Chapter4 Medium Access Control Sublayer(1)

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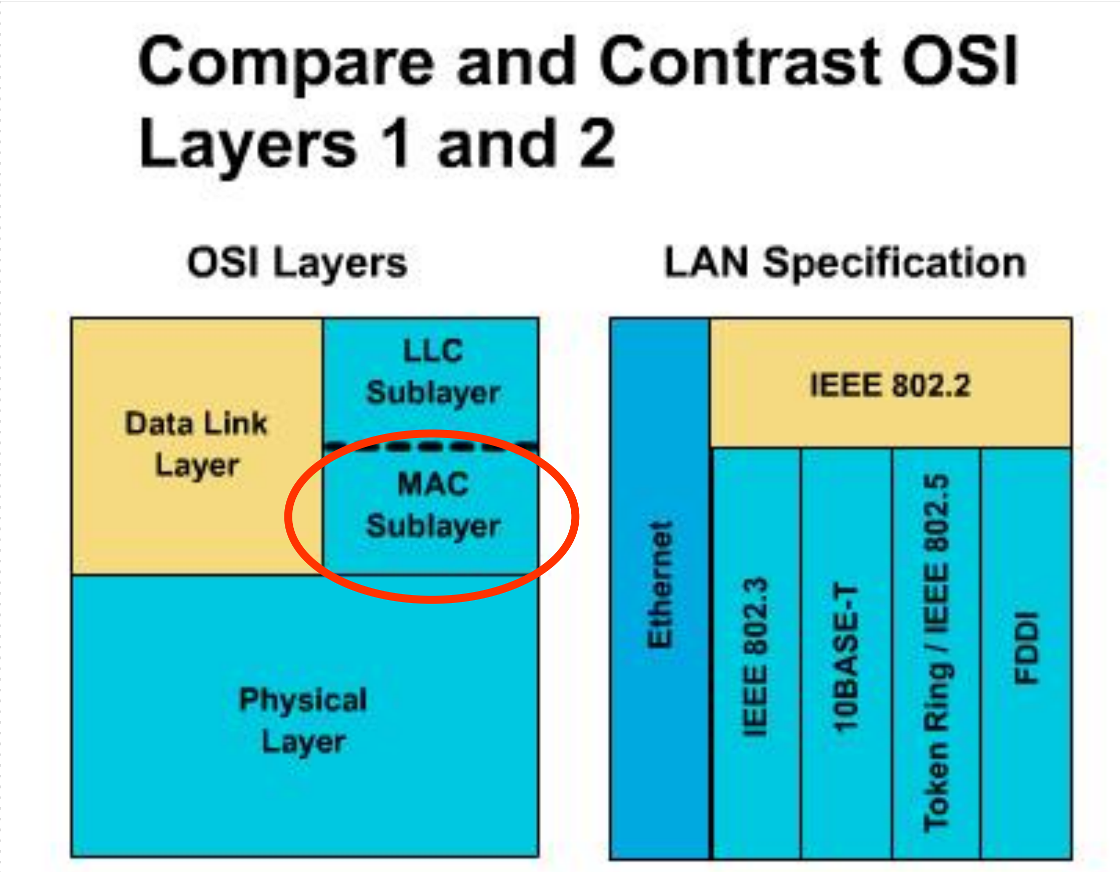
Position of MAC sublayer

Medium Access Control



Main content of this chapter

- Multiple access protocol
- A real system(LAN): Ethernet
  - IEEE802.3
- Data Link Layer Switching
  - Bridge
  - switch

Contents of this lecture

- Learn random access protocol(随机访问协议)
- Master pure ALOHA and slotted ALOHA
- Master the characteristics of each type of CSMA
  - 1-P CSMA
  - CSMA/CD
- Learn collision-free protocol (无冲突的协议)
  - Bit-Map
  - Binary Countdown

The problem of Broadcast network

- **Data communication**
  - **Unicast（单播）： One - to - One**
  - **Broadcast（广播）： One - to - Everyone**
  - **Multicast（组播）： One - to - A group**
- **In any broadcast network, the key issue is how to allocate a single broadcast channel among multiple competing users.**
- **Broadcast channels are sometimes referred to as multiaccess channels or random access channels.**

What is MAC?

