

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?**



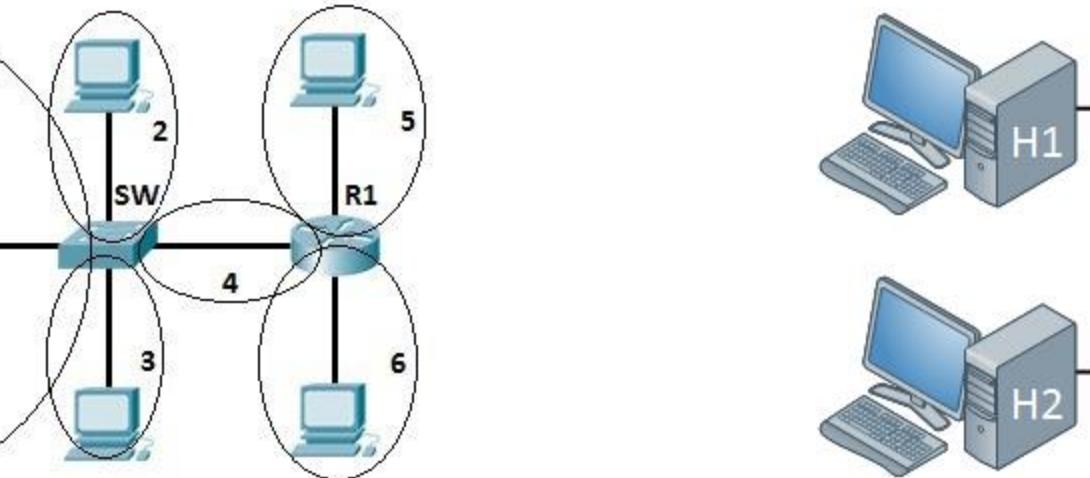
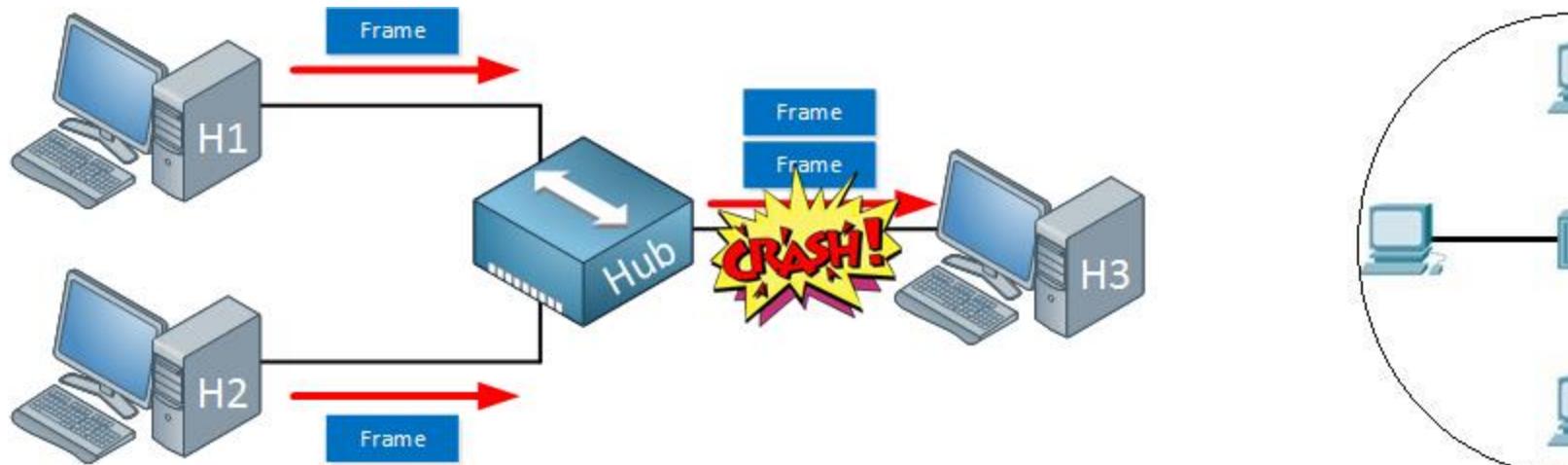
简介 – 类比

- 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?**



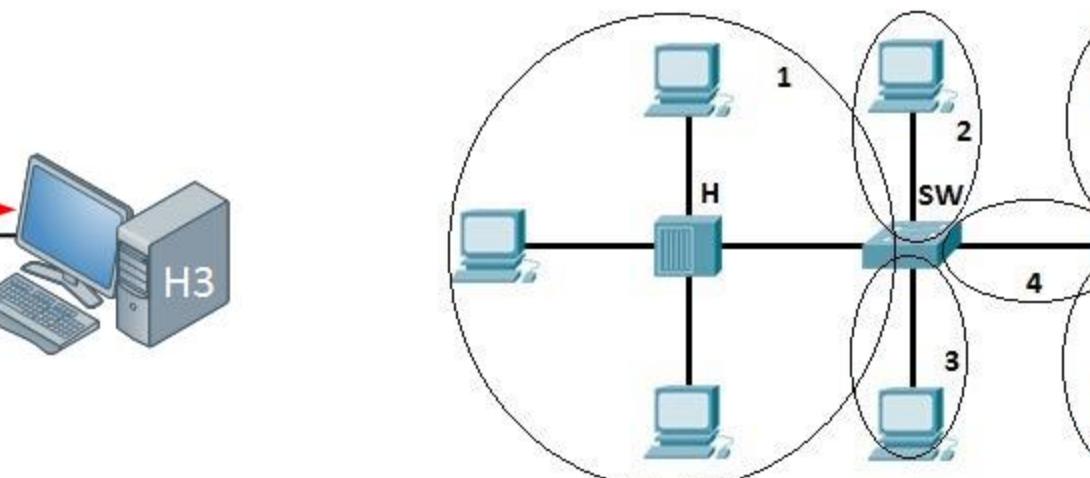
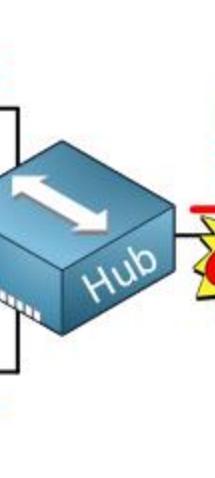
Collision Domain

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



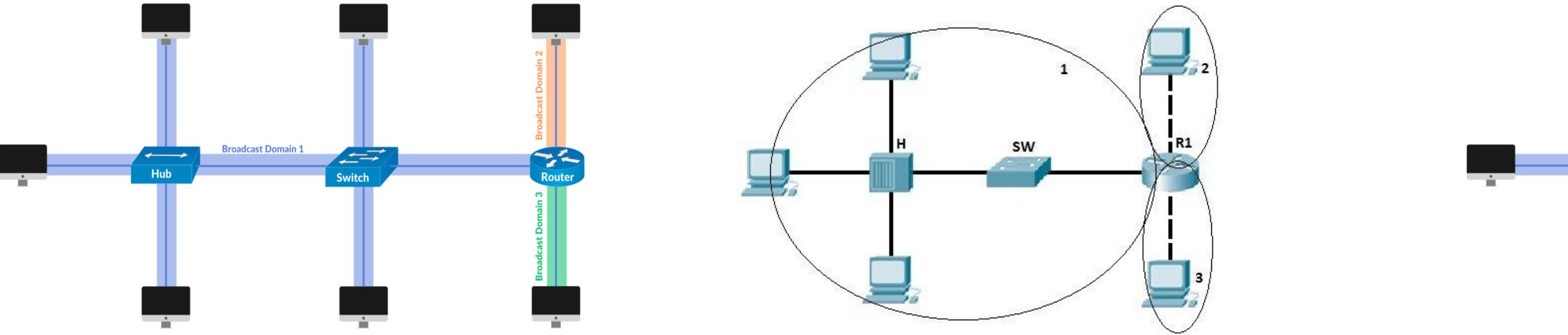
冲突域

- 一个 **冲突域** 是网络中可能发生数据包 **冲突** 的区域。



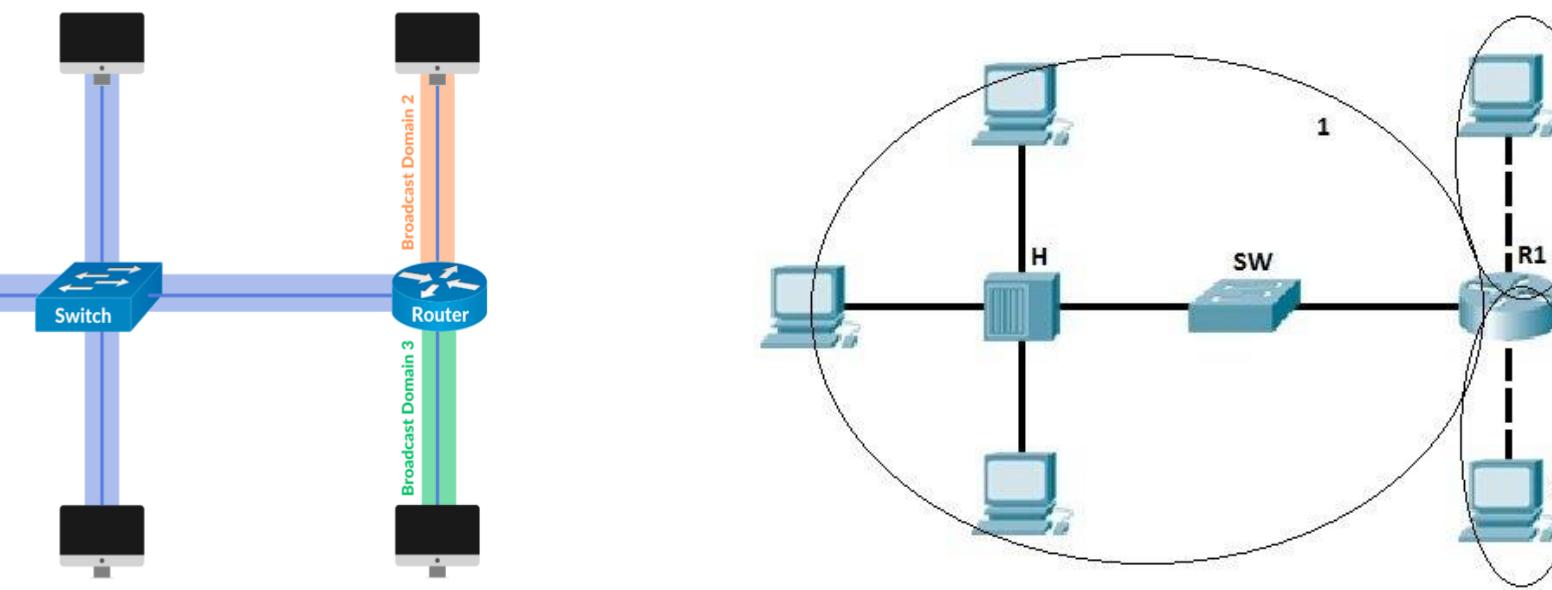
Broadcast Domain

- 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.

• 一个 **中心**

设备

- 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

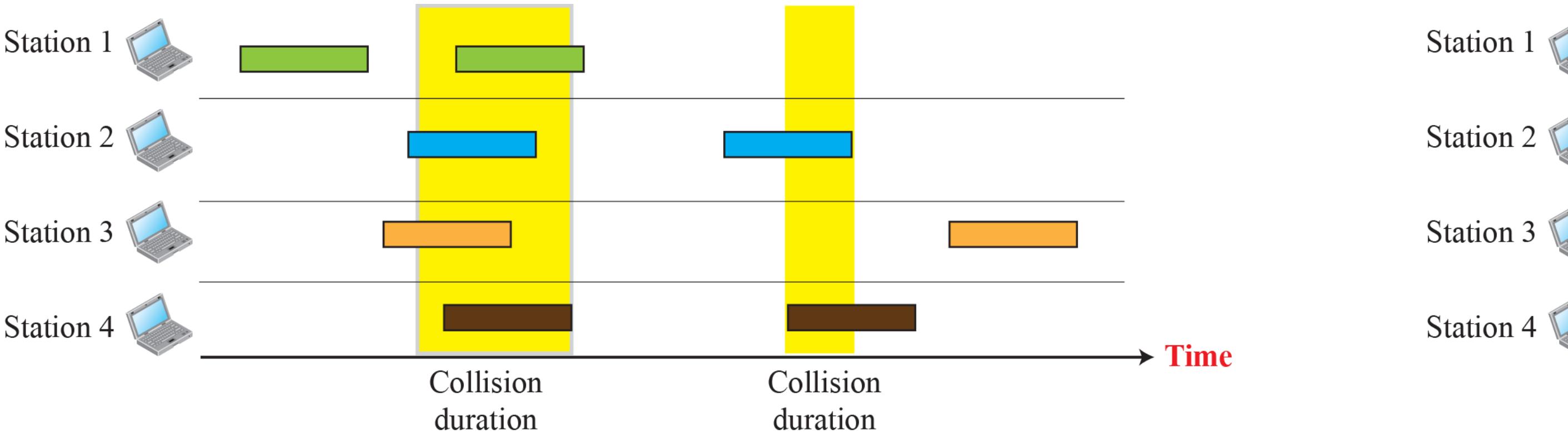
Pure ALOHA

- 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.

