COMP 3721
Introduction to Data Communications

09a - Week 9 - Part 1

Learning Outcomes

- By the end of this lecture, you will be able to
  - Explain what are MAC (Media Access Control) protocols and how they function.

Introduction

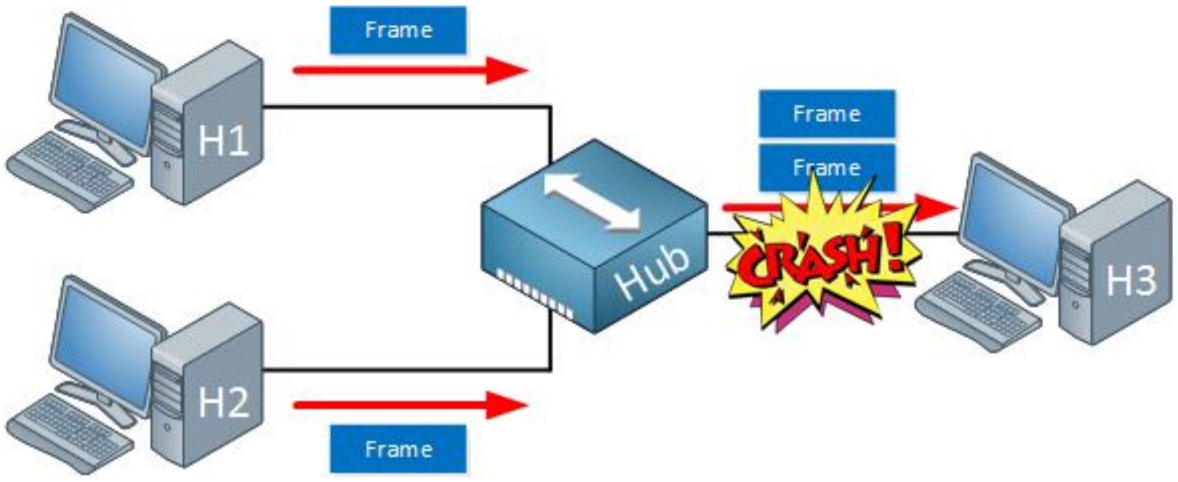
- A **broadcast link**
  - Can have **multiple sending and receiving nodes** all connected to the same, single, shared broadcast channel.
- Why is the term **broadcast** used?
  - The term **broadcast** is used here because when any one node transmits a frame, the channel broadcasts the frame and each of the other nodes receives a copy.
- Examples of **broadcast link-layer technologies**
  - Ethernet
  - Wireless LANs (WLAN)
- We need **multiple-access protocols** to coordinate access to a multipoint (broadcast) link.

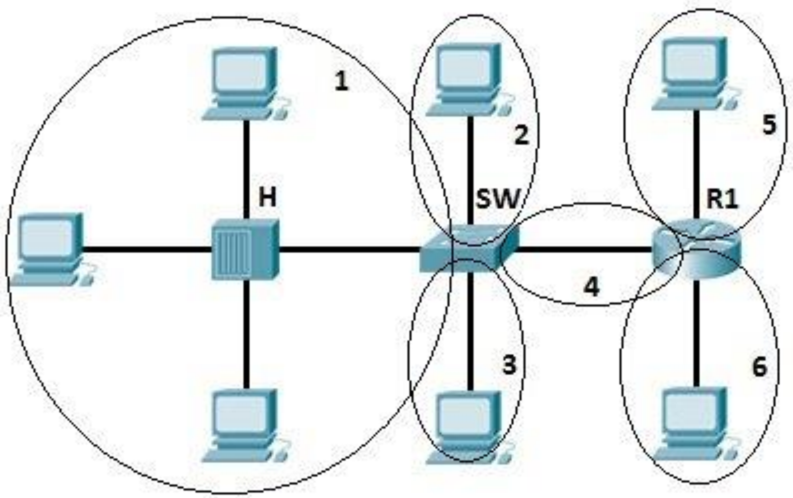
Introduction – Analogy

- Controlling the access to the medium is similar to the rules of speaking in an assembly.
  - Broadcast medium: **Air**
  - **Who** gets to talk (transmit into the channel) and **when**?

Collision Domain

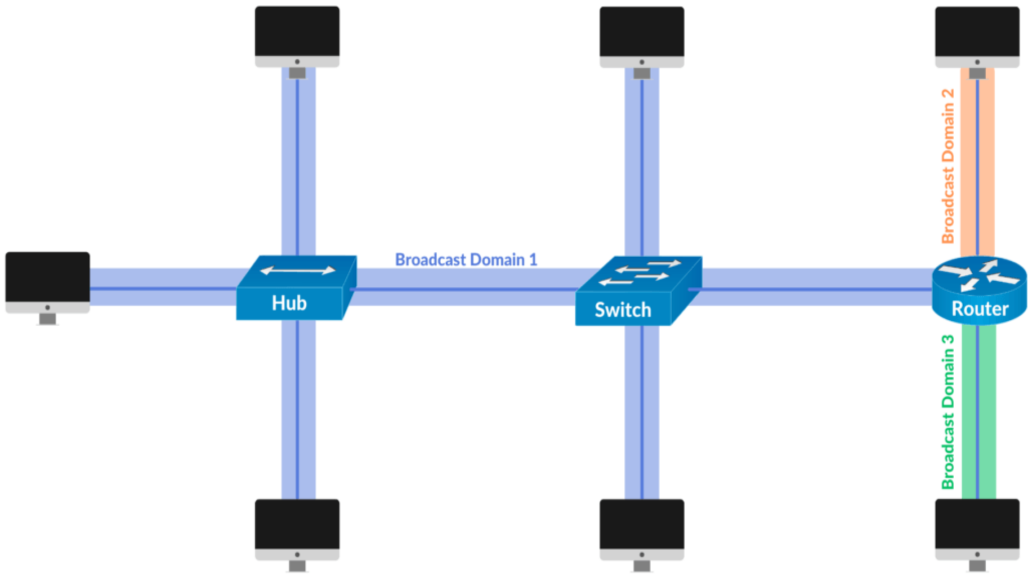
- A collision domain is the part of a network where packet collisions can occur.

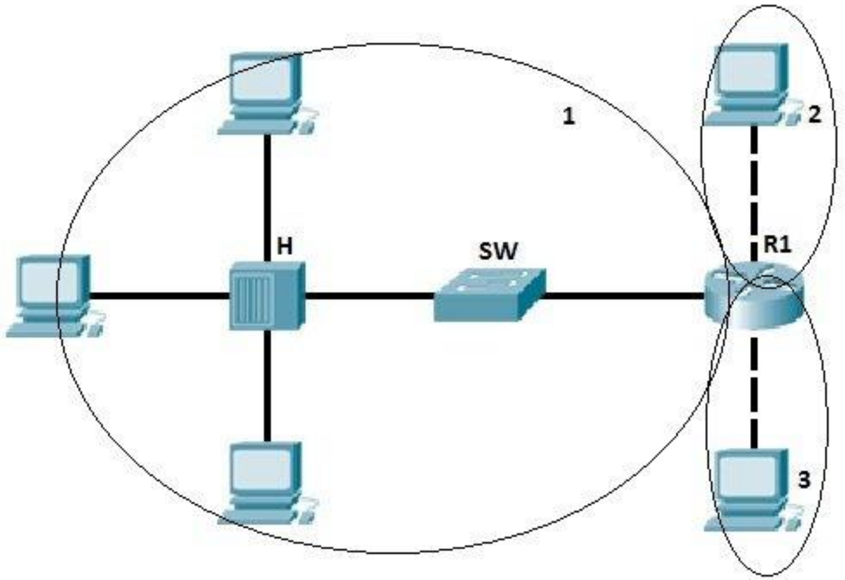




Broadcast Domain

- A **broadcast domain** is a domain in which a **broadcast** is forwarded. A broadcast domain contains all devices **that can reach each other** at the data link layer (OSI layer 2) by using **broadcast**.
  - IEEE 802.3 defines the **broadcast address** as a **destination MAC address** of **FF-FF-FF-FF-FF-FF**





Collision and Broadcast Domain in Network Devices

- A **Hub**
  - Is neither a collision domain separator nor a broadcast domain separator.
- A **Switch**:
  - Is a **collision domain separator** because each port on it is in a different collision domain. As a result, messages sent by devices connected to separate ports never collide.
- A **Router**:
  - Is a **broadcast domain separator** and a **collision domain separator**. A broadcast message sent from one network to another will never be received because the router will never permit it to flow.

MAC Sublayer of the Data-Link Layer

- **MAC** (**Media Access Control**) **sublayer** includes protocols to **handle access** to a **shared** (**broadcast**) link.
- Three categories of multiple-access protocols:
  1. **Random-access protocols**
  2. **Channelization protocols** (aka **channel-partitioning protocols**)
  3. **Controlled-access protocols** (aka **taking-turn protocols**)

Random Access (Contention) Protocols

- No station is superior to another station, and none is assigned control over another.
- Each station can transmit when it desires; on the condition that it follows the **predefined procedure**, including **testing the state of the medium**.
- A station that has data to send uses a procedure defined by the **protocol** to **decide** on **whether to send** – This decision depends on the state of the medium (**idle** or **busy**).

Random Access (Contention) Protocols

- Two features:
  1. **Random access**
     - No scheduled time for a station to transmit.
     - Transmission is random among the stations.
  2. **Contention among the stations to access the medium**
     - No rules specify which station should send next.
     - Stations compete with one another to access the medium.

