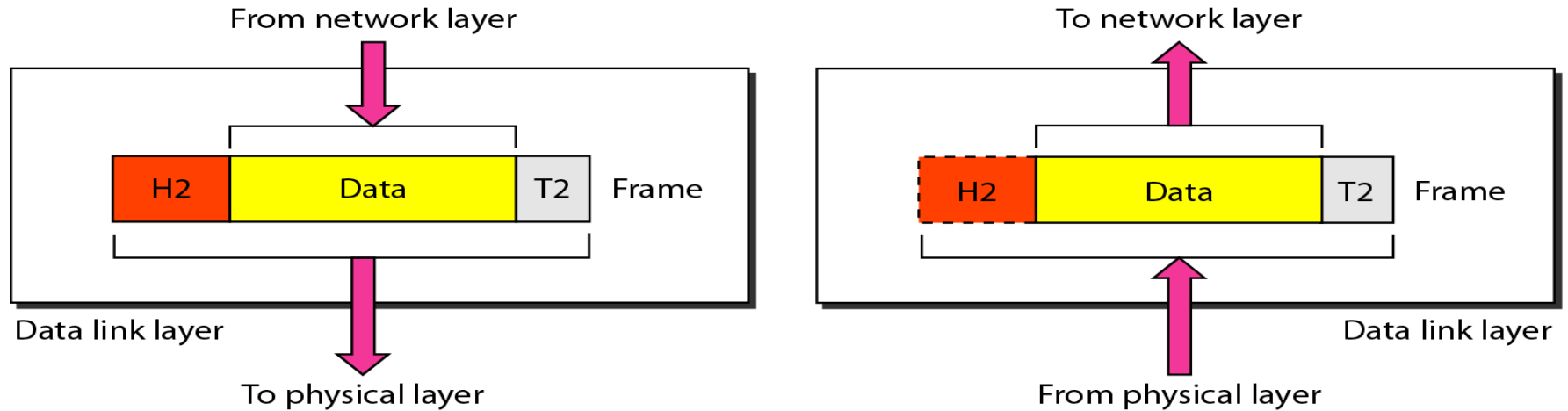


Data Link Layer



The data link layer is responsible for moving frames from one hop (node) to the next

Functions of the Data Link Layer (local focus)

Specific things that DLL does in order to accomplish the general functions of handling errors and regulating data flow

Framing: divides the stream of bits received from the network layer into manageable data units called frames

Error Control: adds reliability to the physical layer by adding mechanisms to detect and retransmit damaged, duplicate, or lost frames. Both detection and correction schemes may be used

Flow Control (imposes a flow control mechanism to prevent sender from “swamping” or overwhelming the receiver which is normally built into the protocol

Media access control determines which device has control over the link at any given time when two or more devices are connected to the same link

Addressing adds a header to the frame to define the addresses of the sender and receiver of the frame

Data link layer divided into two functionality-oriented sub-layers

- Data link control and
- Medium Access Control

The Medium Access Control Sub-layer

Medium Access Control

There are Two categories of network links

- Those using point-to-point connections
- Those using broadcast channels

In any broadcast network

- How to determine who gets to use the channel when there is competition for it?
- **Broadcast channels** are sometimes referred to as **multi-access channels or random access channels**

Multiple-access problem: when a channel is shared among many nodes, the problem arises to when each node should access the channel

Protocols used to determine who goes next on a multi-access channel belongs to MAC layer

Distributed system is the key matter which makes this issue hard as there is no one in-charge in the system



MAC Protocols

MAC is important in LANs, particularly critical to the performance of wireless LANs as wireless is naturally an open, shared, and broadcast medium/channel

MAC allows several stations connected to the transmission medium to transmit over it and to share its capacity

- A *MAC protocol is used to resolve potential **contention** and **collision*** when using the communication medium
- MAC protocols define rules to force distributed nodes to access wireless medium in an orderly and efficient manner

Ingredients of MAC Protocols

- **Carrier sense (CS)**
 - Hardware capable of sensing whether transmission taking place in vicinity
- **Acknowledgments**
 - When collision detection not possible, link-layer mechanism for identifying failed transmissions
- **Backoff mechanism**
 - Method for estimating contention and deferring transmissions
- **Collision detection (CD)**
 - Hardware capable of detecting collisions
- **Collision avoidance (CA)**
 - Protocol for avoiding collisions

Propagation Vs Transmission

Propagation	Transmission
How long it takes <i>one</i> bit to <i>travel</i> from one end of the medium to the other or time it takes the signal to travel from source to destination	How long it takes to get <i>all</i> the bits <i>into</i> the medium in the first place or time it takes the sender to transmit all bits of the packet
It is proportional to the length of the medium (length/speed or distance/speed)	It is ----- packet length/data rate
Propagate means to move something in a medium.....	Transmit means to send something.....
Therefore, propagation delay is the time taken by an object to pass through a medium	Whereas transmission delay is the time taken to transfer something
It depends on the distance between source and receiver and also the medium through which it is travelling	It depends on the length of object which is to be transmitted and the rate at which the object is transmitted

Propagation Vs Transmission

- Packet transmission time: Example
 - Consider a 100 Mbit/s Ethernet, and the maximum packet size of 1520 bytes
 - Then Maximum packet transmission time
 - $1520 \times 8 \text{ bit} / (100\,000\,000 \text{ bit/s}) = \text{----- } \mu\text{s}$
- Packet propagation time: Example
 - Consider wireless communication with maximum distance of 100 meter between sender and receiver
 - Then Maximum link propagation delay
 - $\approx 100 \text{ m} / (300\,000\,000 \text{ m/s}) = \text{----} \mu\text{s}$

