

# **COMP 3721**

## **Introduction to Data Communications**

**09a - Week 9 - Part 1**

# **COMP 3721数据通信导论**

**09a - 第9周 - 第1部分**

# 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.

# 学习目标

- 在本讲座结束时，您将能够
  - 解释什么是MAC（媒体访问控制）协议及其工作原理。

# 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.

# 简介

- 广播链路
    - 可以有 **多个发送和接收节点**，全部连接到同一个单一的共享广播信道。
  - 为何使用术语 **广播**？
    - 此处使用术语 **广播** 是因为当任何一个节点发送一个帧时，该信道会广播该帧，所有其他节点都会接收到一份副本。
  - 广播链路层技术的 **示例**
    - 以太网
    - 无线局域网（WLAN）
- 我们需要**多路访问协议**来协调对多点（广播）链路的访问。

# 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**?



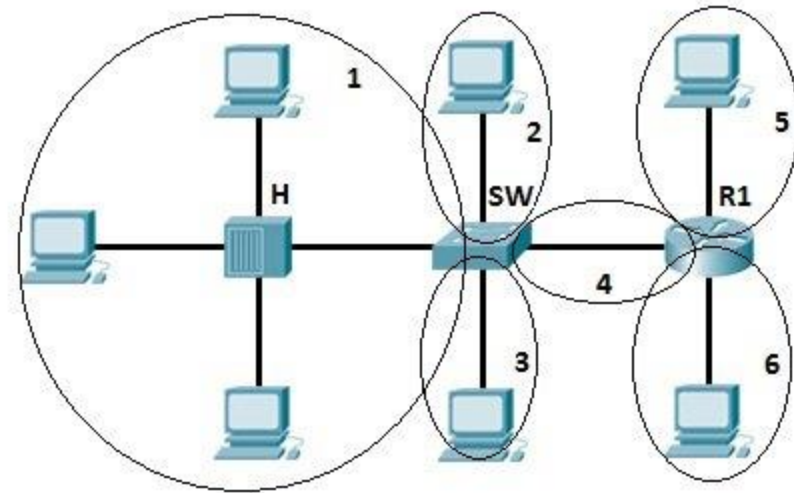
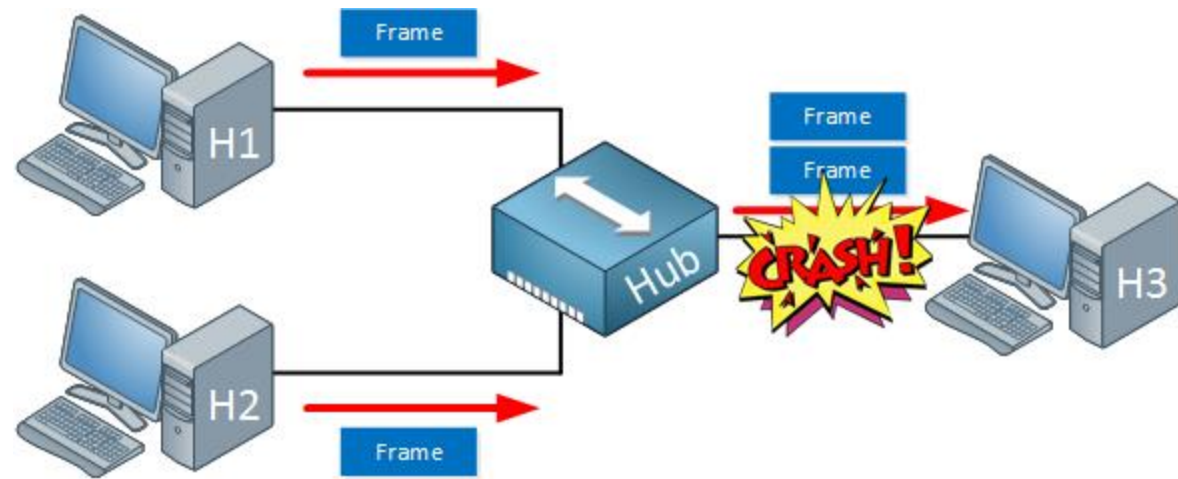
# 简介 – 类比

- 控制对通信介质的访问类似于会议中发言的规则。
  - 广播介质: **空气**
  - 谁** 可以发言 (向信道发送信号) 以及 **何时**?



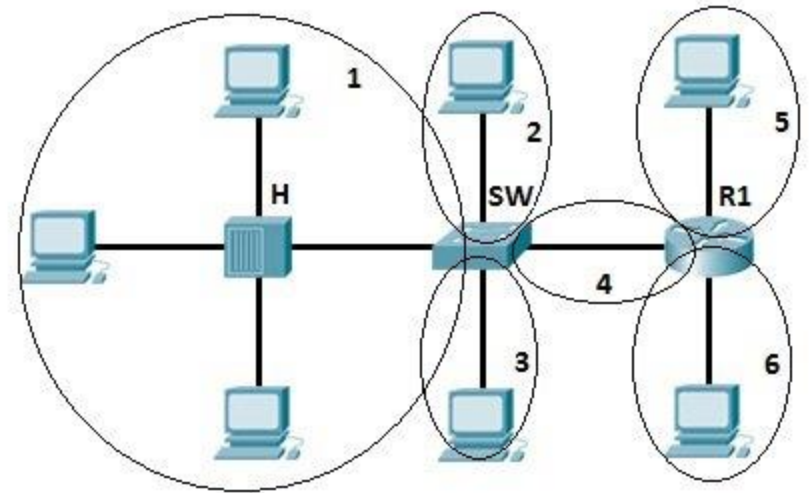
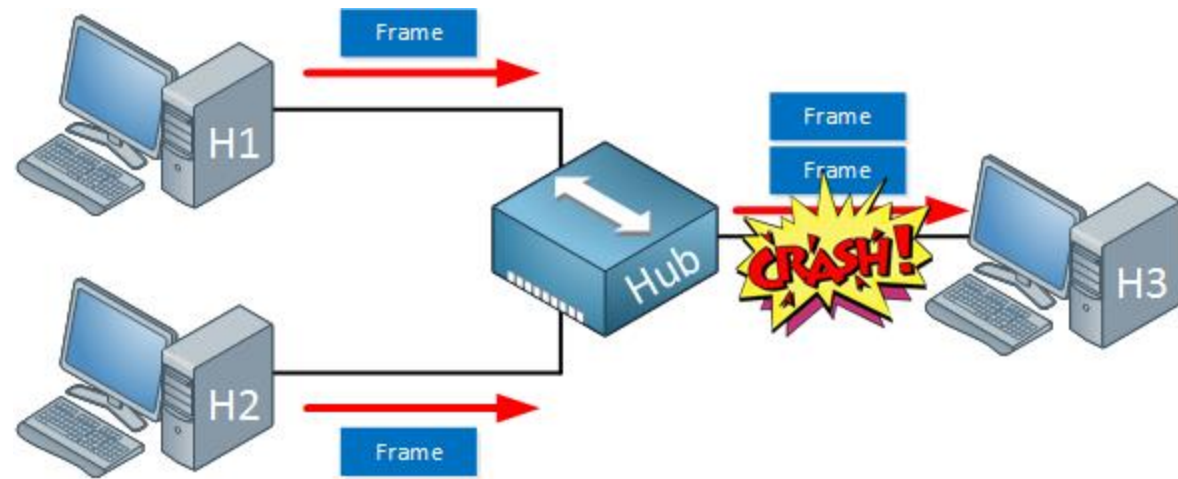
# Collision Domain

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



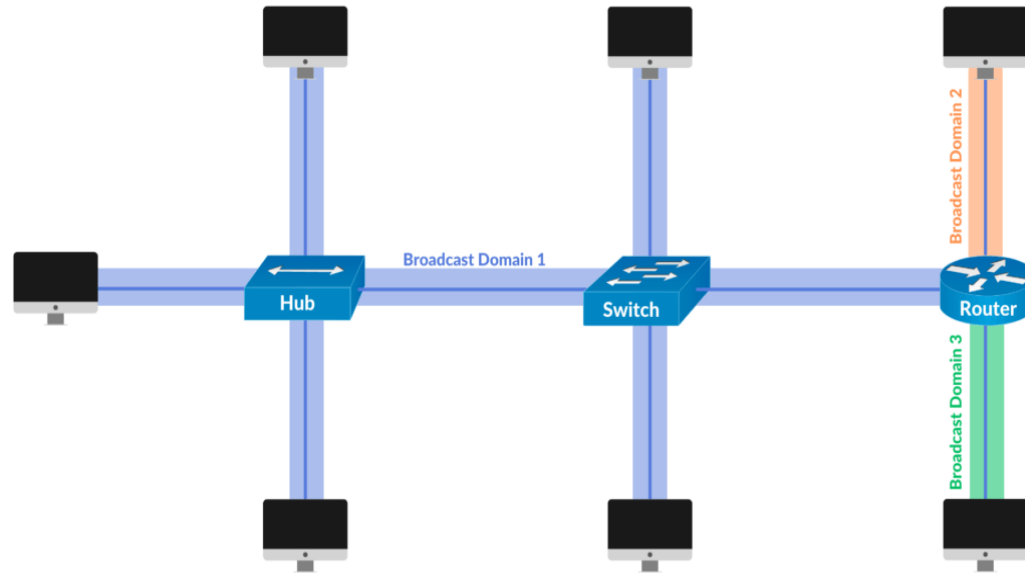
# 冲突域

- 一个 **冲突域** 是网络中可能发生数据包 **冲突** 的区域。



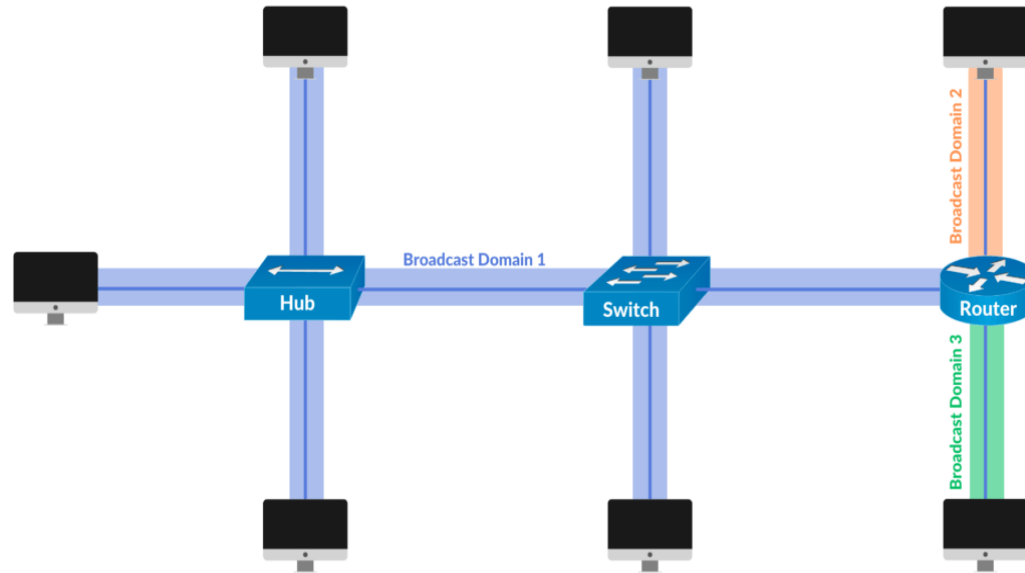
# Broadcast Domain

- 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**



# 广播域

- 一个 **广播域** 是指广播会被转发的范围。广播域包含所有在数据链路层（OSI 第 2 层）通过 **广播** 相互通信的设备。能够相互到达的设备集合，它们在**广播**时可达。
  - IEEE 802.3 将 **广播地址** 定义为目的 MAC 地址为 **目的 MAC 地址** 的 **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.

# 网络中的冲突域和广播域设备

- 一个 **中心**
  - 既不是冲突域的分隔设备，也不是广播域的分隔设备。
- 一个 **开关**:
  - 是 **冲突域分隔设备**，因为其每个端口都位于不同的冲突域中。因此，连接在不同端口上的设备发送的消息永远不会发生冲突。
- 一个 **路由器**:
  - 是 **广播域的分隔符** 和 **冲突域的分隔符**。从一个网络发送到另一个网络的广播消息永远不会被接收，因为路由器绝不会允许其通过。

# 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**)

# 数据链路层的MAC子层-链路层

- **MAC (媒体访问控制) 子层**包含用于**处理访问**共享 (**广播**) 链路的协议。
- 多路访问协议的三种类别:
  1. **随机访问协议**
  2. **信道化协议** (又称**信道划分协议**)
  3. **受控访问协议** (又称**轮转协议**)

# 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**).

# 随机访问（竞争）协议

- 没有站点优于其他站点，也没有站点被指定来控制其他站点。
- 每个站点都可以在希望时传输数据，但必须遵循 **预定义的规程**，包括 **检测信道状态**。
- 有数据要发送的站点使用由 **协议** 定义的规程来 **决定** 是否进行发送 —— 该决策取决于信道的状态（**空闲**或**忙**）。

# 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.

# 随机访问（争用）协议

- 两个特点：
  1. **随机访问**
    - 没有为站点安排传输的固定时间。
    - 各站点之间的传输是随机的。
  2. **各站点争用信道以访问介质**
    - 没有规则规定哪个站点应该下一个发送。
    - 各站点相互竞争以获取介质访问权。

# 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?

# 随机访问（竞争）协议

- 如果有多个站点尝试发送数据，则会产生访问冲突（**碰撞**）—帧将被 **破坏** 或 **修改**。
- 为了避免碰撞或在发生碰撞时解决冲突，每个站点都遵循一种 **规程**，以回答以下问题：
  - **何时**访问介质？
  - **如果介质忙，该**做什么？
  - **如果发生访问冲突（碰撞），该**做什么？
  - **如何**判断传输的成功或失败？

# Categories of Random-Access Protocols

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

# 随机接入协议的类别-接入协议

- 纯ALOHA (ALOHA)
- 时隙ALOHA
- CSMA:
  - CSMA/CD
  - CSMA/CA

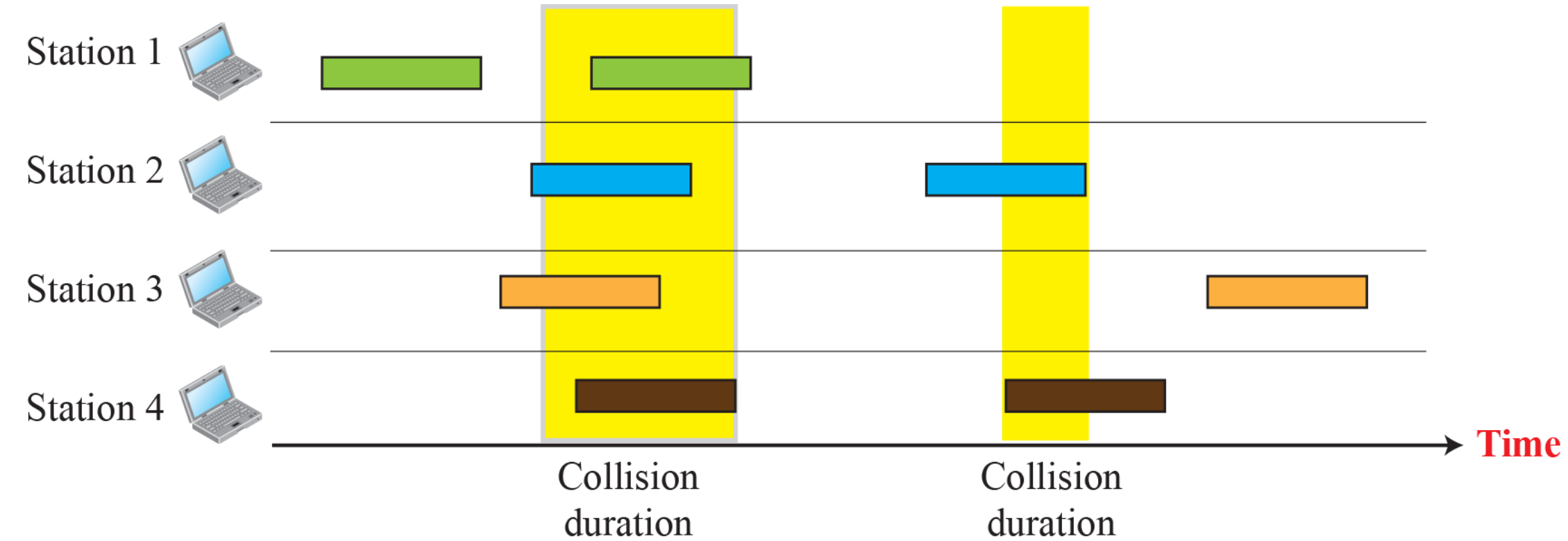
# Pure ALOHA

- 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.

