy level during transmission, idleness, or collision



Energy levels: Zero, Normal, Abnormal

Throughput

- Greater than that of pure or slotted ALOHA
- Maximum throughput depends on
  - Value of G
  - persistence method and
  - the value of p

- ***Example:***
  - For G=1 and p=1, Throughput is 50%
  - For nonpersistent method throughput can gone up to 90% when G is in between 3 and 8

Application

- Traditional Ethernet LAN with the data speed of 10Mbps use this CSMA/CD

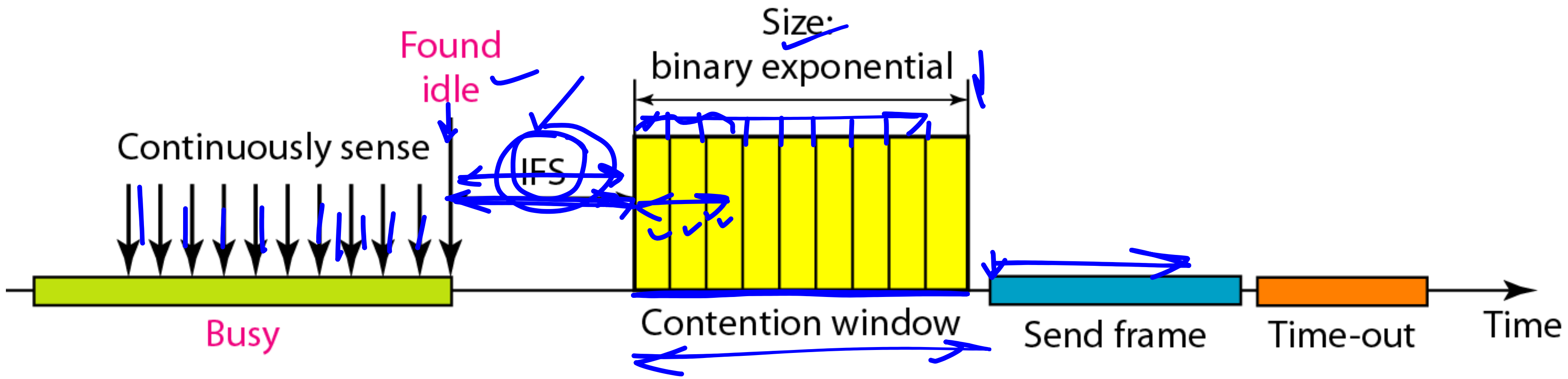
Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA)

- Originally invented for wireless networks
- Collisions are avoided through ***three strategies***
  - Interframe space (IFS)
  - Contention window
  - Acknowledgements

Interframe Space (IFS)

- Even if the channel is idle transmission is deferred
  - Not send the data immediately
- Wait for period of time called ***interframe space (IFS)***
- *IFS* time allows the front of the transmitted signal by the distant station to reach this station
- Different IFS time can be assigned to different station to prioritize stations or frame time
- After IFS time if the channel is still idle
  - Station can transmit data but after waiting for another time.
    - This waiting time is called ***contention window***

Timing in CSMA/CA



Contention Window

- Contention window is an amount of time divided into slots
  - Number of slots may change according to binary backoff strategy
  - It is set to one slot the first time and then *double each time the station cannot sense the idle channel after IFS time*

Contention Window

- Ready station choose a certain amount of slots randomly as its waiting time
  - This makes the difference from p-persistent
- The station needs to sense the channel after each slot
- If the station found the channel busy
  - Does not restart the process
  - It stops the timer and restarts it when the channel is sensed idle
  - This gives priority to the station with the longest waiting time

Acknowledgements

- Even the use of IFS and contention window
  - Still there be collision
  - Data may be corrupted during transmission
- The positive acknowledgement and time-out timer can help guarantee the receiver has received the frame

Note

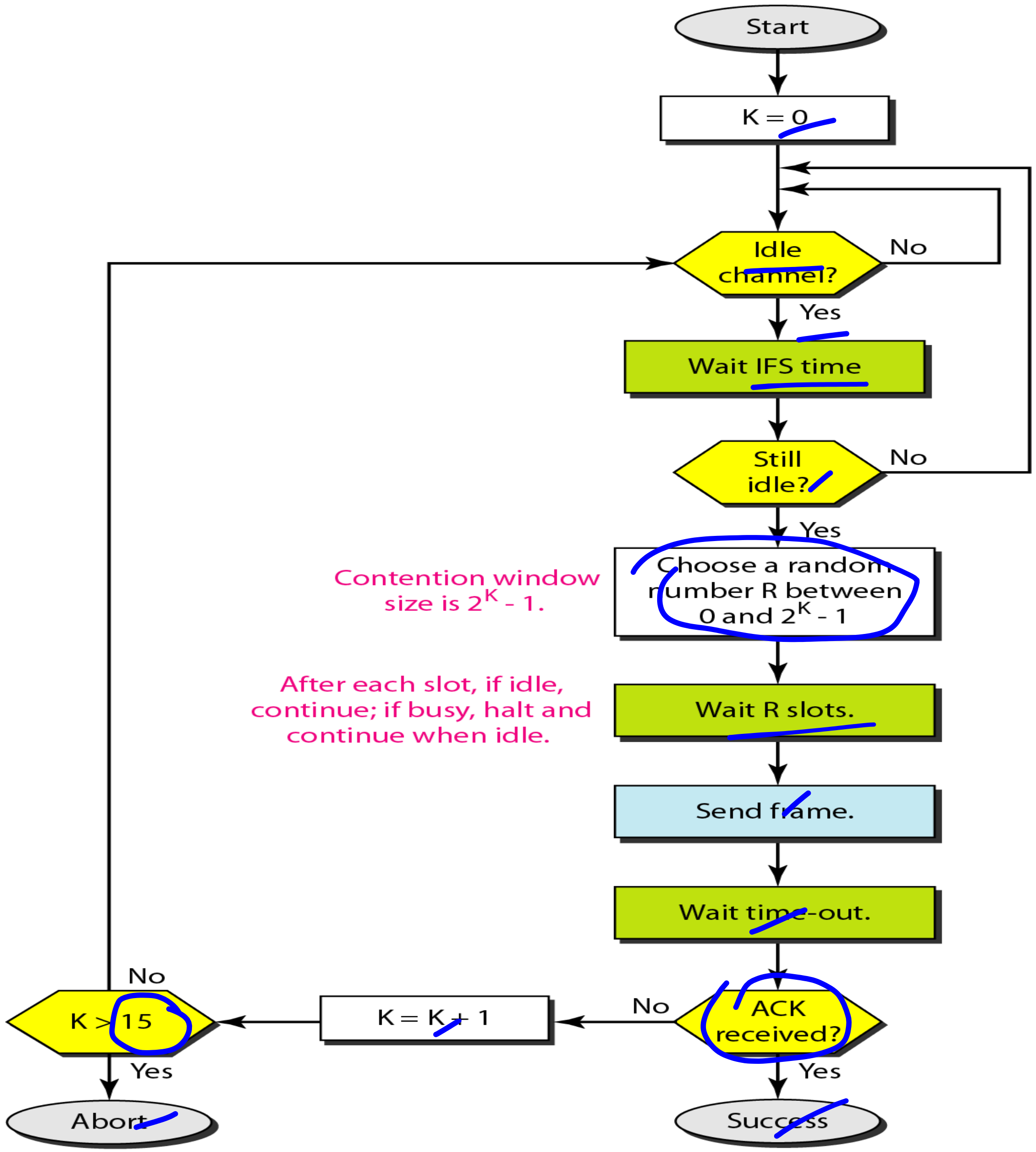
In CSMA/CA, the IFS can also be used to define the priority of a station or a frame.

Note

- **In CSMA/CA, if the station finds the channel busy, it does not restart the timer of the contention window**

- **It stops the timer and restarts it when the channel becomes idle.**

Flow diagram for CSMA/CA



Mathematical Examples

- ***Example 1:*** Consider a CSMA/CD network that transmits data at a rate of 100Mbps over a 1Km cable with no repeaters. If the minimum frame size required for the network is 1250 bytes, what is the signal speed (in Km/sec) in the cable?