- The protocol used to determine who goes next on a multiaccess channel belong to sublayer of the data link layer called the MAC(Medium Access Control) sublayer
- The MAC sublayer is especially important in LANs, many of which use a multiaccess channel as the basis for communication.

Allocating channel

- There are two methods of allocating channels:
  - static allocation
    - the channel is like a circuit – only one person is allowed to use it.
    - unused bandwidth will be lost （wasted）
  - dynamic allocation
    - the channel is open, with some computers being able to access unused bandwidth from others.
    - there is no dedicated bandwidth

Static allocation

- FDM（频分多路复用Frequency Division Multiplexing）
- TDM（时分多路复用 Time Division Multiplexing）

Problem of Static Channel Allocation

- Under what circumstances FDM is efficient ?
  - When there is only a small and fixed number of users, and each of which has a heavy (buffered) load of traffic
- What's the problem with FDM ?
  - If fewer than N users are currently interested in communication, some portions of spectrum will be wasted.
  - If more than N users want to communicate, some of them will be denied permission
  - Even the number of users is N and constant, when some users are quiescent, no one else can use their bandwidth so it is simply wasted.
  - For bursty data traffic (peak traffic to mean traffic ratio of 1000:1), the allocated small subchannel will be idle most of the time but unable to handle the peak traffic.

Poor Performance Of Static FDM

- Without FDM
  - channel capacity C bps
  - arrive rate λ frames/sec
  - mean frame length 1/μ bit/frame
  - mean time delay T

$$T = \frac{1}{\mu C - \lambda}$$

- With FDM
  - divide into N subchannels
  - each subchannel capacity **C/N** bps
  - Mean input rate λ/N

$$T_{FDM} = \frac{1}{\mu(C/N) - (\lambda/N)} = \frac{N}{\mu C - \lambda} = NT$$

- Precisely the same arguments that apply to FDM also apply to time division multiplexing (TDM).

Dynamic Channel Allocation

- **Before we get to dynamic allocation, we have to consider 5 key assumptions:**
  1. **Station Model**
  2. **Single Channel Assumption**
  3. **Collision Assumption**
  4. **Continuous/Slotted Time**
  5. **Carrier/No Carrier Sense**

1 – Station Model

- The model consists of N independent **stations** (also called **terminals**).
- Each station **generates frames** for transmission.
- Once a frame has been generated, the station is **blocked and does nothing** until the frame has been successfully transmitted.

2 – Single Channel Assumption

- It is the heart of the model.
- A single channel is available for all communication.
- As far as the hardware is concerned, all stations are equivalent.
- But protocol software may assign priorities to different stations.

3 – Collision Assumption

- If two frames are transmitted at the same time, they will "collide".
- In a collision, both frames are completely lost.
- A collided frame must be retransmitted again later.
- All stations can detect collisions.
- There are no errors other than collisions.

4 – Continuous/Slotted Time

- Continuous Time
  - Time is treated as a continuum.
  - Time is not divided into discrete intervals.
  - Frame transmission can begin at any instant.
- Slotted Time
  - Time is divided into discrete intervals (slots).
  - Frame transmissions always begin at the start of a slot.
  - A slot may contain 0, 1, or more frames.
    - 0 frames = idle slot
    - 1 frame = successful transmission
    - 2+ frames = collision
- Some systems use one and some systems use the other. But for a given system, only one of them holds.

5 – Carrier/No Carrier Sense

- Carrier sense（载波侦听）
  - Stations can tell if the channel is in use before sending
  - If the channel is sensed as busy, no station will attempt to use it until it goes idle.
- No carrier sense （非载波侦听）
  - Stations do not sense the channel before trying to use it.
  - Only later can they determine whether the transmission was successful.
- LANs generally have carrier sense.
- Note that the word "carrier" in this sense refers to an electrical signal on the cable.