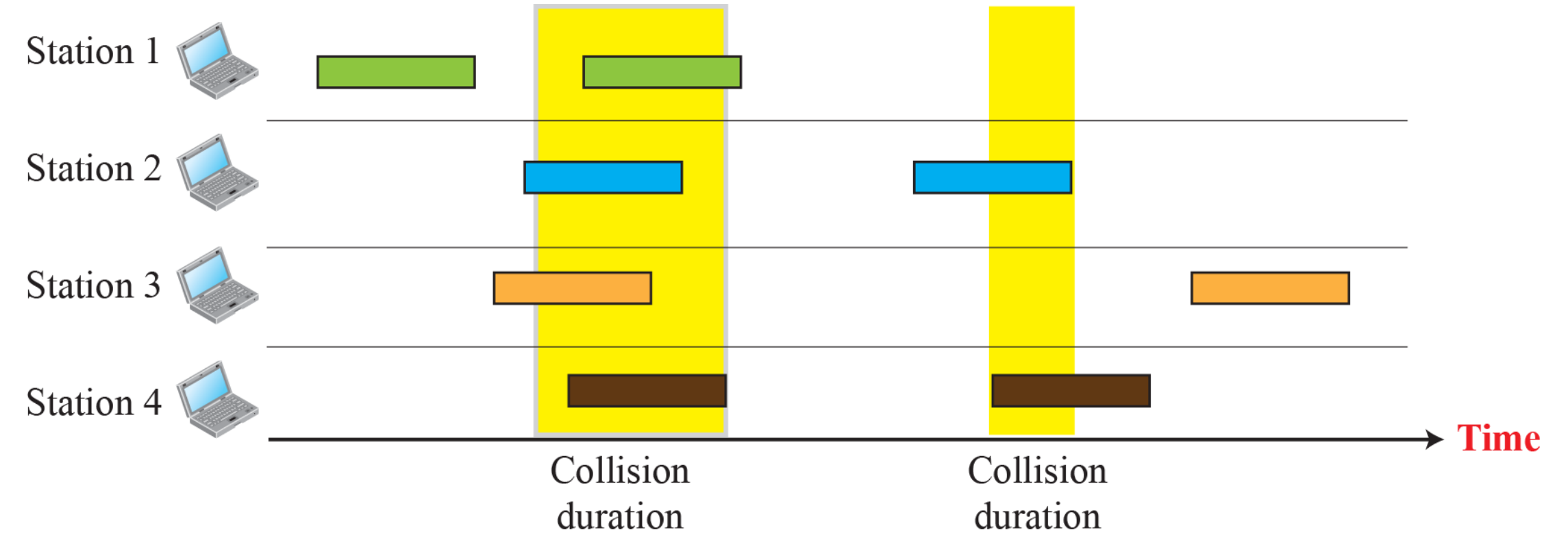
# 纯ALOHA

- 也称为 **ALOHA**
- 最早的随机访问协议
- 于20世纪70年代初在夏威夷大学开发
- ALOHA → **夏威夷语**中表示爱、关怀、和平、同情和仁慈的词语
- 专为 **无线电（无线）局域网**设计
  - 但它可用于任何共享介质
- 其思想是每个站点在有帧要发送时就随时**发送一个帧**:
  - **可能发生碰撞**来自不同站点的帧之间。

# Pure ALOHA Frame Collisions Example



# 纯ALOHA帧冲突示例



# 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.

# 纯ALOHA协议

- 依赖于接收方的**确认信息**。
- 如果在超时时间内未收到确认信息，站点会认为帧（或确认信息）已丢失，**并重新发送**该帧。
- **退避时间 ( $T_B$ )**:
  - 当超时时间结束后，每个站点在重新发送帧之前需等待一段**随机时间**。
  - 一个**随机值 ( $R$ )**，其大小取决于传输失败的尝试次数 ( $K$ )。
  - 经过**最大重传尝试次数**后，站点必须放弃并稍后重试。

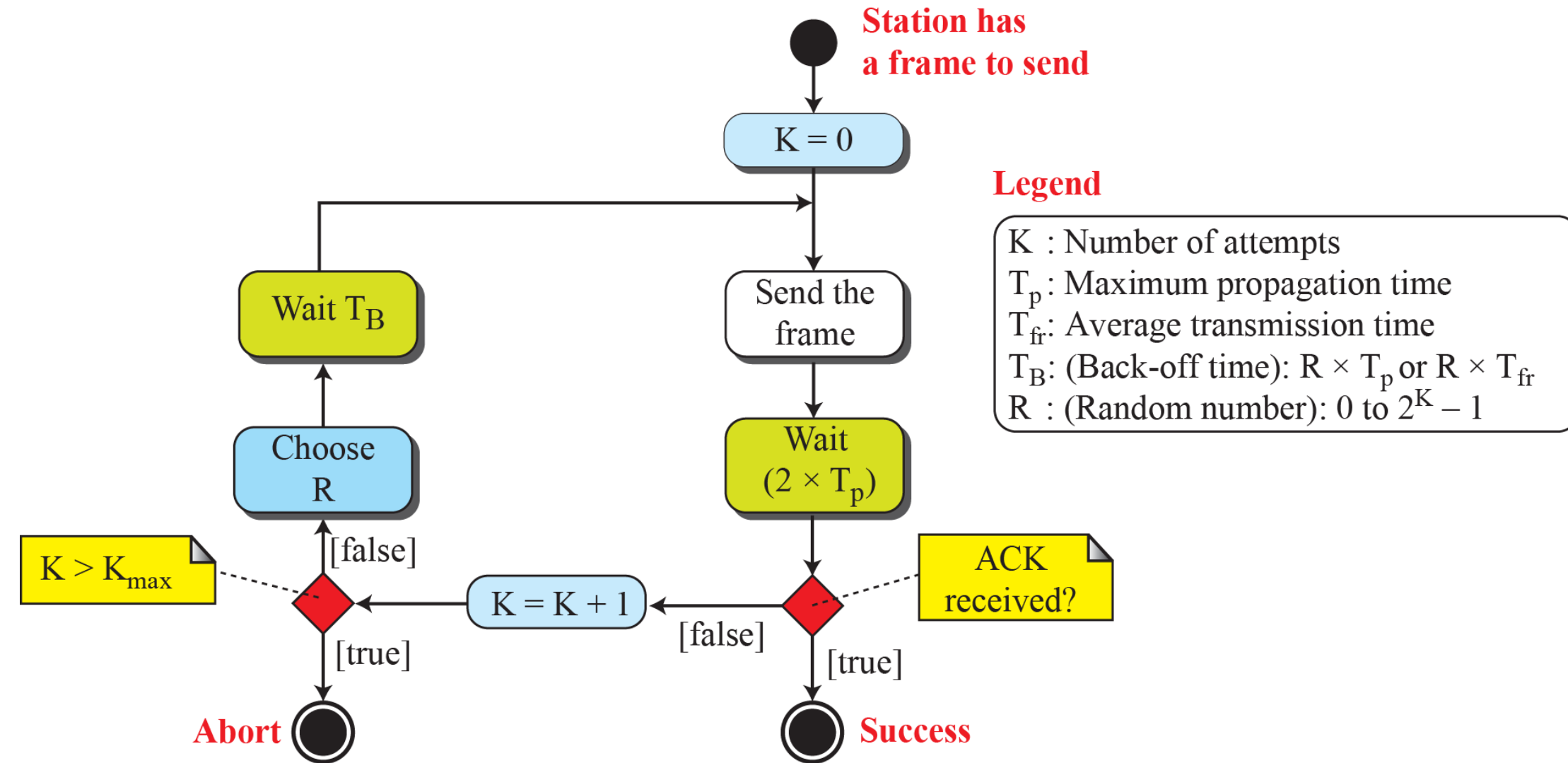
# Pure ALOHA Procedure

- **Maximum Propagation Time (Delay) ( $T_p$ ):**
  - The amount of time required to send a frame between the two most widely separated stations.
  - $T_p = \text{distance} / \text{propagation speed}$
  - 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.
  - $T_{fr} = \text{frame size} / \text{transmission rate (data rate)}$

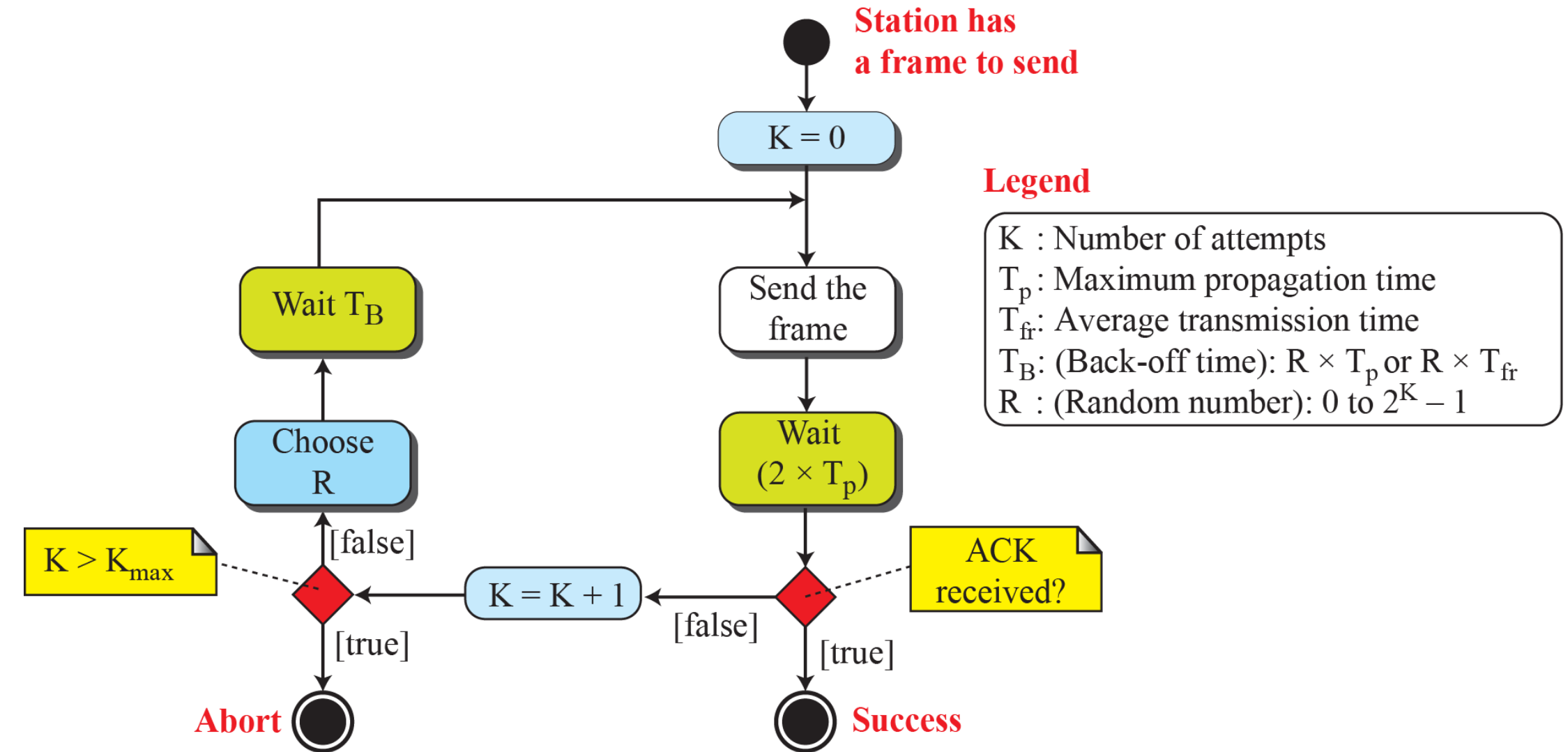
# 纯ALOHA过程

- **最大传播时间（延迟） ( $T_p$ ) :**
  - 在两个相距最远的站点之间发送一个帧所需的时间。
  - $T_p = \text{距离} / \text{传播速度}$
  - 最大可能的**往返**传播延迟为  $2 \times T_p$
  - **超时时间**等于  $2 \times T_p$
- **平均传输时间 ( $T_{fr}$ ) :**
  - 发送一个帧所需的平均时间。
  - $T_{fr} = \text{帧大小} / \text{传输速率 (数据速率)}$