Ans:

Frame transmission time $\boldsymbol{T_{fr}} = \boldsymbol{2\times T_p}$ to avoid the collision

Given B = 100 Mbps and Frame size L = 1250 bytes

So, $T_{fr} = (1250 \times 8) / (100 \times 10^6)$ sec

Let speed of the signal is S m/s

Now, $T_p = 1000/S$ sec

Using the values of T_{fr} and T_p we have $(1250 \times 8) / (100 \times 10^6) = 2 \times 1000/S$

➔ $S = 20000$Km/sec

Mathematical Examples

- ***Example 2:*** A 2 Km long broadcast LAN has 10^7 bps bandwidth and uses CSMA/CD. The signal travels along the wire at 2×10^8 m/s. What is the minimum packet size on this network?

Ans:

$t_{fr} = 2 \times T_p$

$T_{fr} = \frac{L}{B}$

$t_p = \frac{D}{S}$

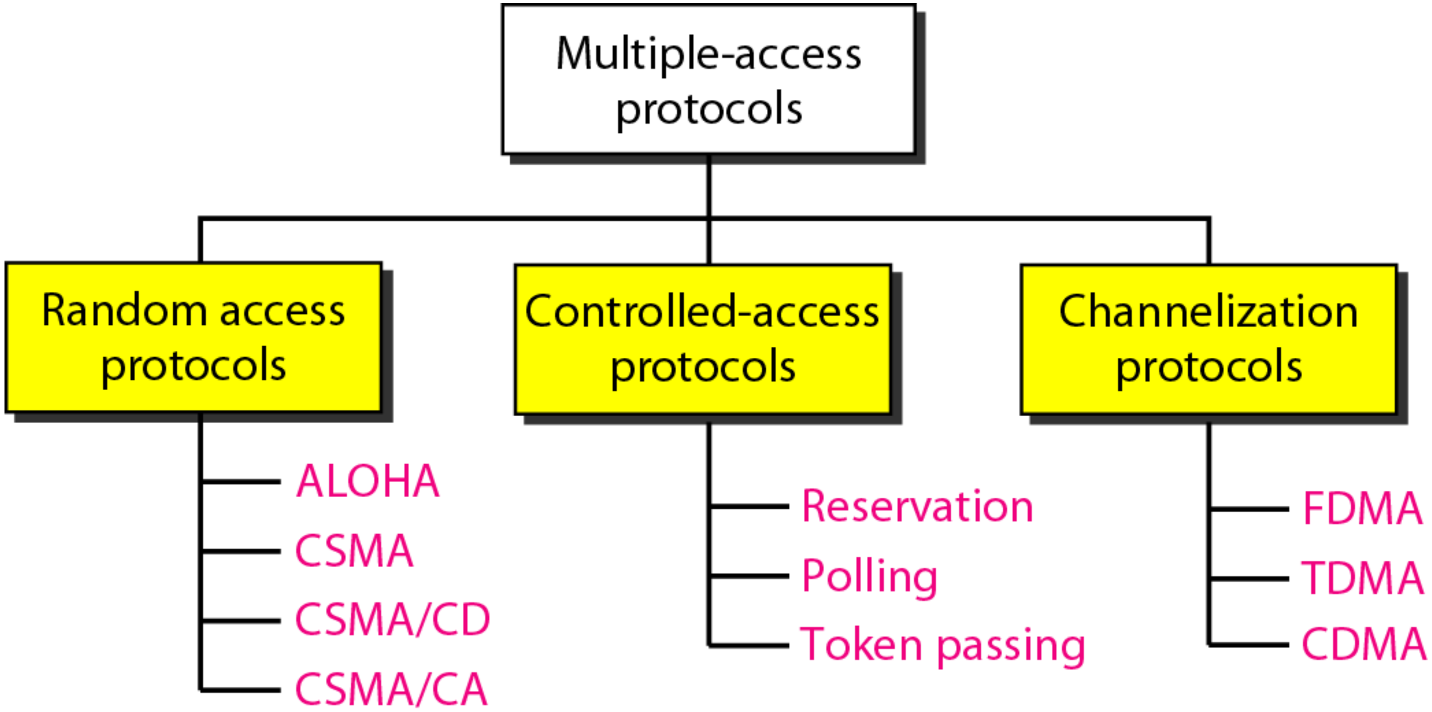
$\frac{L}{B} = 2 \times \frac{D}{S}$

$\Rightarrow L = \frac{2 \times D \times B}{S}$

$\boxed{L = \frac{2 \times D \times B}{S}} = \frac{2 \times 2000 \times 10^7}{2 \times 10^8}$

$= 200$ bits

$= 25$ bytes


Multiple-access protocols
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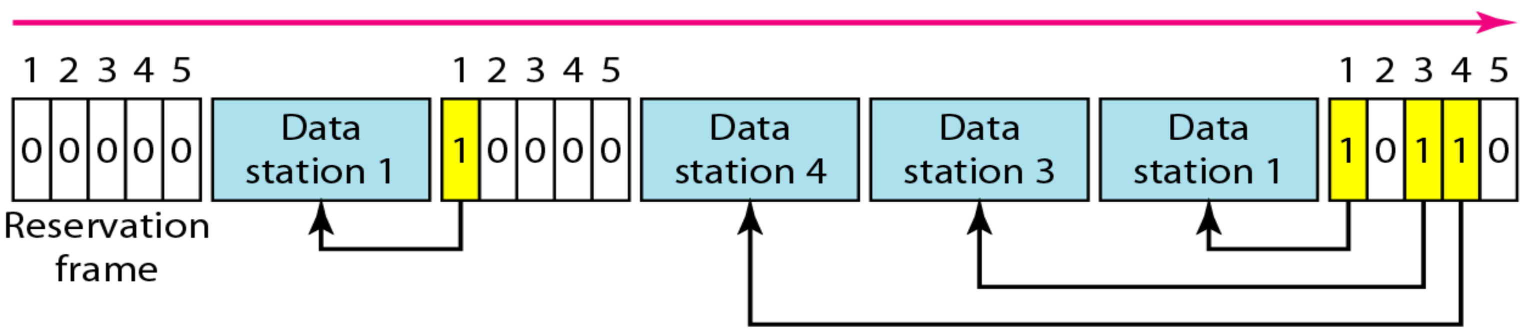
Controlled Access

- ***In controlled access, the 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.***
- ***There are three popular controlled-access methods***
  - **Reservation**
  - **Polling**
  - **Token Passing**

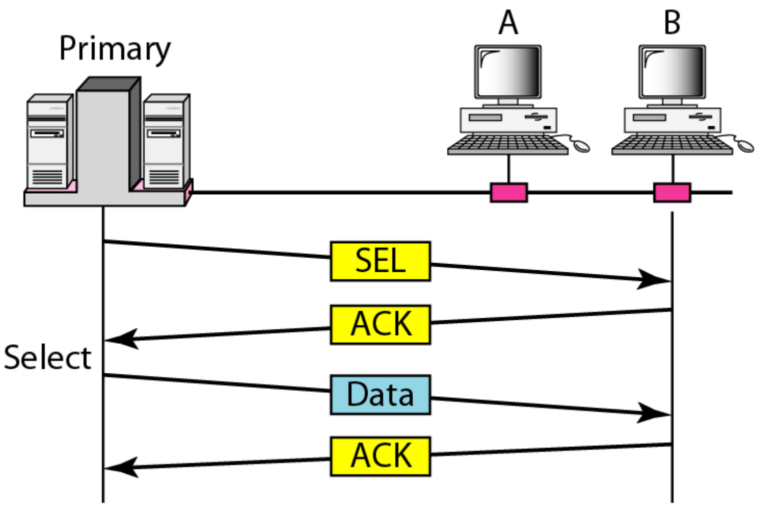
Reservation access method

- A station need to make a reservation before sending the data
- Time is divided into intervals and in each interval, a reservation frame precedes the data frames sent in that interval
- If there are N stations in the system, there are exactly N reservation mini slots in the reservation frame
  - Each mini slots belong to a station
  - When a station needs to send a data frame, it first reserve its own slot and then send their data frame after the reservation frame