Random Access (Contention) Protocols

- If more than one station tries to send data, there is an access conflict (**collision**)—the frames will be either **destroyed** or **modified**.
- To avoid collision or to resolve it when it happens, each station follows a **procedure** that answers the following questions:
  - **When** to access the medium?
  - **What** to do if the medium is busy?
  - **What** to do if there is an access conflict (collision)?
  - **How** to determine the success or failure of the transmission?

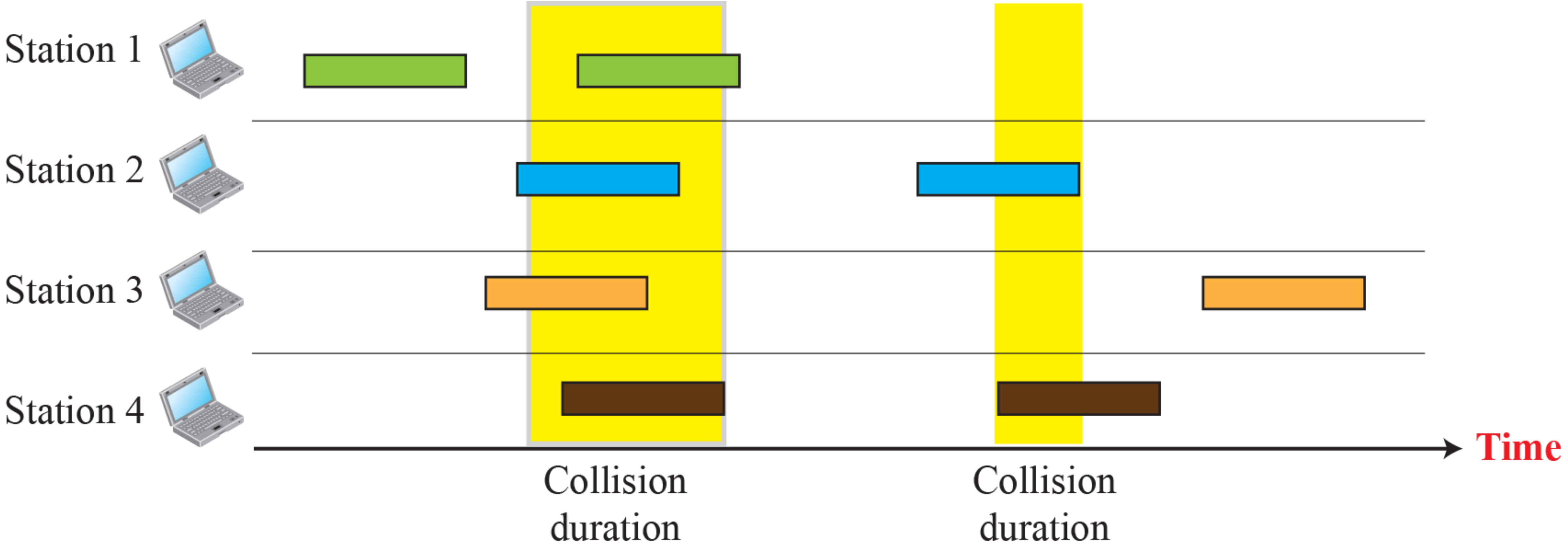
Categories of Random-Access Protocols

- Pure ALOHA (ALOHA)
- Slotted ALOHA
- CSMA:
  - CSMA/CD
  - CSMA/CA

Pure ALOHA

- Also called **ALOHA**
- The earliest random-access protocol
- Developed at the University of Hawaii in early 70's
- ALOHA → the **Hawaiian word** for love, affection, peace, compassion and mercy
- Designed for a **radio** (**Wireless**) **LAN**
  - But it can be used on any shared medium
- Idea is that each station sends a frame **whenever** it has a frame to send:
  - **Possibility of collision** between frames from different stations.

Pure ALOHA Frame Collisions Example



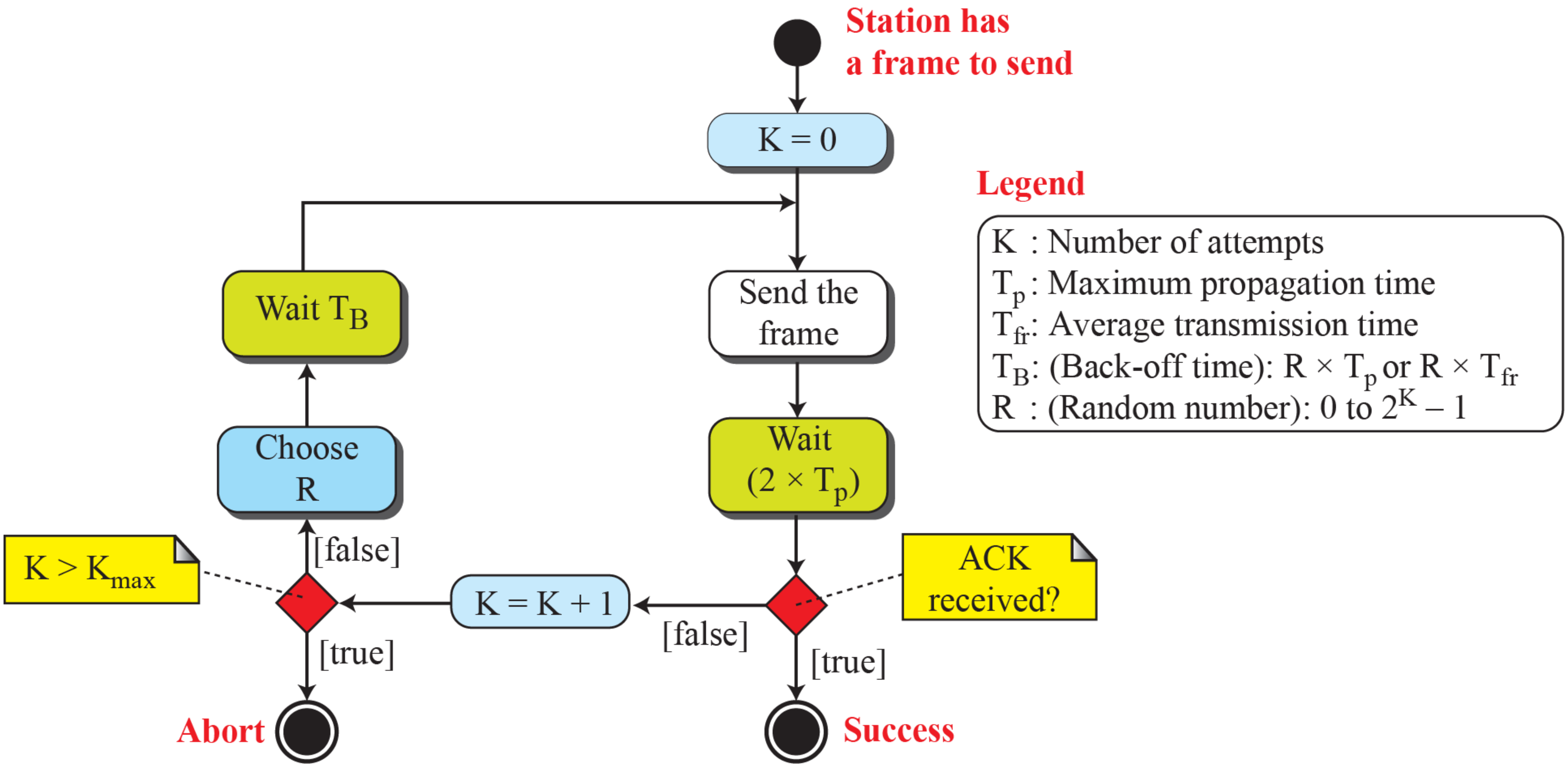
Pure ALOHA Procedure

- Relies on **acknowledgements** from the receiver.
- If the acknowledgment does not arrive after a time-out period, the station assumes that the frame (or the acknowledgment) has been destroyed and **resends** the frame.
- **Backoff time** (T_B):
  - When the time-out period passes, each station waits a **random amount** of time before resending its frame.
  - A **random value** (R) that depends on the number of attempted unsuccessful transmissions (K).
  - After a **maximum number of retransmission attempts** (K_{max}) a station must give up and try later.