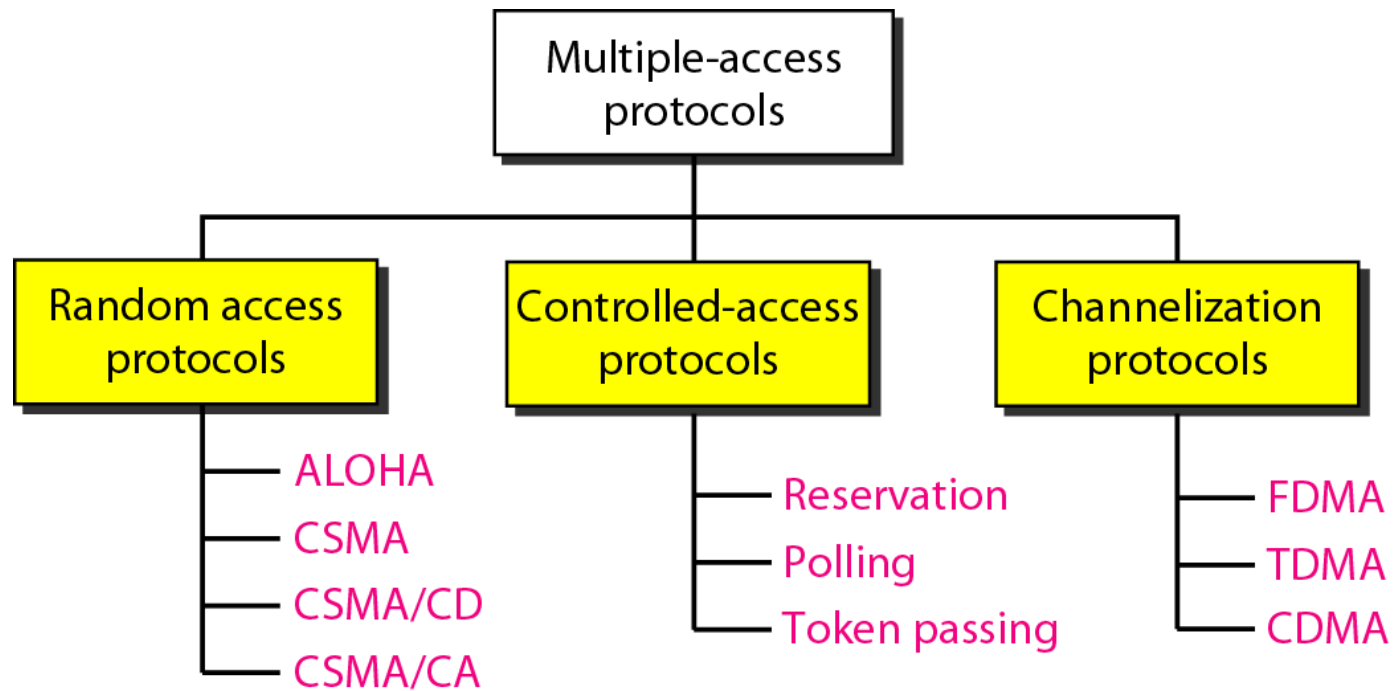
Example

A 1000 byte packet is sent from your home to a server. It is first sent over a 10 Mbps wireless link. Once it has been received completely, it is then sent over a 100 Mbps ISP link. The propagation delay of the wireless link is 500 nanoseconds and the propagation delay of the ISP link is 10ms. *How long does it take (in milliseconds) for the packet to reach the server?*

A 1000 byte packet is sent from your home to a server. It is first sent over a 1 Mbps cellular link. Once it has been received completely, it is then sent over a 100 Mbps ISP link. The propagation delay of the cellular link is 1 ms and the propagation delay of the ISP link is 5 ms. *How long does it take for the packet to reach the server?*

Your Answer	Score	Explanation
<input type="radio"/> 7.01 ms		
<input type="radio"/> 6 ms		
<input checked="" type="radio"/> 14.08 ms	✓ 1.00	$1000 \times 8 / 1000 + 1 + 1000 \times 8 / 100000 + 5$

Taxonomy of multiple-access protocols



Random multiple access protocols

- In **random access** or **contention** methods,
 - No station is superior to another station and
 - No station 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
 - A station can transmit
 - When it desires
 - Provided it obeys the mechanism defined by the protocol
 - Such as verification of state of medium

Random multiple access protocols

- Stations transmit without any schedule
- Methods are called *random access* because
 - transmission is random among the stations
- Also called *contention methods*
 - Stations have competition to access the common medium that can lead to conflicts
 - no rules specify which station should transmit next
- *Access collision*
 - If more than one stations try to send
 - Frames can be either destroyed or modified

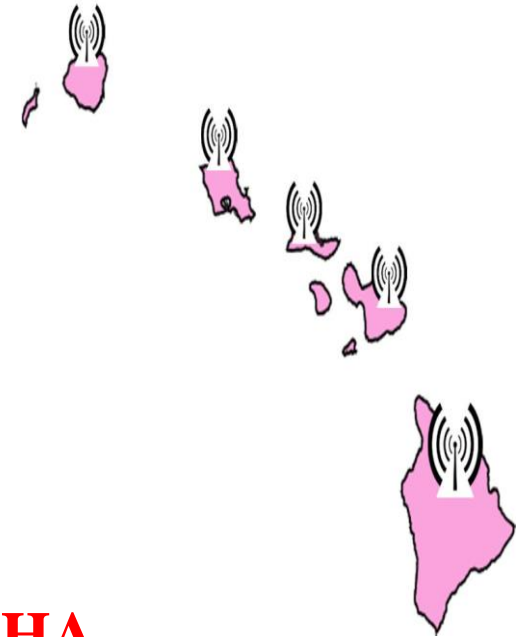
Random multiple access protocols

- To avoid access collision or resolve when it happens, a node follows a procedure that tackles the following:
 - When to access the medium
 - What to do if medium busy
 - How to determine the transmission failure or success
 - What to do in the situation of collision

ALOHA Network

(Areal LOcations of Hazardous Atmospheres)

- Norm Abramson devised a new protocol at the University of Hawaii for multiple access
 - When should nodes send?
- computer network connecting the Hawaiian islands in the late 1960s with wireless links