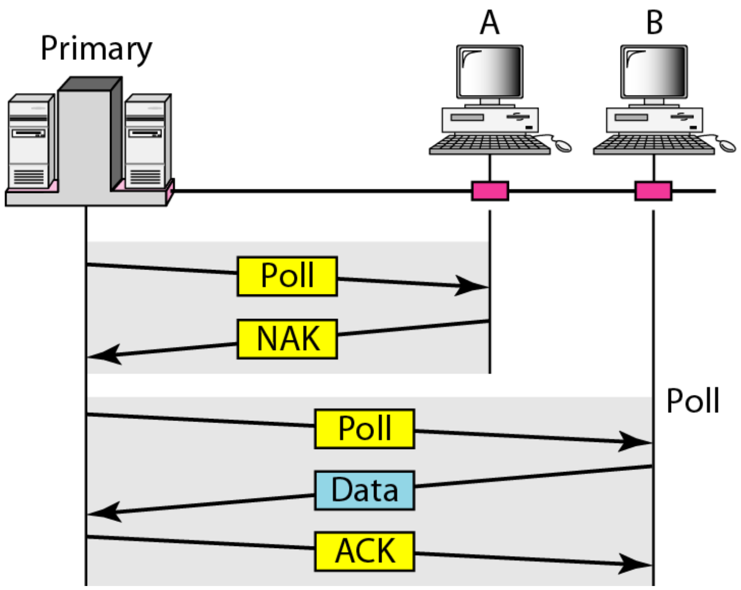


Polling access method

- Polling works with topologies in which one device is designated as a *primary station and the other devices are secondary stations*
- All data exchanges must be made through the primary device even when ultimate destination is a secondary device
- The primary device controls the link
    - The secondary devices follows its instructions
- It is up to the primary device to determine which device is allowed to use the channel at a given time



- ***Primary wants to send the data***
- ***Primary sends SEL frame containing address of the intended device***



- ***Poll function is used to solicit transmission from the secondary device***

Token-passing access method

- The stations are organized in a logical ring
  - For each station there is a predecessor and successor
  - Current station is the station accessing the channel
- The right to this access has been passed from the predecessor to the current station
- The right will be passed to the successor when the current station has no more data to send

Token-passing access method

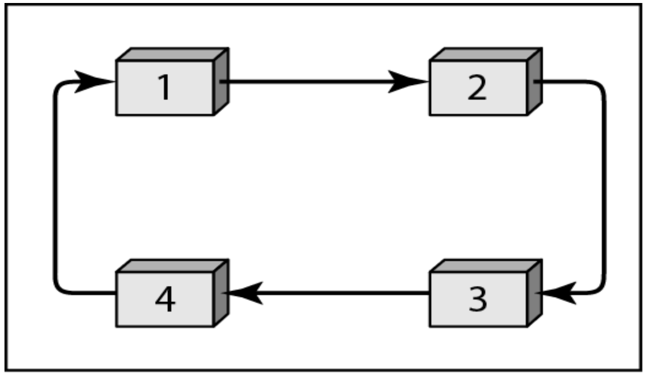
- Right to access the channel is managed by a special packet called ***token*** that circulates through the ring
- Station posses the token has the right to access the channel and send its data
- When the station has no more data to send
  - Releases the token and passes to the successor
- The station cannot send data until it receives the token again in the next round

Token Management : Functions

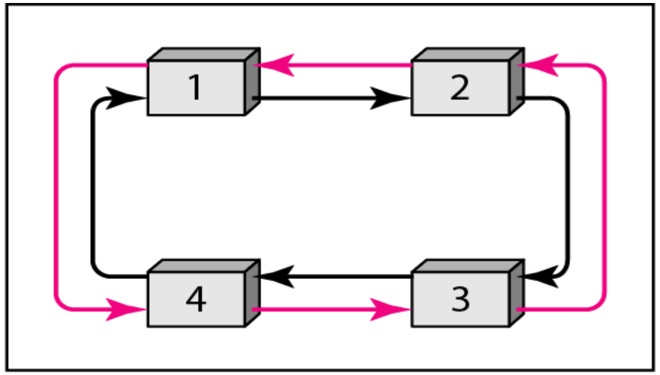
- Stations must be ***limited in the time*** they can have possessions of the token
- The token must be monitored to ensure it has not been destroyed or lost
  - **Example:** *Station holding a token fails, the token will be lost*
- Stations are also assigned priority and to the types of data being transmitted
- Token management is needed to make low priority stations release the token to the high priority stations

Topologies: Token-passing access method

Token can pass only to the successor



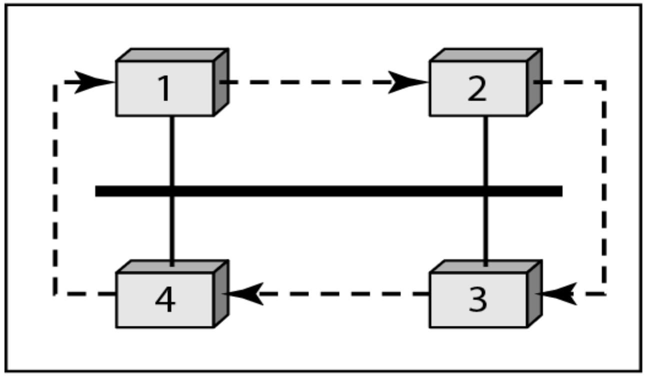
a. Physical ring



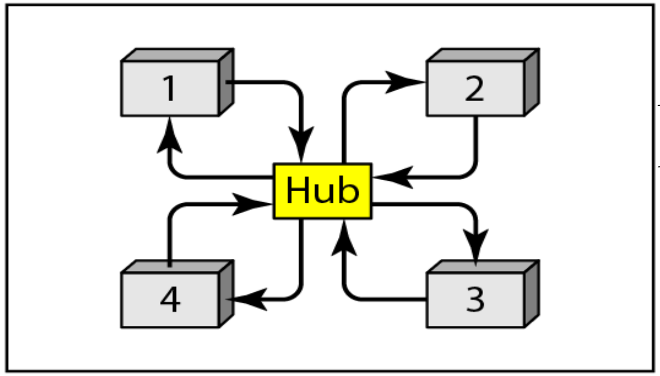
b. Dual ring

Ex: FDDI, CDDI

Ex: Token Bus LAN, Standardize by IEEE



c. Bus ring



d. Star ring

Ex: Token Ring LAN designed by IBM

- ***FDDI: Fiber Distributed Data Interface***
- ***CDDI: Copper Distributed Data Interface***