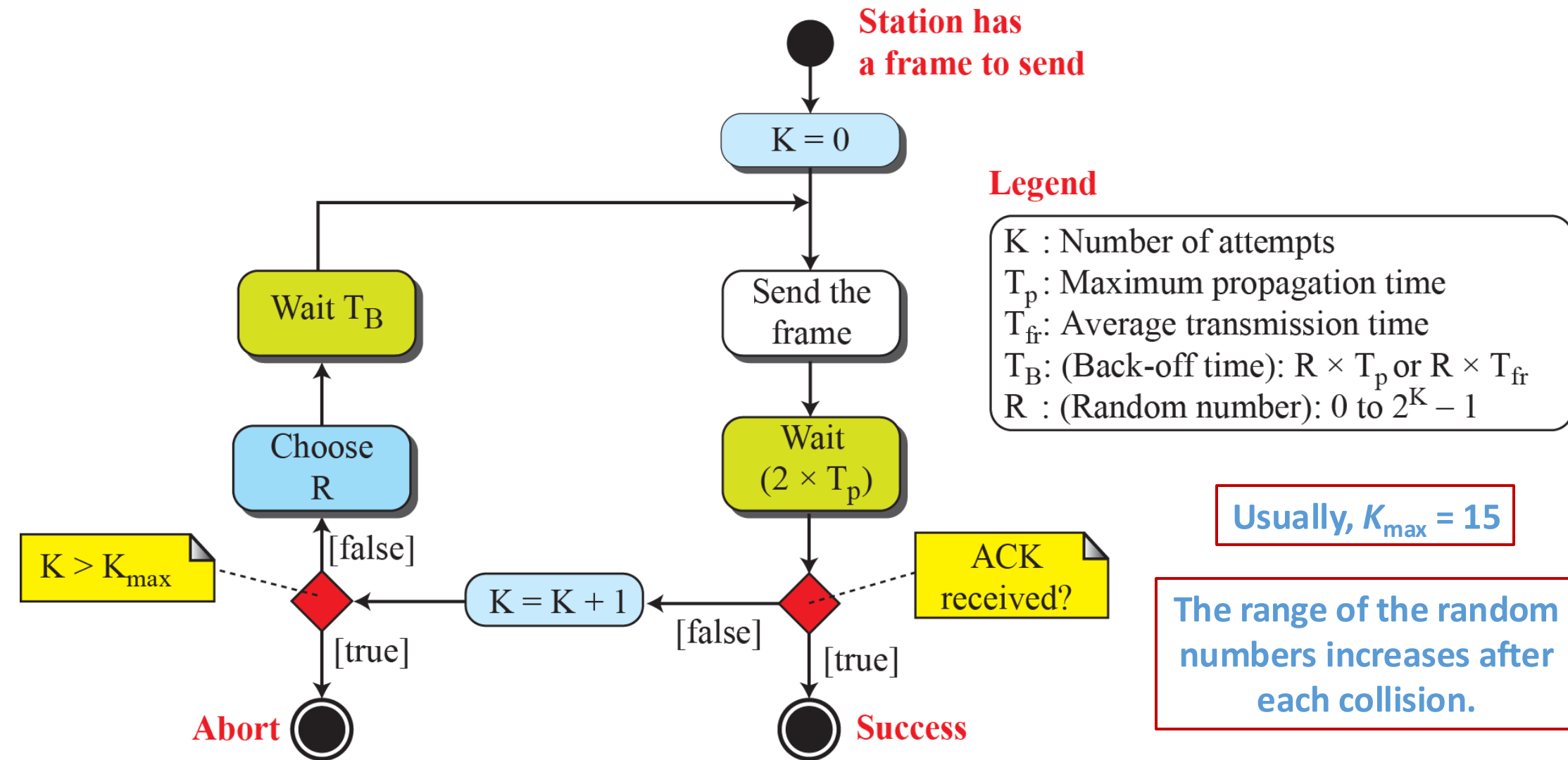
# Pure ALOHA Procedure



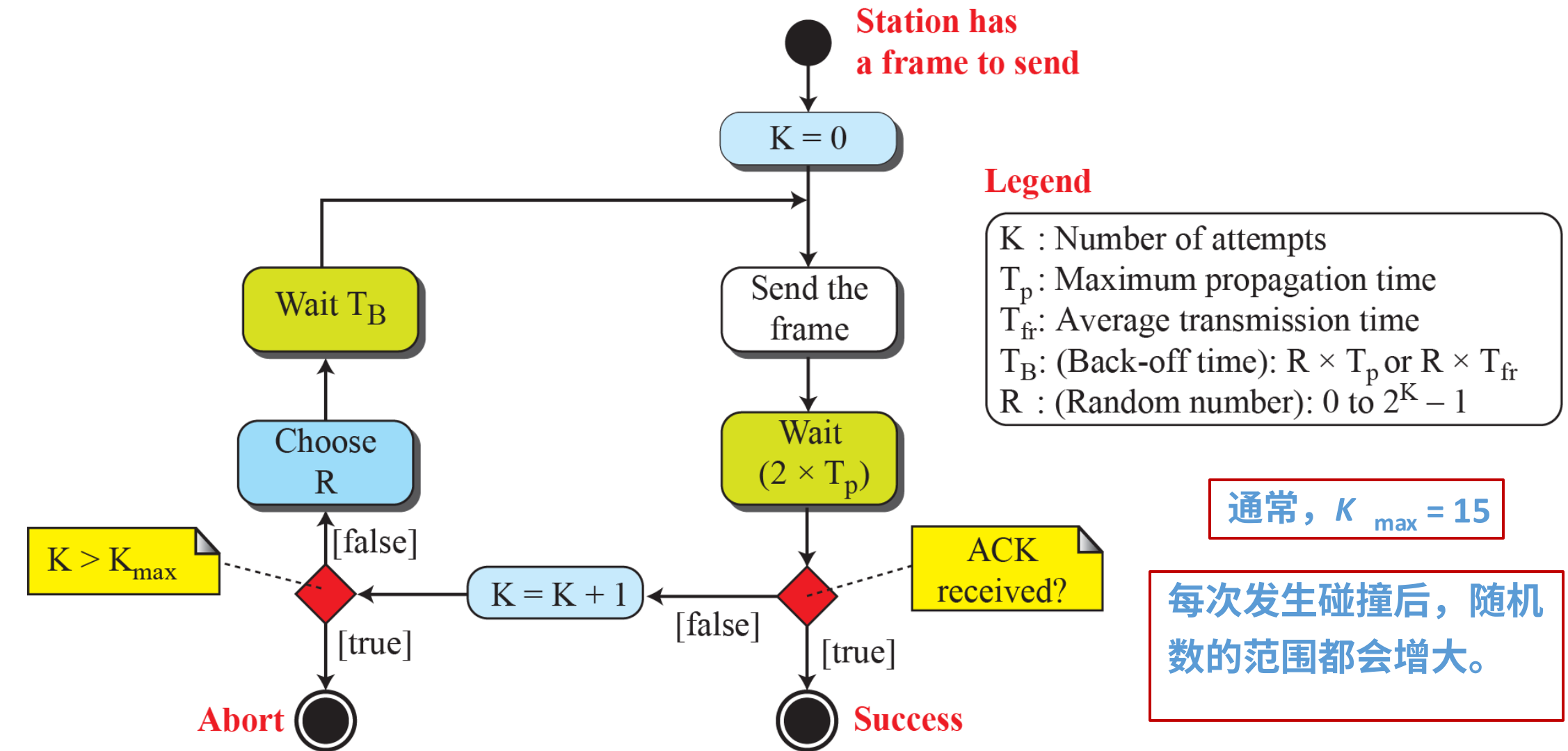
# 纯ALOHA过程



# Pure ALOHA Procedure



# 纯ALOHA协议



## 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  $T_B$ ?

## 纯ALOHA– 示例1

- 无线ALOHA网络上的站点之间最大距离为600公里。假设信号以 $c = 3 \times 10^8$  m/s的速度传播， $T_p$ 的值是多少？如果 $K = 2$ ， $T_B$ 的值是多少？

# Pure ALOHA – Example 1

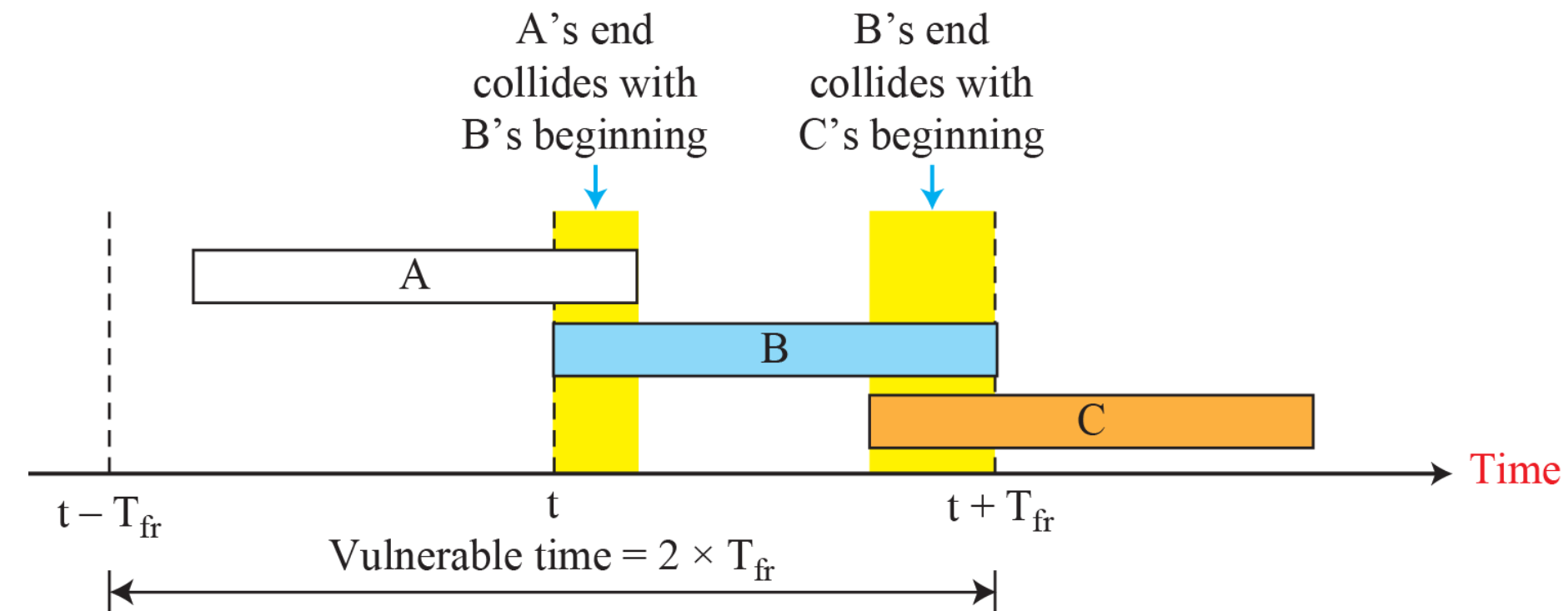
- The stations on a wireless ALOHA network are a maximum of 600 km apart. If we assume that signals propagate at  $c = 3 \times 10^8$  m/s, what is the value of  $T_p$ ? If  $K = 2$ , what is the value of  $T_B$ ?
- **Answer:**
  - $T_p = \text{distance} / \text{propagation speed} = (600 \times 10^3) / (3 \times 10^8) = \mathbf{2 \text{ ms}}$
  - $R$  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  **$\{0, 2, 4, 6\} \text{ ms}$**

# 纯ALOHA – 示例1

- 无线ALOHA网络上的站点之间最大距离为600公里分开。如果我们假设信号以 $c = 3 \times 10^8$  m/s的速度传播， $T_p$ 的值是多少？如果 $K = 2$ ， $T_B$ 的值又是多少？
- **答案:**
  - $T_p = \text{距离} / \text{传播速度} = (600 \times 10^3) / (3 \times 10^8) = \mathbf{2 \text{ ms}}$
  - $R$  的取值范围是 0 到  $(2^2 - 1) \rightarrow R \in \{0, 1, 2, 3\}$
  - $T_B = R \times T_p \rightarrow T_B$  可以从  **$\{0, 2, 4, 6\} \text{ ms}$**  中的任意值

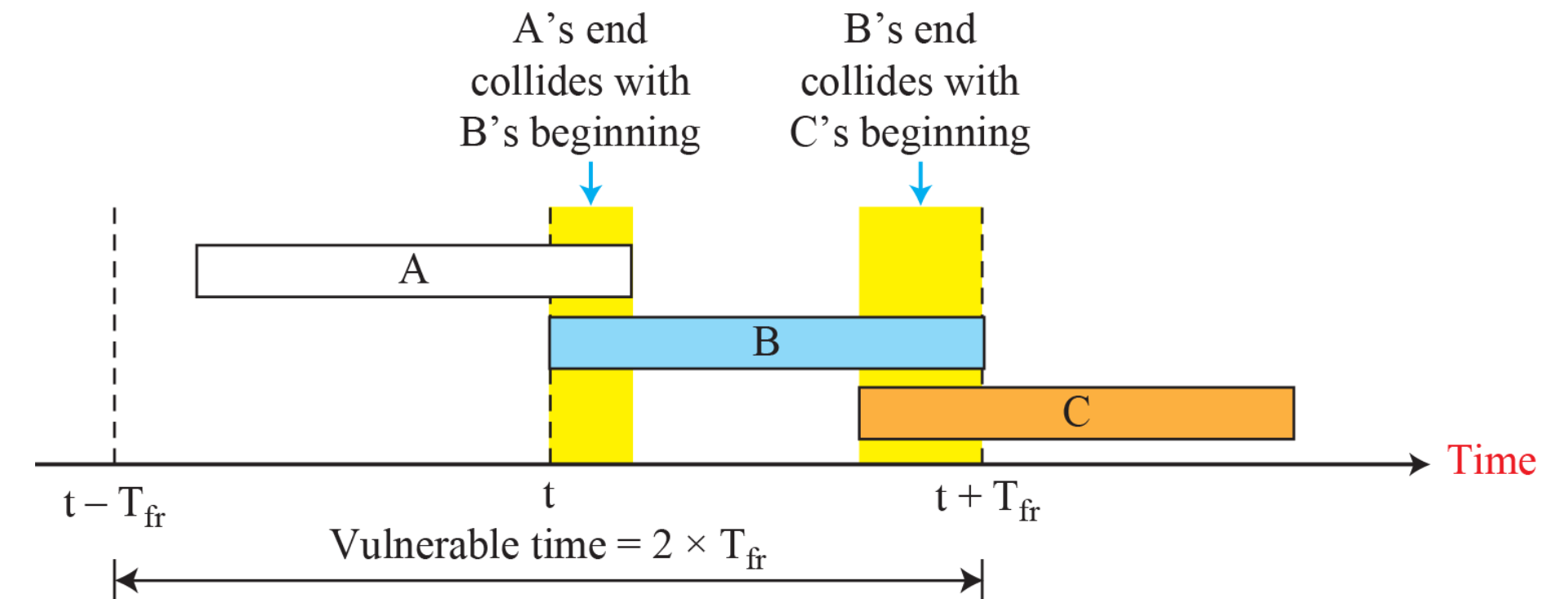
# Pure ALOHA Vulnerable Time

- **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.



# 纯ALOHA易受攻击时间

- **易受攻击时间**: 可能发生碰撞的时间长度。纯ALOHA的易受攻击时间为  $2 \times T_{fr}$ .
- 图示为站点B的易受攻击时间。



## 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?

## 纯ALOHA – 示例2

- 一个纯ALOHA网络在200 kbps的共享信道上传输200比特的帧。要使该帧无冲突，需要满足什么条件？

## 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?
- **Answer:**
  - $T_{fr} = \text{frame size} / \text{transmission rate (data rate)} = 200 \text{ bits} / 200 \text{ kbps} = 0.001 \text{ s} = 1 \text{ ms}$
  - The **vulnerable time** is  $2 \times T_{fr} = 2 \times 1\text{m} = 2 \text{ ms}$
  - 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.

## 纯ALOHA– 示例2

- 一个纯ALOHA网络在200 kbps的共享信道上传输200比特的帧。要使该帧无冲突，需要满足什么条件？
- **答案：**
  - $T_{fr} = \frac{\text{帧大小}}{\text{传输速率 (数据速率) 比特 / kbps} \cdot \text{s ms}} = \frac{200}{200} = 0.001 = \text{帧大小} / \text{传输速率 (数据速率) 比特} / \text{kbps} \cdot \text{s ms}$
  - 易受冲突影响的时间段**为**  $2 \times T_{fr} = 2 \times 1\text{m} = 2 \text{ ms}$
  - 这意味着**没有站点**应在本站开始传输前1毫秒内发送，并且**在本站发送期间的1毫秒时间段内，不应有其他站点开始发送。**

# 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.

# 纯ALOHA吞吐量

- $G$ : 系统在一个**帧传输时间内**生成的帧的平均数量。
- 那么，纯ALOHA的**吞吐量**（成功传输的帧的平均数量）为  $S = G \times e^{-2G}$
- 最大吞吐量  $S_{\max} = 0.184$  当  $G = 1/2$ 
  - 通过将  $S$  对  $G$  的导数设为 0。
  - OR
  - $G = 1/2$  可产生最大吞吐量，因为**易受攻击时间**是**2 倍的帧传输时间**。因此，如果一个站点在此易受攻击时间内仅生成一个帧（且其他站点在此期间不生成任何帧），该帧将成功到达目的地。

## Pure ALOHA – Example 3

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

## 纯ALOHA– 示例3

- 一个纯ALOHA网络在200 kbps的共享信道上传输200比特的帧。如果整个系统（所有站点合计）每秒产生1000个帧，请计算吞吐量？并解释该结果。

## Pure ALOHA – Example 3

- A pure ALOHA network transmits 200-bit frames on a shared channel of 200 kbps. Compute the throughput of the system (all stations together) produces 1000 frames per second? Explain the result.
- **Answer:**
  - $T_{fr} = 200 \text{ bits} / 200 \text{ kbps} = 1 \text{ ms}$
  - 1000 frames per second  $\rightarrow$  1 frame per millisecond (1 frame per frame transmission time)  $\rightarrow G = 1$
  - $S = G \times e^{-2G} = 0.135$  (13.5%)
  - This means that only **135 frames** ( $1000 \times 0.135$ ) out of 1000 will probably survive.

## 纯ALOHA– 示例3

- 一个纯ALOHA网络在200 kbps的共享信道上传输200比特的帧。如果整个系统（所有站点合计）每秒产生1000个帧，请计算吞吐量？并解释结果。
- **答案:**
  - $T_{fr} = 200 \text{ bits} / 200 \text{ kbps} = 1 \text{ ms}$
  - 1000 每秒帧数  $\rightarrow$  1 每毫秒帧数（每个帧传输时间1帧）  $\rightarrow G = 1$
  - $S = G \times e^{-2G} = 0.135$  (13.5%)
  - 这意味着，在1000个帧中，可能只有 **135个帧** ( $1000 \times 0.135$ ) 能够成功传输。

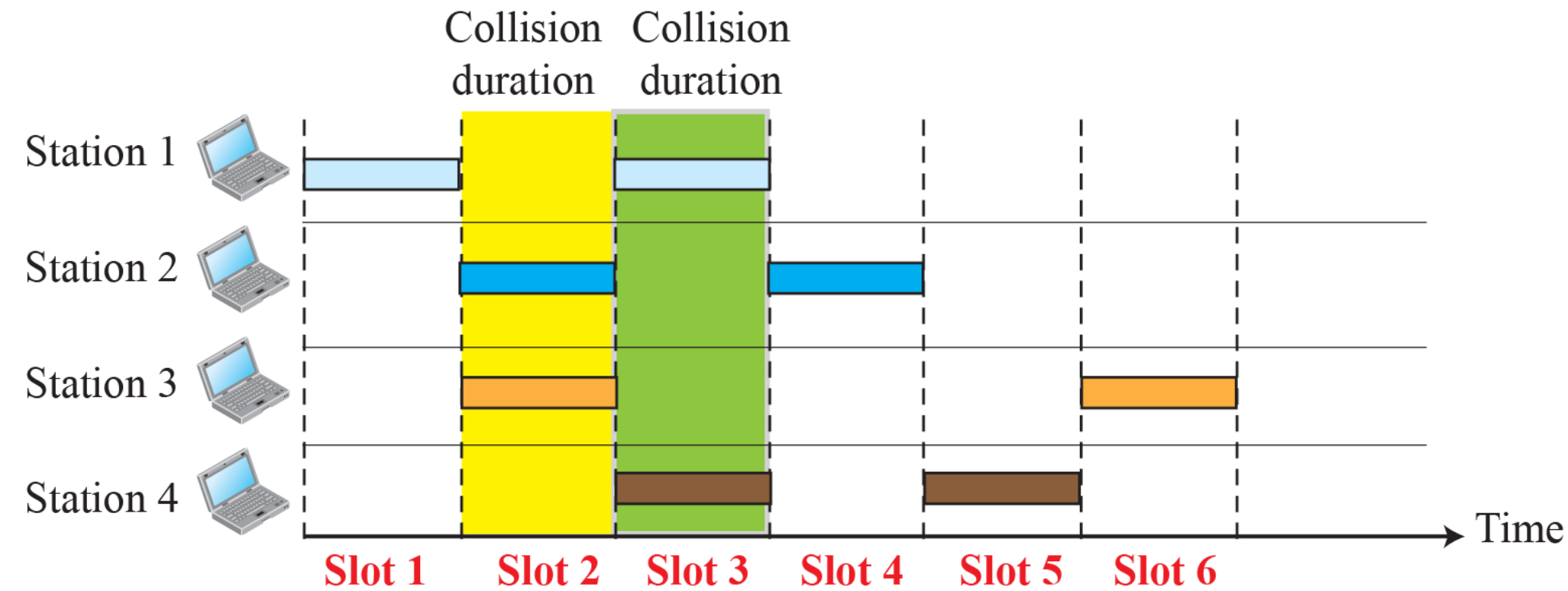
# Slotted ALOHA

- 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.