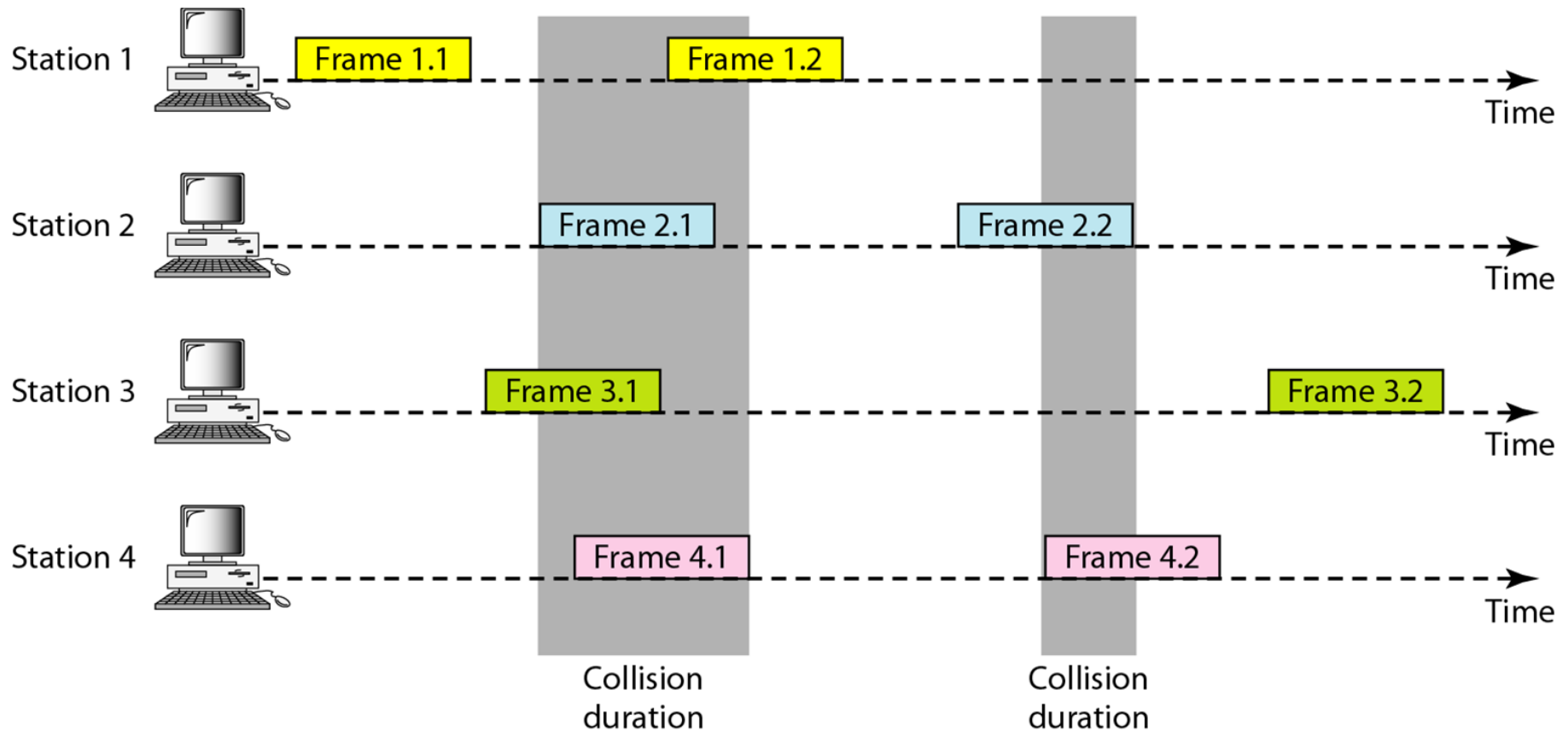
Use of very simple procedure: **Multiple access**
All random access methods evolved from ALOHA

Principal of pure ALOHA:

- If you have data to send, send the data
- If the message collides with another transmission (no ACK received), sender waits random time before trying again (resend)

Frames in a pure ALOHA network:

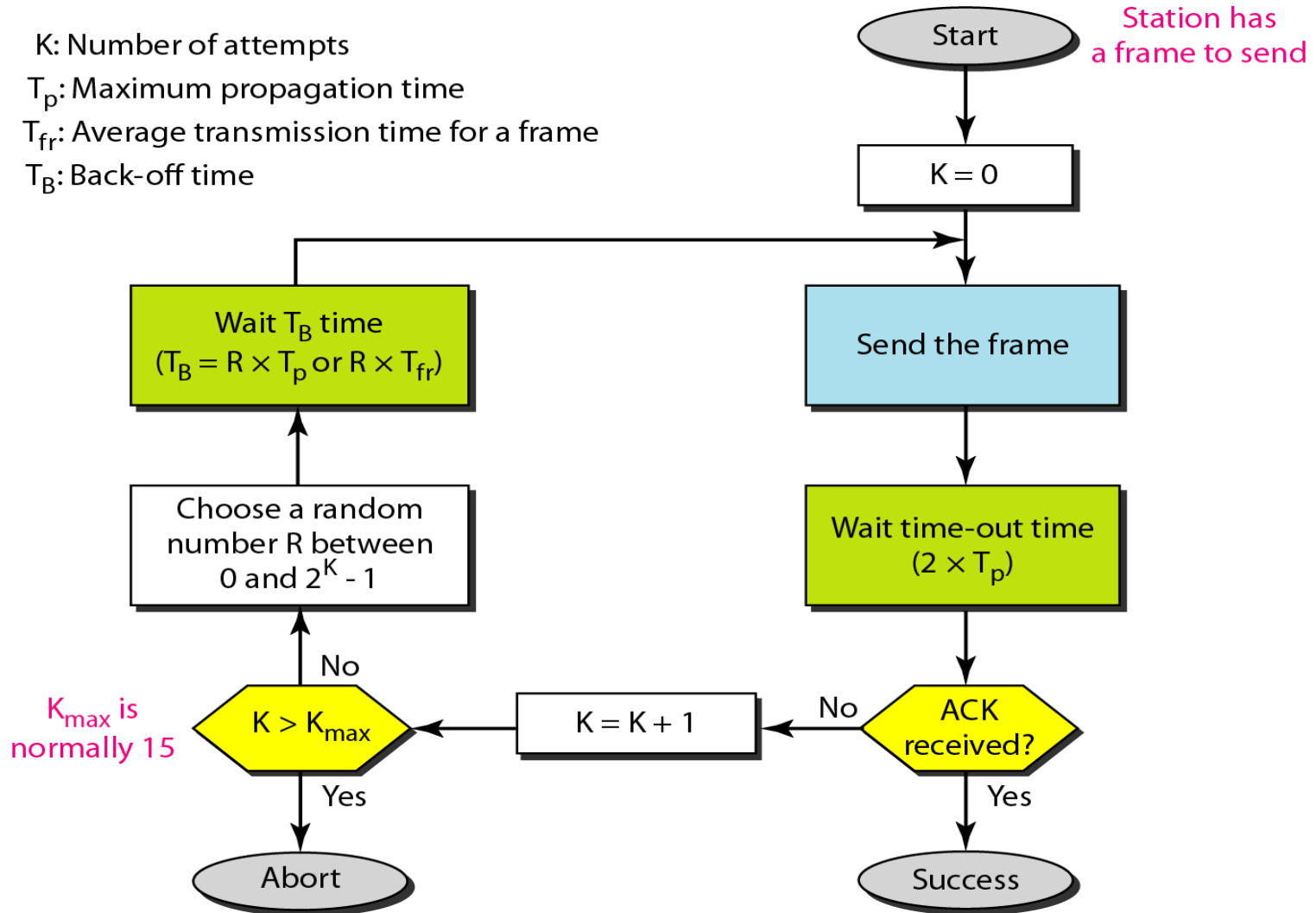
4 stations each with 2 frames contending with one another for access to the shared channel



Pure ALOHA

- Even if one bit of a frame coexists on the channel with one bit from another frame: **There is a collision**
- Resend the frames that have been destroyed during transmission
- **It relies on ACKs from receiver**
 - If no ACK received after a **time-out period**, then assumes that frame has been destroyed and resend the frame
- If all collided stations retransmit after time out: **Frame may collide again**
- Pure ALOHA dictates that each station waits a random amount of time (**back-off time: T_B**) before resending its frame
 - The randomness helps in avoiding more collisions
- To **prevent congestion** of the channel with retransmitted frames
 - a station must give up after a maximum number of retransmission attempts **K_{max}** and try later