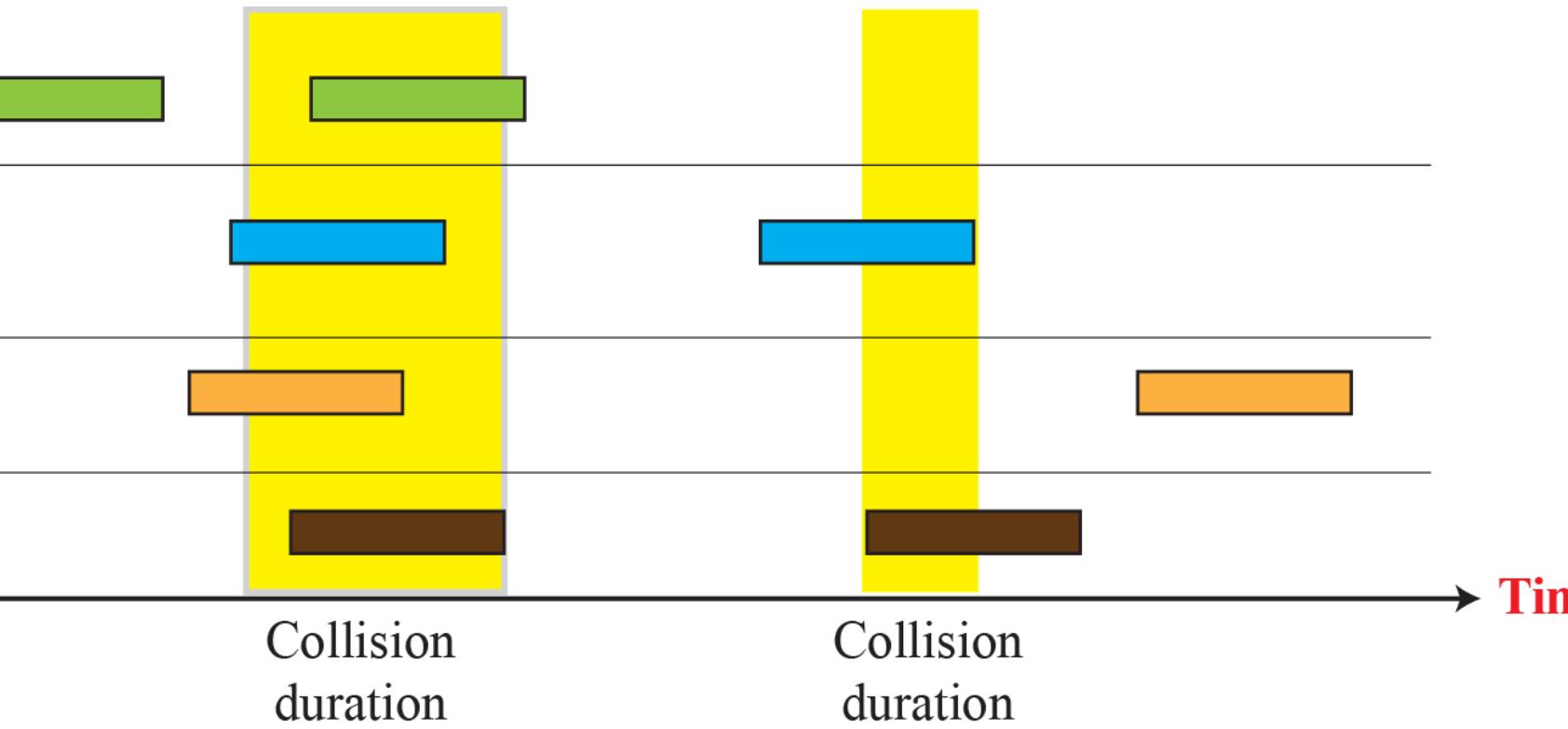
纯ALOHA

- 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**。

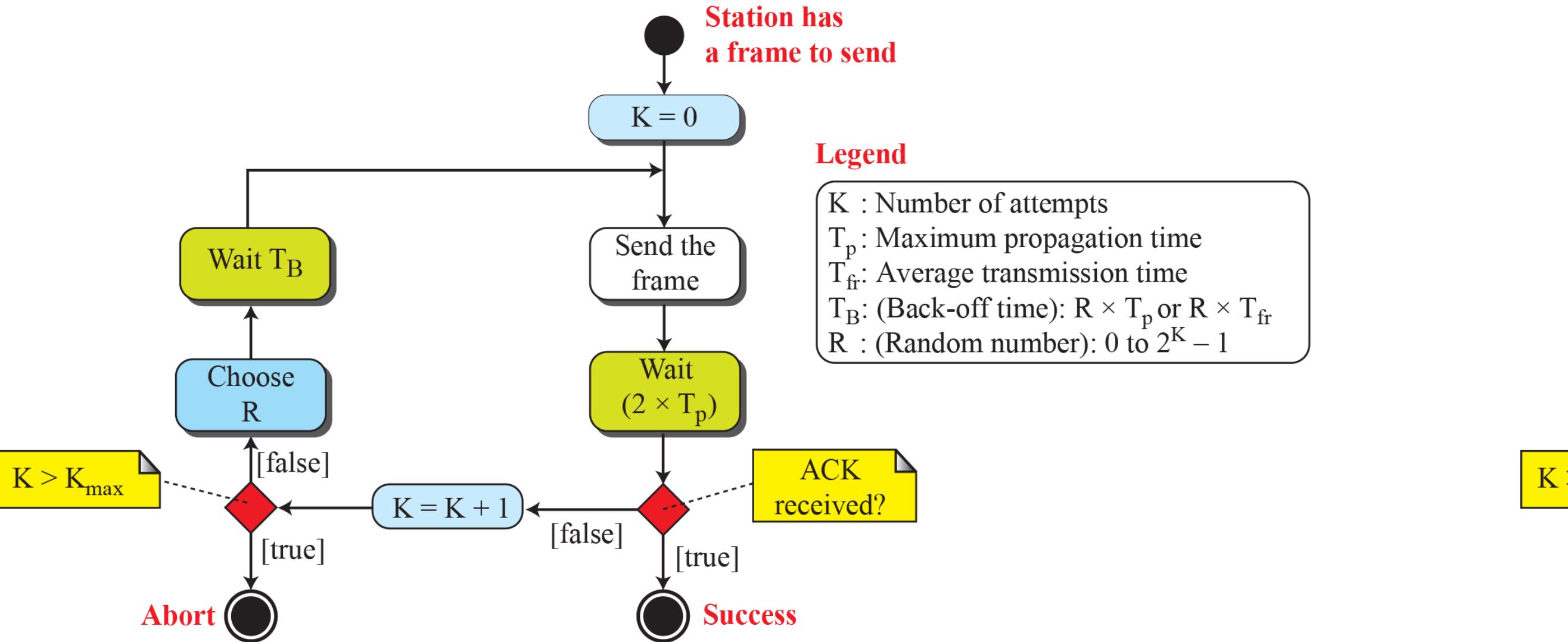
Pure ALOHA Procedure

- 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.
 - $T_{fr} = \text{frame size} / \text{transmission rate (data rate)}$

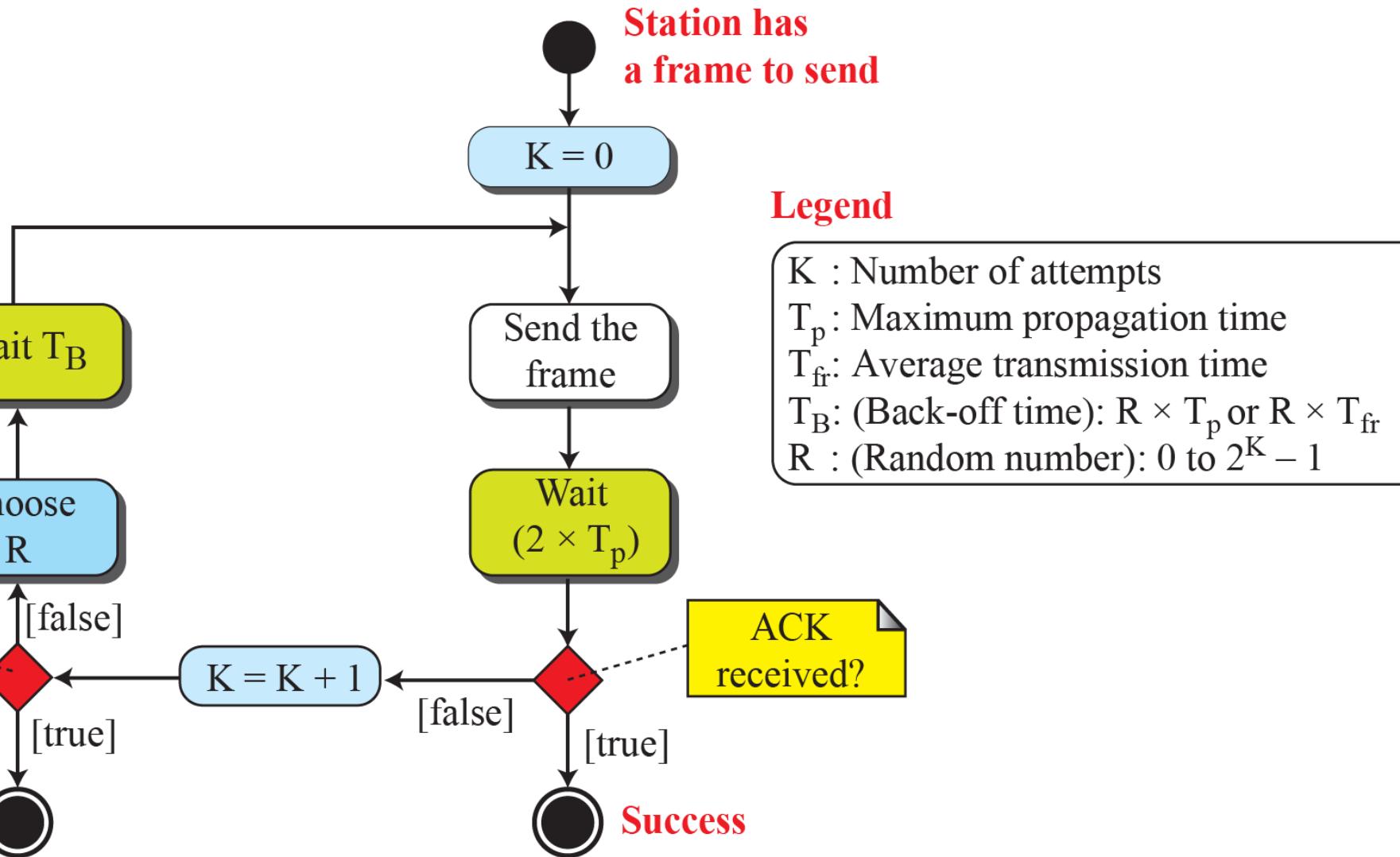
纯ALOHA过程

- 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。
 - $T_{fr} = \text{帧大小} / \text{传输速率（数据速率）}$

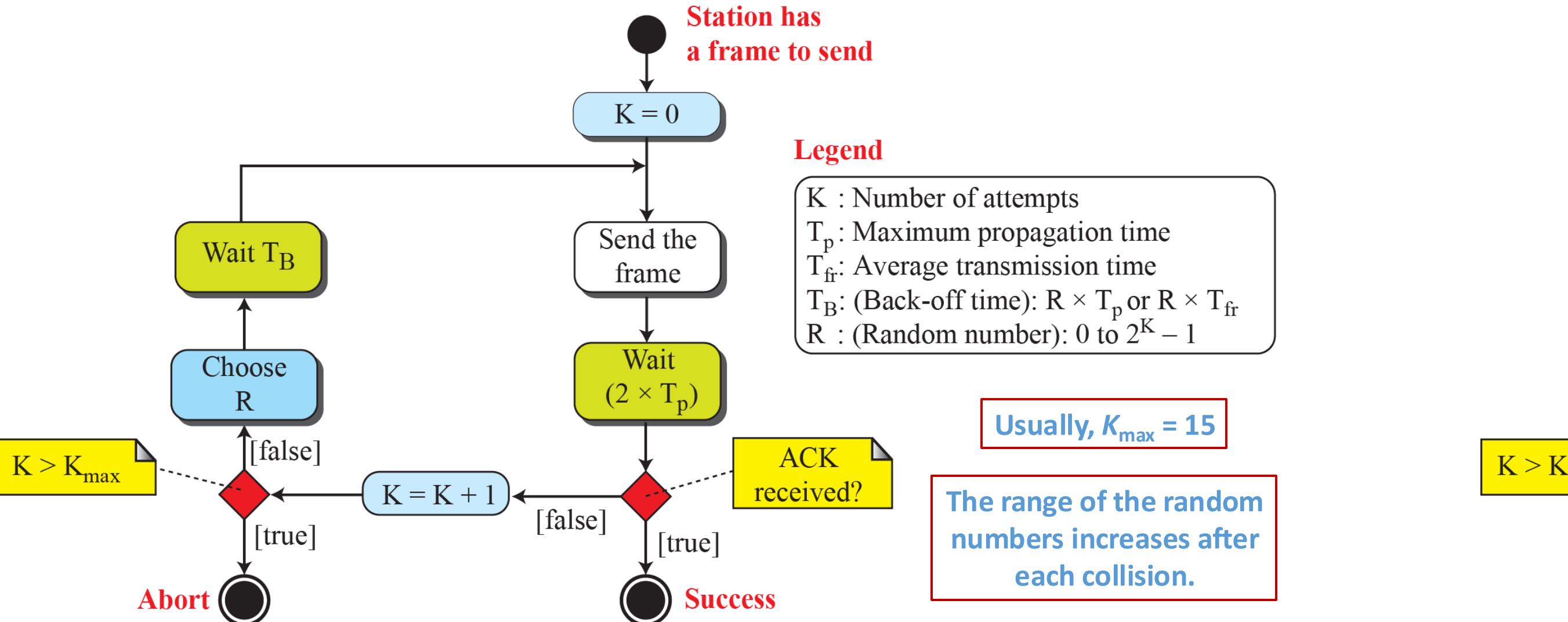
Pure ALOHA Procedure



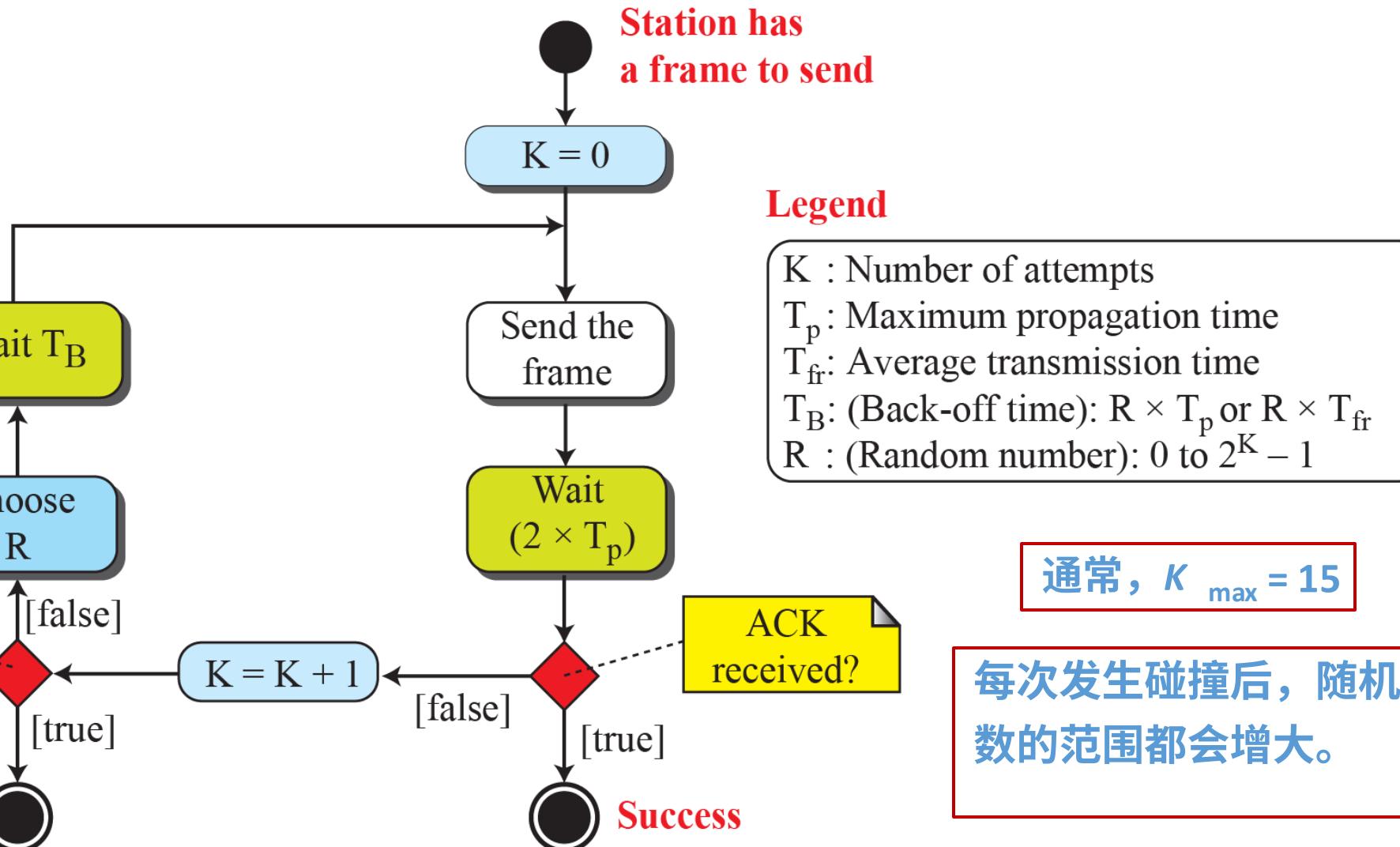
纯ALOHA过程



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:**

- $T_P = \text{distance} / \text{propagation speed} = (600 \times 10^3) / (3 \times 10^8) = 2 \text{ ms}$
- 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