# 时隙 ALOHA

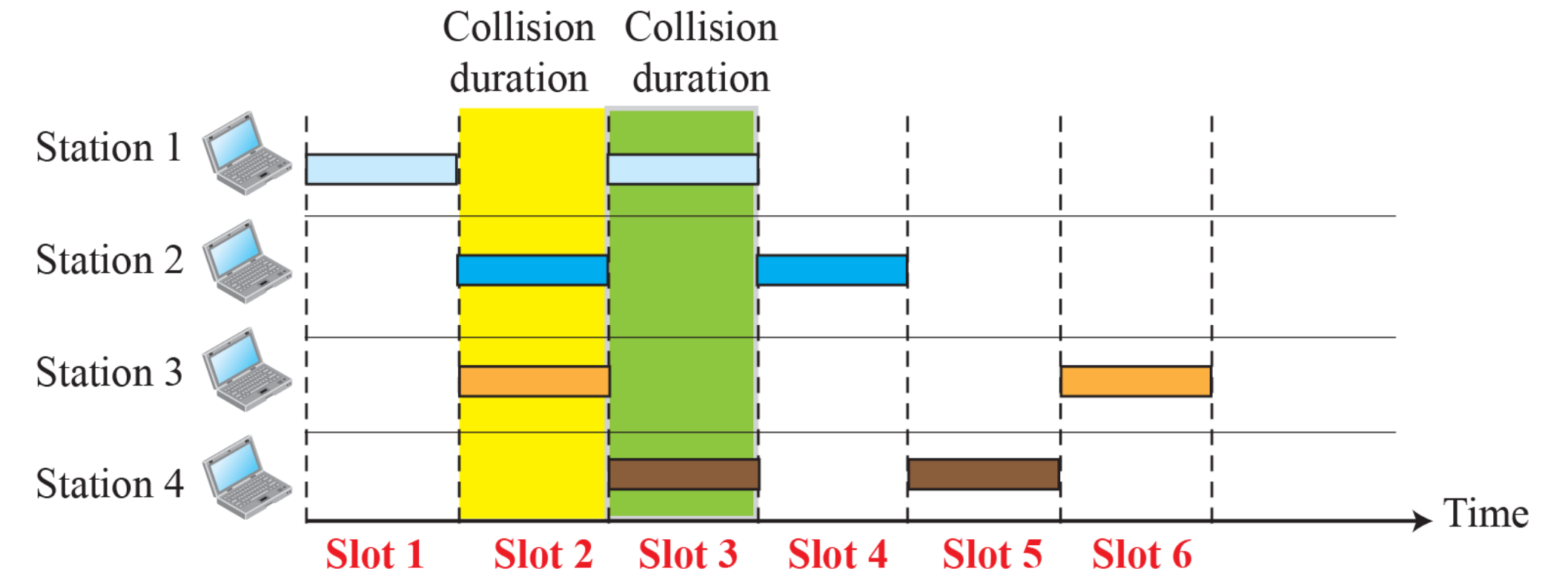
- 提高了纯ALOHA的效率。
- 时间被划分为每 $T_{fr}$ 秒一个的时隙，且站点被强制仅能在时隙开始时发送。

# Slotted ALOHA Frame Collisions



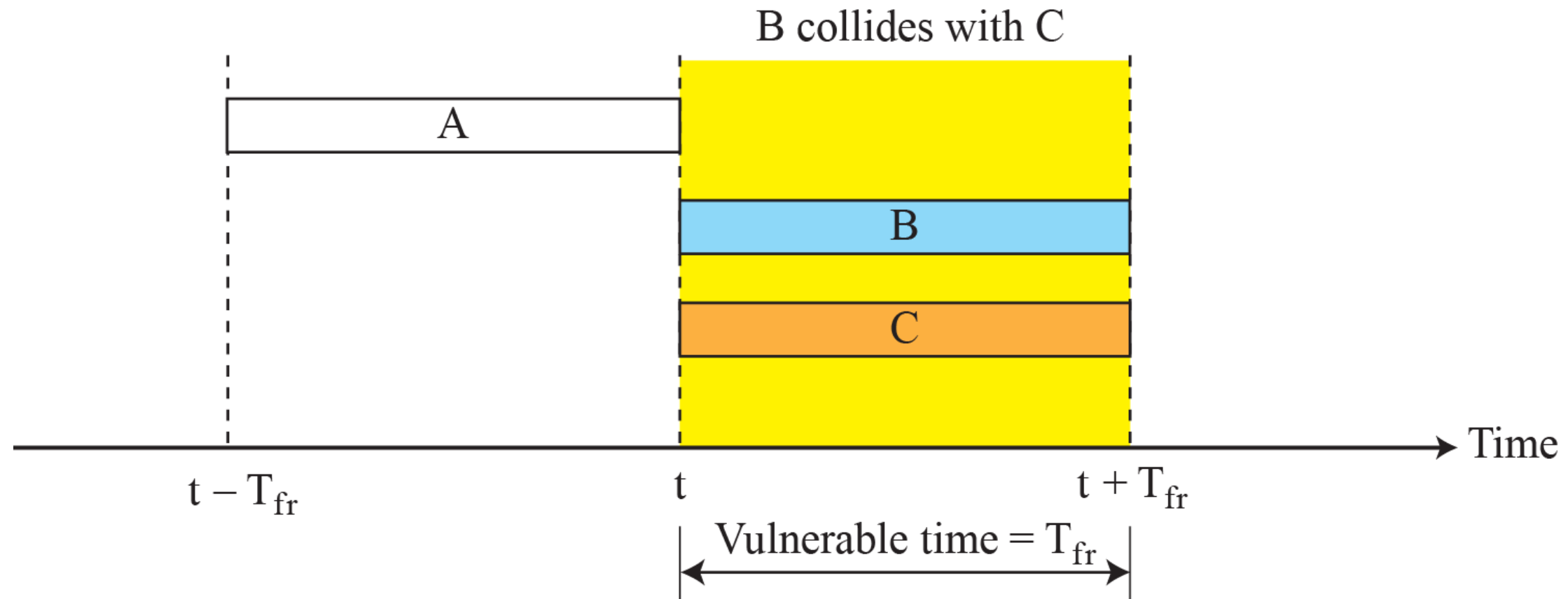
- There is still the possibility of collision if two stations try to send at the beginning of the same time slot.

# 时隙ALOHA帧冲突

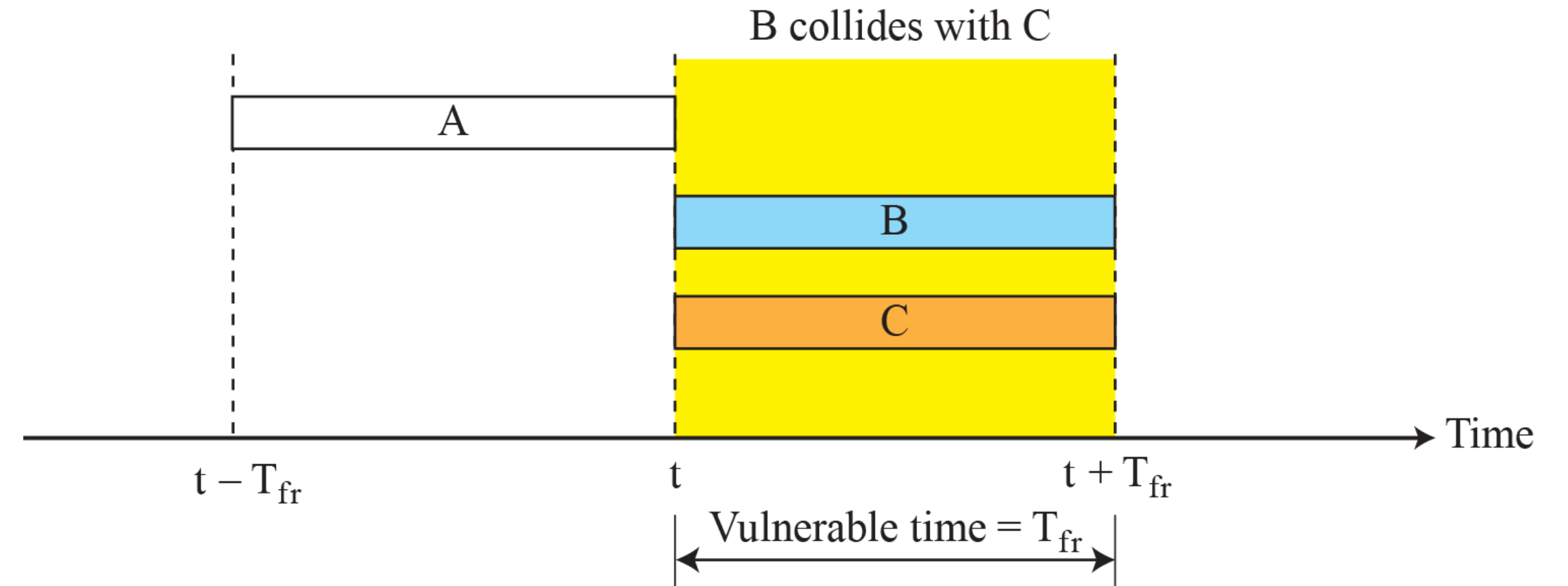


- 如果两个站点尝试在同一个时隙的开始时刻发送，仍然可能发生冲突。

# Slotted ALOHA Vulnerable Time



# 时隙ALOHA易受攻击时间



# 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.

# 时隙ALOHA吞吐量

- 时隙ALOHA的**吞吐量**为 $S = G \times e^{-G}$
- 最大吞吐量 $S_{\max} = 0.368$  当 $G = 1$ 
  - 如果在一个帧传输时间内生成了一个帧，那么这些帧中有36.8%能够成功到达目的地。
- $G = 1$  产生最大吞吐量，是因为**易受冲突影响的时间**等于**帧传输时间**。因此，如果一个站点在此易受冲突影响的时间内仅生成一个帧（且在此期间没有其他站点生成帧），该帧将成功到达目的地。

## 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.

## 时隙 ALOHA – 示例

- 一个时隙 ALOHA 网络在速率为 200 kbps 的共享信道上传输 200 比特的帧。如果整个系统（所有站点合计）每秒产生 1000 个帧，吞吐量是多少？请解释你的结果。

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

# 时隙ALOHA – 示例

- 一个时隙ALOHA网络在200 kbps的共享信道上传输200比特的帧。如果系统（所有站点合计）每秒产生1000个帧，吞吐量是多少？请解释你的结果。
- **答案:**
  - $T_{fr} = 200 \text{ 比特} / 200 \text{ kbps} = 1 \text{ 毫秒}$
  - 1000 每秒帧数  $\rightarrow$  1 每毫秒一帧（每帧传输时间发送一帧）  $\rightarrow G = 1$
  - $S = G \times e^{-G} = 0.368$  (36.8%)  $\rightarrow$  最大吞吐量
  - 这意味着只有 **368 帧** ( $1000 \times 0.368$ ) 可能会从 1000 帧中幸存下来。

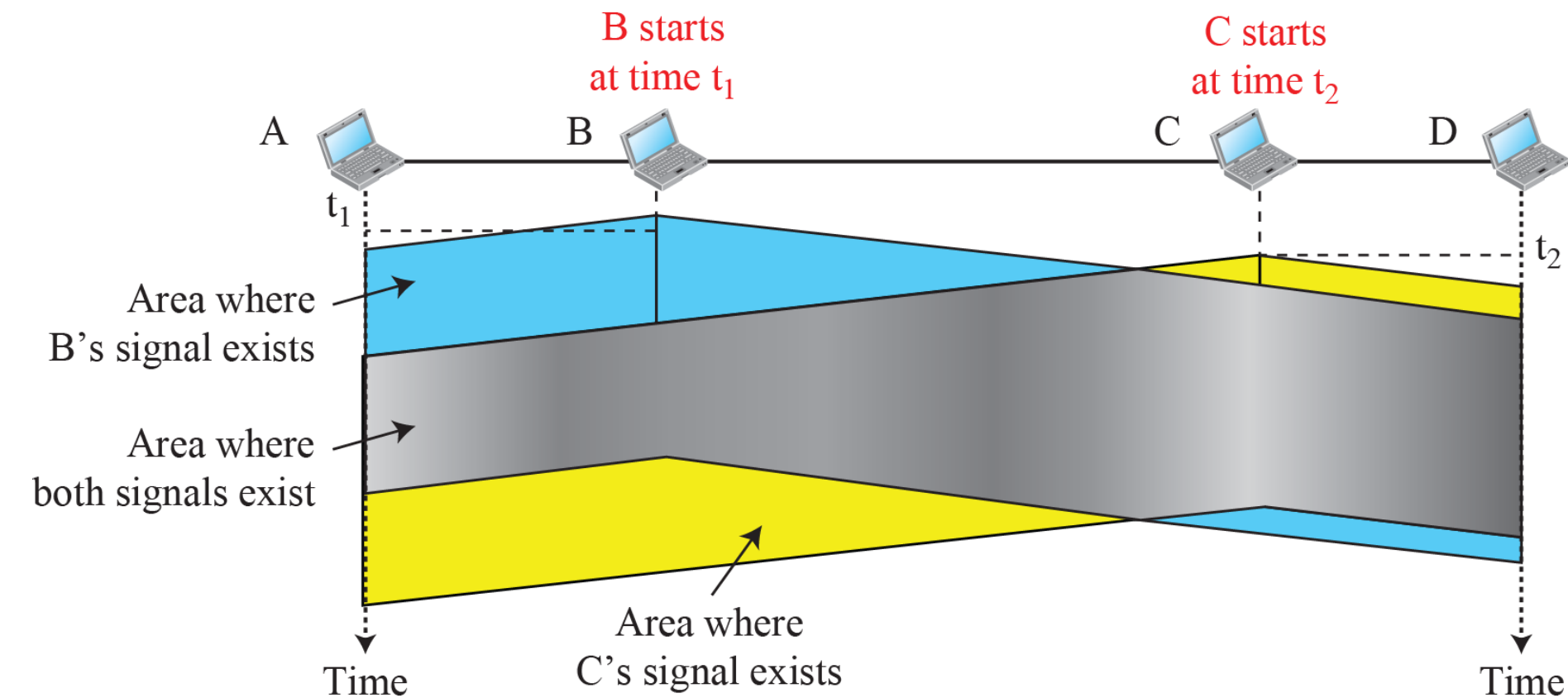
# CSMA

- **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

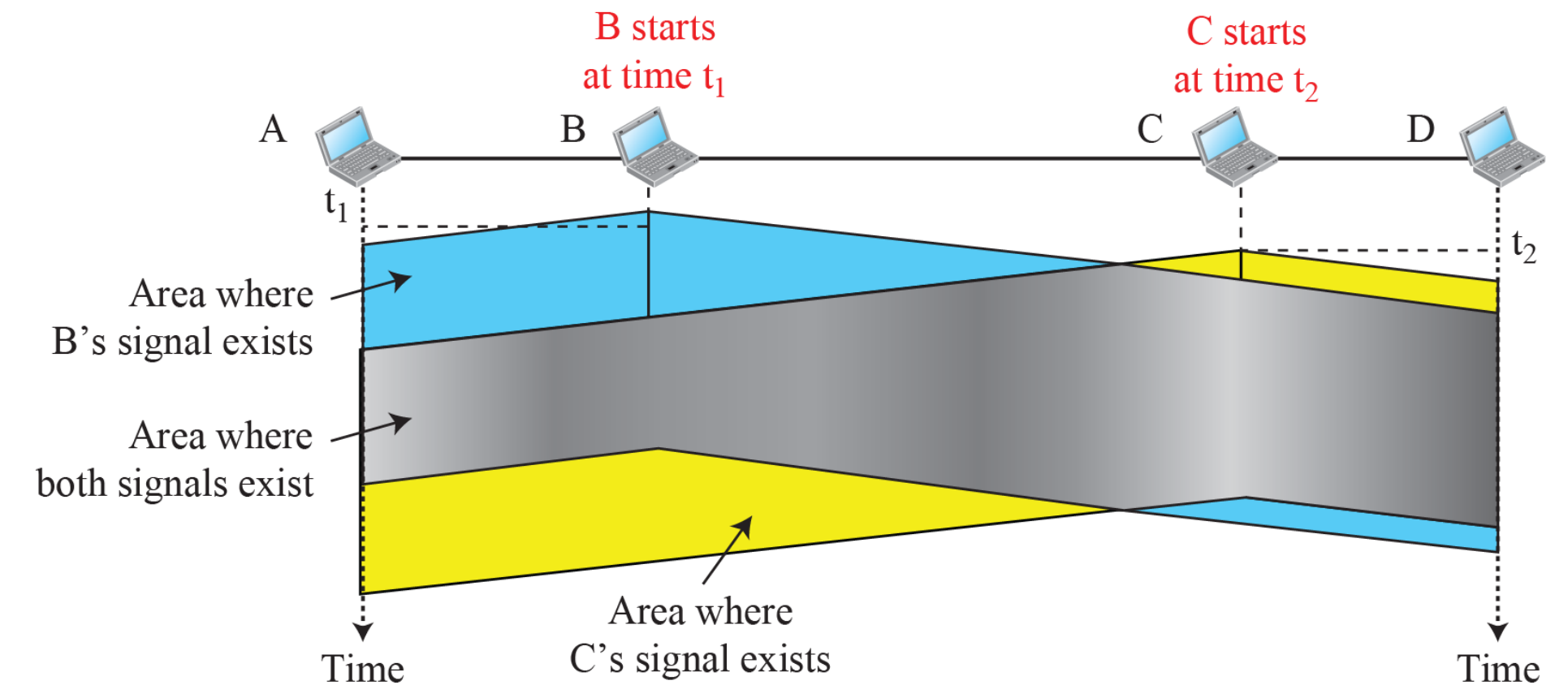
- **载波侦听多路访问 (CSMA)**
- 旨在**尽量减少碰撞的可能性**，从而提高性能。
- 每个站点**在使用介质前先进行侦测 (先侦测后发送)**。
  - 降低发生碰撞的可能性