Multiple access protocol

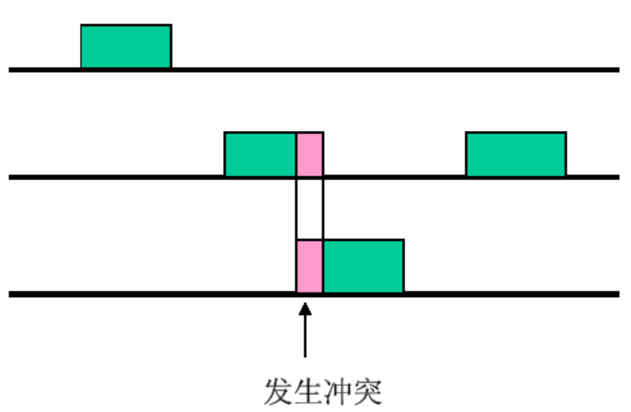
- Random Access Protocol（随机访问协议）
  - Characteristic：compete using channel, maybe result in collision
  - Typical random access protocol
    - ALOHA
      - Pure ALOHA；slotted (分隙,分槽）ALOHA
    - CSMA
    - CSMA/CD（Ethernet）
- 受控访问协议（ Controlled Access ）
  - Characteristic：is allocated channel, no collision

ALOHA Protocol

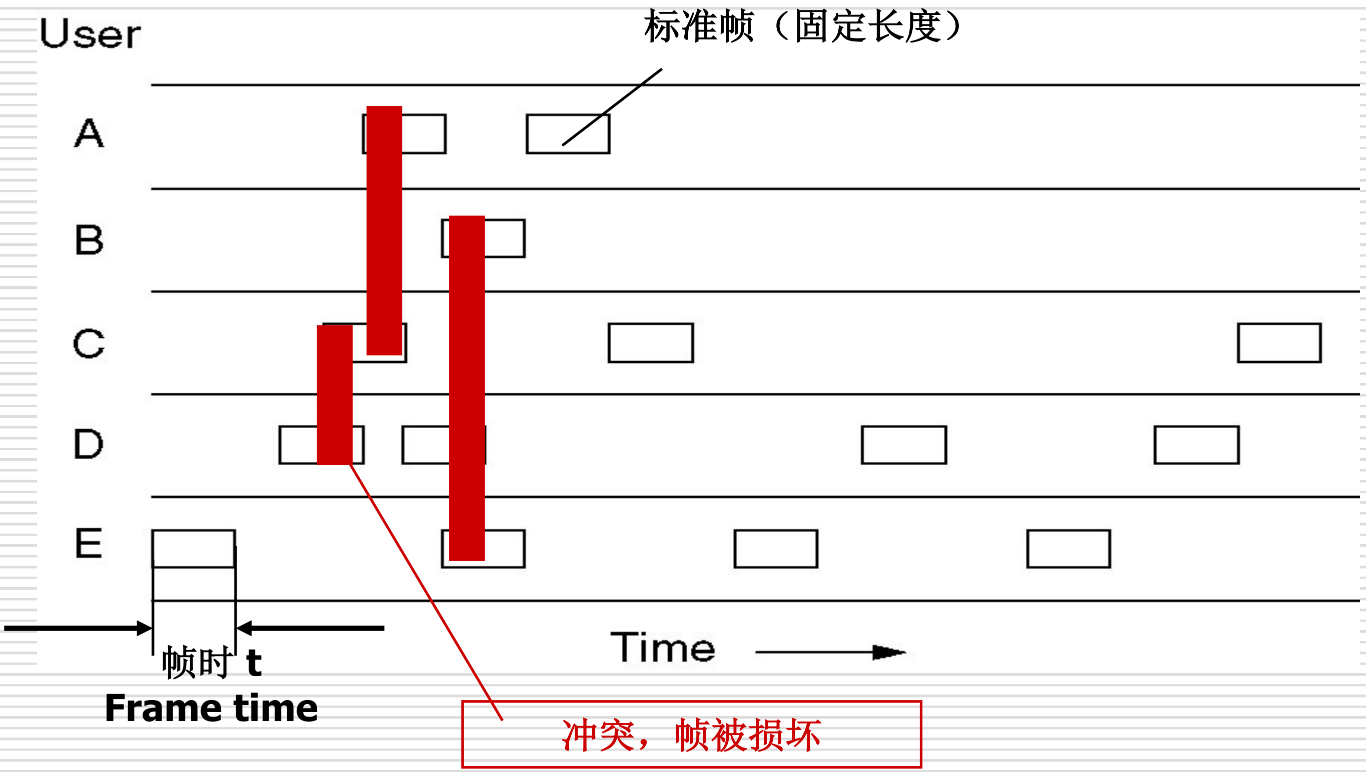
- Norman Abramson and his colleagues at the university of Hawaii devised in the 1970s
- Two version
  - Pure ALOHA
  - Slotted ALOHA (分隙ALOHA协议)