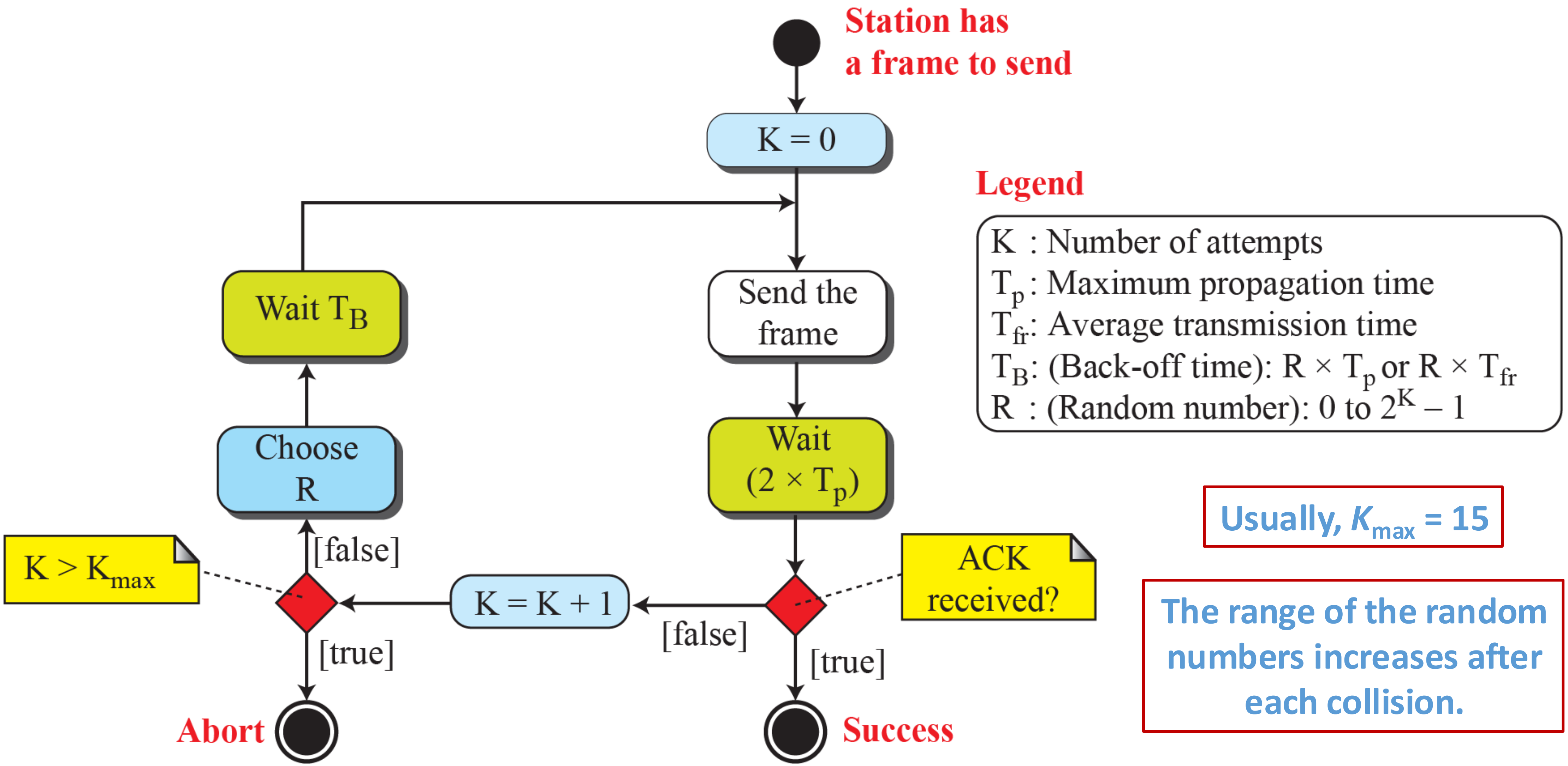
Pure ALOHA Procedure

- **Maximum Propagation Time** (**Delay**) (T_P):
  - The amount of time required to send a frame between the two most widely separated stations.
  - T_P = distance / propagation speed
  - Maximum possible **round-trip** propagation delay is $2 \times T_P$
  - **Time-out period** is equal to $2 \times T_P$
- **Average Transmission Time** (T_{fr}):
  - The average amount of time required to send out a frame.
  - T_{fr} = frame size / transmission rate (data rate)

Pure ALOHA Procedure



Pure ALOHA Procedure



Usually, $K_{max} = 15$

The range of the random numbers increases after each collision.

Pure ALOHA – Example 1

- The stations on a wireless ALOHA network are a maximum of 600 km apart. If we assume that signals propagate at $c = 3 \times 10^8$ m/s, what is the value of T_P? If $K = 2$, what is the value of T_B?

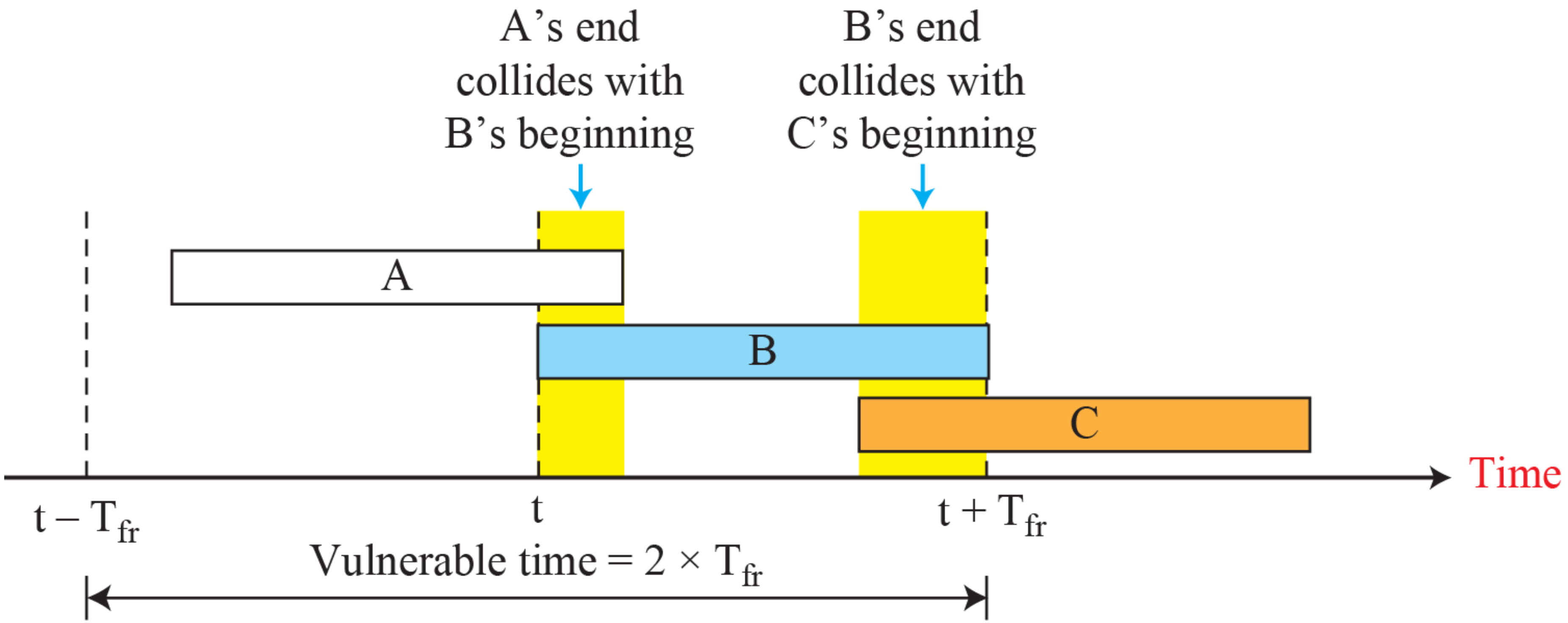
Pure ALOHA – Example 1

- The stations on a wireless ALOHA network are a maximum of 600 km apart. If we assume that signals propagate at $c = 3 \times 10^8$ m/s, what is the value of T_P? If $K = 2$, what is the value of T_B?

- **Answer**:
  - T_P = distance / propagation speed = $(600 \times 10^3) / (3 \times 10^8)$ = **2 ms**
  - R in range of 0 to $(2^2 - 1) \rightarrow R \in \{0, 1, 2, 3\}$
  - $T_B = R \times T_P \rightarrow T_B$ can be any value from **{0, 2, 4, 6} ms**

Pure ALOHA Vulnerable Time

- **Vulnerable time**: The length of time in which there is a possibility of collision. Pure ALOHA vulnerable time is **$2 \times T_{fr}$**.
- Figure shows vulnerable time for station B.



Pure ALOHA – Example 2

- 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?

Pure ALOHA – Example 2

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- **Answer**:
  - T_{fr} = frame size / transmission rate (data rate) = 200 bits / 200 kbps = 0.001 s = 1 ms
  - The **vulnerable time** is $2 \times T_{fr}$ = 2 × 1m = **2 ms**
  - This means **no station** should send **later than 1 ms before this station starts** transmission and **no station should start sending during the period 1 ms** that this station is sending.

Pure ALOHA Throughput

- ***G***: The **average number of frames** generated by the system during **one frame transmission time**.
- Then, the **throughput** (average number of successfully transmitted frames) for pure ALOHA is $S = G \times e^{-2G}$
- The maximum throughput S_{max} **= 0.184** when $G = 1/2$
  - By setting the derivative of *S* with respect to *G* to 0.

    OR
  - *G* = 1/2 produces the maximum throughput because the **vulnerable time** is **2 times the frame transmission time**. Therefore, if a station generates only one frame in this vulnerable time (and no other stations generate a frame during this time), the frame will reach its destination successfully.

Pure ALOHA – Example 3

- A pure ALOHA network transmits 200-bit frames on a shared channel of 200 kbps. Compute is the throughput if the system (all stations together) produces 1000 frames per second? Explain the result.