Procedure for pure ALOHA protocol



Pure ALOHA: 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

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

➤ Value of T_B for different values of

$K = 1, 2, 3$

➤ For $K = 2$,

➤ the range is $\{0, 1, 2, 3\}$

➤ This means that T_B can be 0, 2, 4, or 6 ms, based on the outcome of the random variable

➤ For $K = 3$,

➤ the range is $\{0, 1, 2, 3, 4, 5, 6, 7\}$

➤ This means that T_B can be 0, 2, 4, . . . , 14 ms based on the outcome of the random variable

Pure ALOHA

- Under what conditions will frame A arrive undamaged?
- Let T_{fr} be the time required to send one frame
- If any other user has generated a frame between $t - T_{fr}$ and t , the end of that frame (here B) will collide with beginning of A
- Similarly, any other frame started between t and $t + T_{fr}$ will bump into the end of frame A for station B's frame to be transmitted without any problems, nobody has to be transmitting from time $t - T_{fr}$ and time $t + T_{fr}$, which is 2 times the frame transmission time So Pure ALOHA vulnerable time = $2 \times T_{fr}$

Example

- 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?
- Answer
- Average frame transmission time
- $T_{fr} = 200 \text{ bits} / 200 \text{ kbps} = 1 \text{ ms}$ (data/capacity)
- The vulnerable time is $2 \times 1 \text{ ms} = 2 \text{ ms}$
- This means no station should send later than 1 ms when this station
- starts transmission and It means previous transmission must end before its start no station should start sending during the 1 ms period that this station is sending

Pure ALOHA

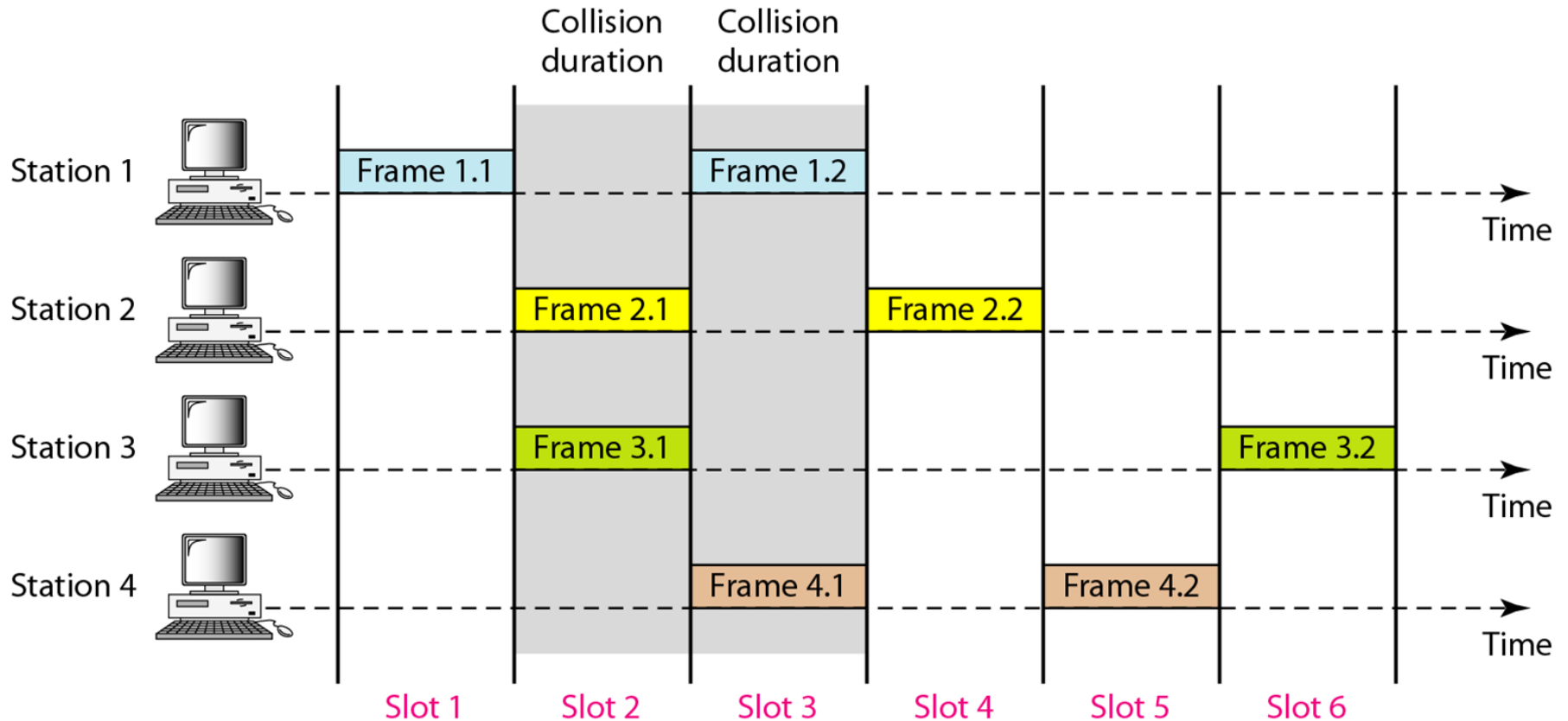
Example

- On a wireless ALOHA network
 - stations are maximum 300 Km apart
 - Assume that signals propagate at 3×10^8 m/s
 - *Maximum propagation time* = $T_p = ?$
 - *Backoff time* = $T_B = ?$ If $K = 1, 2, 3$
- What will be the maximum propagation time and backoff time if stations are 900 Km apart

Slotted ALOHA

- Slotted ALOHA was invented to improve the efficiency of pure ALOHA
- In slotted ALOHA, time is divided into **slots** of **T_{fr} seconds** (average transmission time for a frame) and force the station to send only at the beginning of the time slot
 - A station must wait until the beginning of the next time slot
 - If it misses to transmit at the start of a time slot
- Possibility of collision
 - If two stations try to send at the start of the same time slot

Frames in a slotted ALOHA network



CSMA (Carrier Sense Multiple Access)

- CSMA protocol was developed to minimize the chances of collision, so as to improve the performance
- Improves ALOHA by listening for activity before we send (carrier sense)
- Protocols in which station listen for a carrier (such as an electrical bus, or a band of the electromagnetic spectrum) and act accordingly are called **carrier sense protocols**
- Collision chances can be reduced to great extent
 - if a station senses the channel before trying to use it
- So CSMA is based on the principal of **sense before transmit**
 - If channel sensed idle, transmit entire frame
 - If channel sensed busy, defer transmission
 - **Human analogy: don't interrupt others**

CSMA

- CSMA cannot eliminate the possibility of collision completely
 - it can only reduce the chances of collision
- Collision is possible if two nodes send instantaneously (simply)
- BUT a collision is still possible even if they send at slightly different times
 - it takes time for frames to propagate along the medium
- **The propagation delay is the major concern for the chances of collision**