Basic idea of Pure ALOHA（1/2）

- Let users transmit whenever they have data to be sent.（想发就发）
- A sender can always find out whether or not its frame was destroyed by listening to the channel output .（冲突检测）
- If the frame was destroyed, the sender just waits a random amount of time and sends it again.（重发）



Basic idea of Pure ALOHA（2/2）



- Can send data whenever
- Collision is unavoidable if ≥2 staions send data at the same time

Mathematical description of pure ALOHA

- Frame time(T): the amount of time needed to transmit the standard, fixed length frame(标准帧).
- Assume: new frame is generated according to Poisson distribution (服从泊松分布)
  - New frame per frame-time (users generate)： N (mean value)
  - New frame per frame-time（Channel generate）： G (mean value)
- Analysis：
  - 0< N < 1; low-load N~0; heavy-load N~1
  - G >= N; low-load G=N（no collision）， heavy-load G>N（retransmit）
- Probability

  $Pr[k] = G^k e^{-G} / k!$ (一个帧时内信道中产生k个帧，泊松分布)

  $Pr[k=0] = e^{-G}$ （一个帧时内信道中产生0个帧）

How is the efficiency?

- **Throughout(吞吐率) is S**
  - **Is just offered load, 0<S<1**
  - **If S = 1, frame is sent one by one, there is no slot between sent-frame.**
  - **S value shows line-utility**

How is the efficiency? (cont'd)

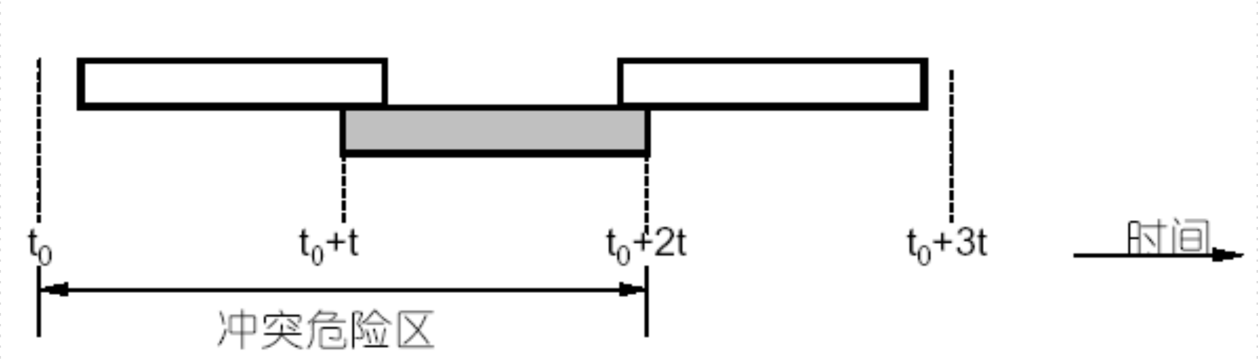
- Carried load(运载负载,网络负载) G
  - The number of the frame generated by all stations (including retransmitted frame)
  - Apparently， G≧S，
    - G=S, only if no collision
    - G>>1， collision is occurred frequently
- P_0：P_0 is the probability which frame sent successfully (no collision).

$$\boxed{S = G \times P_0}$$

How to get P_0?