Pure ALOHA – Example 3

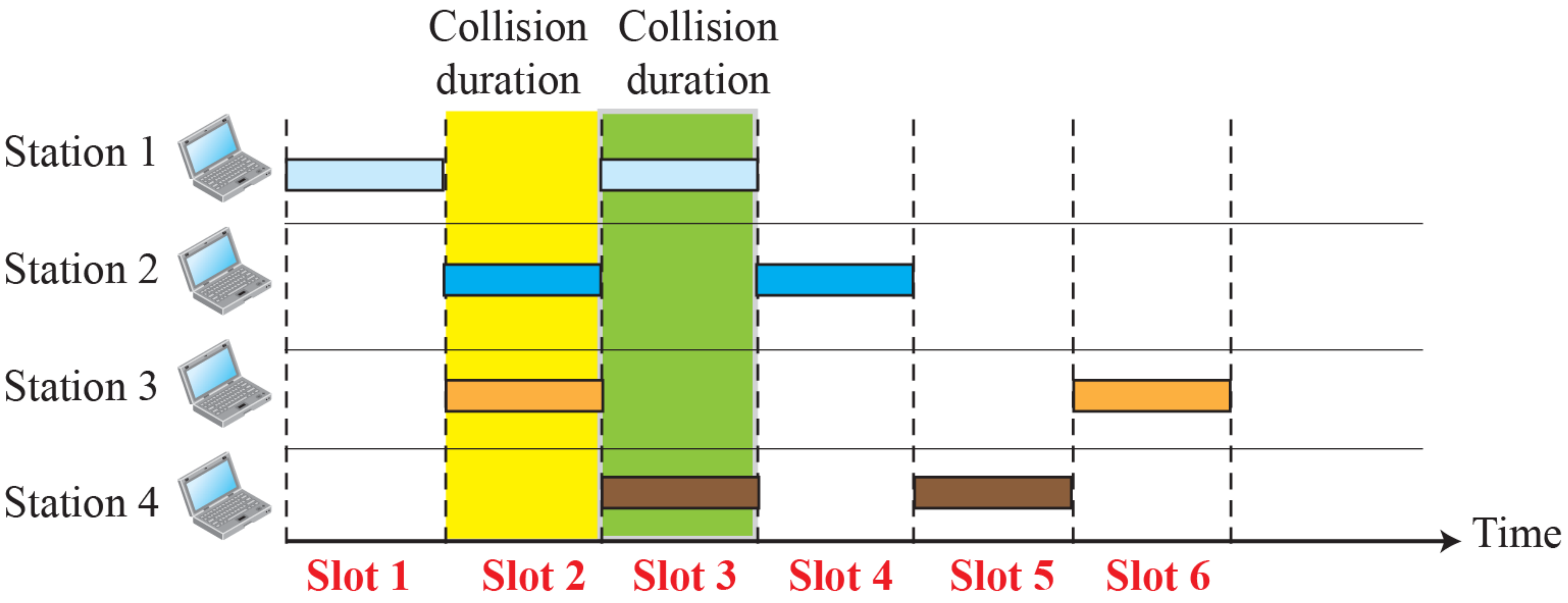
- A pure ALOHA network transmits 200-bit frames on a shared channel of 200 kbps. Compute is the throughput if the system (all stations together) produces 1000 frames per second? Explain the result.

- **Answer**:
  - T_{fr} = 200 bits/200 kbps = **1 ms**
  - 1000 frames per second → 1 frame per millisecond (1 frame per frame transmission time) → $G = 1$
  - $S = G \times e^{-2G}$ = **0.135** (**13.5%**)
  - This means that only **135 frames** (1000 × 0.135) out of 1000 will probably survive.

Slotted ALOHA

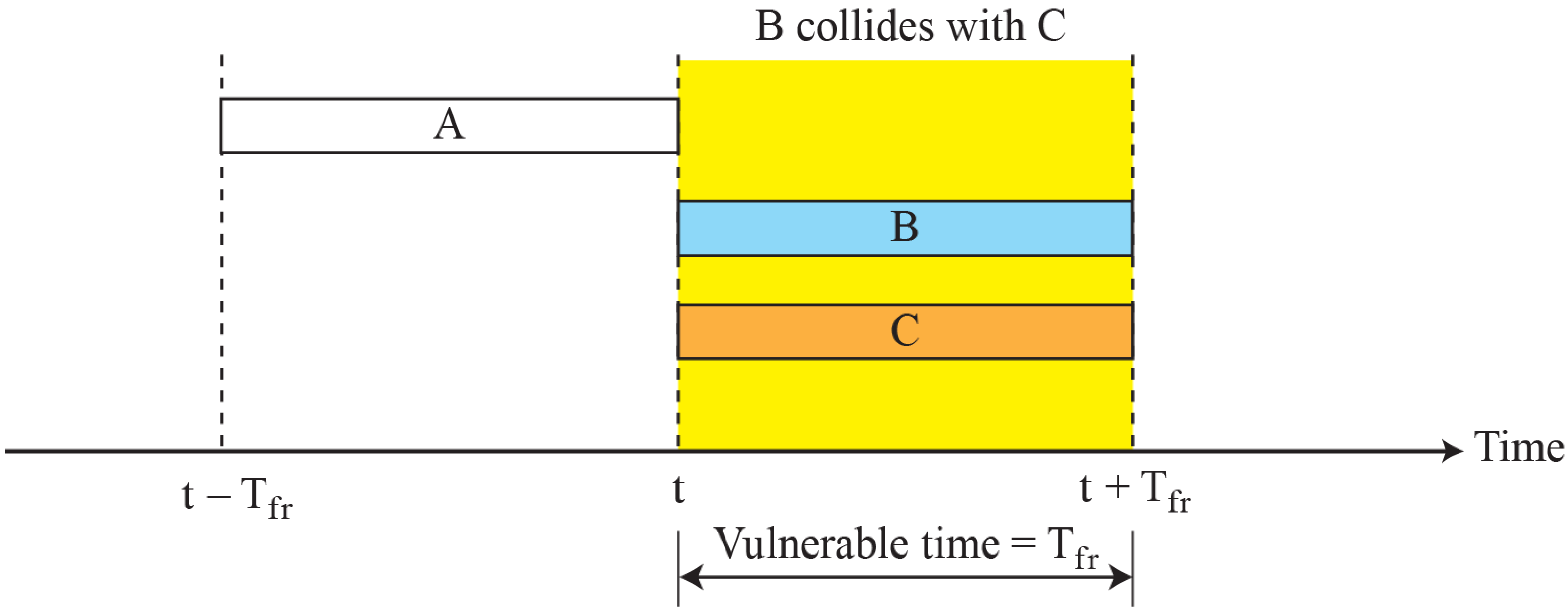
- Improves the efficiency of pure ALOHA.
- The time is divided into slots of T_{fr} seconds, and the station is forced to send only at the beginning of the time slot.

Slotted ALOHA Frame Collisions



- There is still the possibility of collision if two stations try to send at the beginning of the same time slot.

Slotted ALOHA Vulnerable Time



Slotted ALOHA Throughput

- The **throughput** for slotted ALOHA is $S = G \times e^{-G}$
- The maximum throughput $S_{max} = 0.368$ when $G = 1$
  - If one frame is generated during one frame transmission time, then 36.8% of these frames reach their destination successfully.
- $G = 1$ produces maximum throughput because the **vulnerable time** is equal to the **frame transmission time**. Therefore, if a station generates only one frame in this vulnerable time (and no other station generates a frame during this time), the frame will reach its destination successfully.

Slotted ALOHA – 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 1000 frames per second? Explain your result.

Slotted ALOHA – Example

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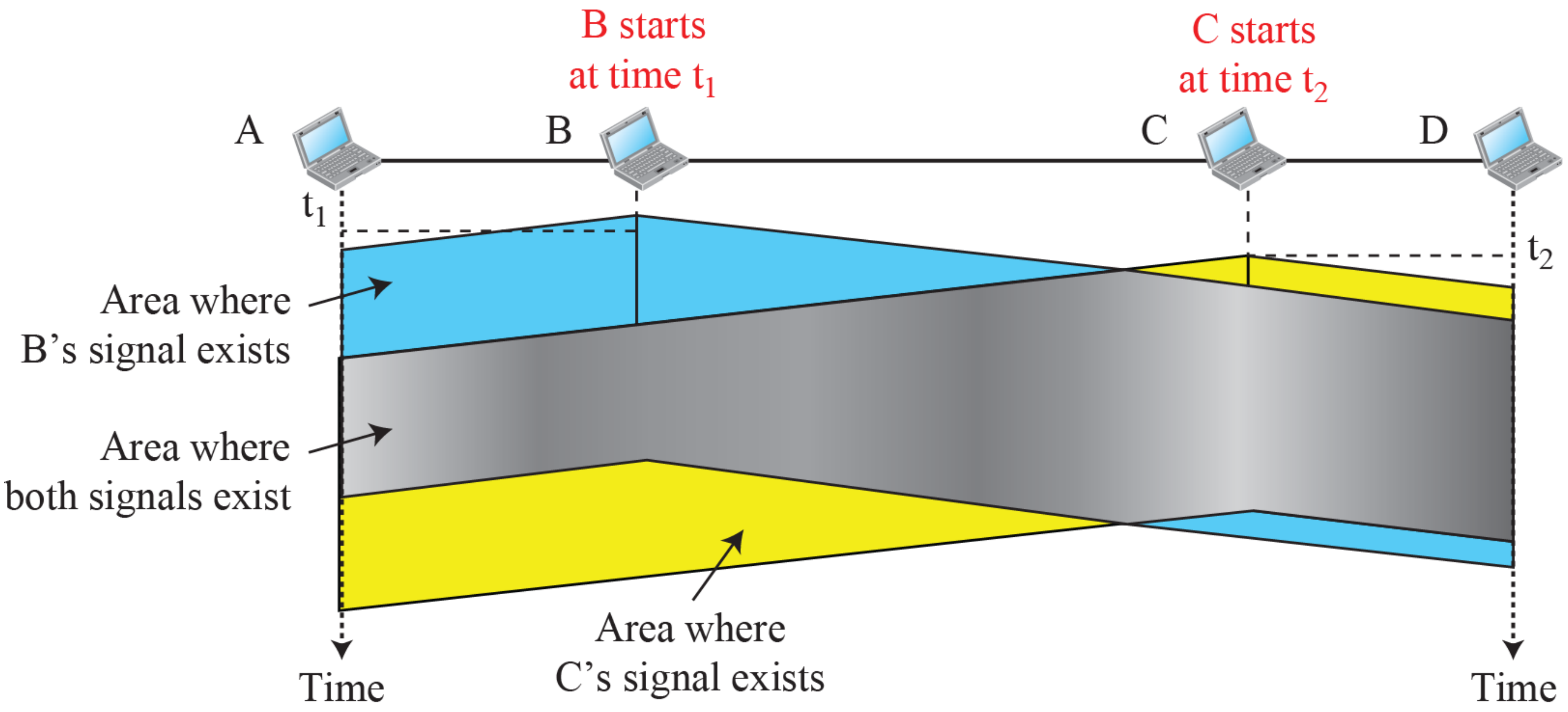
- **Answer**:
  - T_{fr} = 200 bits/200 kbps = **1 ms**
  - 1000 frames per second → 1 frame per millisecond (1 frame per frame transmission time) → $G = 1$
  - $S = G \times e^{-G}$ = **0.368** (**36.8%**) → max throughput
  - This means that only **368 frames** (1000 × 0.368) out of 1000 will probably survive.