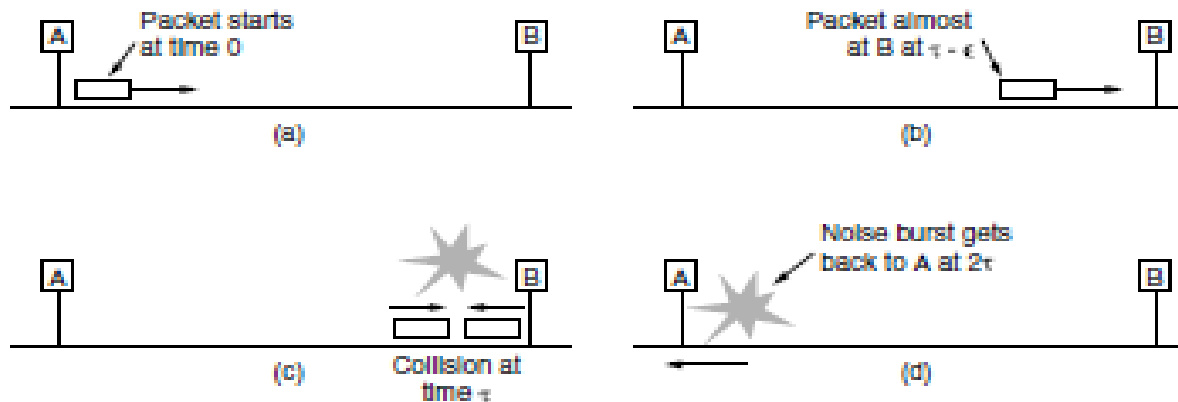


Figure 4-15. Collision detection can take as long as 2τ .

CSMA

- Let station *B* senses the medium at t_1 and finds it idle,
 - so it sends a frame
- At time t_2 ($t_2 > t_1$) 'station *C* senses the medium and finds it idle'
 - because, at this time, the first bits from station *B* have not reached station *C*
 - So, *C* also sends a frame
- The two signals collide and both frames are destroyed
- **CSMA Access Modes**
 - **1-persistent CSMA**
 - **Non-persistent CSMA**
 - **P-persistent CSMA**

➤

1-Persistent CSMA

- station that wants to transmit data, **continuously senses** the channel to check whether it is idle or busy
- If the channel is **busy**
 - the station continues sensing until it becomes idle
- When an idle channel is detected
 - The station immediately transmits the frame with probability 1 (**so called 1-persistent CSMA**)
- **It has the highest chance of collision**
 - two or more stations may find channel to be idle at the same time and transmit their frames
 - When the collision occurs, the stations wait a random amount of time and start all over again
- **This mode is used in CSMA/CD**

Drawback 1-Persistent CSMA

- The propagation delay time greatly affects this protocol
 - Let us suppose, just after the station 1 begins its transmission, station 2 also becomes ready to send its data and sense the channel
 - If the signal of station 1 has not yet reached station 2, station 2 will sense the channel to be idle and will begin its transmission. This will result in collision
- Even if propagation delay time is zero, collision will still occur
 - If two stations become ready in the middle of third station's transmission
 - both stations will wait until the transmission of first station ends and both will begin their transmission exactly simultaneously resulting in collision

Non-Persistent CSMA

- A station that has a frame to send senses the channel
 - If the channel is idle,
 - it sends immediately
 - If the channel is busy,
 - it waits a random amount of time, and
 - then senses the channel again
- In non-persistent CSMA the station does not continuously sense the channel for the purpose of capturing it when it detects the end of previous transmission

Non-Persistent CSMA

Advantages of non-persistent

- It reduces the chances of collision
 - because the stations wait a random amount of time
- It is unlikely that two or more stations will wait for same amount of time and will retransmit at the same time

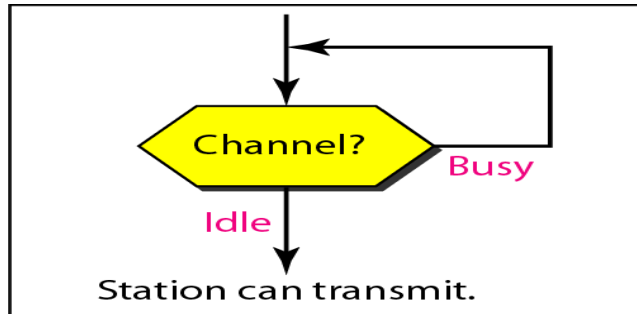
Disadvantages of non-persistent

- It reduces the efficiency of network
 - because the channel remains idle when there may be station with frames to send
- This is due to the fact that the stations wait a random amount of time after the collision

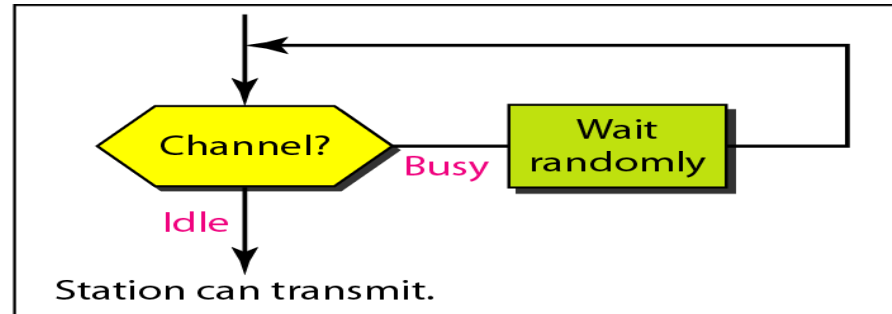
P-Persistent CSMA

- This method is used when channel has time slots such that the time slot duration is equal to or greater than the maximum propagation delay time
- Whenever a station becomes ready to send, it senses the channel
 - If channel is busy, station waits until next slot
 - If the channel is idle, it transmits with a probability p
 - With the probability $q=1-p$, the station then waits for the beginning of the next time slot
 - If the next slot is also idle, it either transmits or wait again with probabilities p and q respectively
 - This process is repeated till either frame has been transmitted or another station has begun transmitting
 - In case of the transmission by another station, the station act as though a collision has occurred and it waits a random amount of time and starts again
- This mode is used in CSMA/CA
- **Advantage:** it reduce collision chances and improve the efficiency of the network