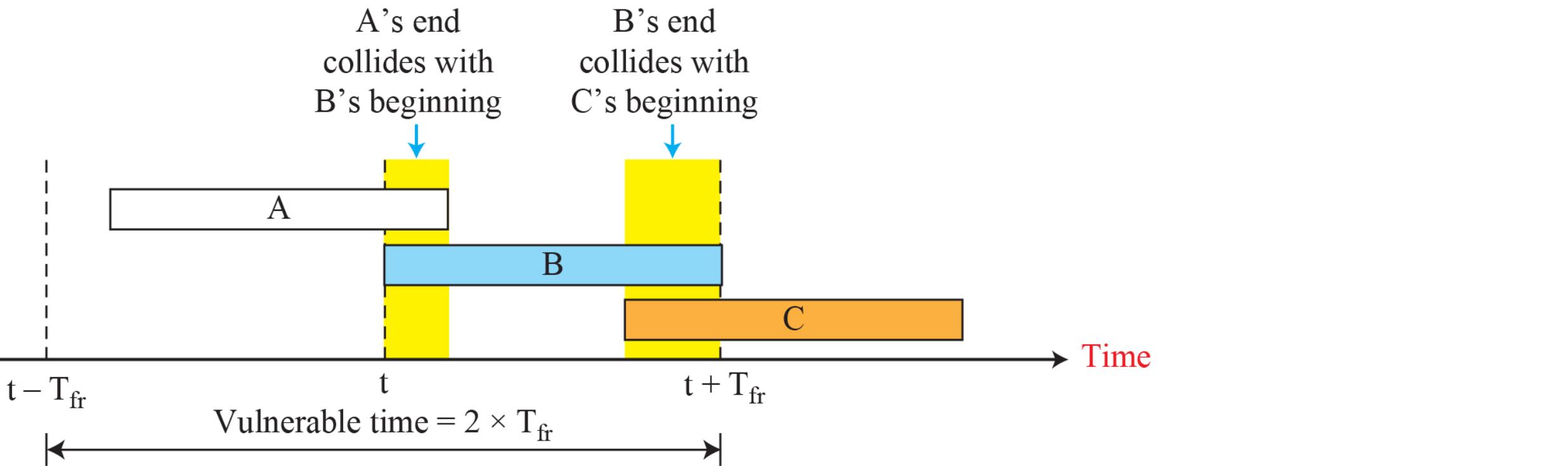
- 无线ALOHA网络上的站点之间最大距离为600公里
分开。如果我们假设信号以 $c = 3 \times 10^8$ m/s的速度传播, T_P 的值是多少?
如果 $K = 2$, T_B 的值又是多少?

- 答案:**

- $T_P = \text{距离} / \text{传播速度} = (600 \times 10^3) / (3 \times 10^8) = 2 \text{ ms}$
- R 的取值范围是 0 到 $(2^2 - 1) \rightarrow R \in \{0, 1, 2, 3\}$
- $T_B = R \times T_P \rightarrow T_B$ 可以是从 $\{0, 2, 4, 6\} \text{ ms}$ 中的任意值

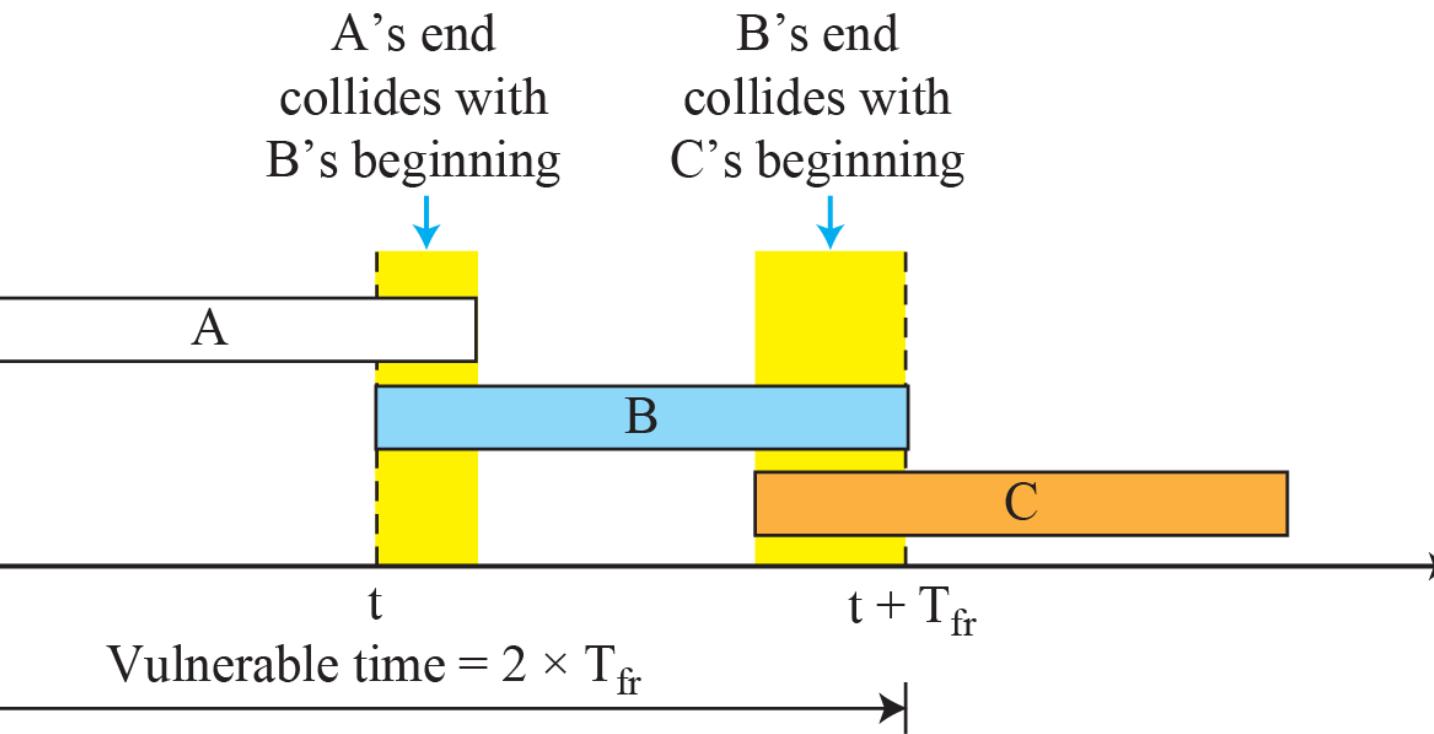
Pure ALOHA Vulnerable Time

- **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：**

- $T_{fr} = \frac{\text{帧大小}}{\text{传输速率 (数据速率)}} = \frac{200}{200 \text{ kbps}} = 0.001 \text{ s} = 1 \text{ ms}$
- 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 is 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 is the throughput if 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 $\rightarrow 1 \text{ frame per millisecond (1 frame per frame transmission time)}$ $\rightarrow G = 1$
- $S = G \times e^{-2G} = 0.135 \text{ (13.5\%)}$
- This means that only **135 frames** (1000×0.135) 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 $\rightarrow 1 \text{ 每毫秒帧数 (每个帧传输时间1帧)}$ $\rightarrow G = 1$
- $S = G \times e^{-2G} = 0.135 \text{ (13.5\%)}$
- 这意味着，在1000个帧中，可能只有 **135个帧** (1000×0.135) 能够成功传输。

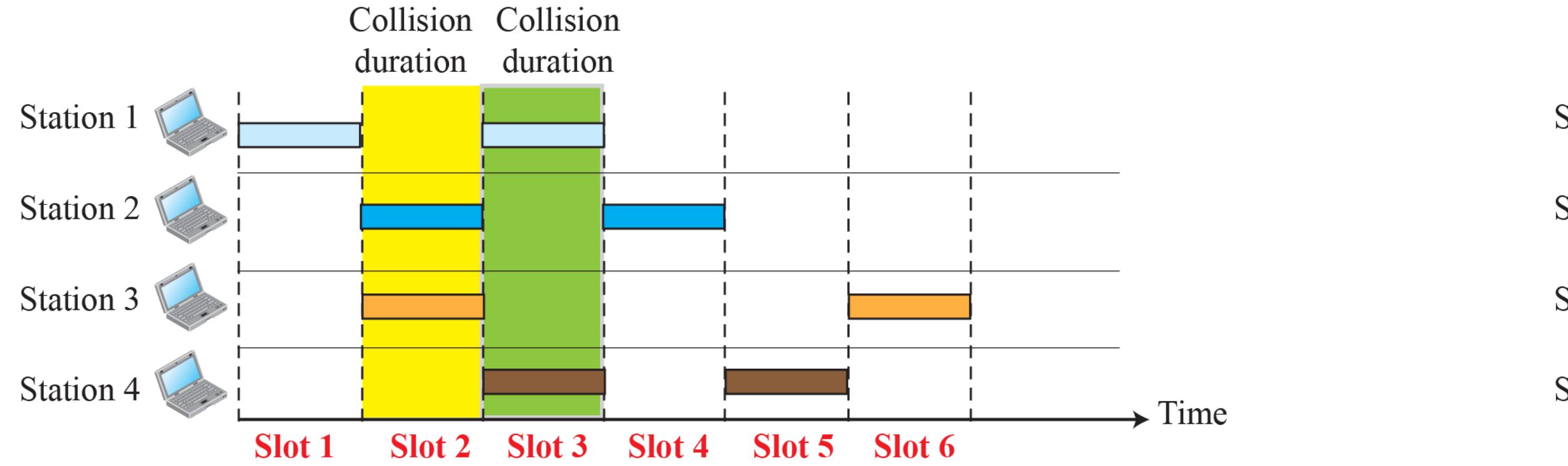
Slotted ALOHA

- 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

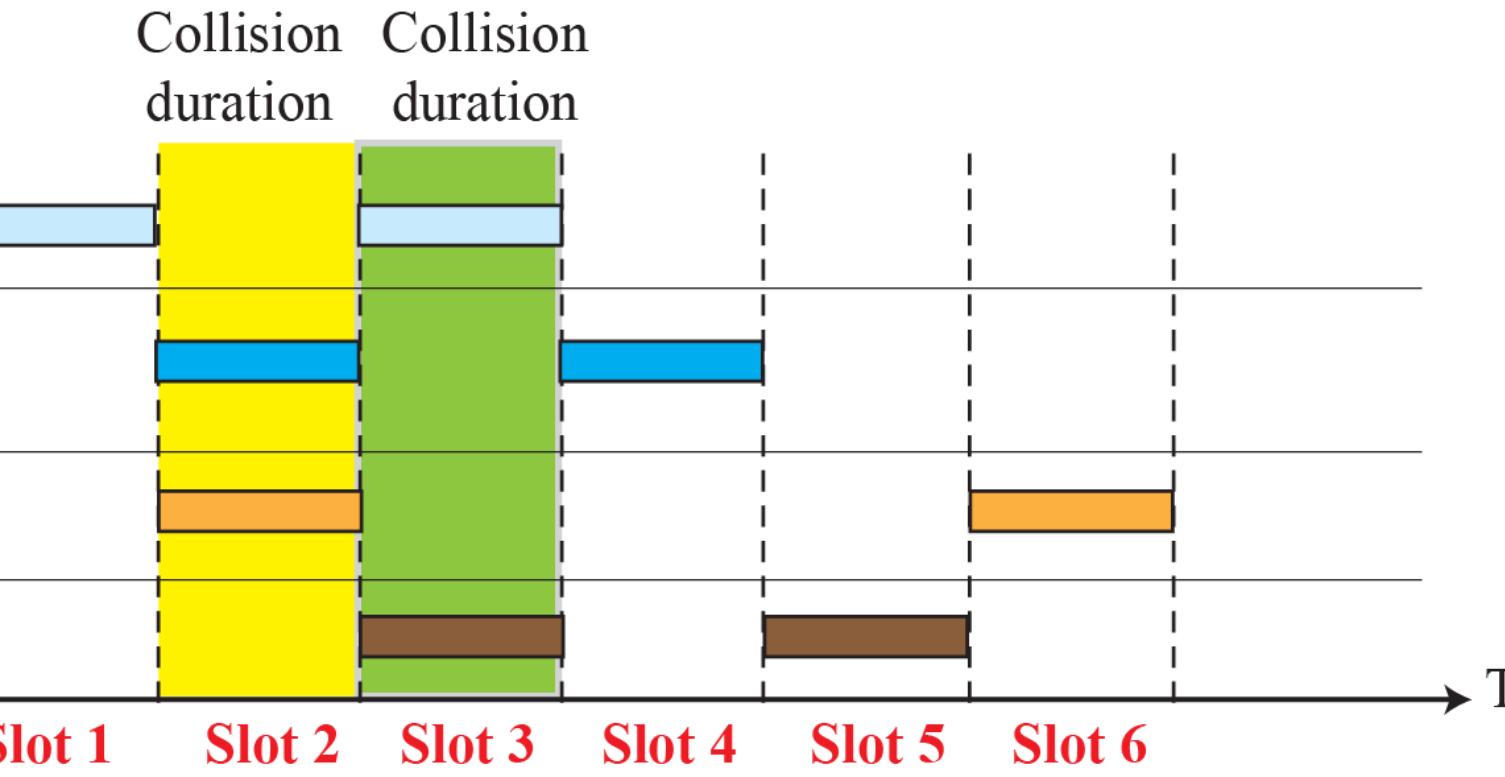
- 提高了纯ALOHA的效率。
- 时间被划分为每 T_{fr} 秒一个的时隙，且站点被强制仅能在时隙开始时发送。

Slotted ALOHA Frame Collisions



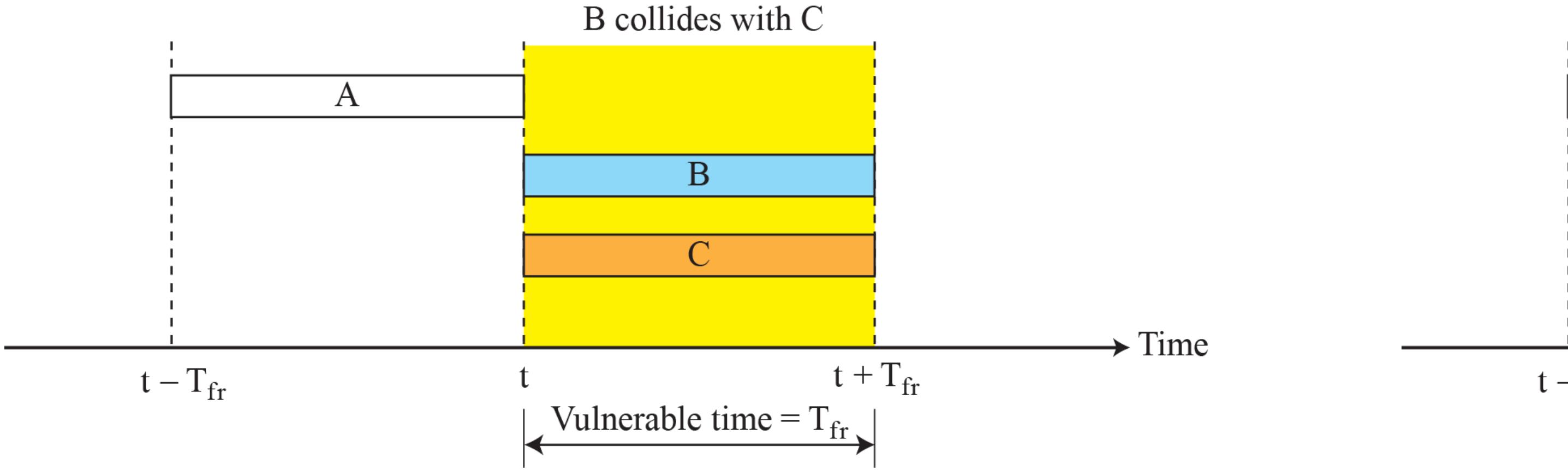
- There is still the possibility of collision if two stations try to send at the beginning of the same time slot.