# CSMA Space/Time Model of a Collision



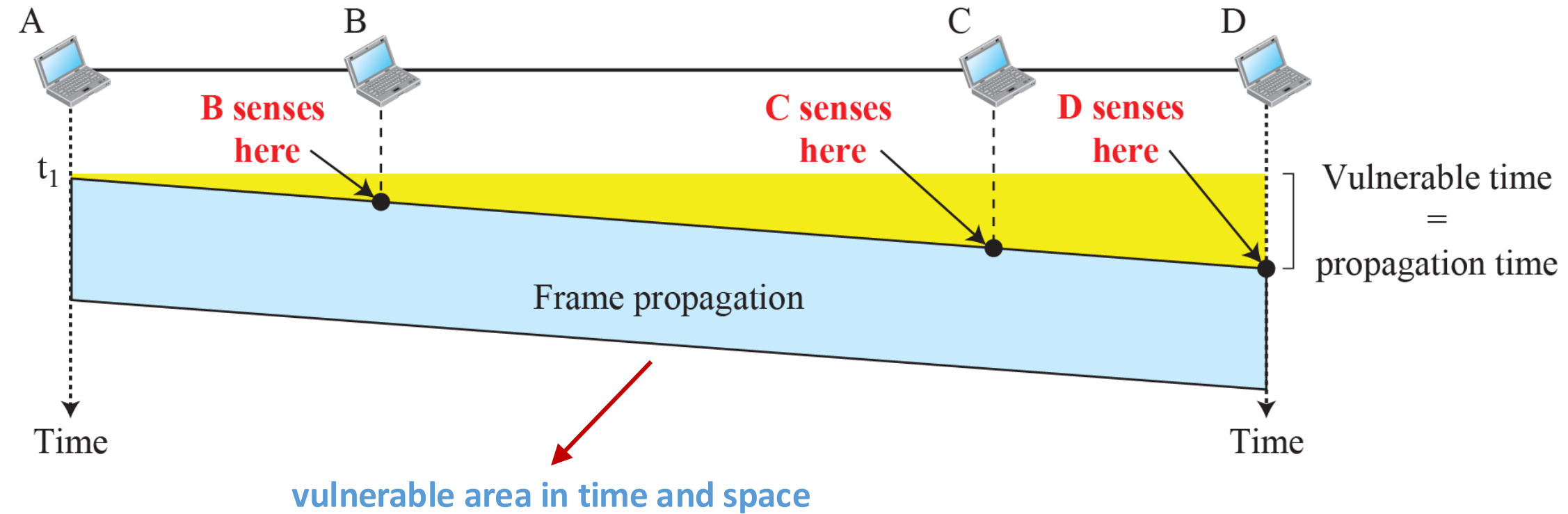
- The possibility of collision still exists! Because of the propagation delay (it takes time for the first bit to reach every station)

# 冲突的CSMA空间/时间模型



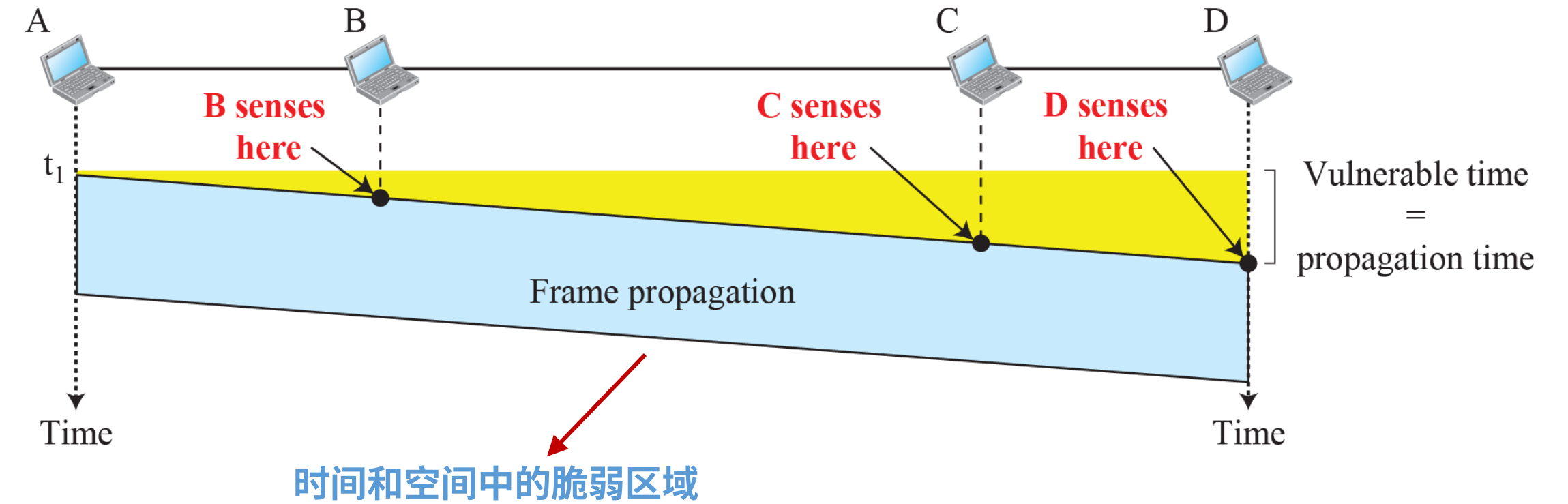
- 仍然存在发生冲突的可能性! 因为传播延迟 (第一个比特需要一定时间才能到达每个站点) 传播

# CSMA Vulnerable Time



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

# CSMA 脆弱时间



CSMA 的易受攻击时间与最大传播时间  $T_p$  相同。

# CSMA Persistence Methods

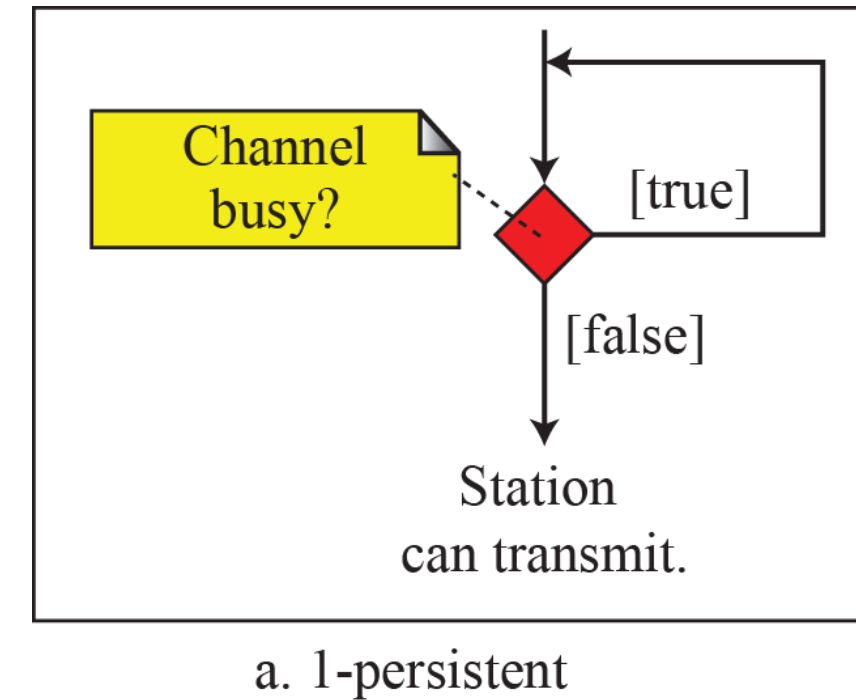
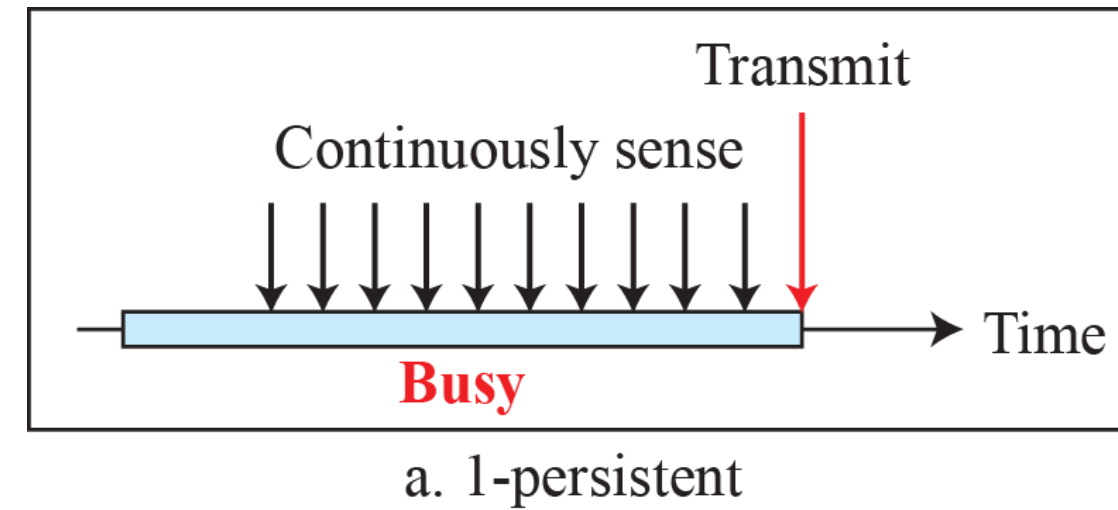
- What should a station do if the channel is **busy**?
- What should a station do if the channel is **idle**?
- Three Persistent methods are designed:
  - **1-persistent**
  - **Non-persistent**
  - **P-persistent**

# CSMA 坚持方法

- 如果信道为 **忙**，站点应该做什么？
- 如果信道为 **空闲**，站点应该做什么？
- 设计了三种坚持方法：
  - **1-坚持**
  - **非坚持**
  - **P-持续**

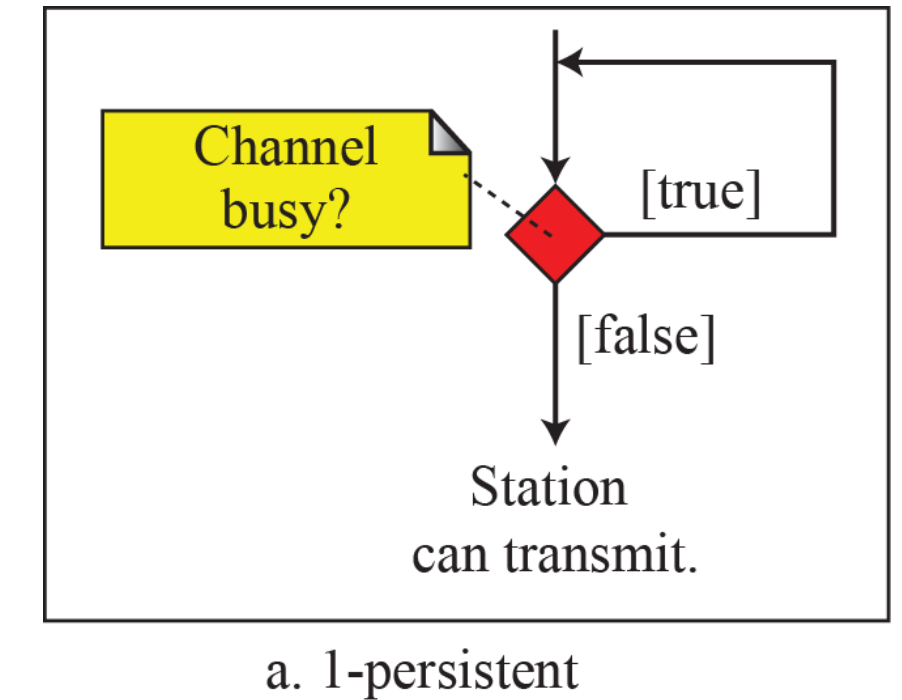
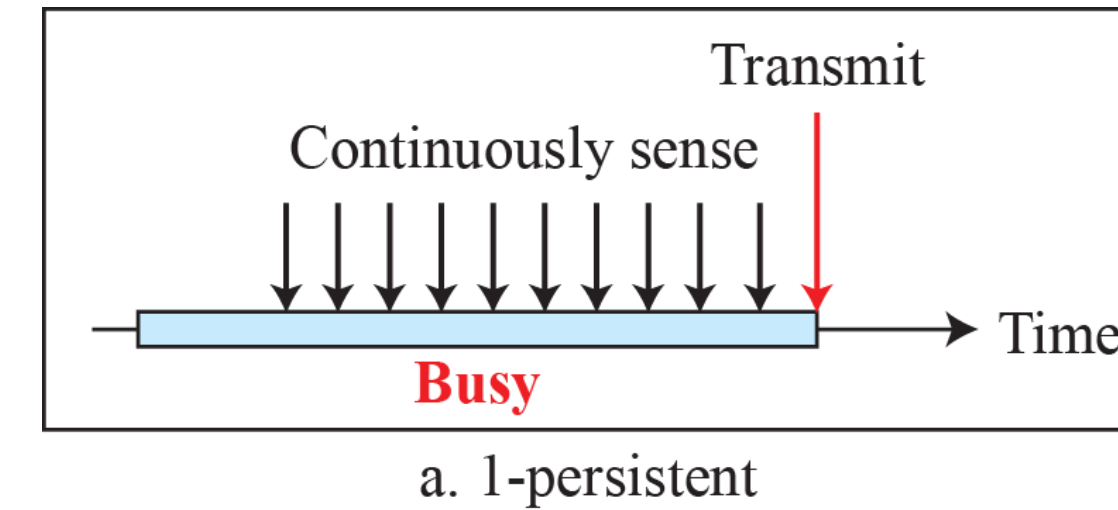
# CSMA 1-Persistent Method

- Used in **Ethernet**. Highest chance of collision.