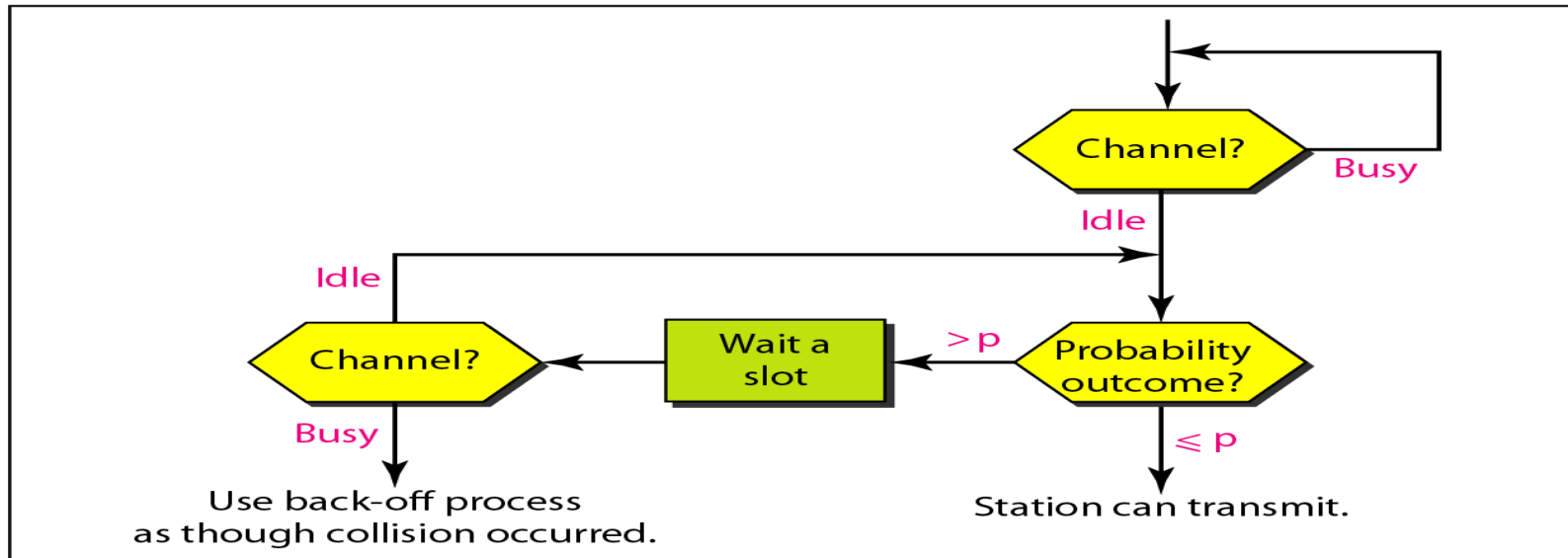
Flow diagram for three persistence methods



a. 1-persistent

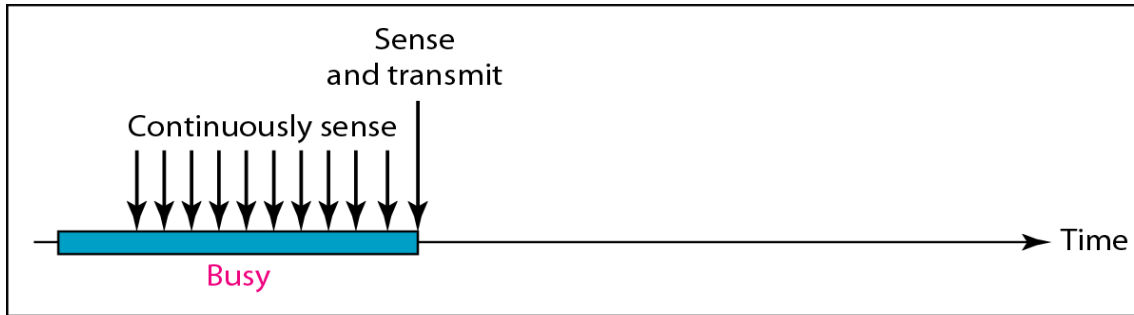


b. Nonpersistent

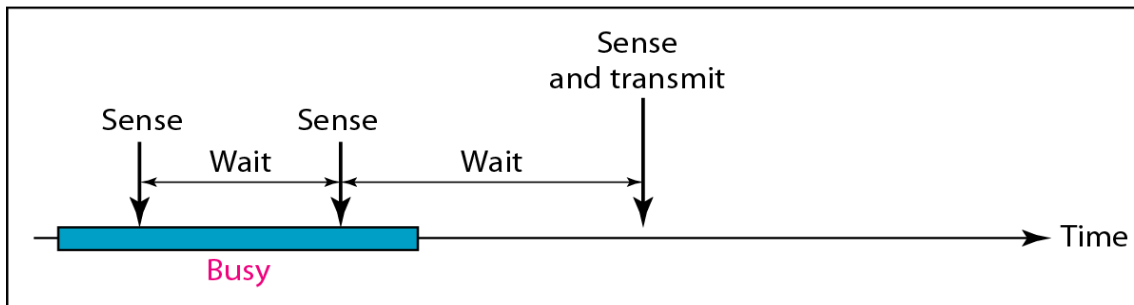


c. p-persistent

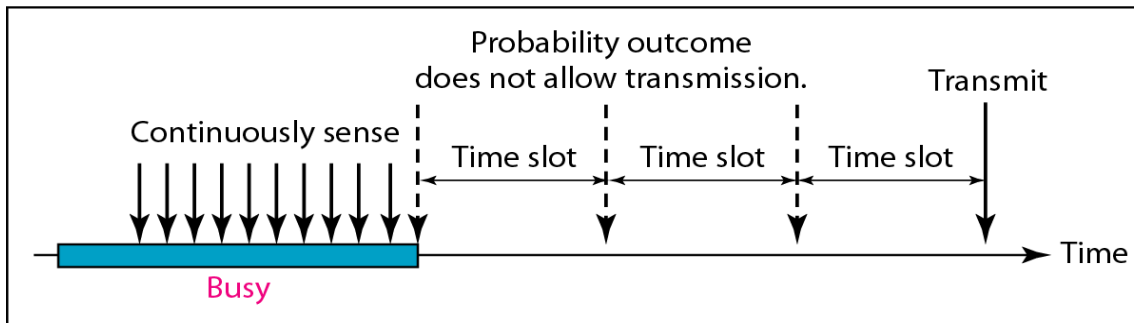
Behavior of three persistence methods



a. 1-persistent



b. Nonpersistent



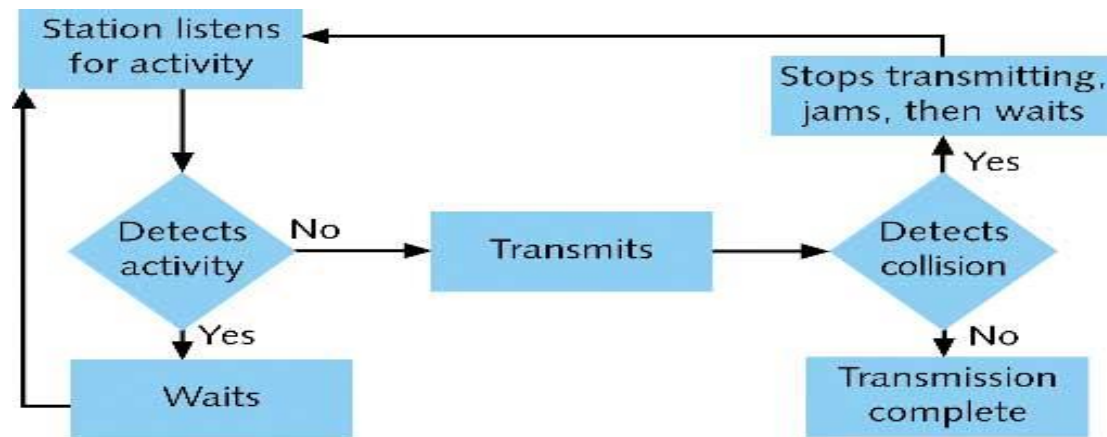
c. p-persistent

- CSMA does not specify any procedure after collision
- CSMA/CD enhances the algorithm to handle the collision