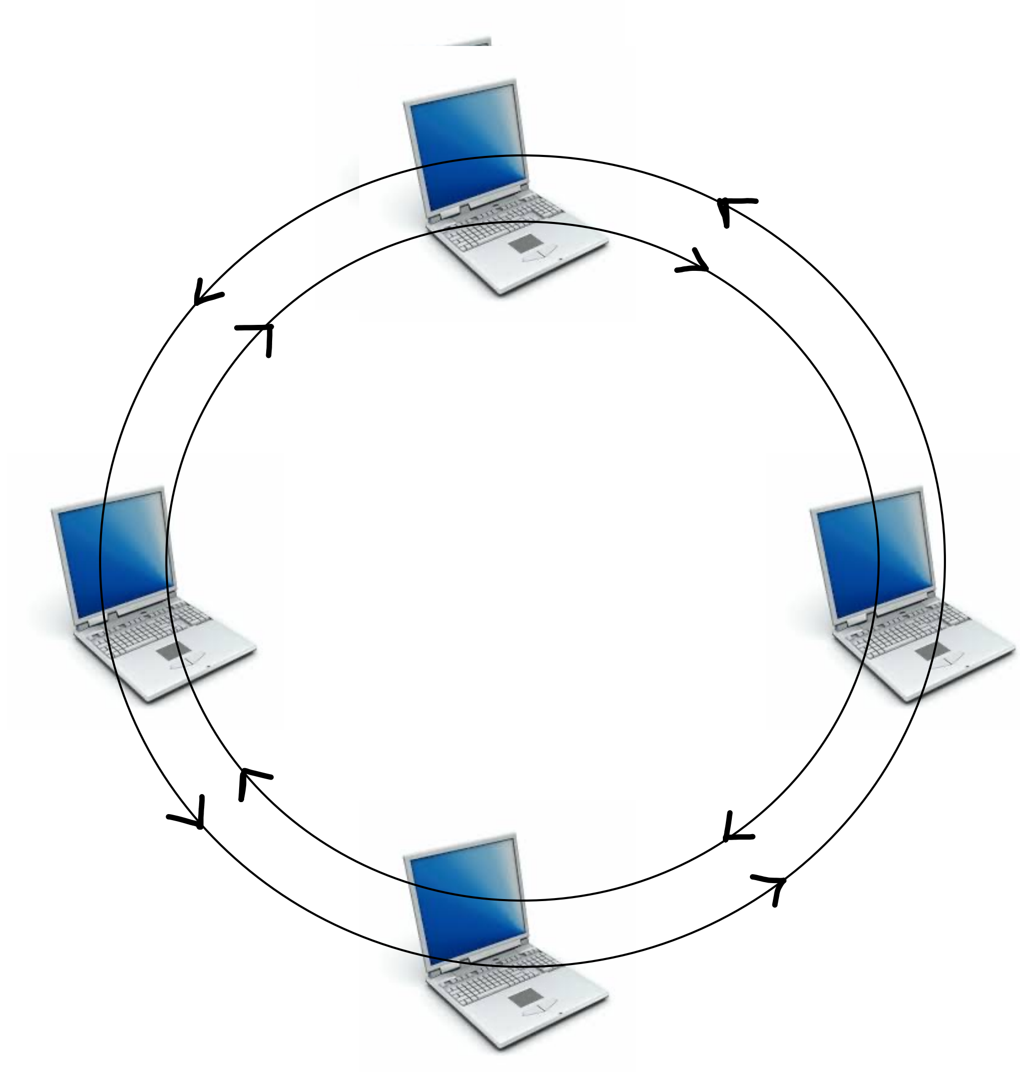
FDDI

- FDDI LAN standard is based on optical fiber as transmission medium
- This standard was developed by ANSI and is given in X3.139-1987
  - Corresponding ISO standard is ISO 9314
- It operates under IEEE 802.2 LLC sublayer allowing it to be integrated easily with other IEEE LANs

FDDI

- FDDI specifies a 100-Mbps token passing, dual ring using fiber-optic cable
  - Dual ring consists of a Primary and a Secondary ring
  - During normal operation, the primary ring is used for data transmission, and the secondary ring remains idle

FDDI



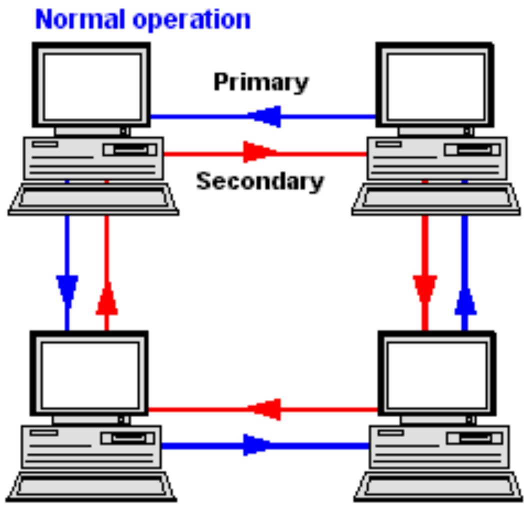
FDDI Ring size and number of stations

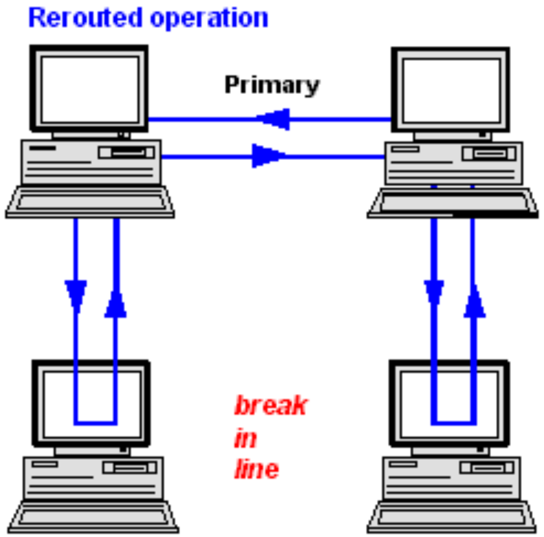
- An unbroken FDDI ring can have size of 100 kms with 500 attached nodes on the ring
- The design is such that the maximum ring length does not exceed 200km when the rings wraps
- The nodes can have separation
  - Up to 2kms on multimode fiber (62.5/125μm)
  - Up to 10 kms on single mode fiber

FDDI

- To accommodate a mixture of stream and bursty traffic, FDDI is designed to handle two types of traffic:
  - ***Synchronous:***
    - Frames that typically have tighter delay requirements (e.g., voice and video)
    - Mainly used for real time applications
    - Each station is assured of token availability and minimum token holding time for transmitting time-critical data frame
  - ***Asynchronous*** frames have greater delay tolerances (e.g., data traffic)