- Dangerous period of collision： 2t
  - Generated frame(mean)： 2G
  - Probability of no collision：

$P_0 = e^{-2G}$（why？）



How to get P_0?(cont'd)

- 生成0帧的概率(即不生成帧的概率)，即是将k=0代入上式，得：$P[0] = e^{-G}$
  - 注意：P_0与P[0]是两个完全不同的概念。
- P_0的含义是在连续两个T的时间内都没有其它帧生成的概率，即连续两个T的时间内都生成0帧的概率(P[0])之乘积。即：
- $P_0 = P[0]P[0] = (e^{-G})^2 = e^{-2G}$

Performance of pure ALOHA

- **Put $P_0 = e^{-2G}$ into $S = GP_0$:**

  $S = Ge^{-2G}$

- **Calculate the maximum of S:**

  $S' = e^{-2G} - 2Ge^{-2G} = 0$

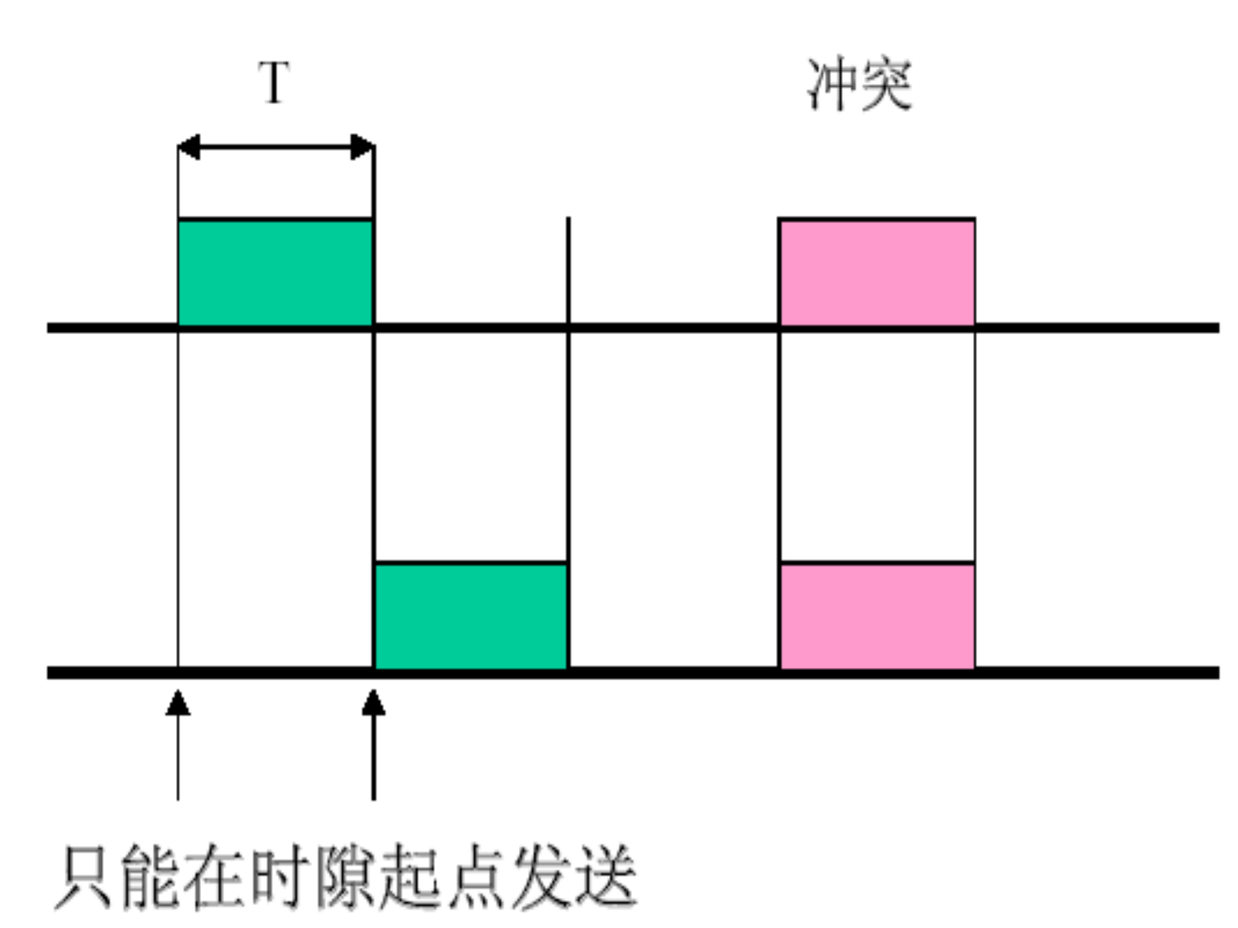
  When $G = 0.5$, $S \cong 0.184$

  That is: the maximum line-utility is 18.4%