时隙ALOHA帧冲突

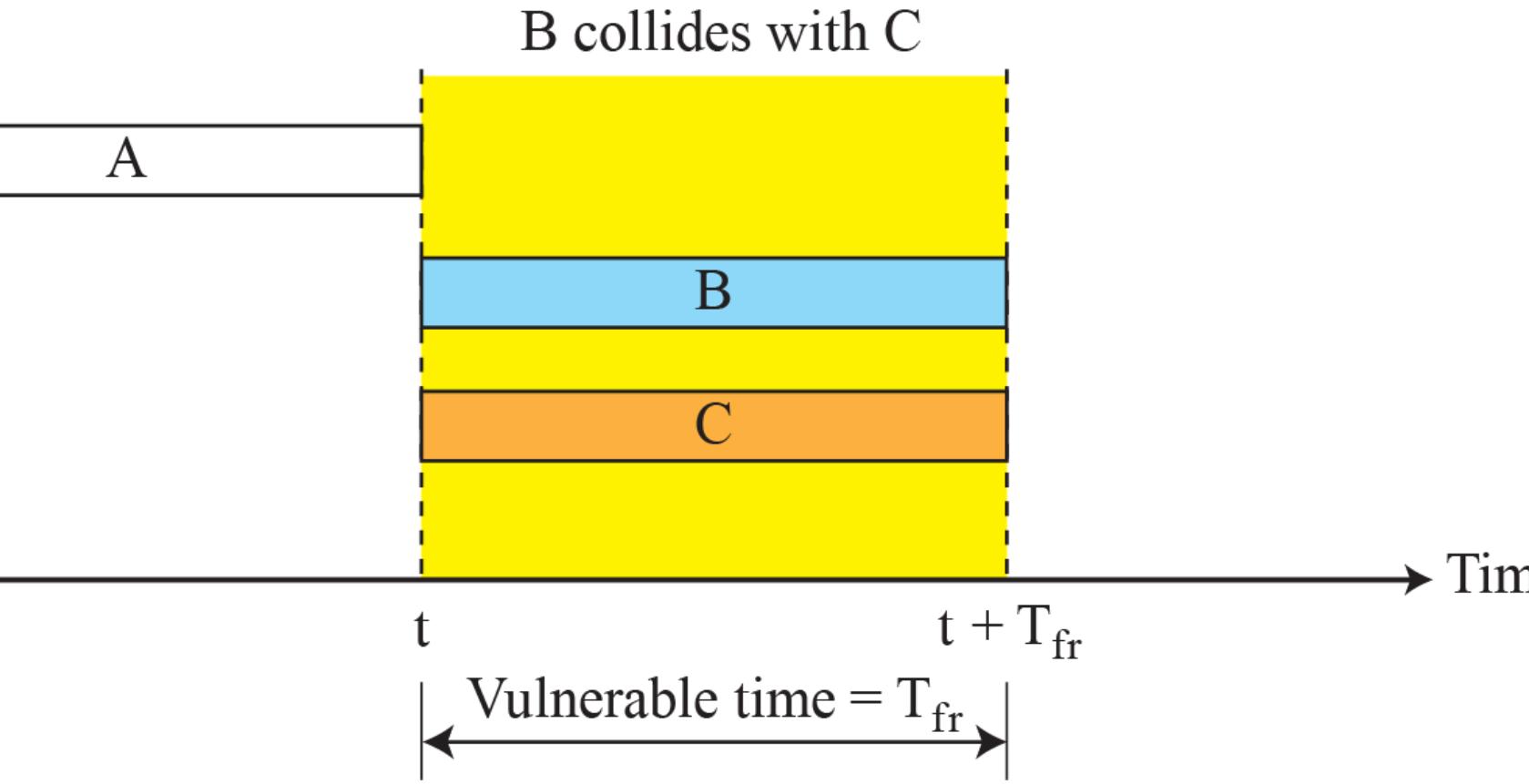


- 如果两个站点尝试在同一个时隙的开始时刻发送，仍然可能发生冲突。

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 $\rightarrow 1 \text{ frame per millisecond (1 frame per frame transmission time)}$ $\rightarrow G = 1$
- $S = G \times e^{-G} = 0.368 \text{ (36.8\%)}$ \rightarrow max throughput
- This means that only **368 frames** (1000×0.368) 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 $\rightarrow 1 \text{ 每毫秒一帧 (每帧传输时间发送一帧)}$ $\rightarrow G = 1$
- $S = G \times e^{-G} = 0.368 \text{ (36.8\%)}$ \rightarrow 最大吞吐量
- 这意味着只有 **368 帧** (1000×0.368) 可能会从 1000 帧中幸存下来。

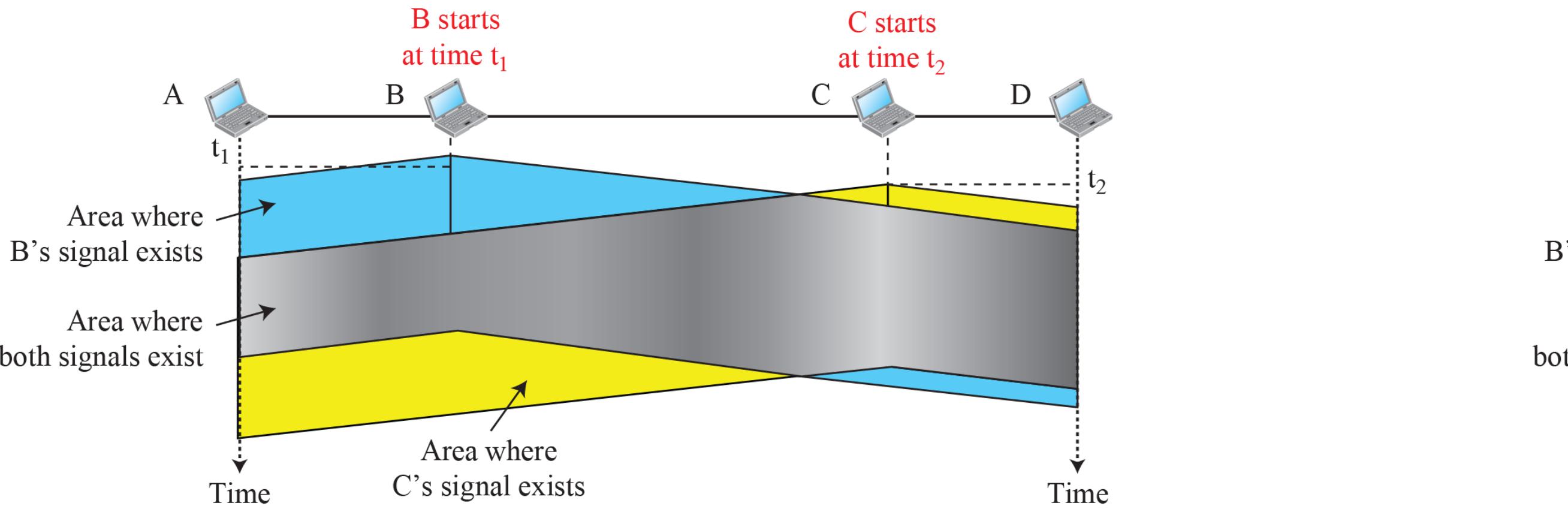
CSMA

- 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

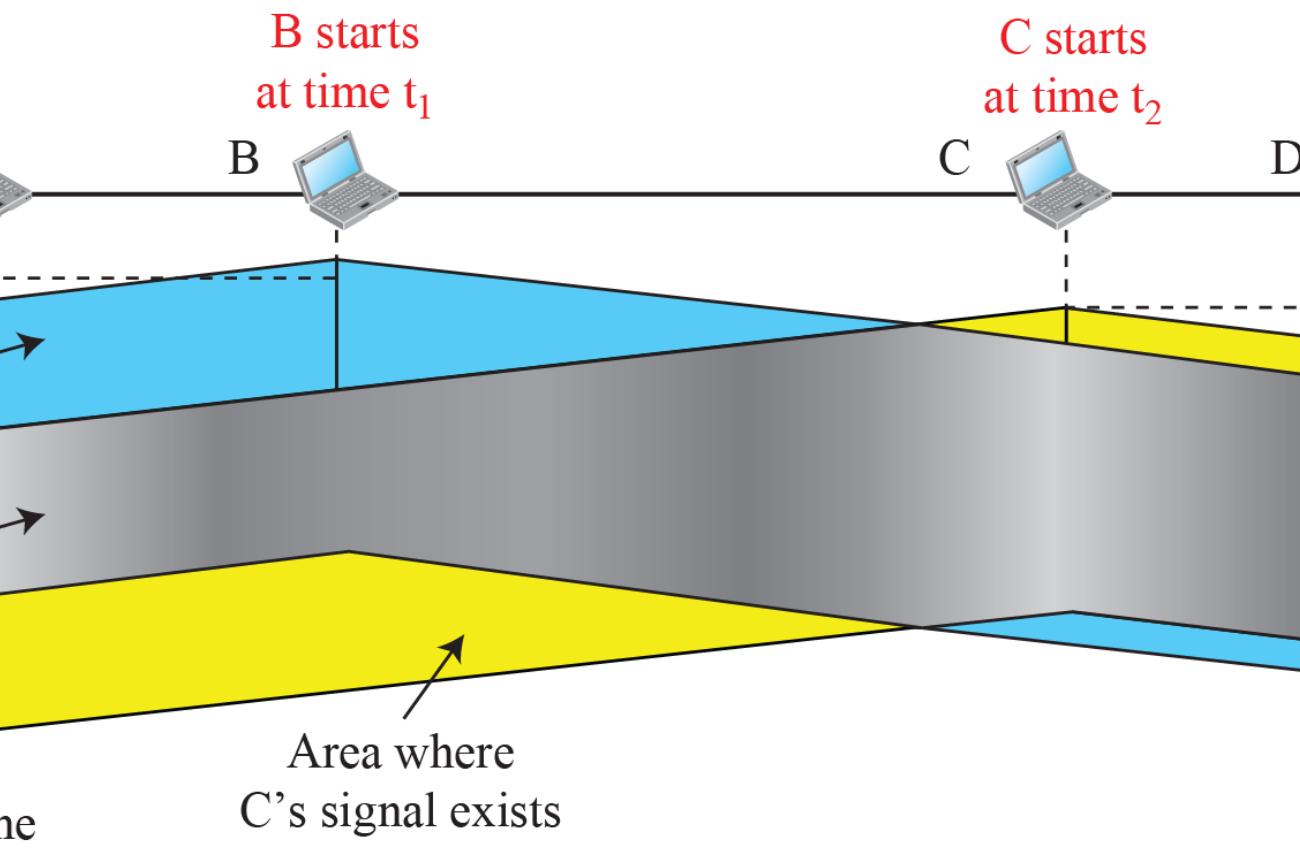
- 载波监听多路访问 (CSMA)
- 旨在尽量减少碰撞的可能性，从而提高性能。
- 每个站点在使用介质前先进行侦测（先侦测后发送）。
 - 降低发生碰撞的可能性

CSMA Space/Time Model of a Collision



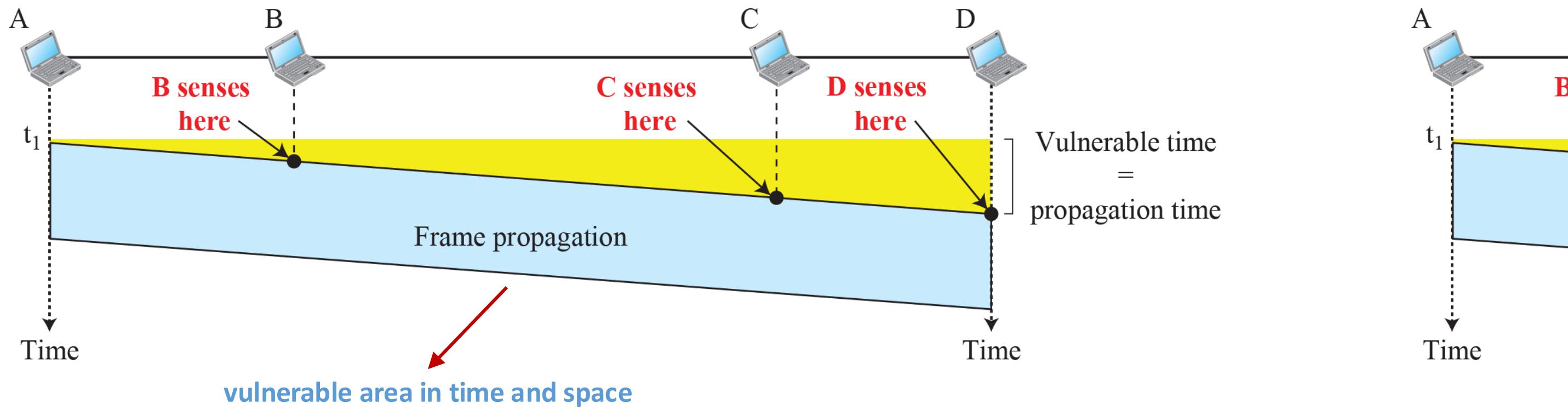
- The possibility of collision still exists! Because of the propagation delay (it takes time for the first bit to reach every station)