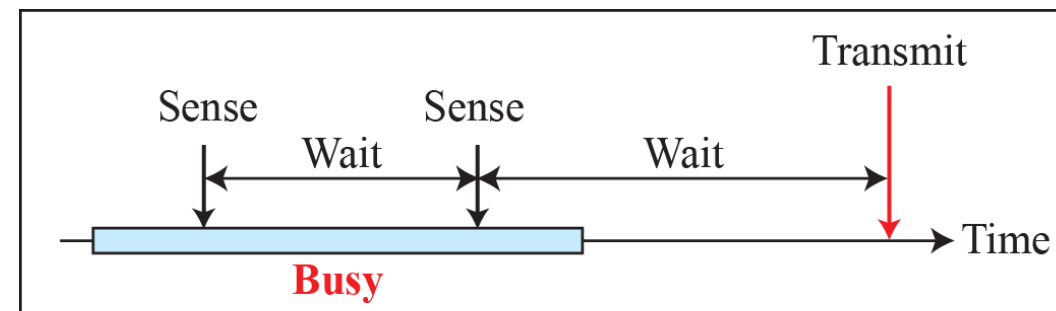
# CSMA 1-坚持方法

- 用于 **以太网**。碰撞概率最高。

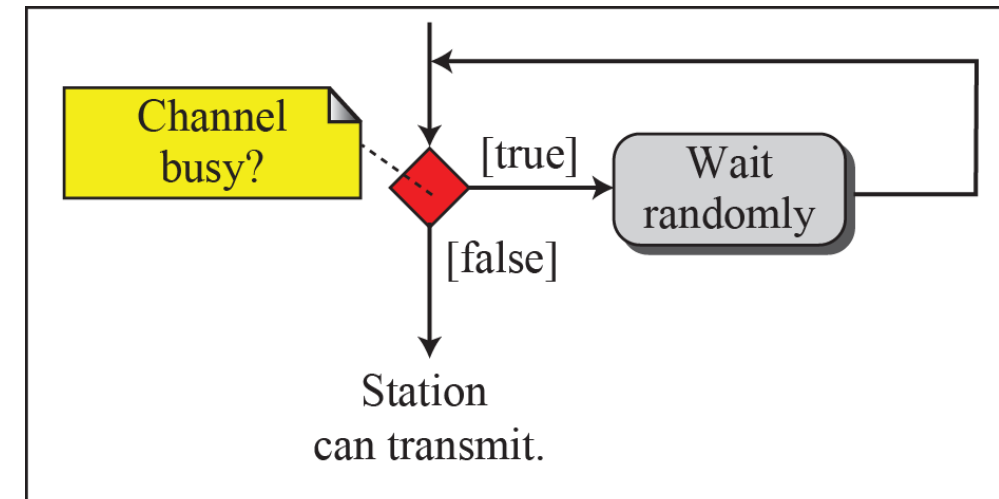


# CSMA Non-persistent Method

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



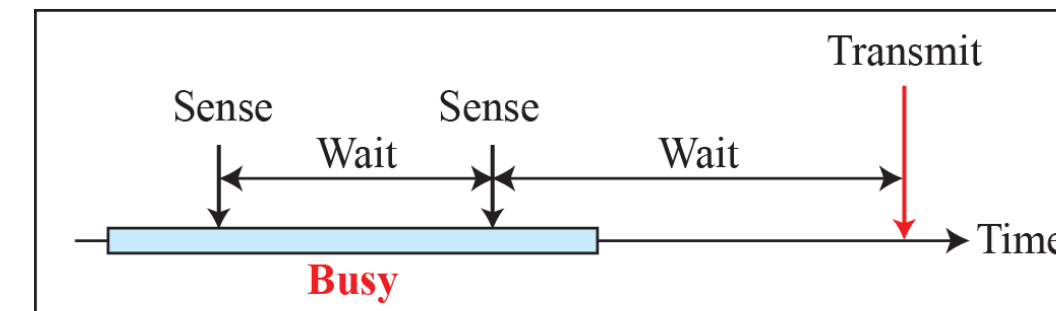
b. Nonpersistent



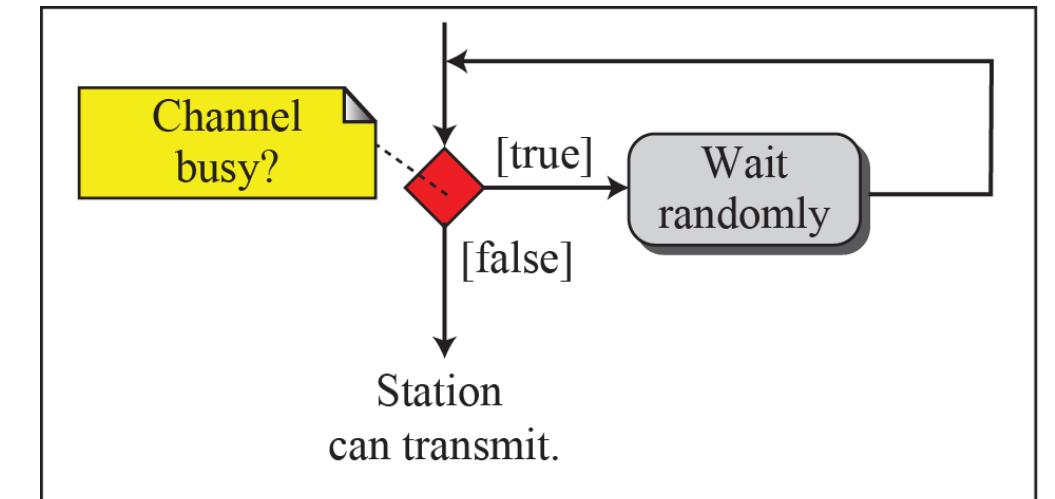
b. Nonpersistent

# CSMA 非-坚持方法

- 降低了发生冲突的可能性，但降低了效率（当可能有站点有待发送的帧时，信道仍保持空闲）。



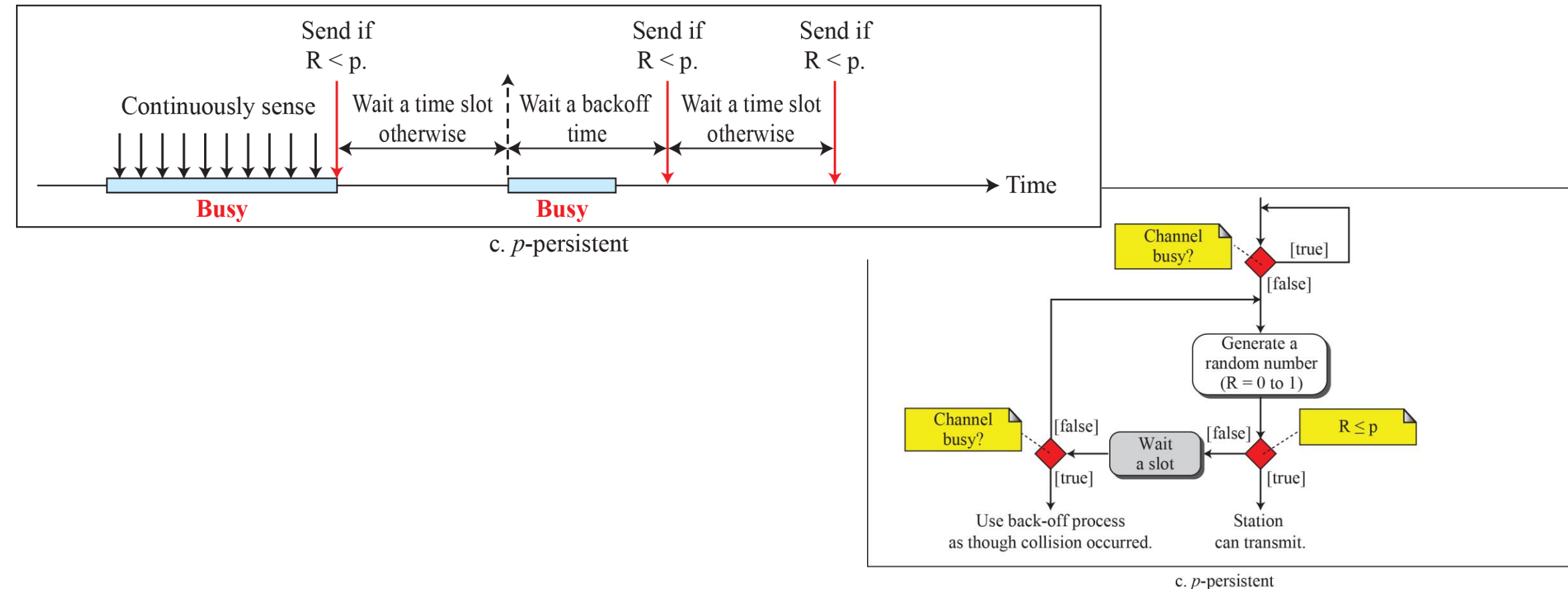
b. Nonpersistent



b. Nonpersistent

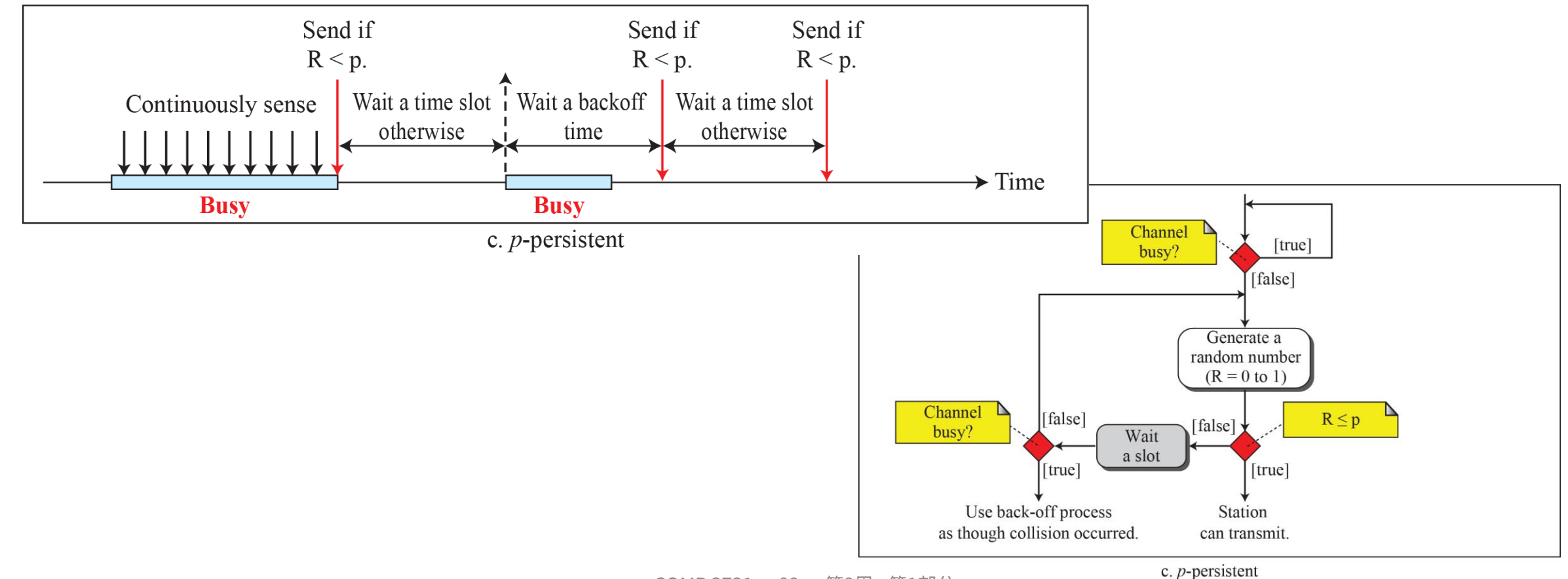
# CSMA P-persistent Method

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

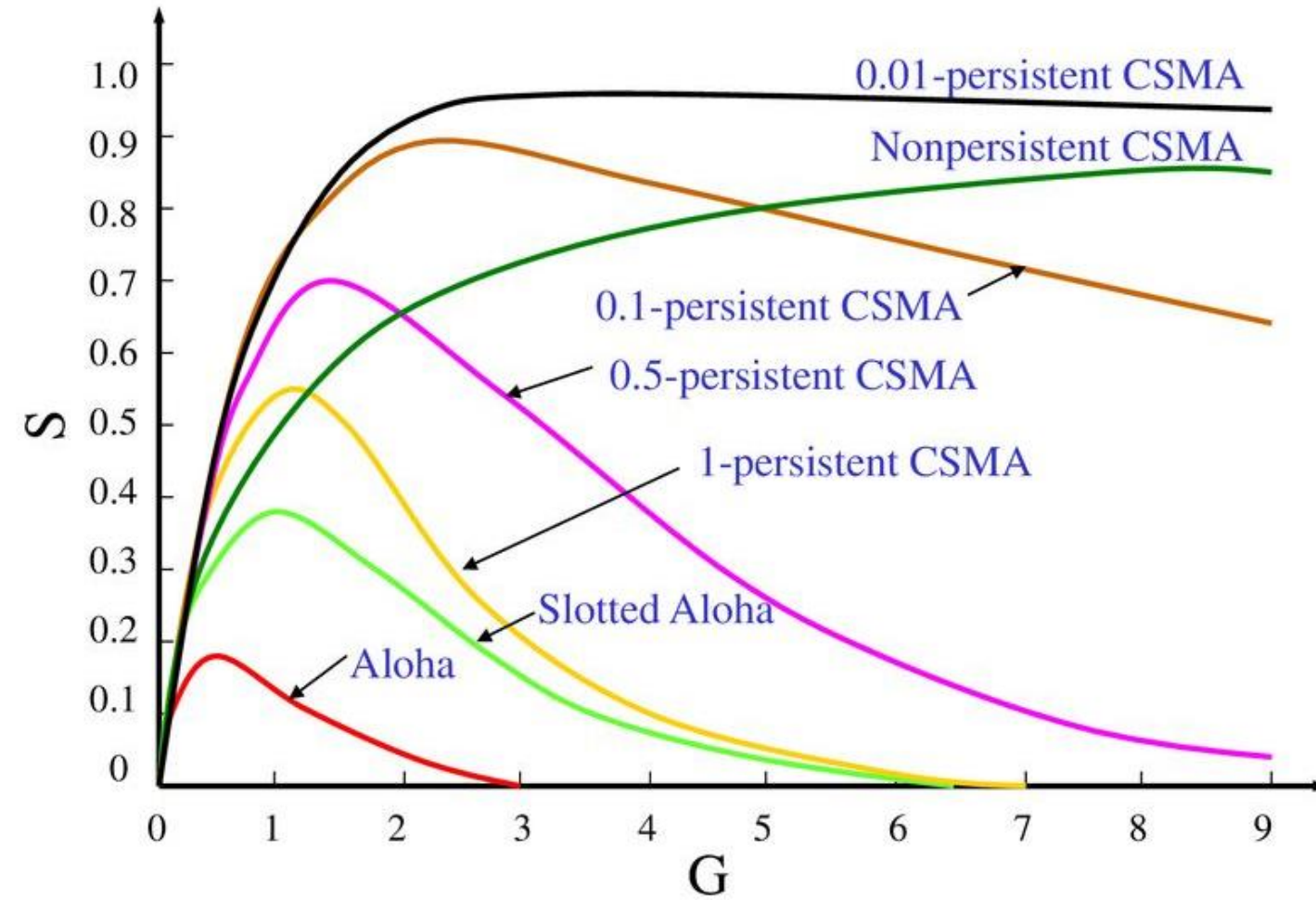


# CSMA P持续方法

- 时隙持续时间等于或大于最大传播时间。
- 降低了发生冲突的可能性，并提高了效率。

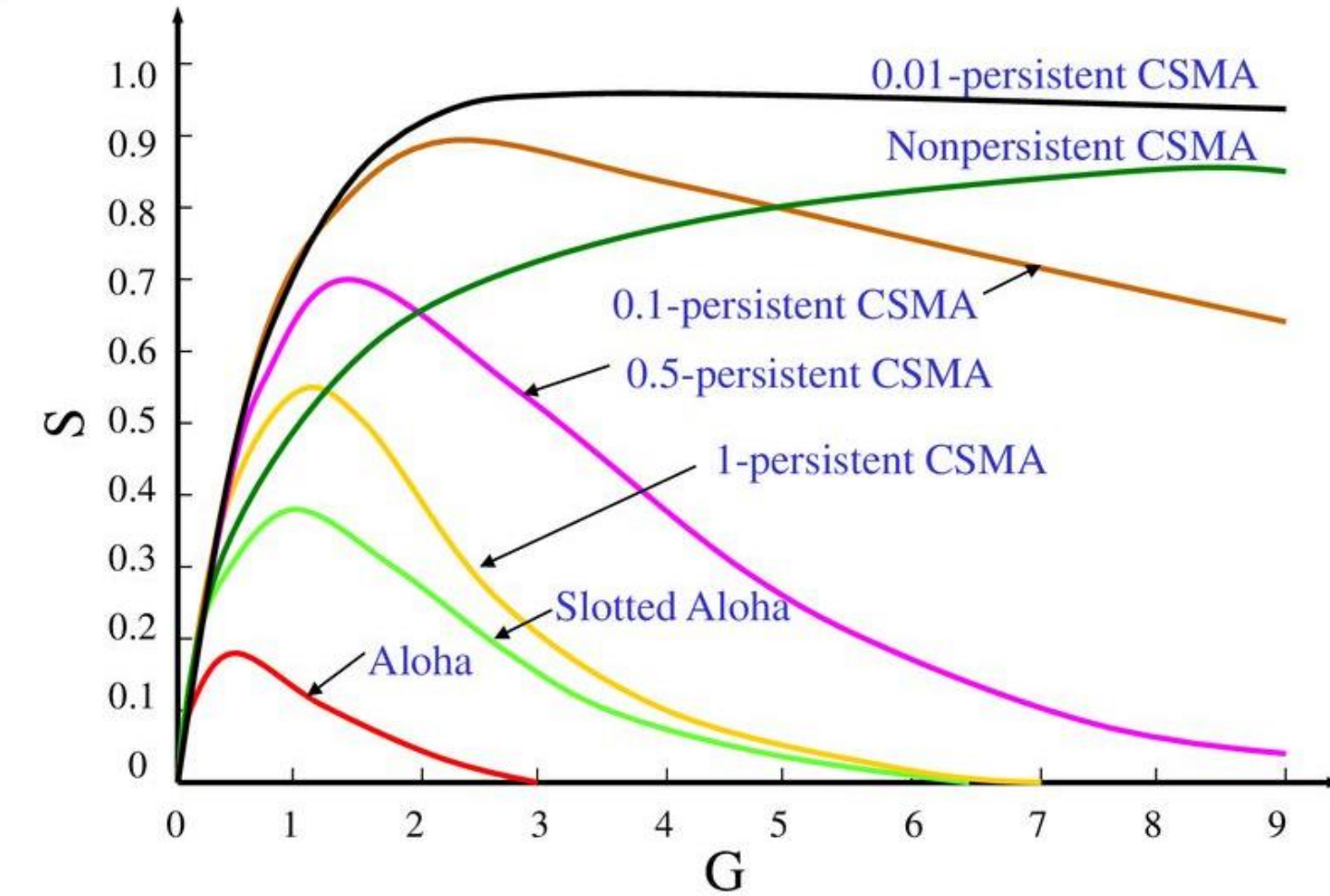


# Throughput



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# 吞吐量



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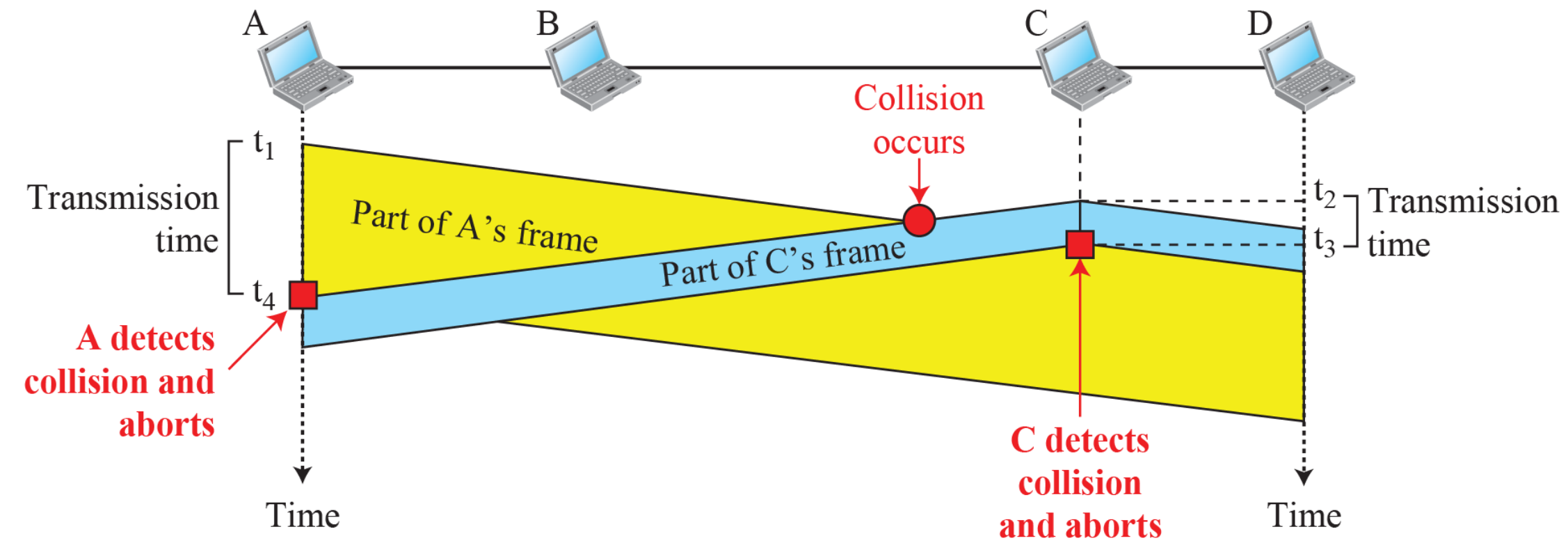
# CSMA/CD

- **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.