Physical Topology

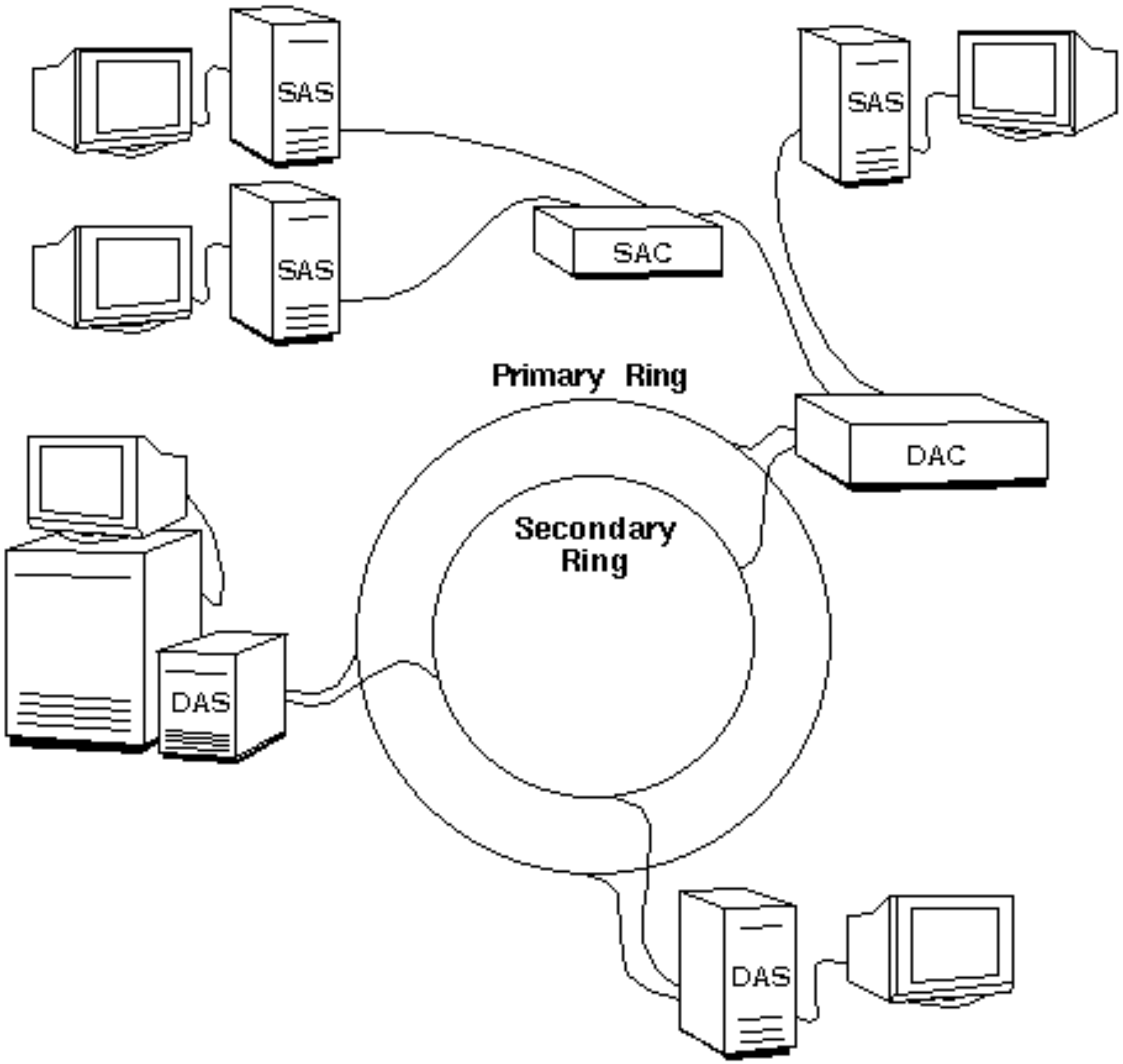




Types of FDDI Stations

- FDDI defines four types of devices that are connected on an FDDI:
  - Dual attachment station(DAS)
  - Single attachment station(SAS)
  - Dual attachment concentrator (DAC)
  - Single attachment concentrator(SAC)

Types of FDDI Stations



FDDI Data Encoding

- Cannot use differential Manchester because 100 Mbps FDDI would require 200 Mbaud!
- Instead each ring interface has its own local clock.
- Outgoing data is transmitted using this clock.
  - Incoming data is received using a clock that is frequency and phase locked to the transitions in the incoming bit stream

FDDI Data Encoding

- Data is encoded using a 4B/5B encoder.
  - For each four bits of data transmitted, a corresponding 5- bit codeword is generated by the encoder.
  - There is a maximum of two consecutive zero bits in each symbol.

FDDI Data Encoding

- The symbols are then shifted out through a NRZI encoder which produces a signal transition whenever a 1 bit is being transmitted and no transition when a 0 bit is transmitted ! guarantees a signal transition at least every two bits.
- Local clock is 125MHz. This yields 100 Mbps (80% due to 4B/5B).

MAC Frame Format in FDDI

- Token frame

16	2	2	2 symbols
Preamble	SD	AC	ED

- Data/Control Frame

(In symbols)

16	2	2	2	12	12		8	1	3
Preamble	SD	AC	FC	DA	SA	Data	FCS	ED	FS

SD: Start Delimiter
AC: Access Control
ED: End Delimiter
FC: Frame Control

DA: Designation Address
SA: Source Address
FCS: Frame Check Sequence
FS: Frame Status

MAC Frame Format in FDDI

- **Preamble:**
  - Used for clock synchronization as there is no master clock source in FDDI
  - It consists of 16 idle symbols (11111).
- **Start Delimiter:**
  - It is the flag indicating start of the frame
  - It consists of two symbols J(11000) and K(10001)
  - J and K contain code violations for their identification

MAC Frame Format in FDDI

- **Frame Control (FC):**
  - It is two symbols long field and contains the following bits

C	L	F	F	N	N	N	N

- ***Class bit (C):*** Indicates whether data field contains synchronous (C = 1) or asynchronous (C = 0) data.
- ***Address length bit (L):*** It indicates the size of the address field, 4 (L =0) 0r 12(L=1) symbols
- ***Frame format bits (FF):*** These two bits identify the type of the frame, data frame or control frame

  FF = 00, C = 0 : SMT(Station management) control frame
  FF= 00, C = 1 : MAC control frame, e.g. Token, Claim token or control frame
  FF = 01 : data frame with LLC PDU
  FF = 10, 11 : Reserved

- ***Control bits (NNNN) :*** NNNN bits identify the type of control frame

0010	***Beacon***
0011	***Claim Token***
0000	***Token***

MAC Frame Format in FDDI

- Destination Address(DA):
  - This is 4 or 12 symbols long
  - 4 symbols long addresses are never used, though the standard provides for them
- Source Address(SA):
  - This is 4 or 12 symbols long
  - 4 symbols long addresses are never used, though the standard provides them

MAC Frame Format in FDDI

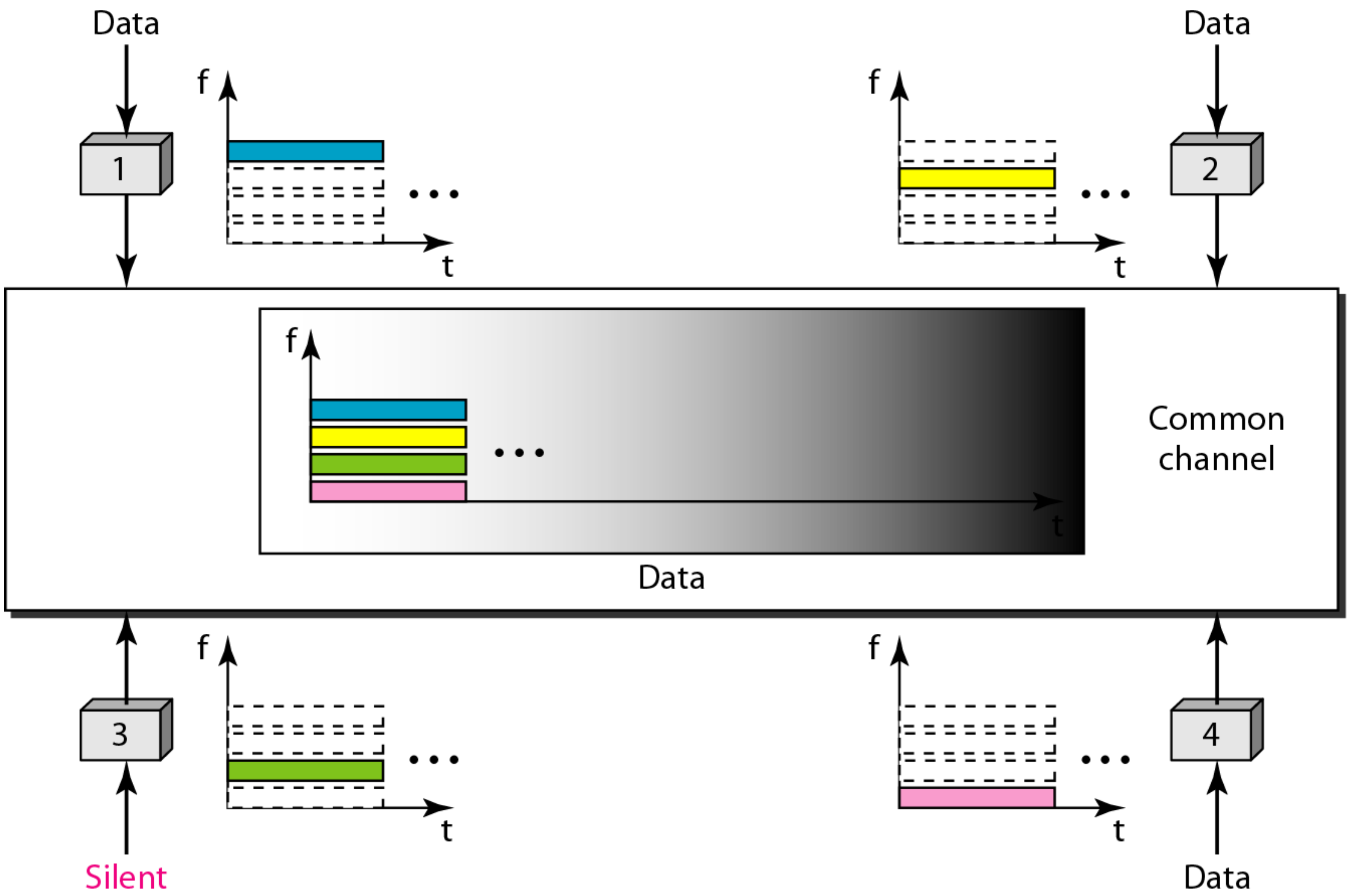
- **Data:**
  - Data can contain symbols corresponding to 0 to 4478 octets of data
- **Frame Check response (FCS):**
  - It is eight symbols long field and contains CRC sequence for error detection in FC, DA, SA and data fields
- **End Delimiter (ED):**
  - It marks end of the frame
  - It is one symbol long and contains violation symbol T
- **Frame Status (FS):**
  - Contains two address recognized bits (A-bits) and two frame copied bits(C-bits).
  - Every frame is sent with AC=00