Slotted ALOHA(时隙ALOHA)

- Time is divided up into discrete intervals, each interval corresponding to one frame-time.
  - An interval is the time which is used to transmit a frame
- A terminal (station) is not permitted to send until the beginning of the next slot (interval)
- Collision can only be occurred at the very beginning of interval (slot)
  - Once a station compete successfully, and then no collision during this slot(interval)

Slotted ALOHA



Performance of slotted ALOHA

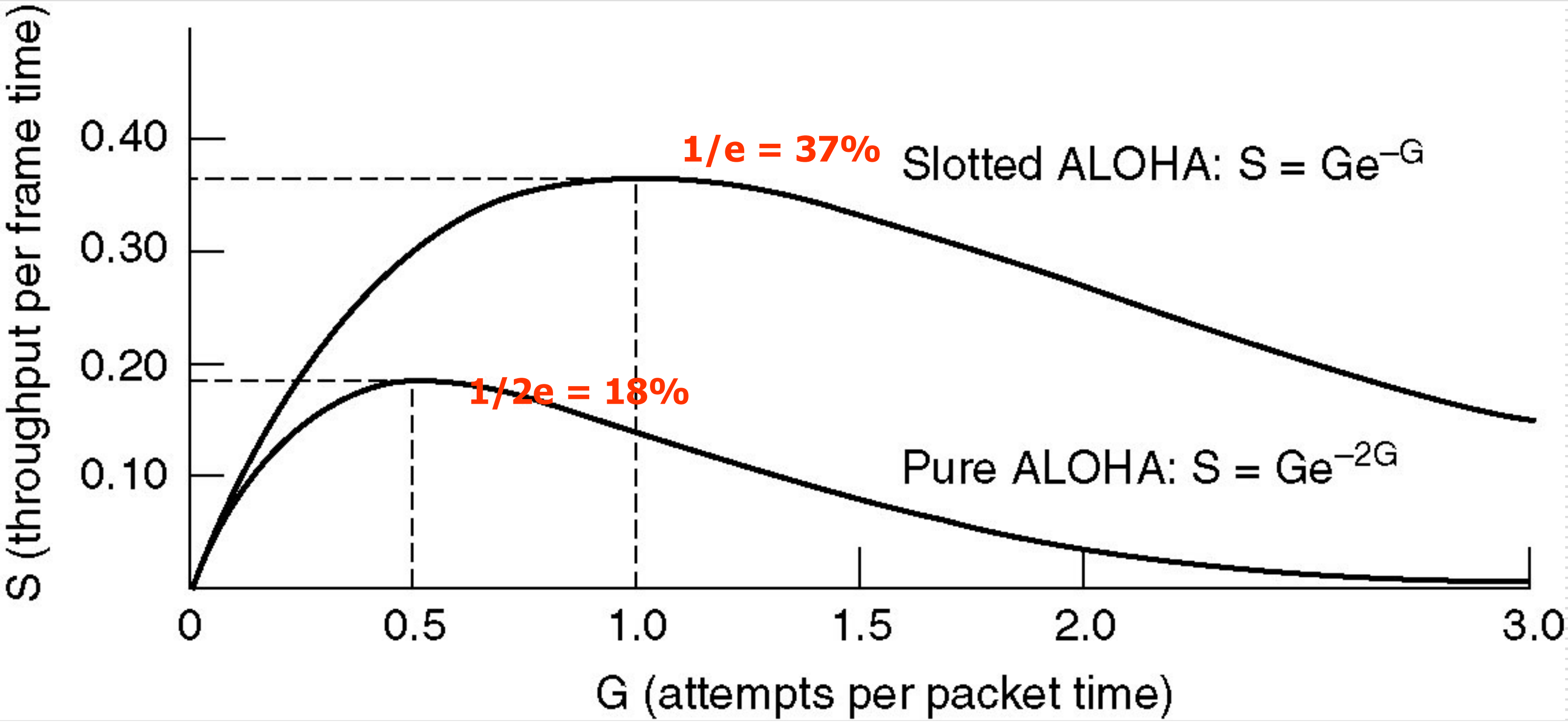
- $P[0] = e^{-G}$
  - $P_0 = P[0] = e^{-G}$（why？）
  - $S = Ge^{-G}$