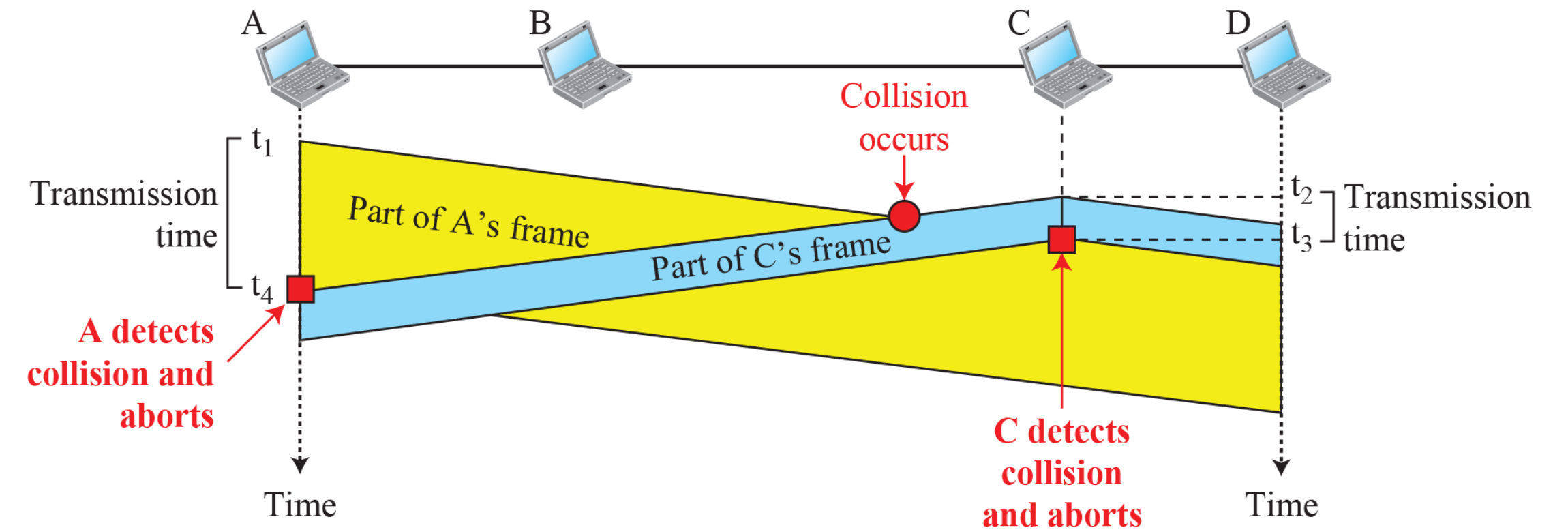
# CSMA/CD

- **带冲突检测的载波侦听多路访问 (CSMA/CD)** 对 CSMA 进行了扩展，以处理**冲突**。
- 一个站点在发送帧后会监控介质，以查看传输是否成功。
  - 如果**成功**：该站点任务完成。
  - 如果发生**冲突**：重新发送该帧。
- 传统的**以太网局域网协议**使用了 CSMA/CD。
  - 基于总线和集线器的星型拓扑结构（当多个节点同时传输时会发生帧冲突）。
  - 适用于 **覆盖较小地理区域的有线广播局域网**。

# CSMA/CD Collision and Abortion



# CSMA/CD 冲突与中止



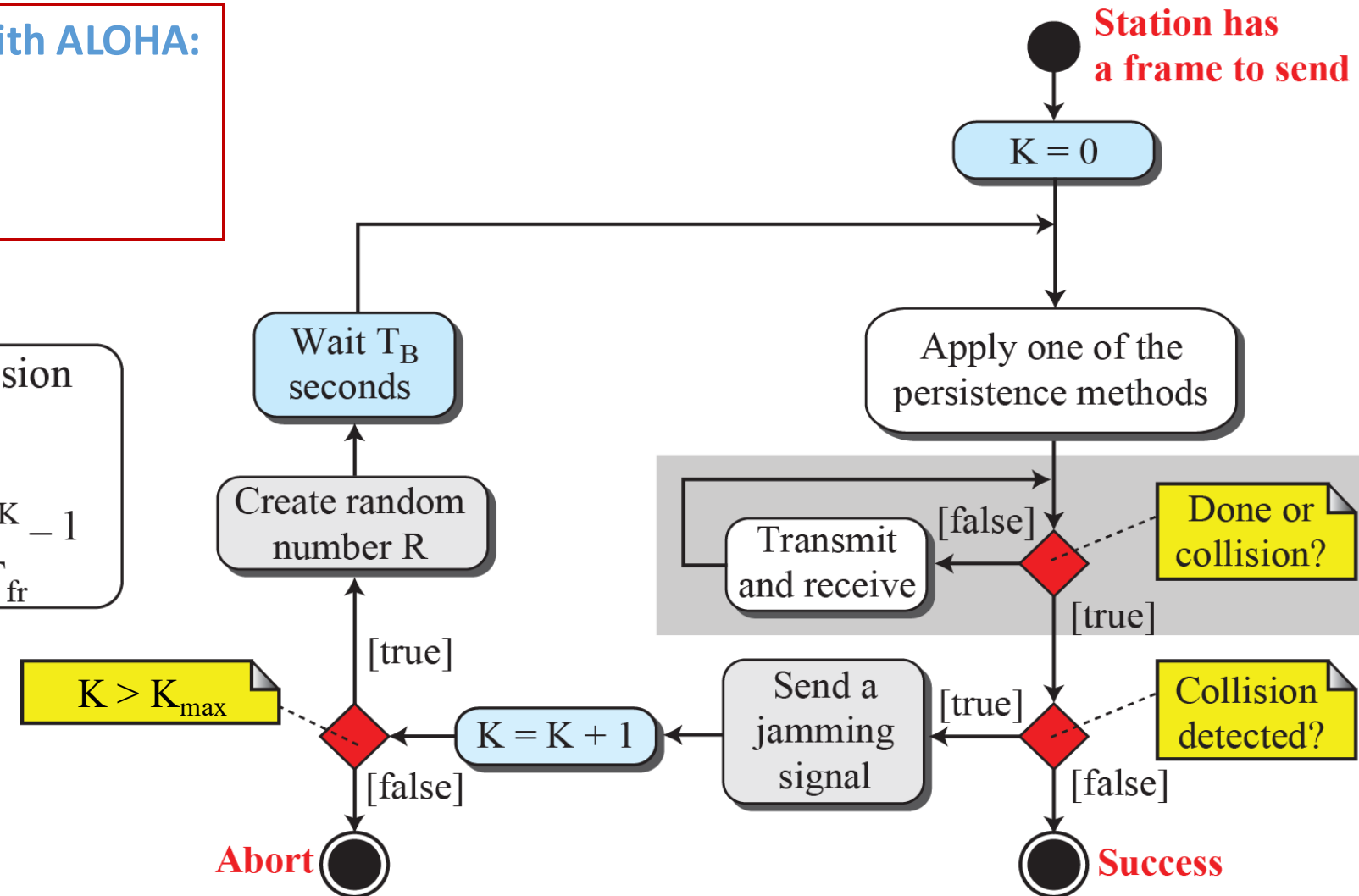
# CSMA/CD Flow Diagram

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) =  $R \times T_{fr}$



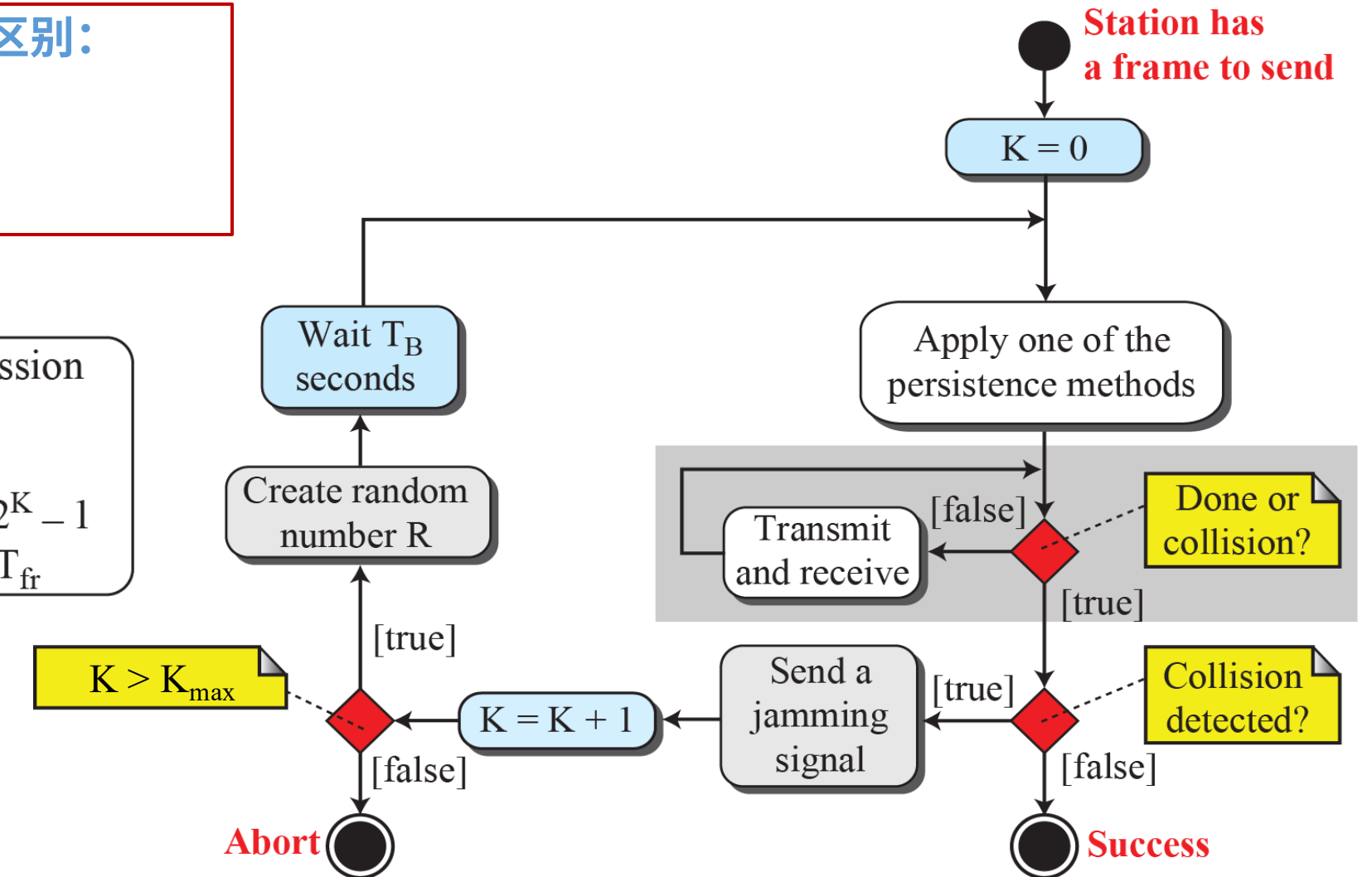
# CSMA/CD 流程图

与 ALOHA 的三个主要区别:

1. 持续过程
2. 帧传输
3. 干扰信号

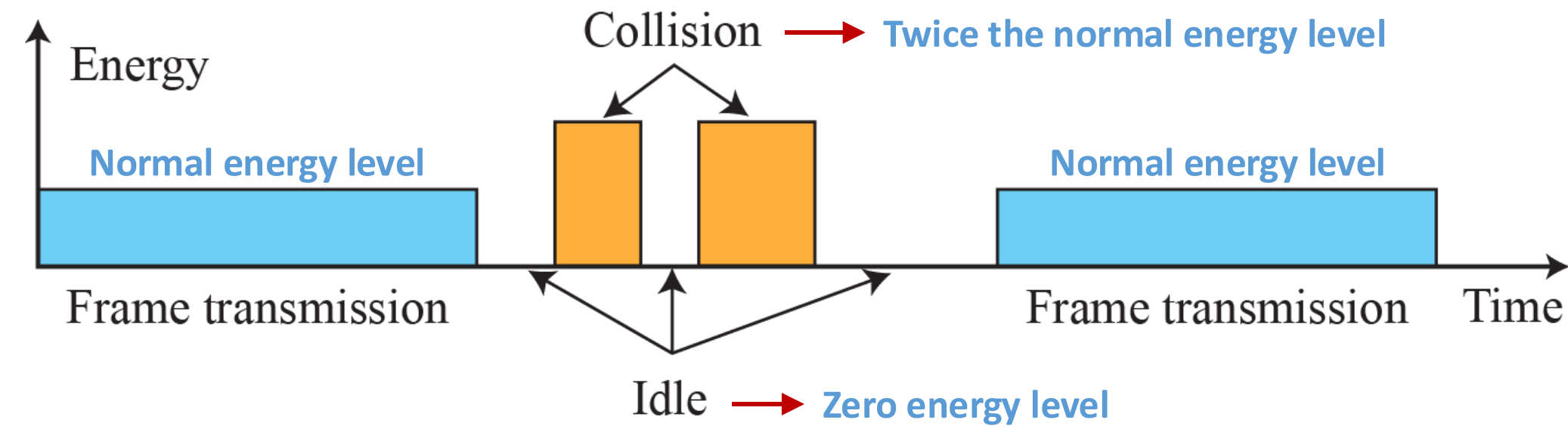
## Legend

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



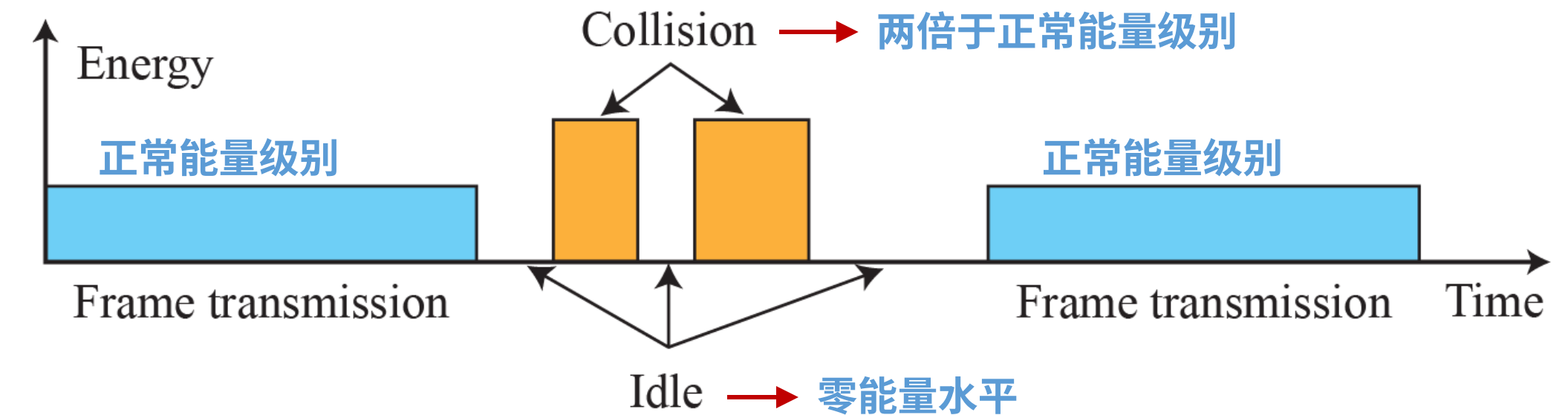
# CSMA/CD Energy Level during Transmission, Idleness, or Collision

- 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.