Channelization

- ***Channelization*** ***is a multiple-access method in which the available bandwidth of a link is shared in time, frequency, or through code, between different stations.***
- ***Three channelization protocols can be considered:***

  - **Frequency-Division Multiple Access (FDMA)**
  - **Time-Division Multiple Access (TDMA)**
  - **Code-Division Multiple Access (CDMA)**

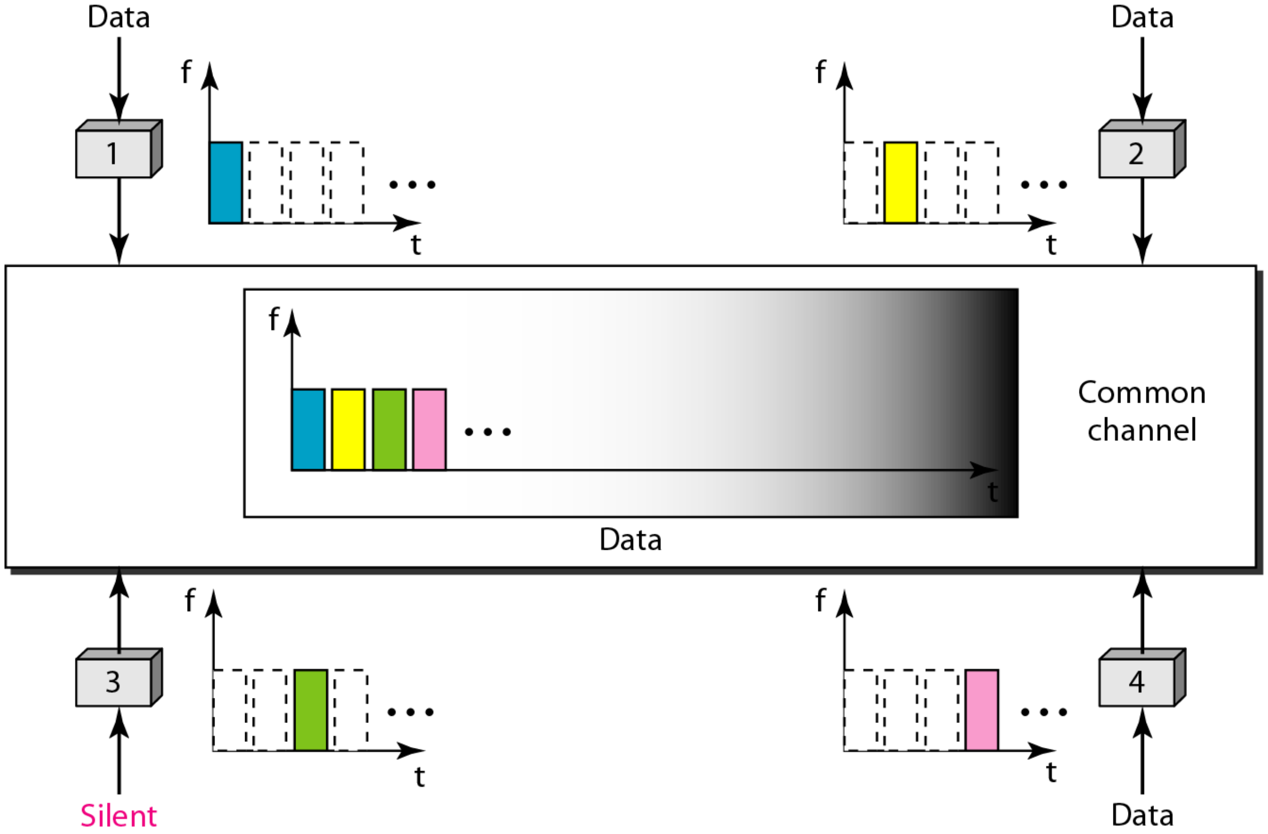
Frequency-division multiple access (FDMA)



Note

In FDMA, the available bandwidth of the common channel is divided into bands that are separated by guard bands.

Time-division multiple access (TDMA)



- ***Main problem*** lies in synchronization between different stations.
  - Each station needs to know the beginning of its slot and the location of its slot
  - This may be difficult because of propagation delay

Note

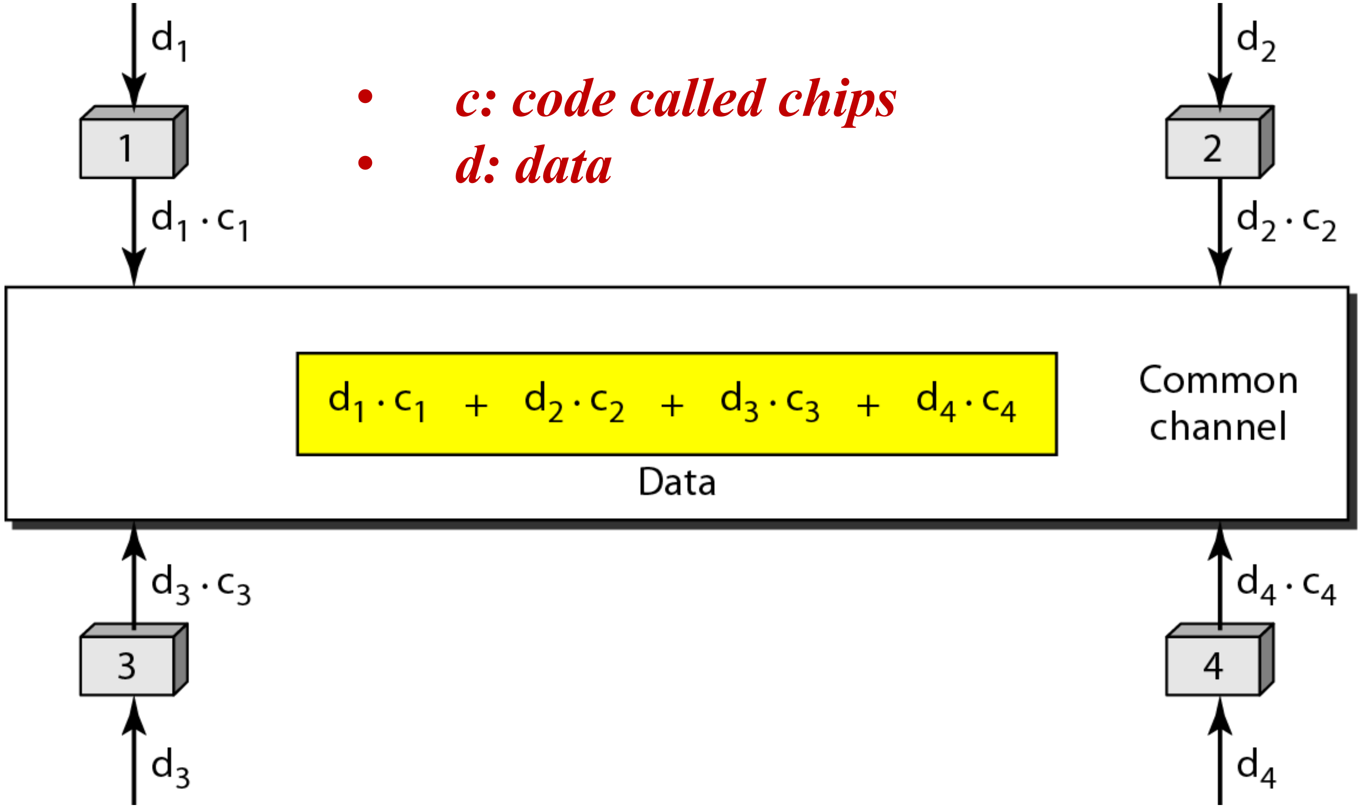
In TDMA, the bandwidth is just one channel that is timeshared between different stations.