冲突的CSMA空间/时间模型



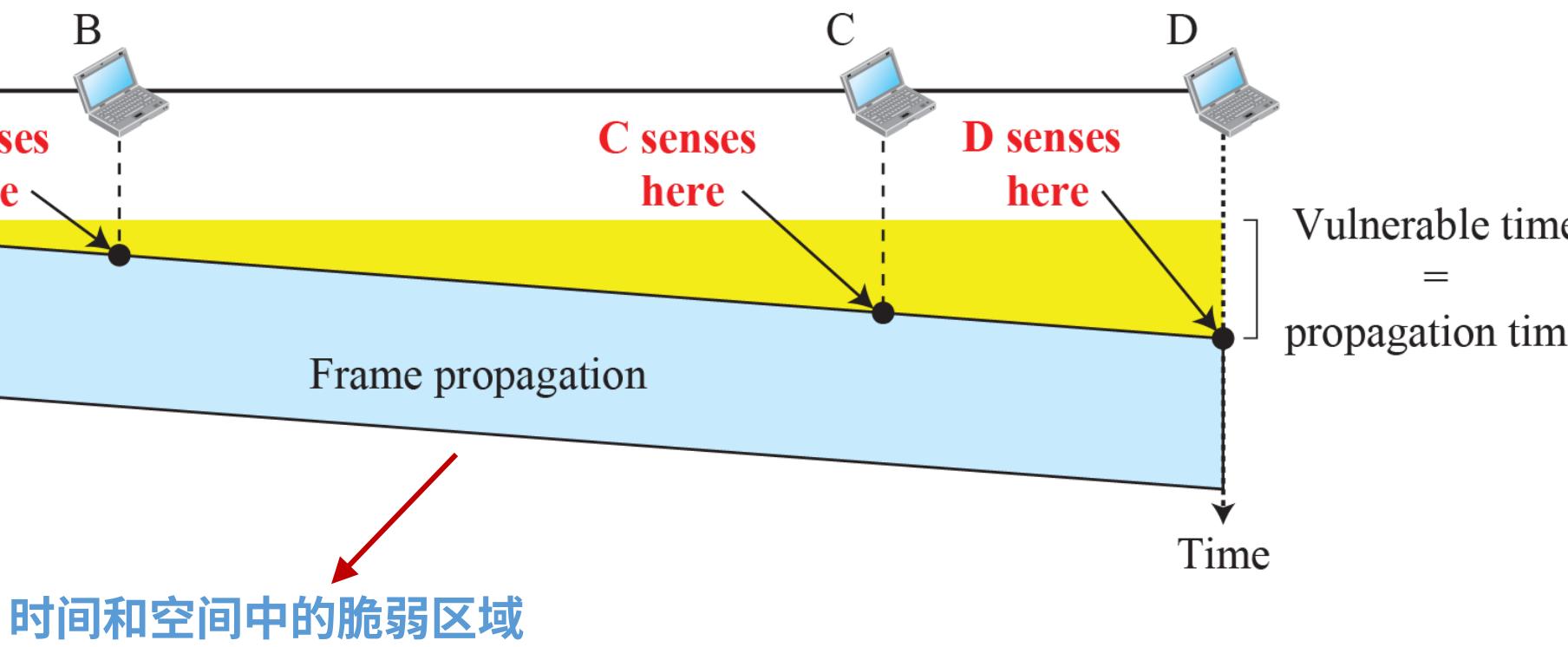
- 仍然存在发生冲突的可能性！因为传播延迟（第一个比特需要一定时间才能到达每个站点）

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

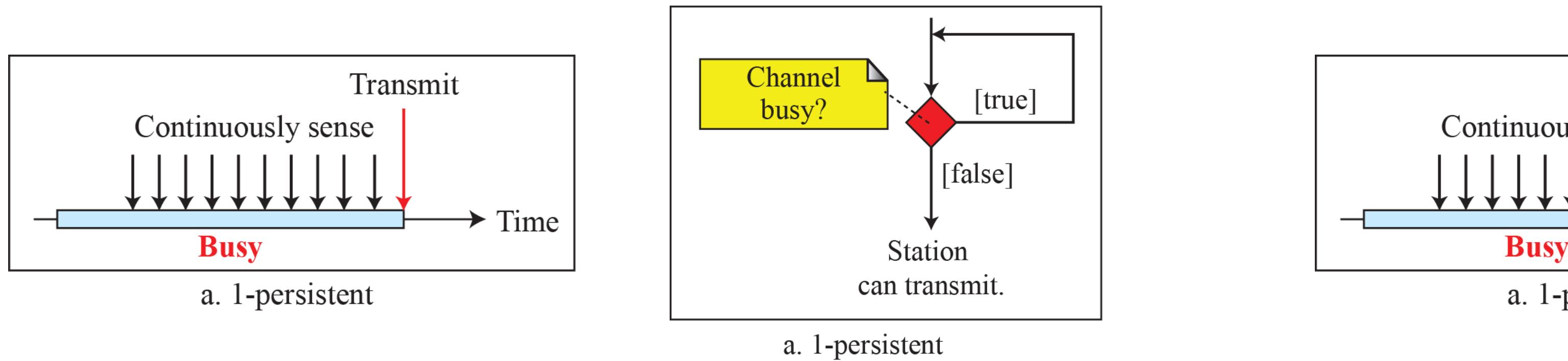
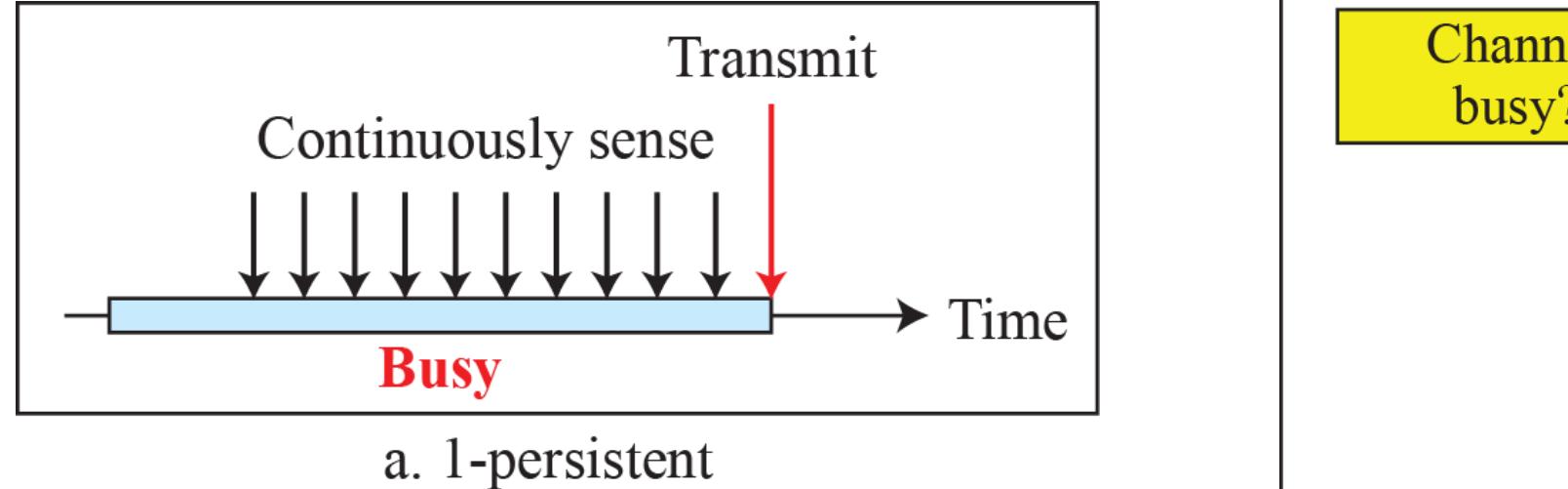
- What should a station do if the channel is **busy**?
- What should a station do if the channel is **idle**?
- Three Persistent methods are designed:
 - **1-persistent**
 - **Non-persistent**
 - **P-persistent**

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**

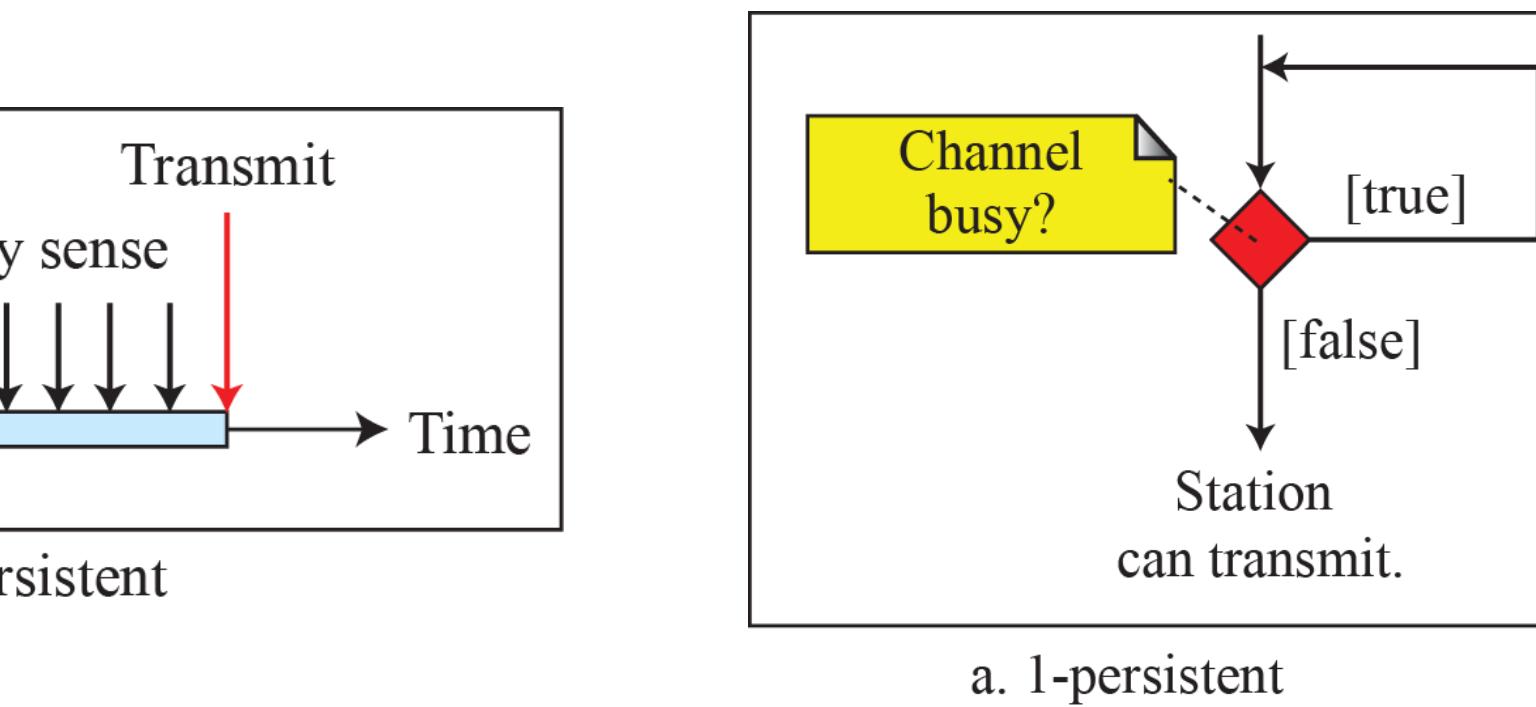
CSMA 1-Persistent Method

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



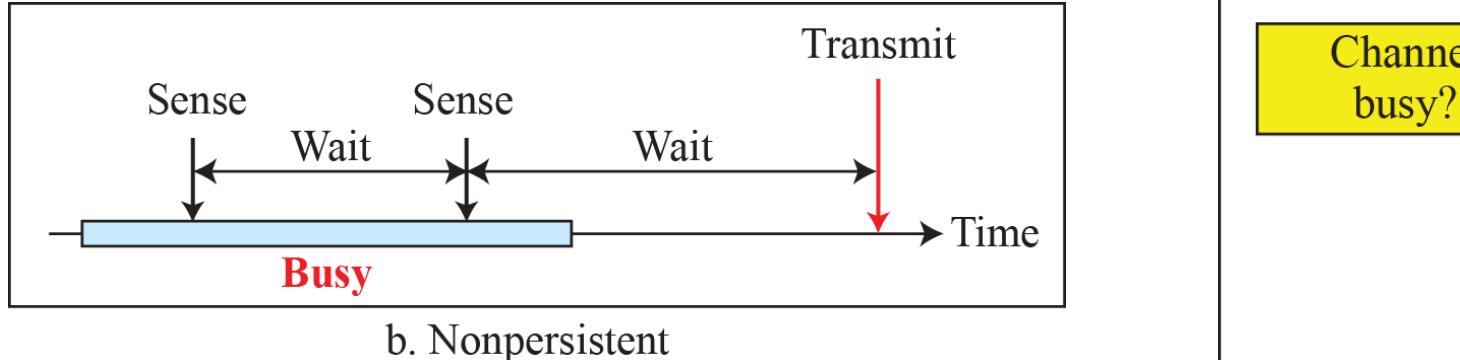
CSMA 1-坚持方法

- 用于 **以太网**。碰撞概率最高。

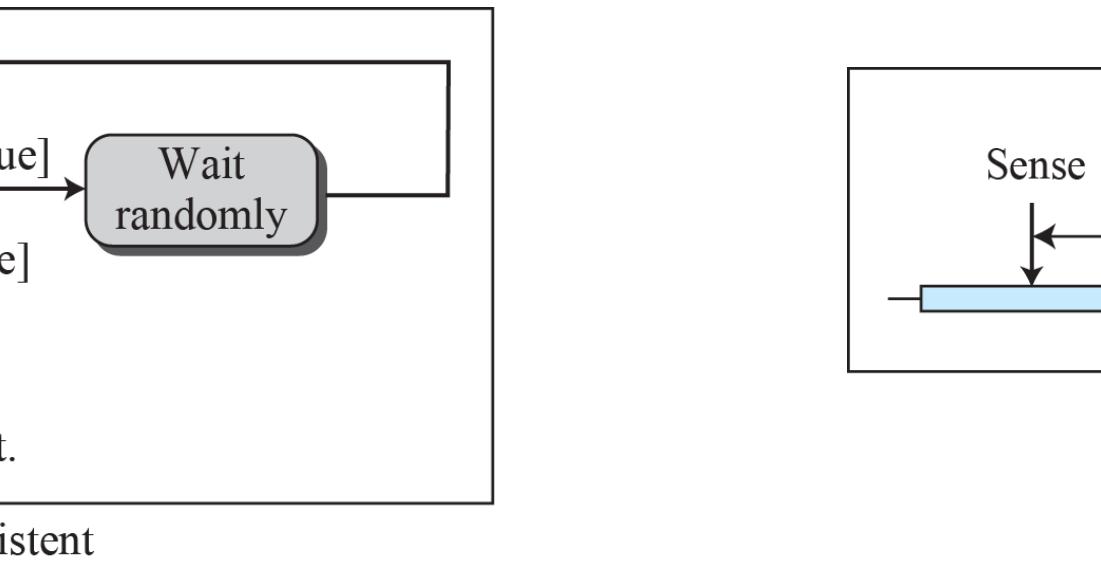


CSMA Non-persistent Method

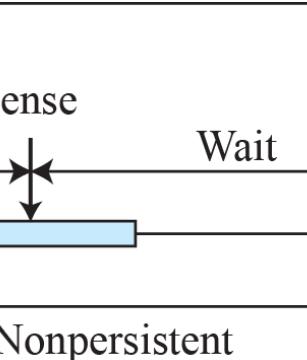
- Reduces the chance of collision but decreases the efficiency (the medium remains idle when there may be stations with frames to send).