CSMA/CD (carrier sense multiple access/ collision detection)

- Persistent and non-persistent CSMA protocols are definitely an improvement over ALOHA because they ensure that no station begins to transmit while the channel is busy
- However, if two stations sense the channel to be idle and begin transmitting simultaneously, their signals will still collide.
- **Another improvement (on top of ALOHA)** is for the stations to quickly detect the collision and abruptly stop transmitting, (rather than finishing them). This scheme saves time and bandwidth

CSMA/CD

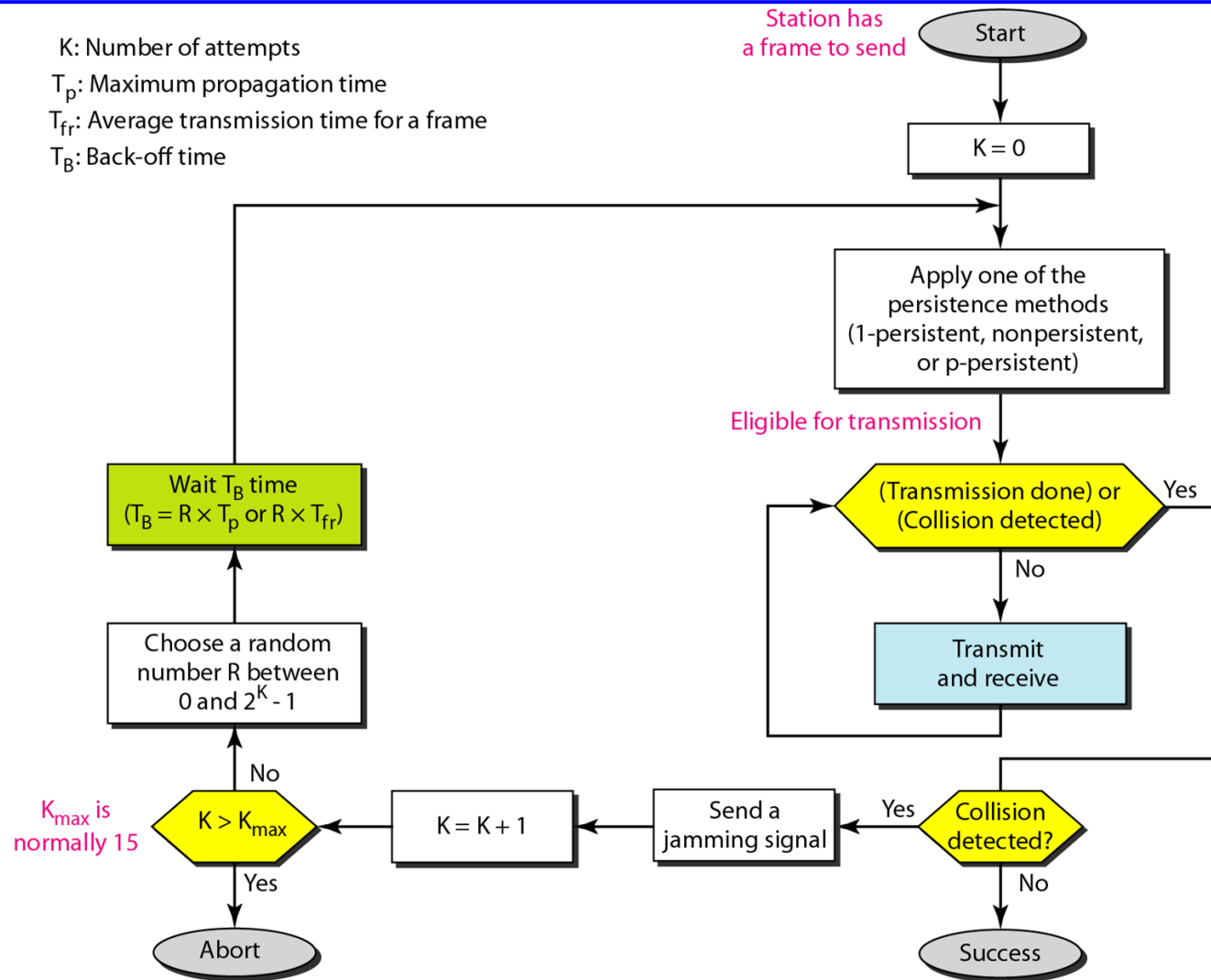


- When a sender detects a collision, it sends a “jam signal”.
 - ❖ Make sure that all nodes are aware of the collision
 - ❖ Length of the jam signal is 32 bit times
- In CSMA/CD, stations abort their transmission when they detect a collision e.g., Ethernet, IEEE802.3
- It is not applicable to wireless systems