CDMA

In CDMA, one channel carries all transmissions simultaneously.

CDMA: Simple idea of communication with code

- ***c: code called chips***
- ***d: data***



Chip sequences

- **Properties:**
  - Each sequence is made up of N elements, N is the number of stations
  - If we multiply a sequence by a number, every element in the sequence is multiplied by that element
  - If we multiply each code by another, ***element by element and then add we get 0 (called inner product)***
  - If we multiply each code by itself, ***element by element, and then add we get the number of stations***
  - Adding two sequences means adding the corresponding elements. The result is another sequence.

Example:

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

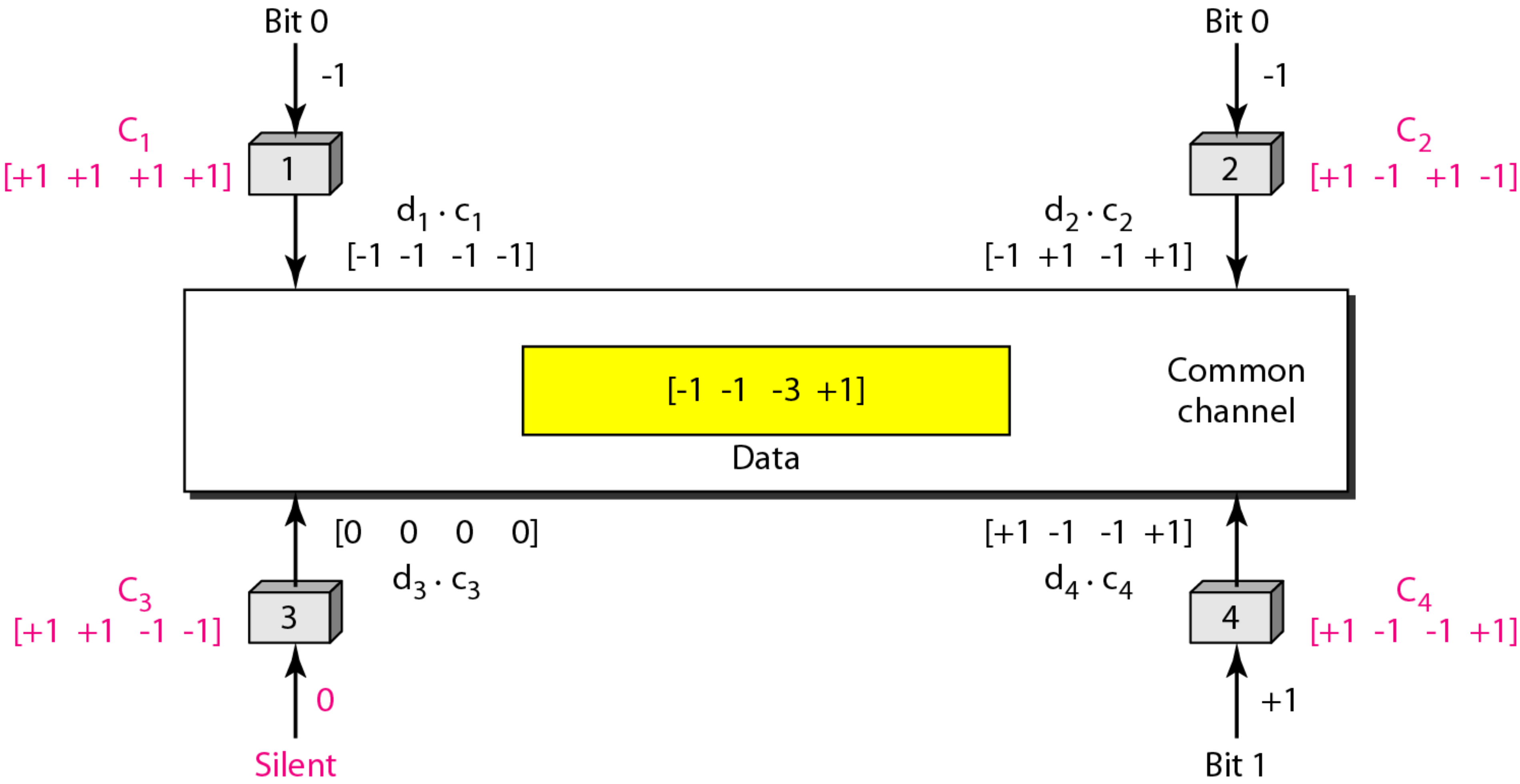
Encoding: Data representation in CDMA

Data bit 0 $\rightarrow$ -1

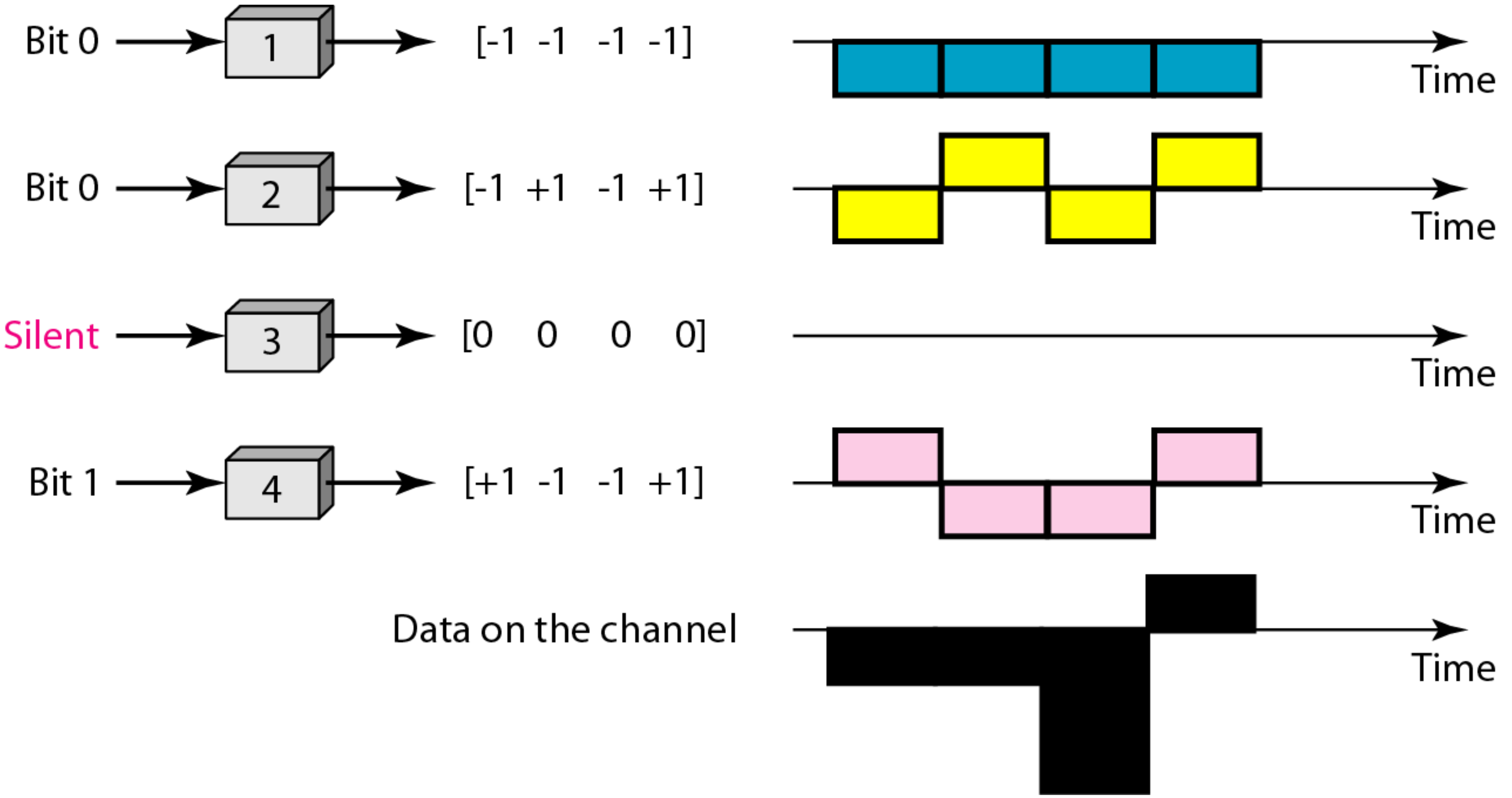
Data bit 1 $\rightarrow$ +1

Silence $\rightarrow$ 0

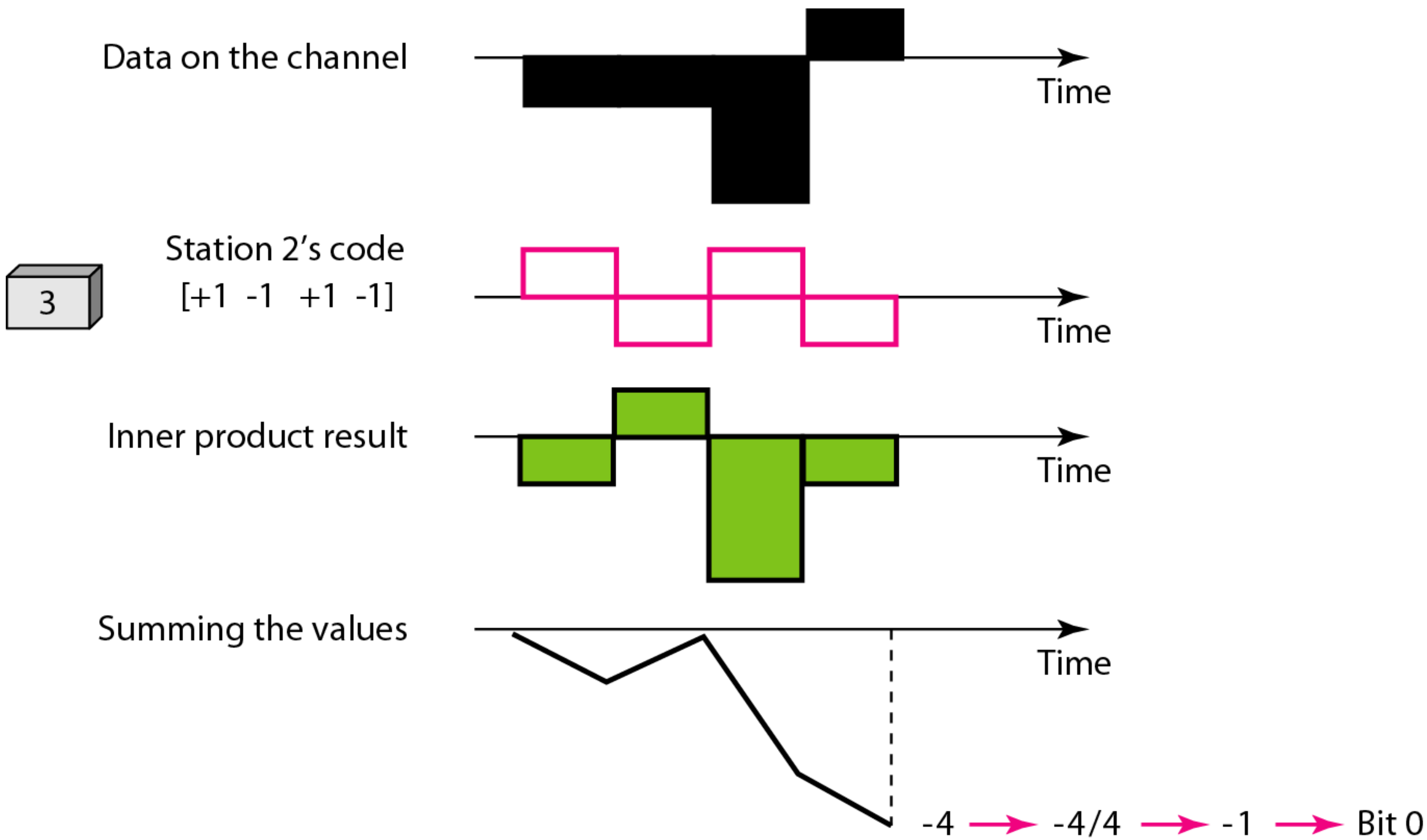
Sharing channel in CDMA



Digital signal created by four stations in CDMA



Decoding of the composite signal for one in CDMA



General rule and examples of creating Walsh tables

$$W_1 = \begin{bmatrix} +1 \end{bmatrix} \qquad W_{2N} = \begin{bmatrix} W_N & W_N \\ W_N & \overline{W_N} \end{bmatrix}$$

a. Two basic rules

$$W_1 = \begin{bmatrix} +1 \end{bmatrix}$$

$$W_2 = \begin{bmatrix} +1 & +1 \\ +1 & -1 \end{bmatrix} \qquad W_4 = \begin{bmatrix} +1 & +1 & +1 & +1 \\ +1 & -1 & +1 & -1 \\ +1 & +1 & -1 & -1 \\ +1 & -1 & -1 & +1 \end{bmatrix}$$