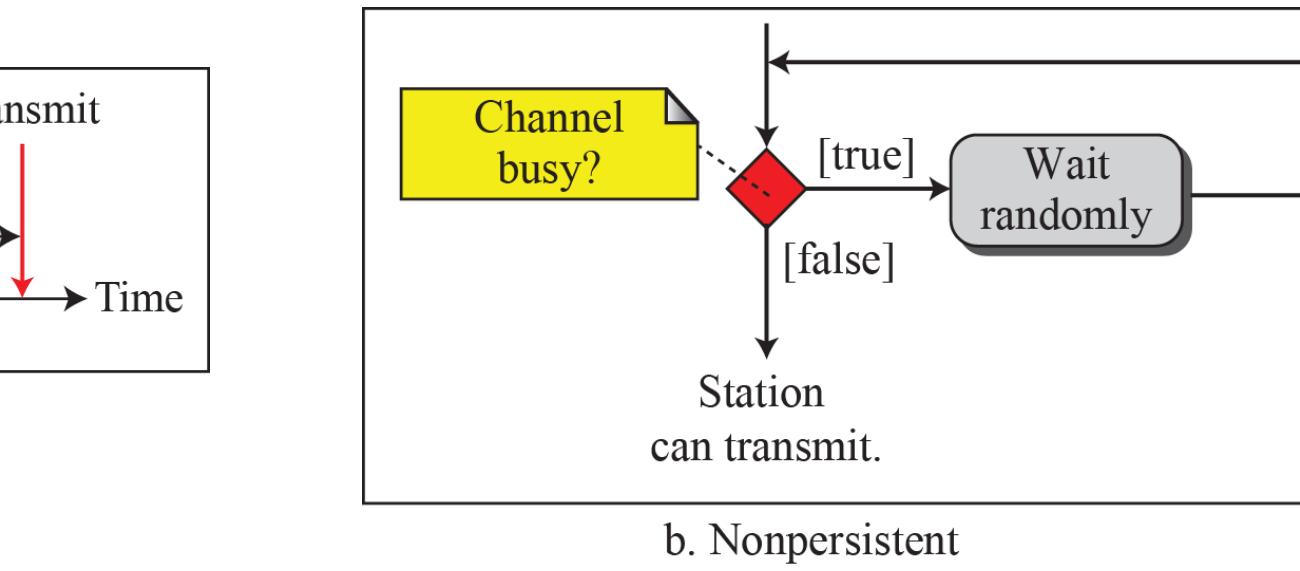
b. Nonpersistent



b. Nonpersistent



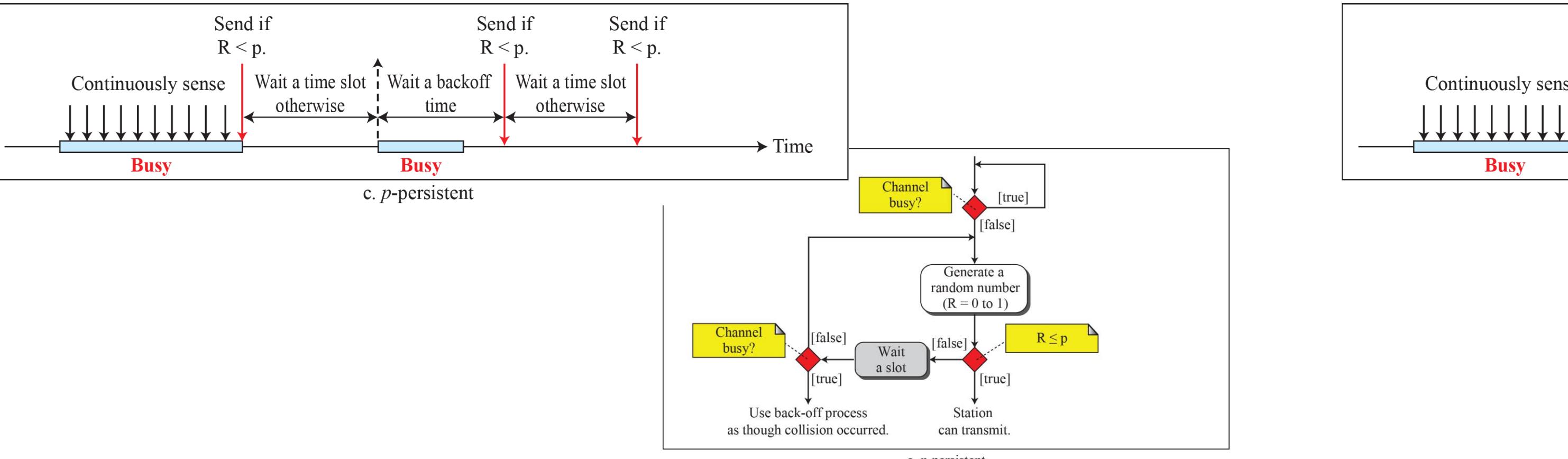
b. Nonpersistent



b. Nonpersistent

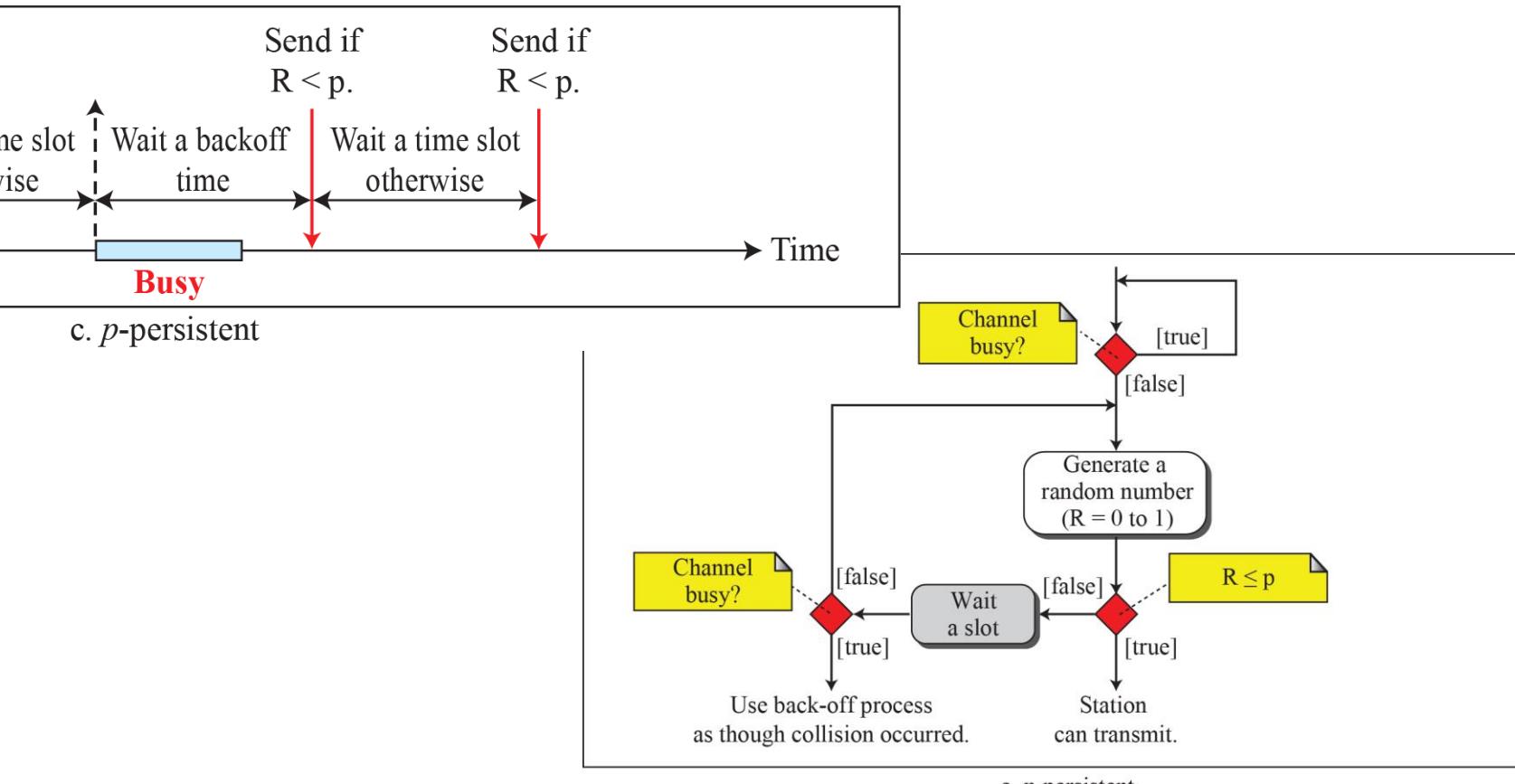
CSMA P-persistent Method

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

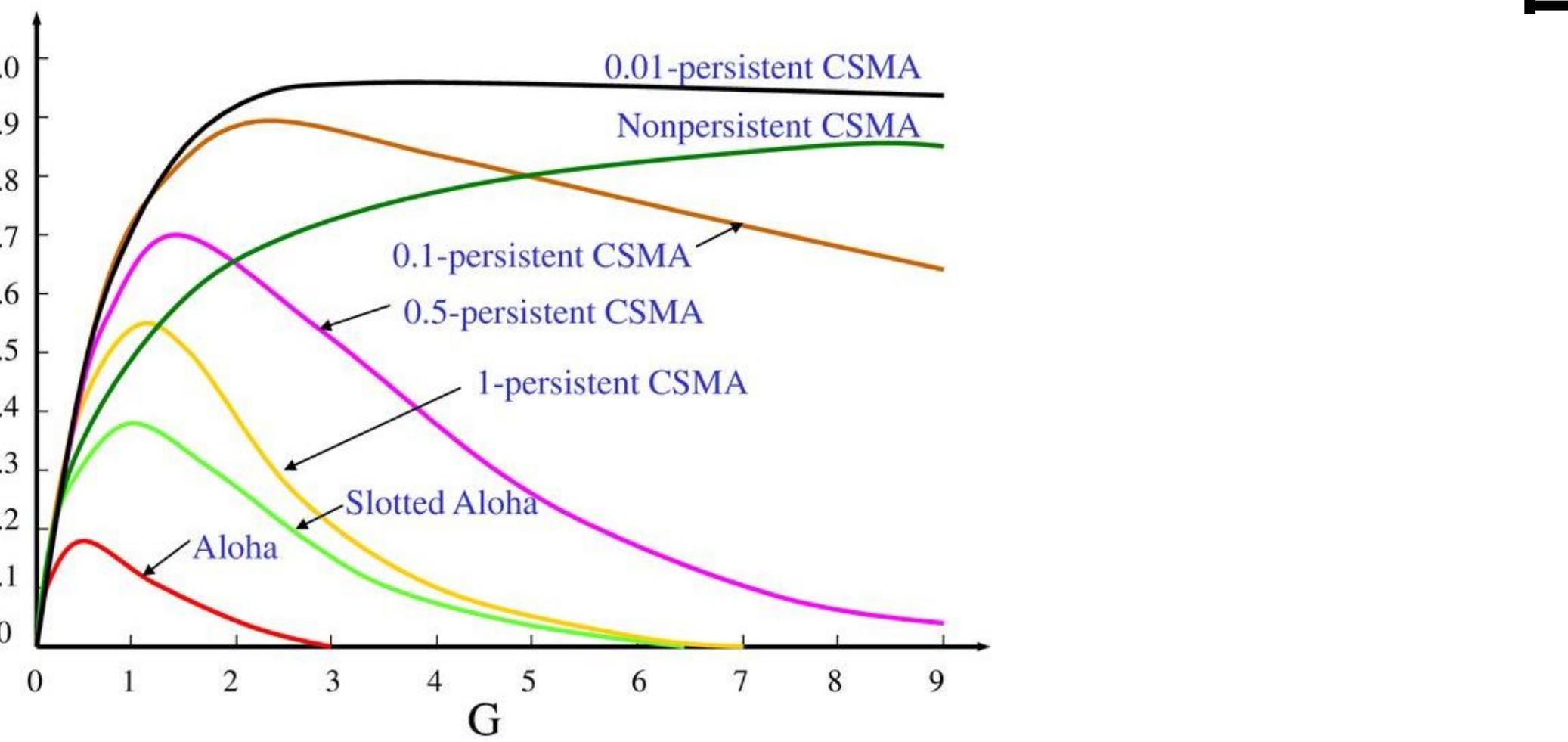


CSMA P持续方法

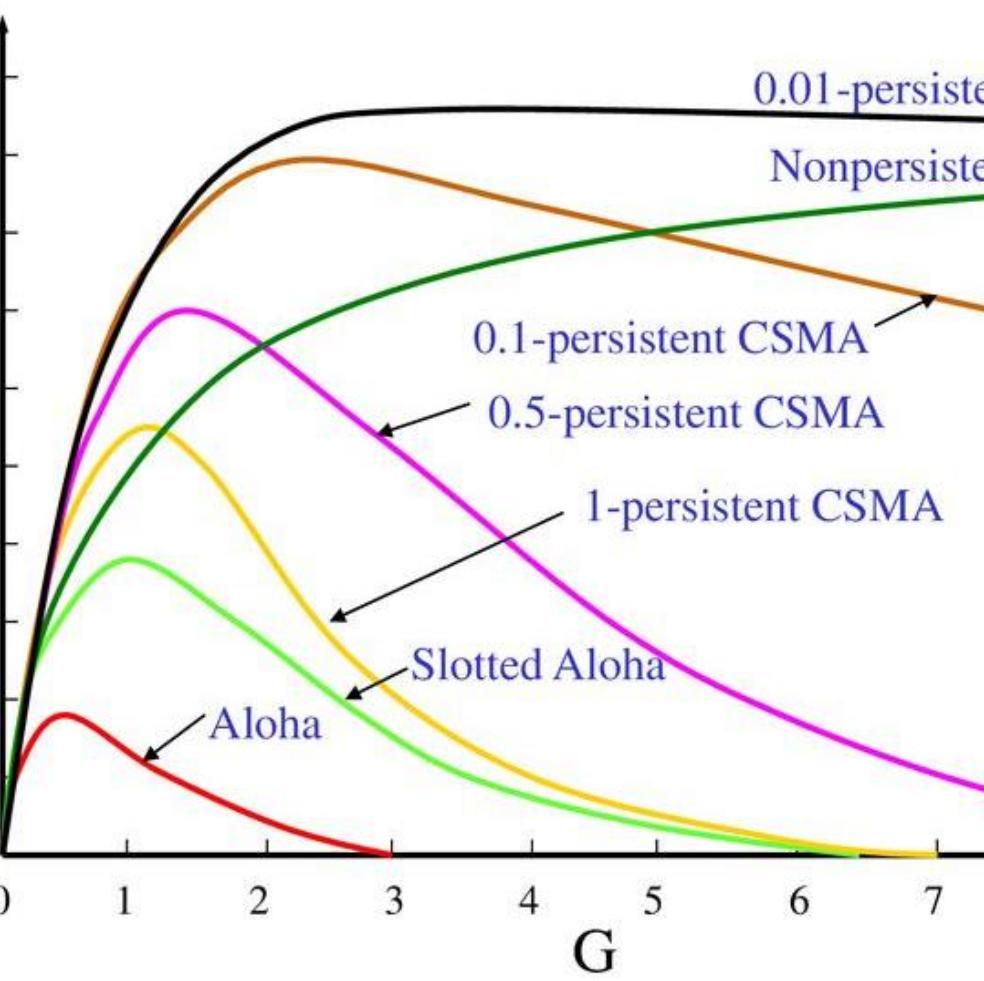
- 时隙持续时间等于或大于最大传播时间。
- 降低了发生冲突的可能性，并提高了效率。