  When G = 1, S can get maximum:

  $S_{max} = 1/e \cong 0.368$

  So, the efficiency double the pure ALOHA

The relation between S and G



Brief summary

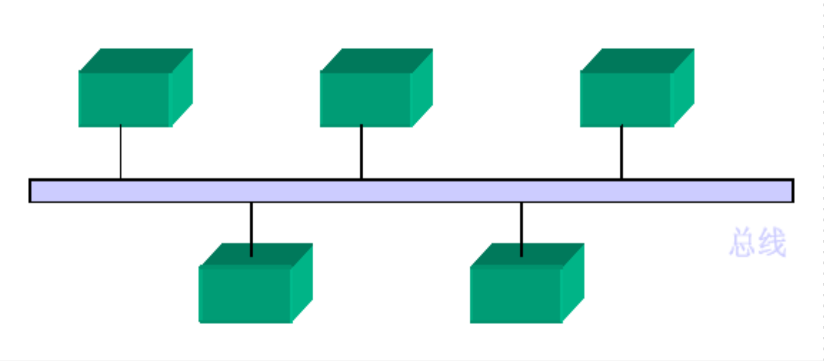
- Pure ALOHA
  - Dangerous period of collision
    - Time length： 2t
    - Generated frame (mean)： 2G
    - Probability of no collision： $P_0 = e^{-2G}$
  - Throughput： $S = G\,P_0 = G\,e^{-2G}$
- Slotted ALOHA
  - Frame-time T is discrete interval
  - Dangerous period of collision ： t
  - Throughput ： $S = G\,P_0 = G\,e^{-G}$

Comparation of pure ALOHA and slotted ALOHA

- **Pure ALOHA:**
  - **A Frame is sent at once when it is generated**
  - **Collision may be occurred all the time**
- **Slotted ALOHA**
  - **Frame is sent only at the very beginning of interval**
  - **Frame is sent successfully once no collision is occurred at the beginning of interval (slot)**

Carrier Sense Protocols

- CSMA：Carrier Sense Multiple Access
- Characteristic： “先听后发”
  - Improve ALOHA
- Types
  - Non-persistent CSMA
  - Persistent CSMA
    - 1-persistent CSMA
    - P-persistent CSMA



Non-persistent CSMA

- Basic idea:
  - ①A station sense channel, if no one else is sending, then it begin sending
  - ②If the channel is already in use, it doesn't sense it ,instead, it waits a random time and repeats①。
- Advantage: Waiting a random time can reduce the probability of collision
- Disadvantage: longer delay (random time, maybe no data is transmitted)

Persistent CSMA (1-persistent)

- Basic idea:
  - ① A station sense channel, if no one else is sending, then it begin sending
  - ②If channel is busy, the station waits and sense it continually, once the channel becomes idle, it begin transmitting
  - ③If collision is occurred, waits a random time and repeats①。
- Advantage: shorter delay than non-persistent
- problem: if 2 or more stations are wait at the same time, once the channel becomes idle, the collision is unavoidable.