CSMA

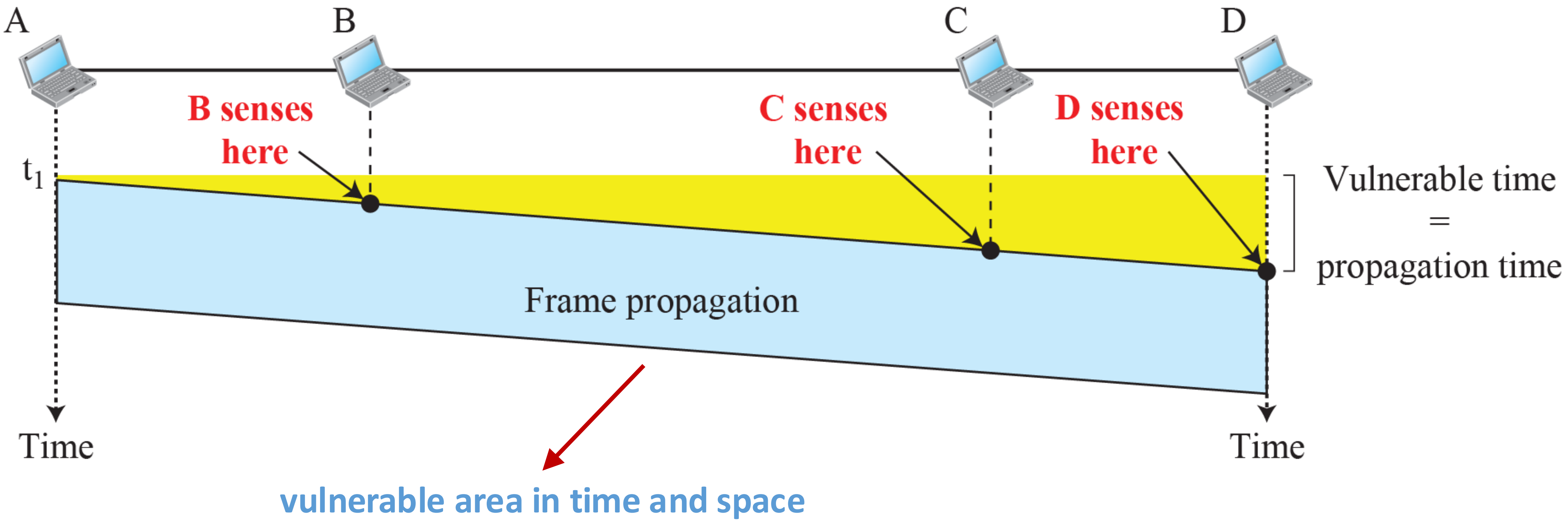
- **Carrier Sense Multiple Access** (**CSMA**)
- Developed to **minimize the chance of collision** and thus improving the performance.
- Each station **senses the medium** before trying to use it (**sense before transmit**).
    - Reducing the possibility of collision

CSMA Space/Time Model of a Collision



- The possibility of collision still exists! Because of the propagation delay (it takes time for the first bit to reach every station)

CSMA Vulnerable Time



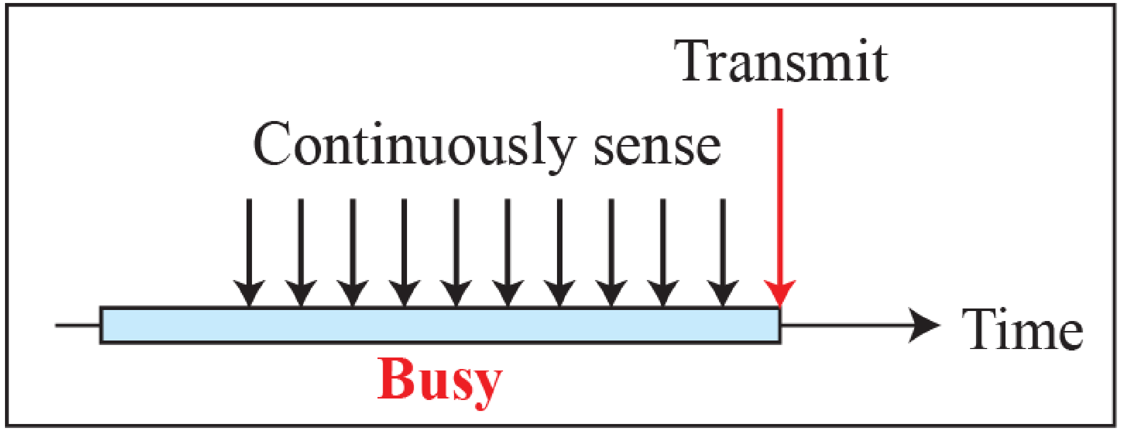
The vulnerable time for CSMA is same as the max propagation time T_p.

CSMA Persistence Methods

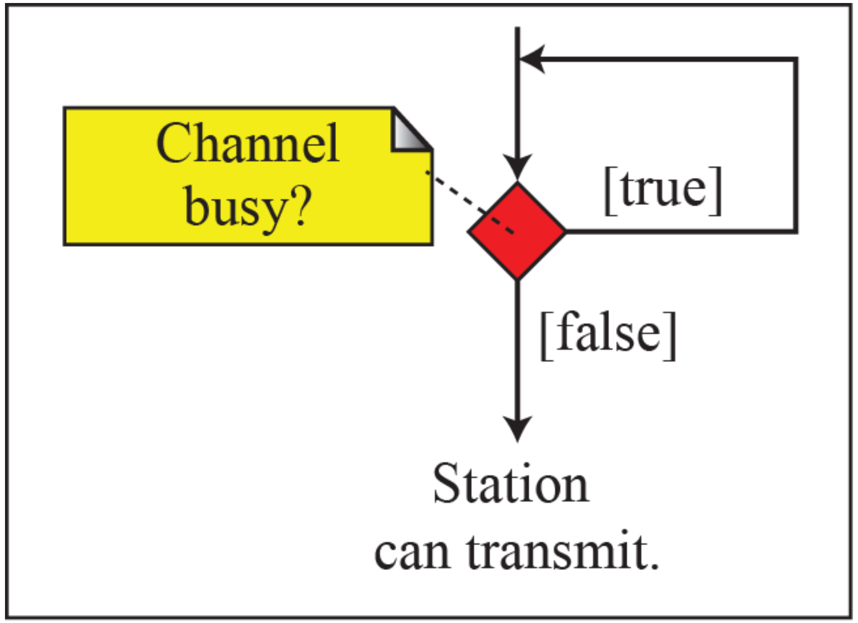
- What should a station do if the channel is **busy**?
- What should a station do if the channel is **idle**?
- Three Persistent methods are designed:
  - **1-persistent**
  - **Non-persistent**
  - **P-persistent**

CSMA 1-Persistent Method

- Used in Ethernet. Highest chance of collision.



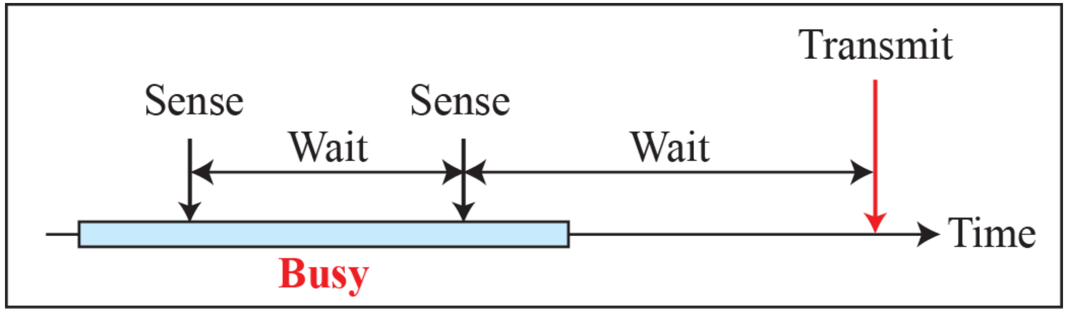
a. 1-persistent



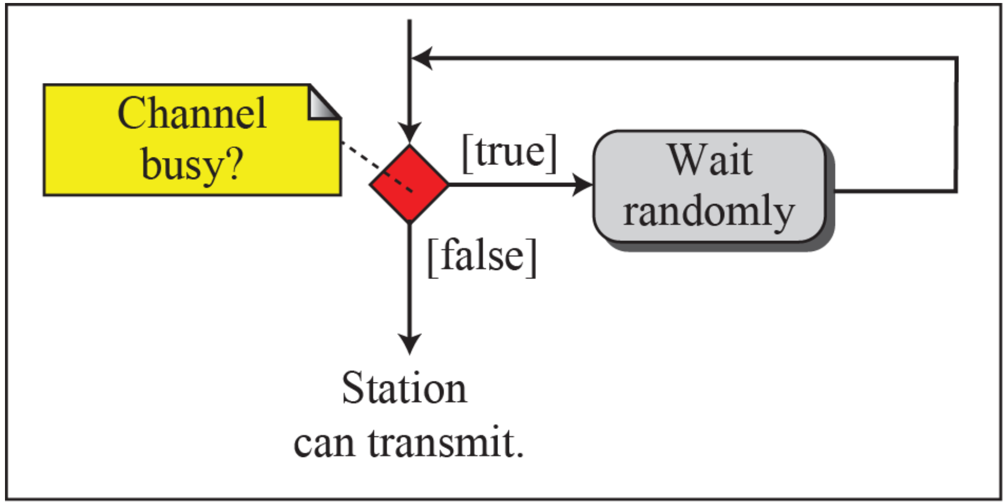
a. 1-persistent

CSMA Non-persistent Method

- Reduces the chance of collision but decreases the efficiency (the medium remains idle when there may be stations with frames to send).