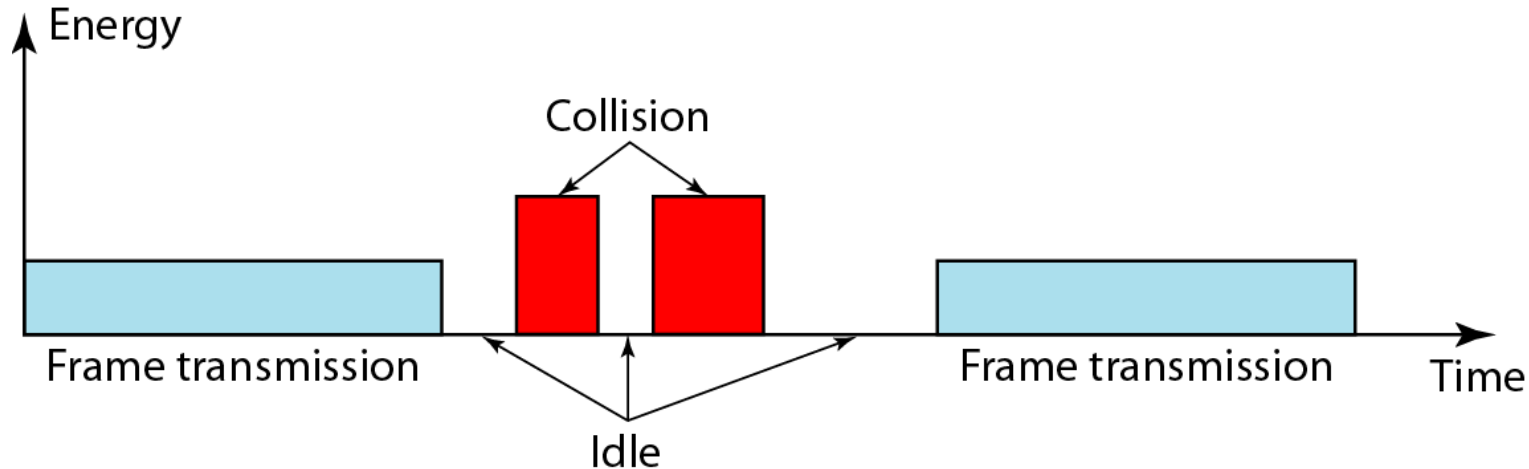
CSMA/CD: Procedure

1. Node has a frame to transmit
2. Sense the medium
 - I. If busy (not idle): wait until becomes free
 - II. If idle: transmit
3. After transmission, check whether collision has occurred
 - I. If collision has detected
 - a) Send a jam signal
 - b) Increment retransmission counter
 - c) Check maximum number of retransmission attempts. If yes, abort transmission
 - d) Based on number of collisions, calculate random backoff time and wait that time
 - e) Repeat from step 2 again
 - II. If no collision detected, transmission is successful
4. Retransmission counters are reset and end frame transmission

Flow diagram for the CSMA/CD



Energy level during transmission, idleness, or collision



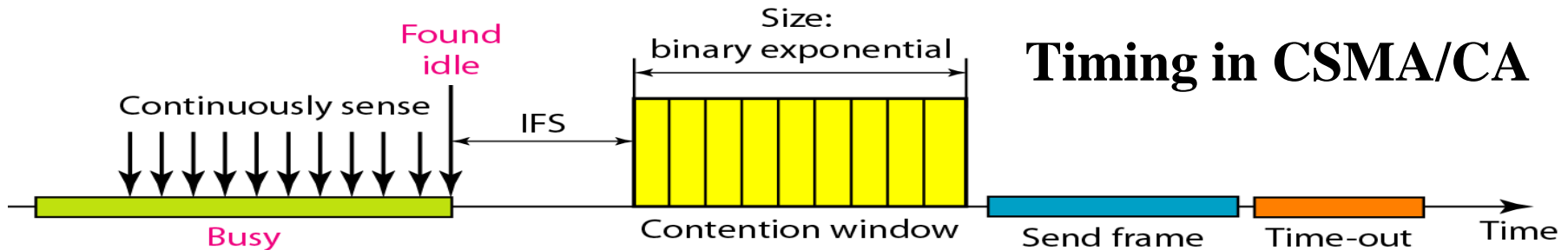
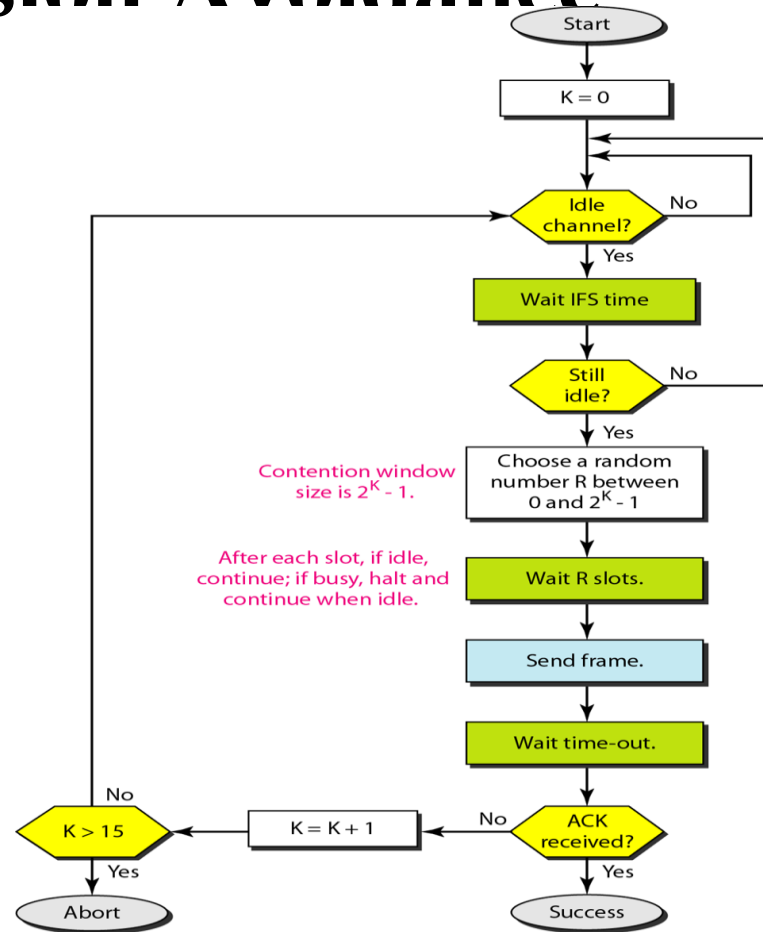
- level of energy in a channel can have three values
 - **Zero:** the channel is idle
 - **Normal:** The station has successfully captured the channel and is sending its frame
 - **Abnormal:** there is a collision and the level of the energy is twice the normal level
- station that has a frame to send or is sending a frame needs to monitor the energy level to determine if the channel is idle, busy, or in collision mode

Collision detection: If the signal, the sender reads back, is different from the signal it is putting out, it knows that a collision is occurring

- In fact, a received signal must not be tiny compared to the transmitted signal
- In *CSMA/CD* : *a station needs to be able to receive while transmitting to detect a collision*
- When there is **no collision**, the station receives **one signal**: its own signal
- When there is **a collision**, the station receives **two signals**: its own signal and the signal transmitted by a second station
- To distinguish between these two cases, the received signals in these two cases must be significantly different

- In a **wired network**, the received signal has almost the same energy as the sent signal because
 - **So in a collision, the detected energy almost doubles**
- Popular CSMA scheme and its variant CSMA/CD developed for wired networks
 - Can not be used directly in wireless networks

CSMA/Collision Avoidance



Timing in CSMA/CA

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. Three popular controlled-access methods are [Reservation, Polling and Token Passing](#)

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. channelization protocols are [Frequency-Division Multiple Access \(FDMA\)](#), [Time-Division Multiple Access \(TDMA\)](#) and [Code-Division Multiple Access \(CDMA\)](#)