Throughput



吞吐量



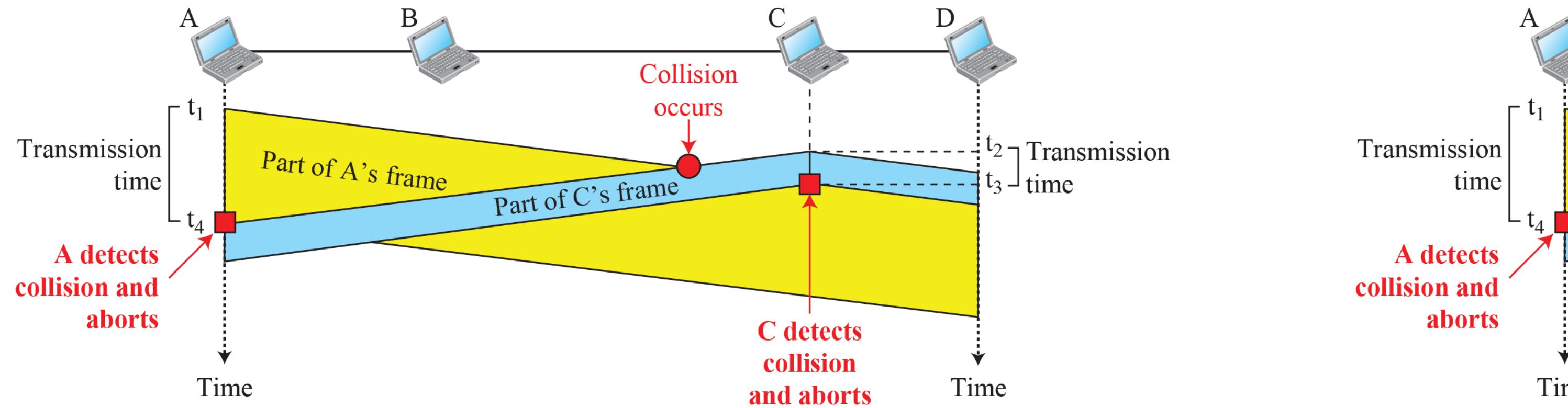
CSMA/CD

- 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.

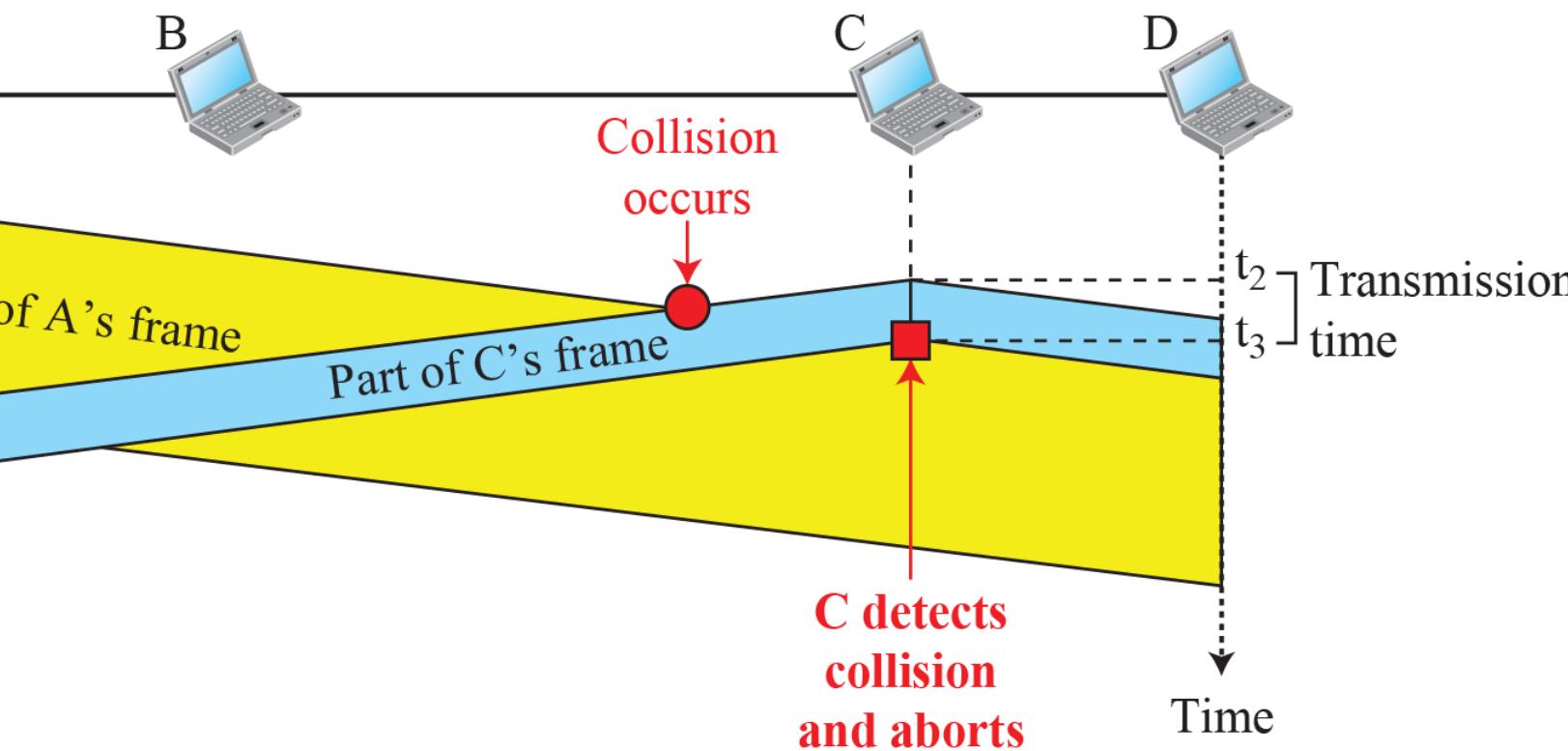
CSMA/CD

- 带冲突检测的载波监听多路访问 (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



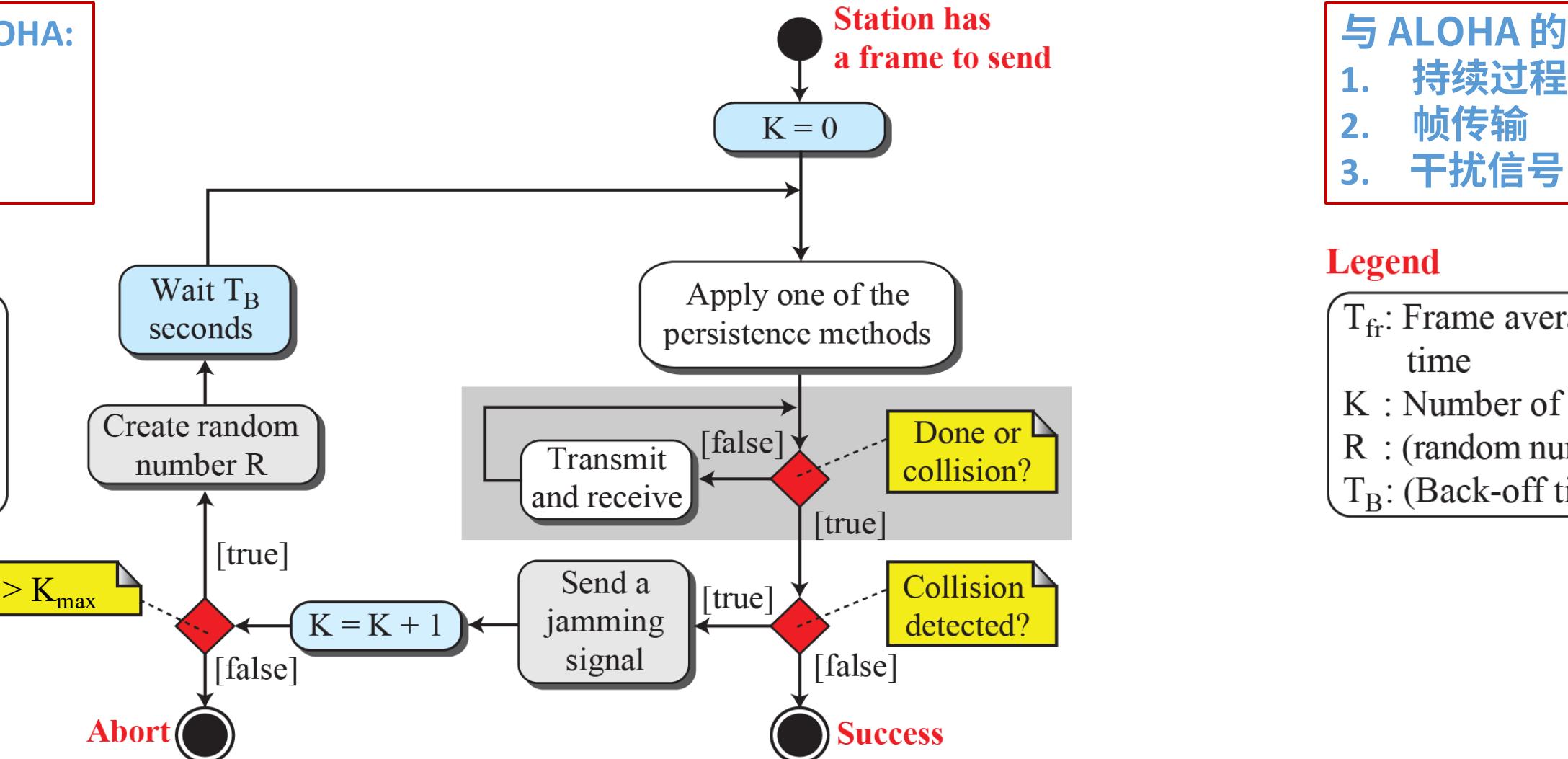
CSMA/CD Flow Diagram

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) = $R \times T_{fr}$



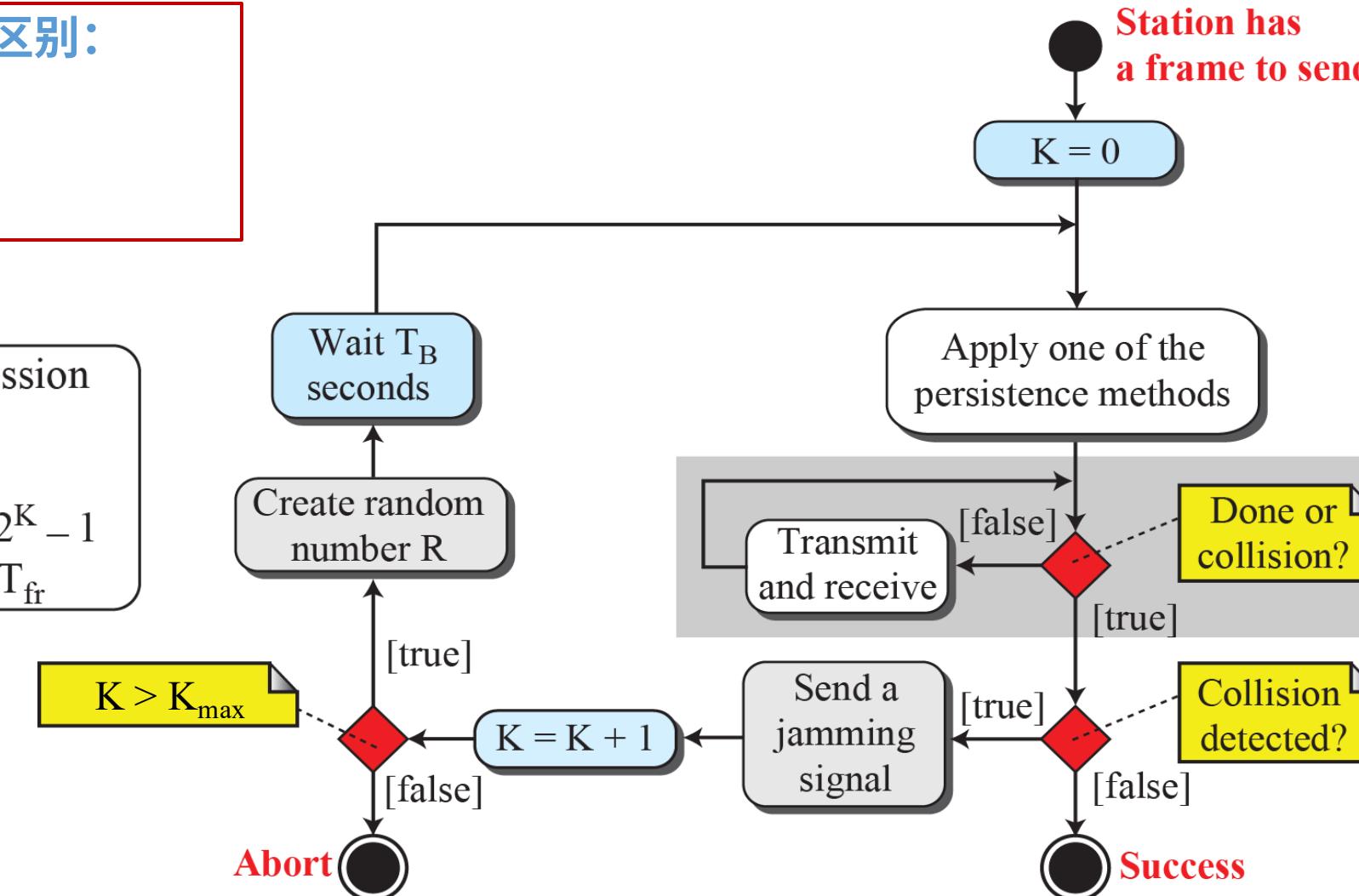
CSMA/CD 流程图

与 ALOHA 的三个主要区别:

1. 持续过程
2. 帧传输
3. 干扰信号

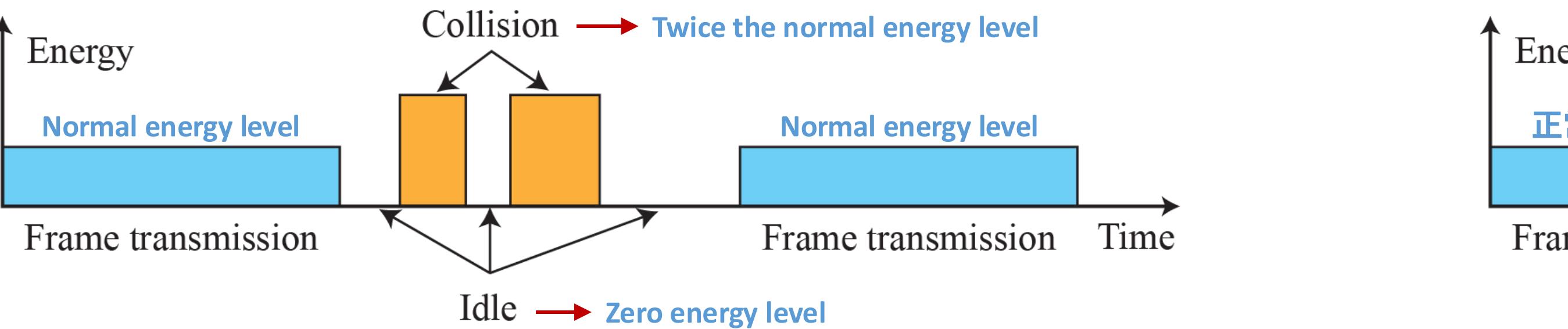
Legend

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



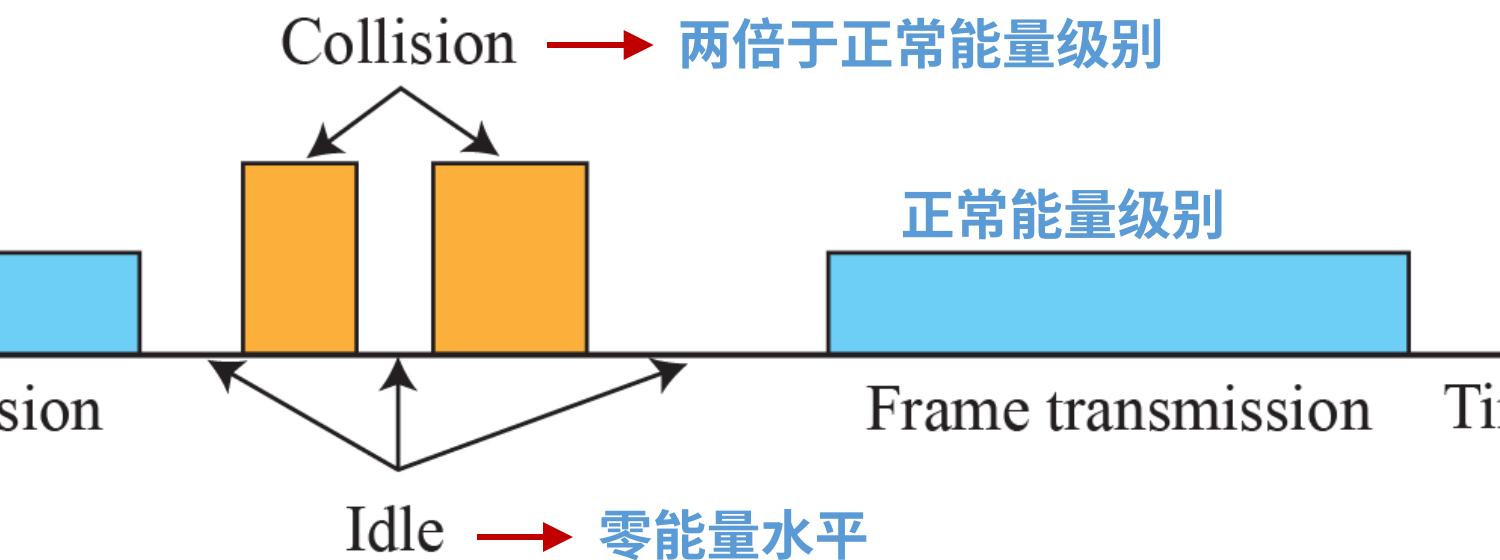
CSMA/CD Energy Level during Transmission, Idleness, or Collision

- 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**

- 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 μ 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 μs 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 μs ，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 μs 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

- 载波监听多路访问/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

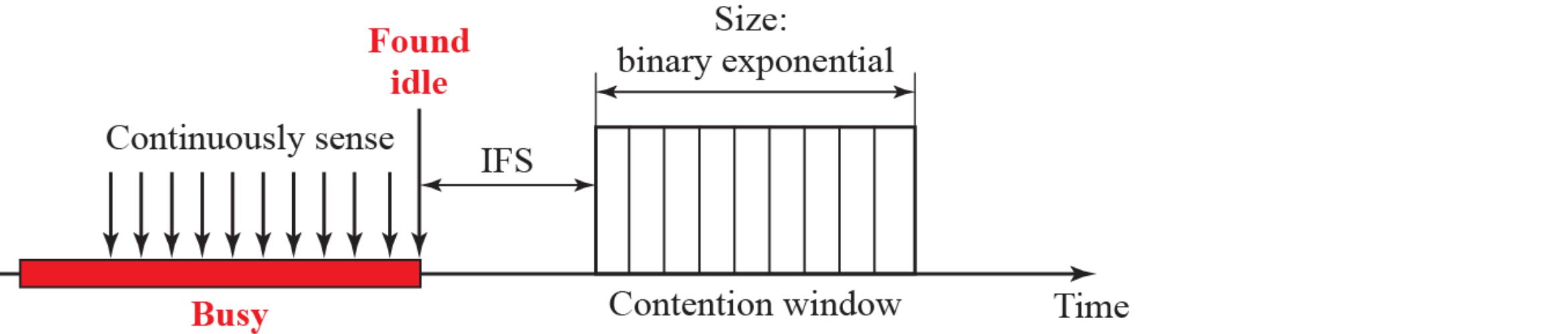
- **Collisions are avoided** by deferring transmission even if the channel is found idle.
 - The station waits for a period of time called the **interframe space** or **IFS**.
 - The **IFS** time allows the front of the transmitted signal by the distant station to reach this station.
 - The **IFS** variable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

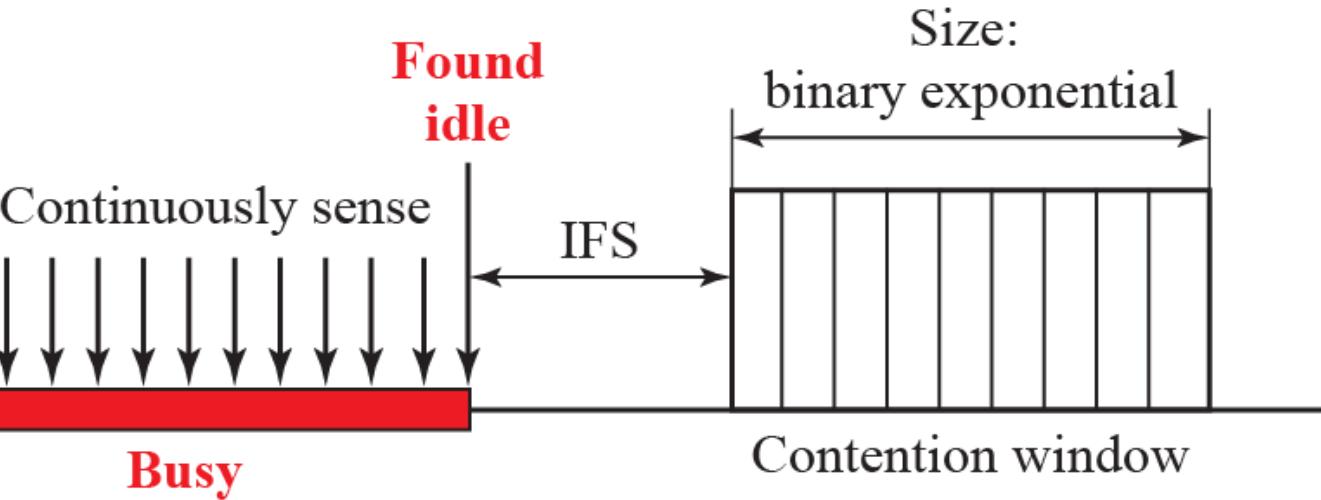
CSMA/CA Contention Window

- 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。

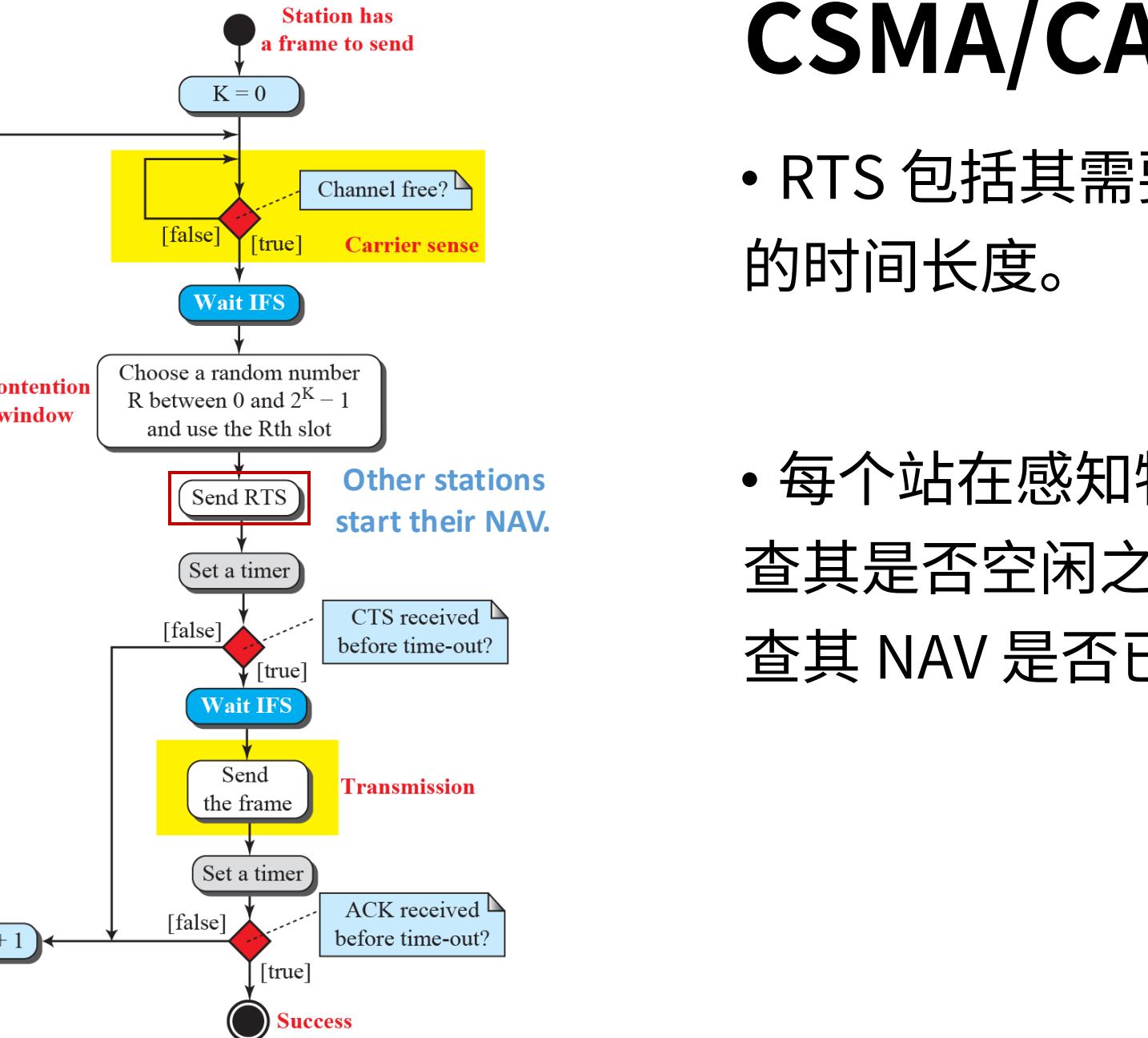


CSMA/CA Flow Diagram

- 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_B : Backoff time
IFS: Interframe Space
RTS: Request to send
CTS: Clear to send

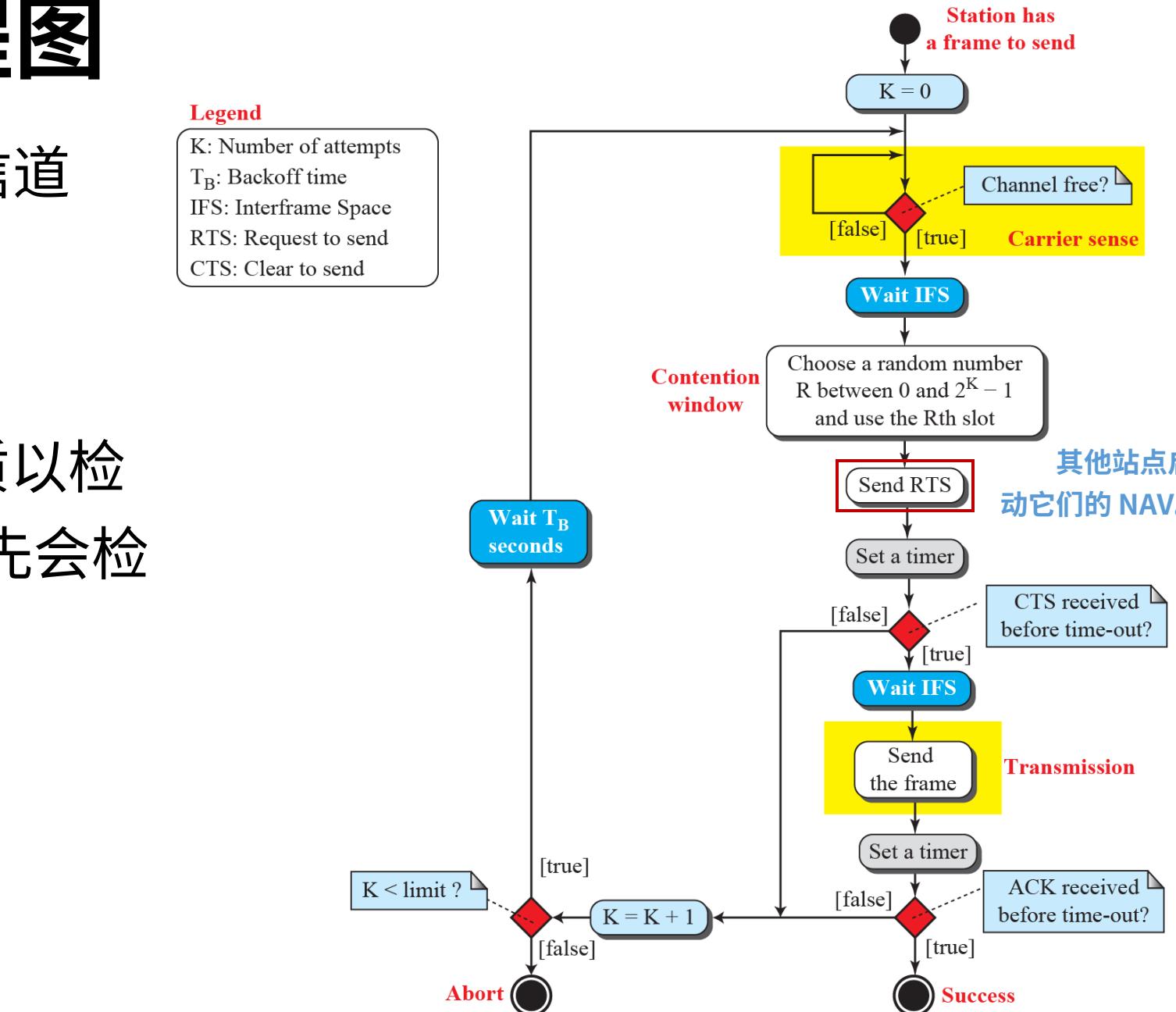


CSMA/CA 流程图

- RTS 包括其需要占用信道的时间长度。

Legend

K: Number of attempts
 T_B : 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）