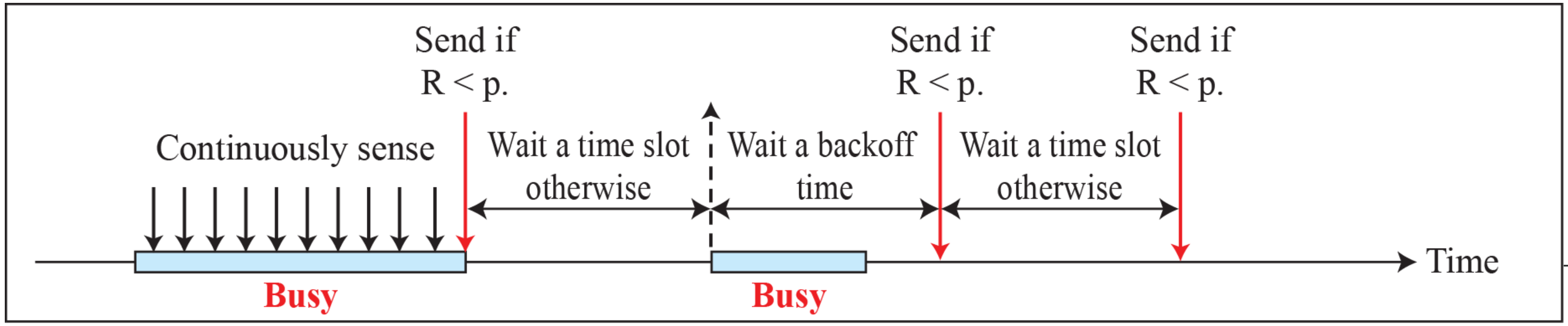
b. Nonpersistent



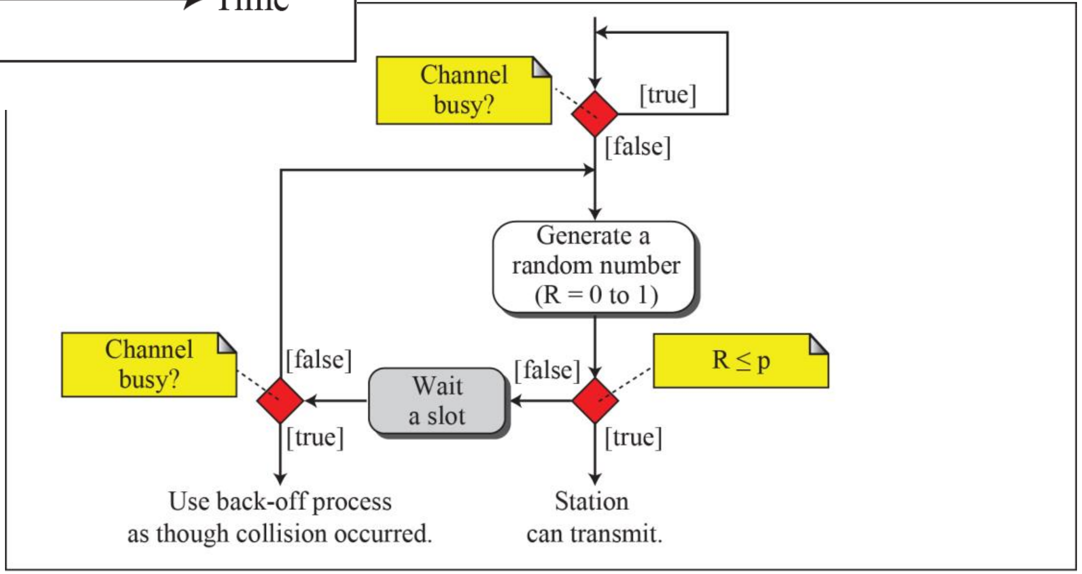
b. Nonpersistent

CSMA P-persistent Method

- Slot duration is equal to or greater than the maximum propagation time.
- Reduces the chance of collision and improves efficiency.