b. Generation of W_1, W_2, and W_4

Note

The number of sequences in a Walsh table needs to be $N = 2^m$.

Example

Find the chips for a network with

a. Two stations ***b. Four stations***

Solution

We can use the rows of W_2 and W_4

a. For a two-station network, we have

[+1 +1] and [+1 −1].

b. For a four-station network we have

[+1 +1 +1 +1], [+1 −1 +1 −1],

[+1 +1 −1 −1], *and* [+1 −1 −1 +1].

Example

What is the number of sequences if we have 90 stations in our network?

Solution

The number of sequences needs to be 2^m. We need to choose $m = 7$ and $N = 2^7$ or 128. We can then use 90 of the sequences as the chips.

Example

Prove that a receiving station can get the data sent by a specific sender if it multiplies the entire data on the channel by the sender's chip code and then divides it by the number of stations.

Solution

Let us prove this for the first station, using our previous four-station example. We can say that the data on the channel

$$D = (d_1 \cdot c_1 + d_2 \cdot c_2 + d_3 \cdot c_3 + d_4 \cdot c_4).$$

The receiver which wants to get the data sent by station 1 multiplies these data by c_1.

Example (continued)

$$
\begin{aligned}
D \cdot c_1 &= (d_1 \cdot c_1 + d_2 \cdot c_2 + d_3 \cdot c_3 + d_4 \cdot c_4) \cdot c_1 \\
&= d_1 \cdot c_1 \cdot c_1 + d_2 \cdot c_2 \cdot c_1 + d_3 \cdot c_3 \cdot c_1 + d_4 \cdot c_4 \cdot c_1 \\
&= d_1 \times N + d_2 \times 0 + d_3 \times 0 + d_4 \times 0 \\
&= d_1 \times N
\end{aligned}
$$

When we divide the result by N, we get d_1.