# 传输期间的CSMA/CD能量级别，空闲或冲突

- 一个有待发送帧或正在发送帧的站点需要监控信道的能量级别，以确定信道处于空闲、忙碌还是冲突状态。



# 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).

# 关于CSMA/CD的更多内容

- **最小帧大小**

- $T_{fr}$  必须至少是最大传播时间  $T_p$  的两倍。
- 在发送帧的最后一个比特之前，发送站必须检测到任何碰撞并中止传输
- **最坏情况**：如果发生碰撞的两个站点之间的距离为 最大距离，则第一个站点的信号需要时间  $T_p$  到达第二个站点，而碰撞的影响又需要另一个时间  $T_p$  才能返回第一个站点。因此，要求第一个站点在经过  $2 \times T_p$  后仍处于发送状态

- **吞吐量<sup>p</sup>**

- 高于纯ALOHA或分槽ALOHA。
- 最大吞吐量出现在不同的 $G$ 值处（超出本课程范围）。

## 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  $25.6\ \mu\text{s}$ , what is the minimum size of the frame?

## CSMA/CD – 示例

- 使用 CSMA/CD 的网络带宽为 10 Mbps。如果最大传播时间（包括设备中的延迟，且忽略发送阻塞信号所需的时间）为  $25.6\ \mu\text{s}$ ，那么帧的最小尺寸是多少？

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

## CSMA/CD – 示例

- 采用 CSMA/CD 的网络带宽为 10 Mbps。如果最大传播时间（包括设备中的延迟，且忽略发送阻塞信号所需的时间）为  $25.6\ \mu\text{s}$ ，则帧的最小尺寸是多少？
- **答案:**
  - **帧的最小传输时间**  $= T_{fr} = 2 \times T_p = 2 \times 25.6 = 51.2\ \mu\text{s}$
  - 在最坏情况下，一个站点需要持续发送  $51.2\ \mu\text{s}$  才能检测到冲突。
  - **帧的最小尺寸**  $= 10\ \text{Mbps} \times 51.2\ \mu\text{s} = 512\ \text{比特} = 64\ \text{字节}$
  - 这实际上是标准以太网帧的最小尺寸。

# 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

- **载波侦听多路访问/冲突避免 (CSMA/CA)**
- 为无线网络而发明。
- 通过以下方式避免冲突：
  - **IFS** (帧间间隔)
  - **CW** (竞争窗口)
  - **NAV** (网络分配向量)：一种用于避免冲突的**定时器** → 关键机制
  - **RTS/CTS** 作为用于**握手**的控制帧。
  - **确认应答** (正向确认和超时机制，以确保接收方已接收到帧)

# CSMA/CA IFS

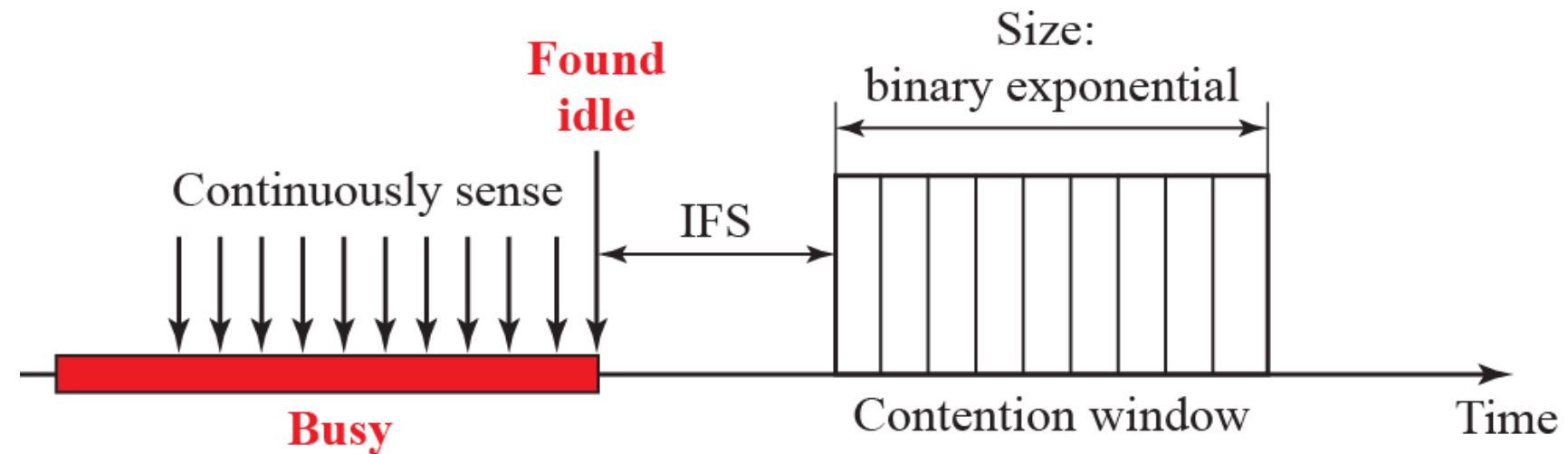
- **Collisions are avoided** by deferring transmission even if the channel is found idle.
  - The station waits for a period of time called the **interframe space** or **IFS**.
  - The **IFS** time allows the front of the transmitted signal by the distant station to reach this station.
  - The **IFS** 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 IFS

- **通过即使信道空闲也延迟传输的方式来避免冲突**，从而避免冲突。
  - 站点会等待一段时间，该时间称为 **帧间间隔** 或 **IFS**。
  - 该 **IFS** 时间允许远处站点发送的信号前沿传播到本站点。
  - 还可以使用 **IFS** 变量来为不同站点或帧类型分配优先级。
    - 例如，被分配较短 **IFS** 的站点具有更高优先级。

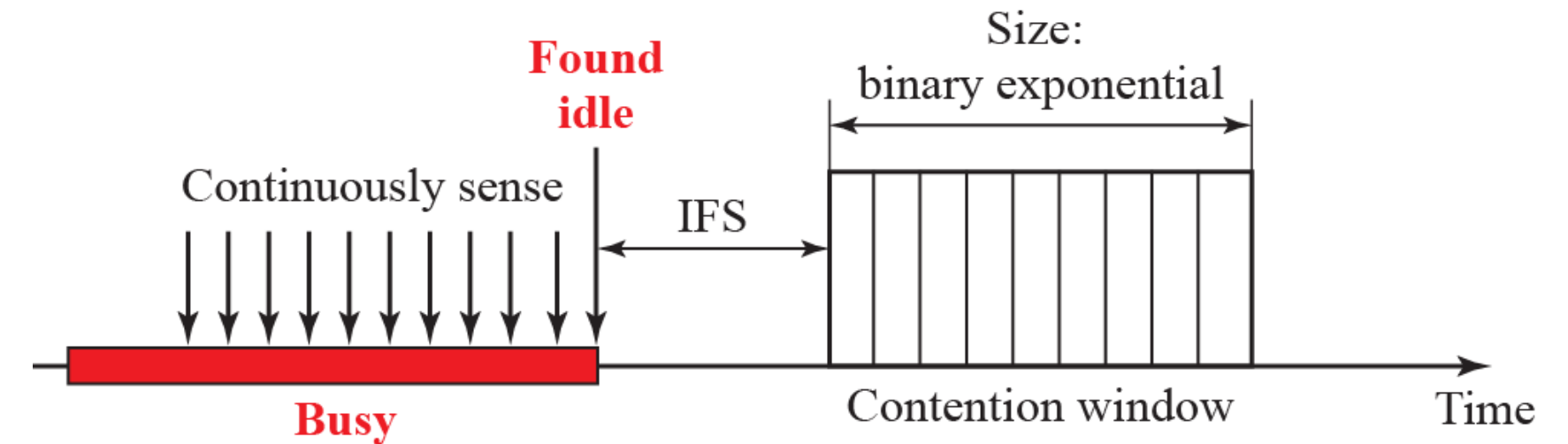
# CSMA/CA Contention Window

- 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 竞争窗口

- 等待 **IFS** 时间后，如果信道仍然空闲，站点可以发送，但仍需等待等于 **竞争窗口** 的时间。
- 该**竞争窗口**是一段划分为时隙的时间。准备发送的站点会选择一个随机数量的时隙作为其等待时间。
- 窗口中的槽数根据 **二进制指数退避策略** 进行变化。

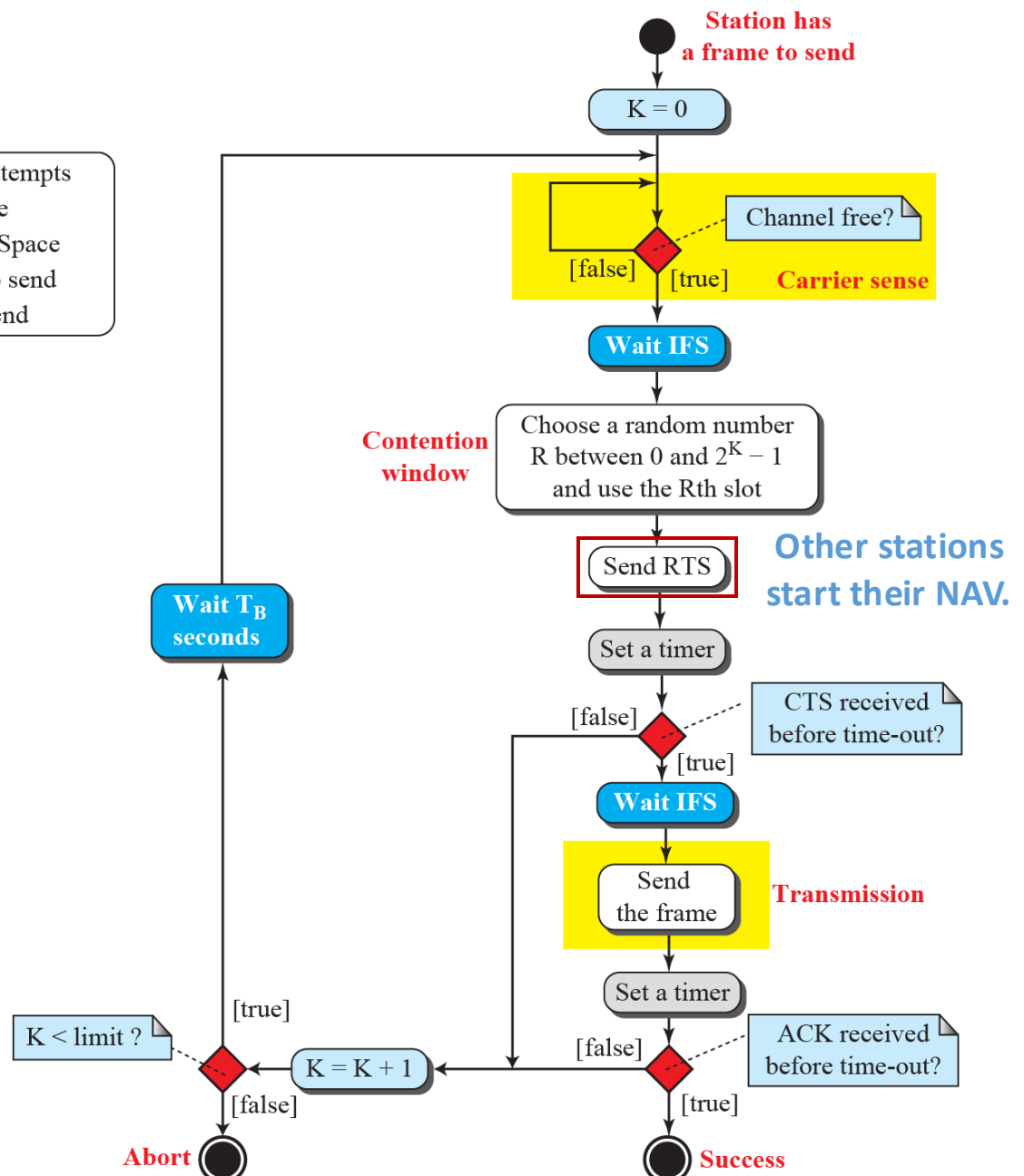


# CSMA/CA Flow Diagram

- 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.

**Legend**

K: Number of attempts  
T<sub>B</sub>: Backoff time  
IFS: Interframe Space  
RTS: Request to send  
CTS: Clear to send

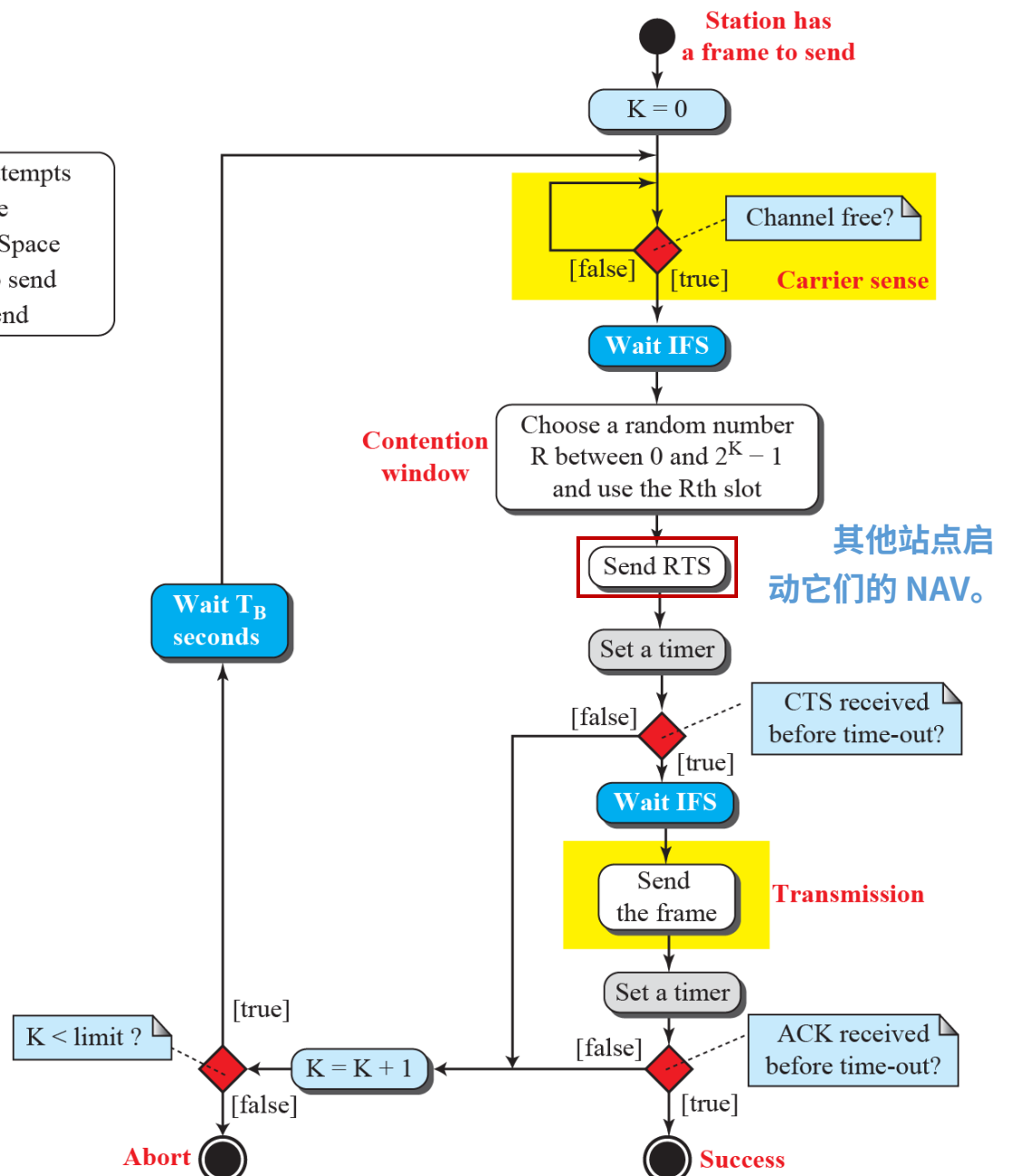


# CSMA/CA 流程图

- RTS 包括其需要占用信道的时间长度。
- 每个站在感知物理介质以检查其是否空闲之前，首先会检查其 NAV 是否已过期。

**Legend**

K: Number of attempts  
T<sub>B</sub>: Backoff time  
IFS: Interframe Space  
RTS: Request to send  
CTS: Clear to send



# Summary

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

# 摘要

- 数据链路层的MAC子层对共享链路的访问控制。
- 我们讨论过的MAC协议
  - 随机访问
  - 信道化

# 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.

# 参考文献

- [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)

# 阅读

- 教材第3章，第3.3节。
- 教材第3章，第3.6节（练习测试）