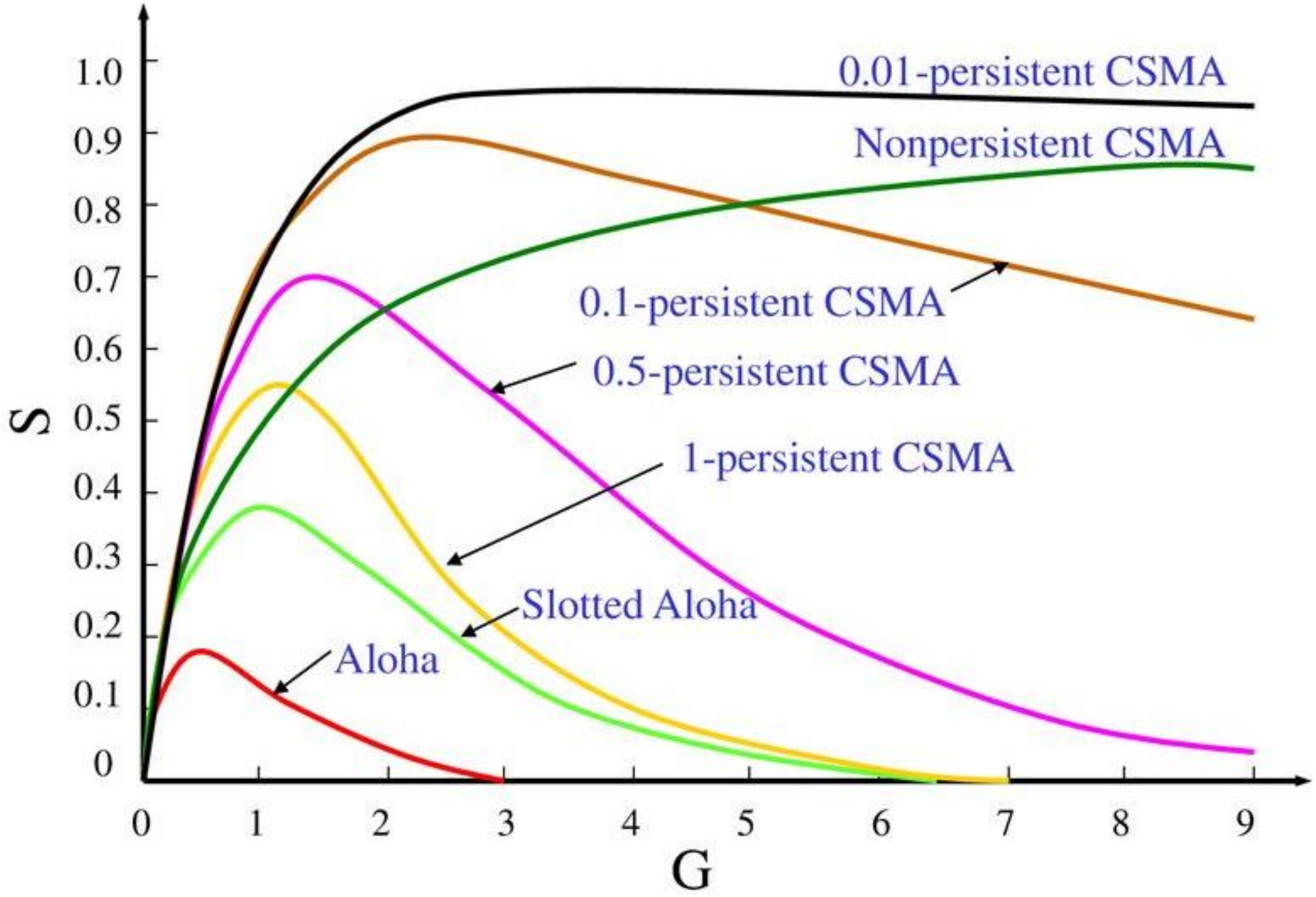


c. *p*-persistent



c. *p*-persistent

Throughput

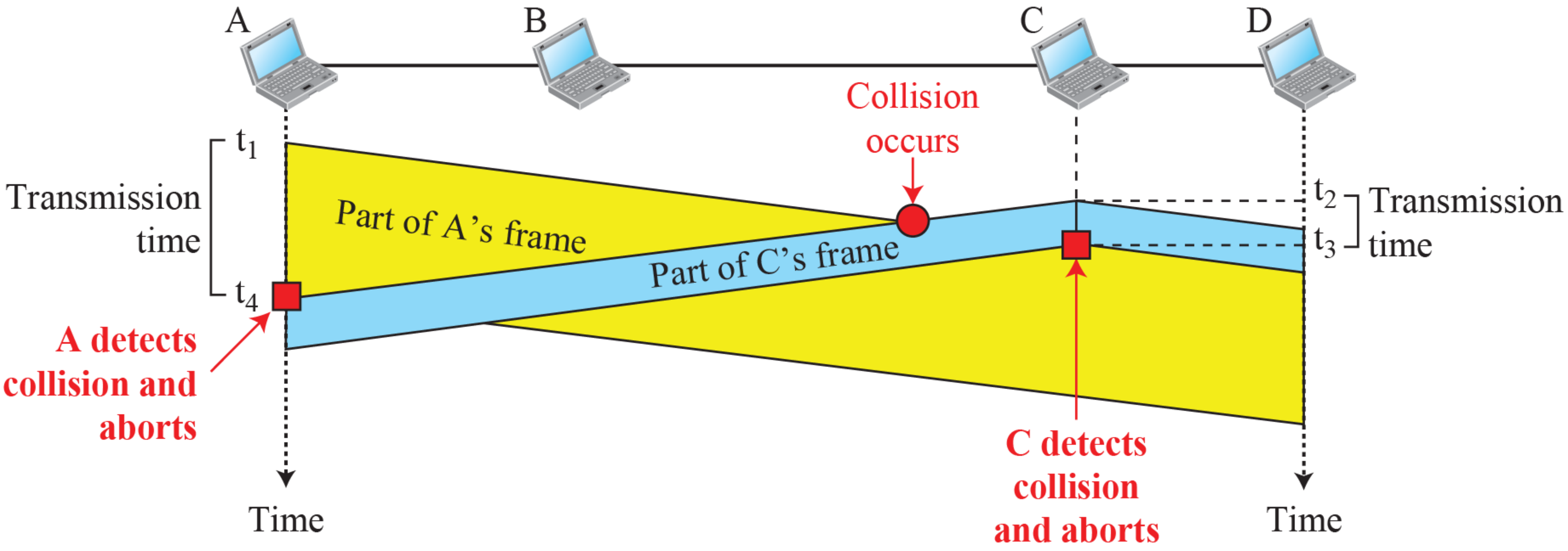


0.01-persistent CSMA
Nonpersistent CSMA
0.1-persistent CSMA
0.5-persistent CSMA
1-persistent CSMA
Slotted Aloha
Aloha
S
G
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
1
2
3
4
5
6
7
8
9

CSMA/CD

- **Carrier Sense Multiple Access with Collision Detection** (**CSMA/CD**) augments CSMA to handle the **collision**.
- A station monitors the medium after it sends a frame to see if the transmission was successful.
  - If **successful**: The station is finished.
  - If **collision**: The frame is sent again.
- The traditional **Ethernet LAN protocol** used CSMA/CD.
  - Bus and hub-based star topologies (frame collisions occur when nodes transmitted at the same time).
  - Effective for a **wired broadcast LAN** spanning a small geographical region.

CSMA/CD Collision and Abortion

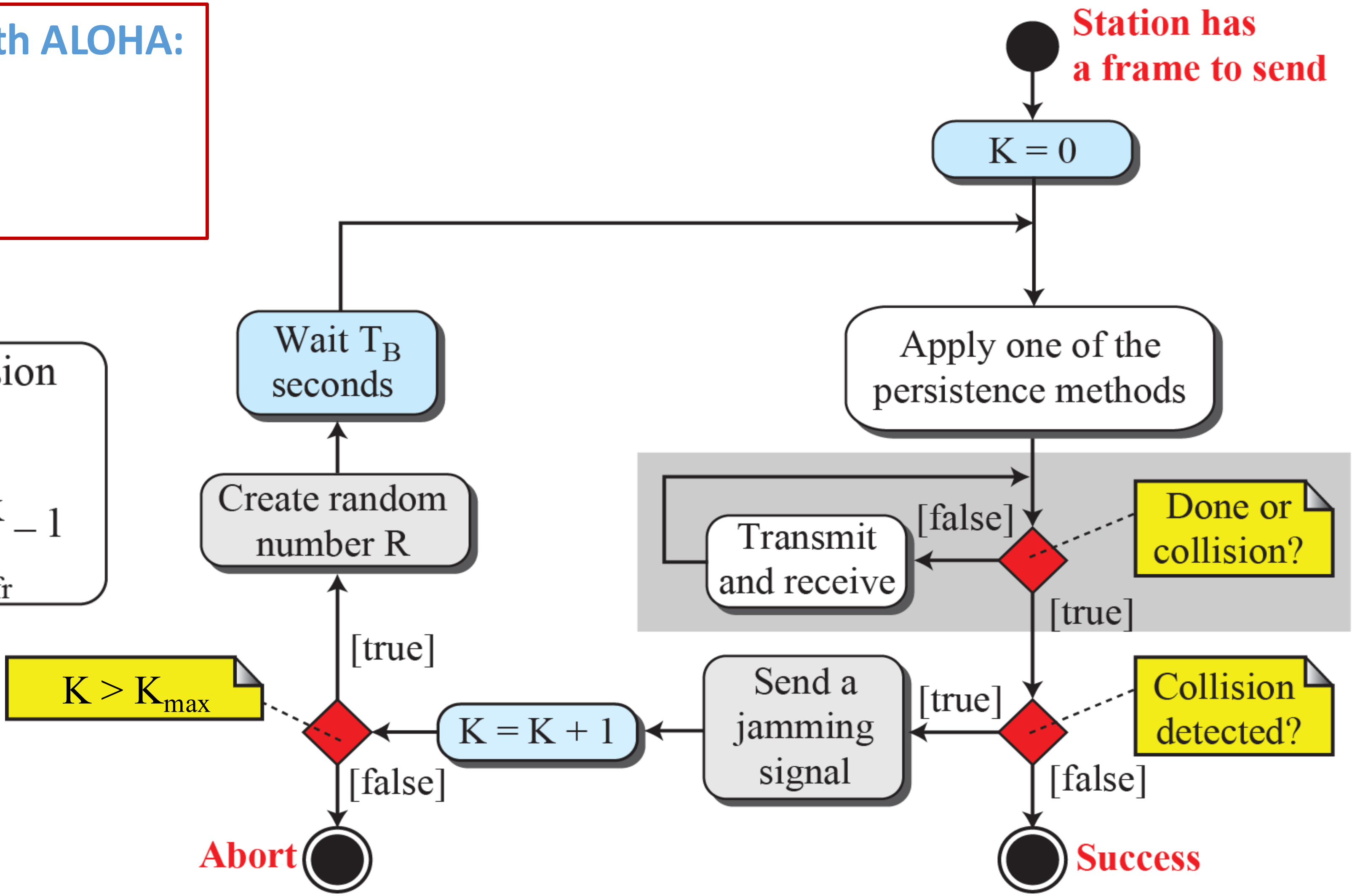


CSMA/CD Flow Diagram

Three main differences with ALOHA:
1. Persistent process
2. Frame transmission
3. Jamming signal

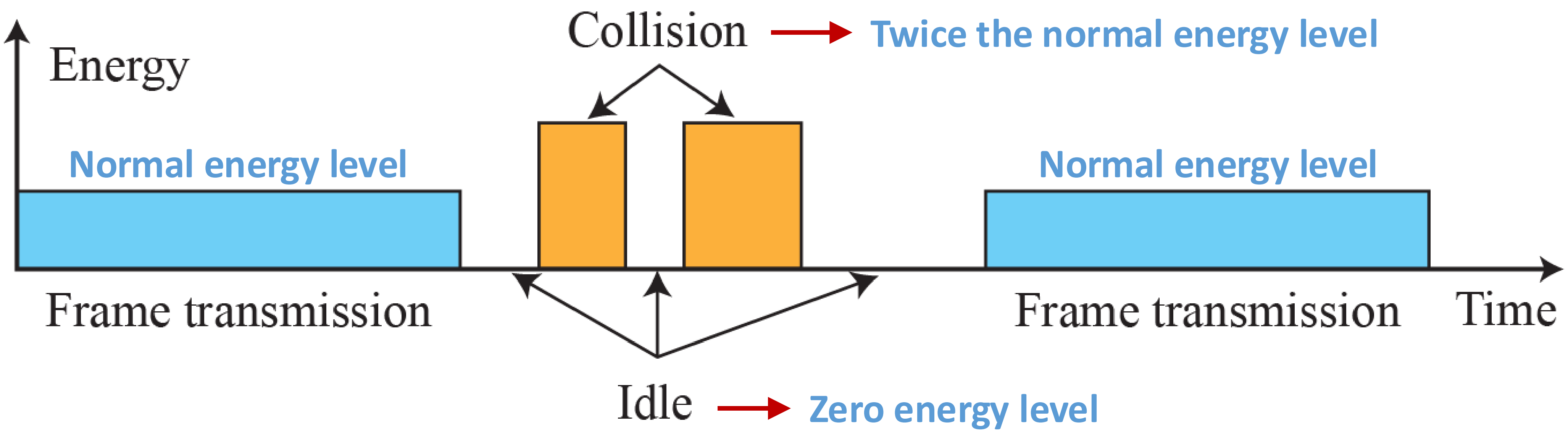
Legend

T_{fr}: Frame average transmission time
K : Number of attempts
R : (random number): 0 to $2^K - 1$
T_B: (Back-off time) = R × T_{fr}



CSMA/CD Energy Level during Transmission, Idleness, or Collision

- A station that has a frame to send or is sending a frame needs to monitor the energy level of the channel to determine if the channel is idle, busy, or in collision mode.



More about CSMA/CD

- **Minimum frame size**
  - T_{fr} must be at least two times the maximum propagation time T_p.
  - Before sending the last bit of the frame, the sending station must detect a collision, if any, and abort the transmission
  - **Worst-case scenario**: if the two stations involved in a collision are the maximum distance apart, the signal from the first takes time T_p to reach the second, and the effect of the collision takes another time T_p to reach the first. So, the requirement is that the first station must still be transmitting after $2 \times T_p$
- **Throughput**
  - Greater than pure or slotted ALOHA.
  - Maximum throughput happens at a different value of G (out of the scope of this course).

CSMA/CD – 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) is 25.6 μs, what is the minimum size of the frame?

CSMA/CD – Example

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- **Answer**:
  - **Minimum frame transmission time** = $T_{fr} = 2 \times T_p = 2 \times 25.6 =$ **51.2 μs**
  - In the worst case, a station needs to transmit for a period of 51.2 μs to detect the collision.
  - **Minimum size of the frame** = 10 Mbps × 51.2 μs = 512 bits = **64 bytes**
  - This is actually the minimum size of the frame for Standard Ethernet.

CSMA/CA

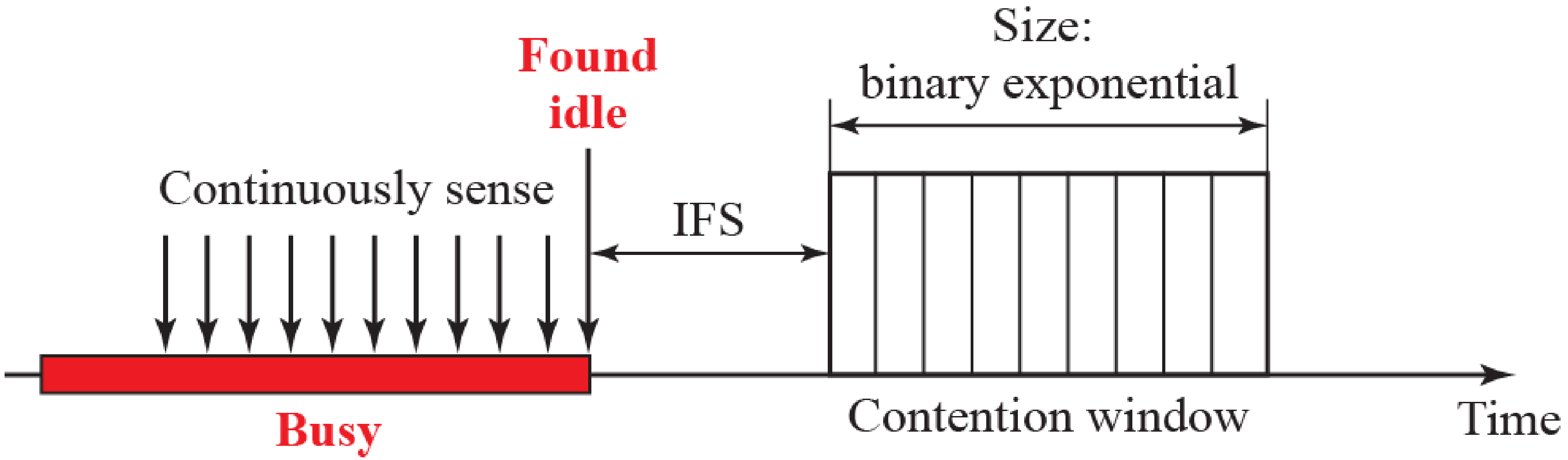
- **Carrier Sense Multiple Access with Collision Avoidance** (**CSMA/CA**)
- Invented for wireless networks.
- Collisions are avoided using:
  - **IFS** (Interframe space)
  - **CW** (Contention window)
  - **NAV** (Network Allocation Vector): a **timer** → key to collision avoidance
  - **RTS/CTS** as control frames for **handshaking**.
  - **Acknowledgements** (positive ack and time-out to guarantee that the receiver has received the frame)

CSMA/CA IFS

- **Collisions are avoided** by deferring transmission even if the channel is found idle.
  - The station waits for a period of time called the **interframe space** or **IFS**.
  - The **IFS** time allows the front of the transmitted signal by the distant station to reach this station.
  - The **IFS** variable can also be used to prioritize stations or frame types
    - E.g., a station that is assigned a shorter **IFS** has a higher priority.

CSMA/CA Contention Window

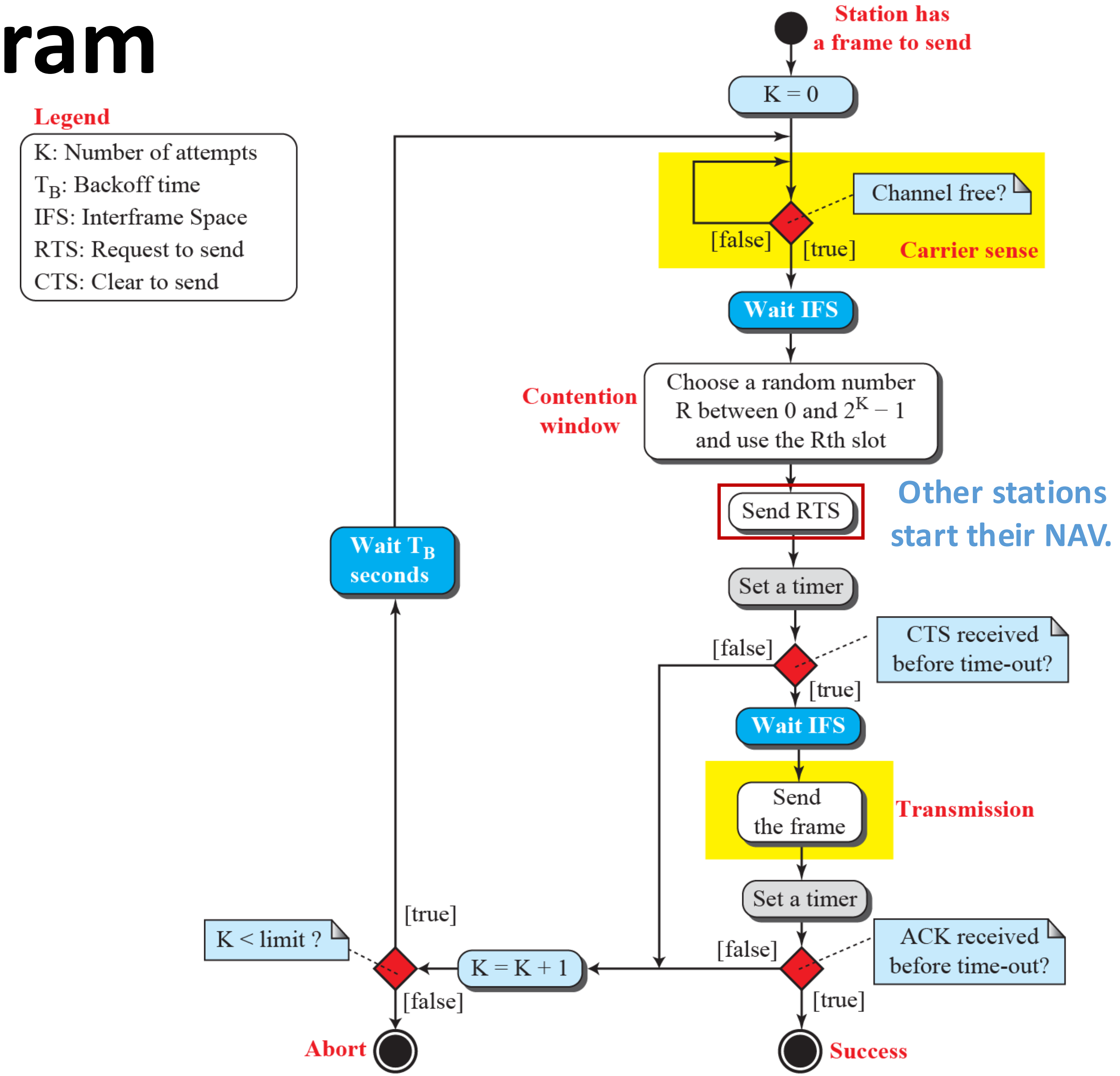
- After waiting an **IFS** time, if the channel is still idle, the station can send, but it still needs to wait a time equal to the **contention window**.
- The **contention window** is an amount of time divided into slots. A station that is ready to send chooses a random number of slots as its wait time.
- The number of slots in the window changes according to the **binary exponential backoff strategy**.



CSMA/CA Flow Diagram

- RTS includes the duration of time that it needs to occupy the channel.

- Each station, before sensing the physical medium to see if it is idle, first checks its NAV to see if it has expired.



Summary

- Handling access to a shared link by MAC sublayer of the data-link layer.
- MAC protocols we discussed
    - Random access
    - Channelization

References

[1] Behrouz A.Forouzan, Data Communications & Networking with TCP/IP Protocol Suite, 6th Ed, 2022, McGraw-Hill companies.

[2] J.F. Kurose, K.W. Ross, Computer Networking: A Top-Down Approach, 7th Ed, 2017, Pearson Education, Inc.

Reading

- Chapter 3 of the textbook, section 3.3.
- Chapter 3 of the textbook, section 3.6 (Practice Test)