P-persistent CSMA

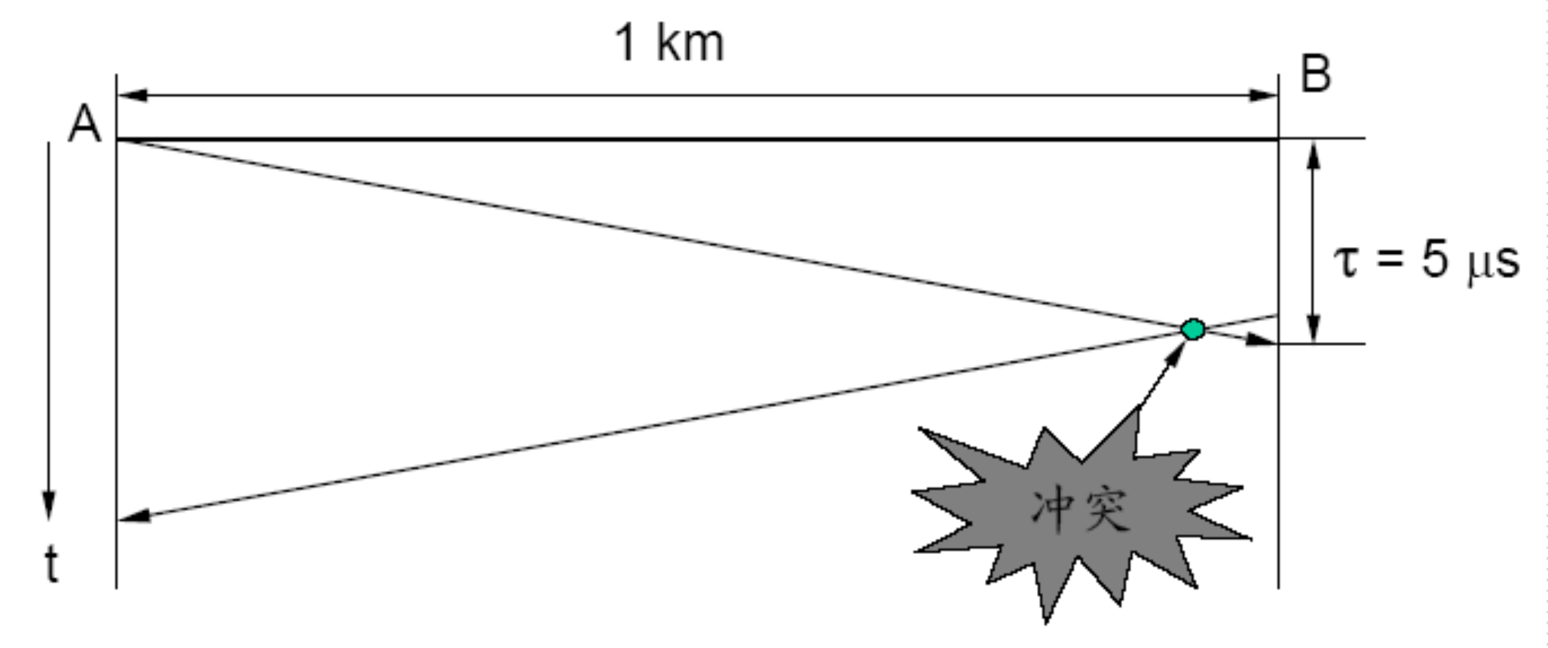
- Basic idea:
  - ① A station sense channel, if no one else is sending, then it transmits with probability p, and delay one unit-time to transmit with probability (1–p)
  - ② If channel is busy, the station waits and sense it continually, once the channel becomes idle, repeats①。
  - ③If a station has delayed its transmission 1 unit time, repeat①。
- So, 1-persistent is a special example of p-persistent

Question

- For 1-persistent CSMA, if a station send its data after sensing the channel is idle, can a collision be occurred?

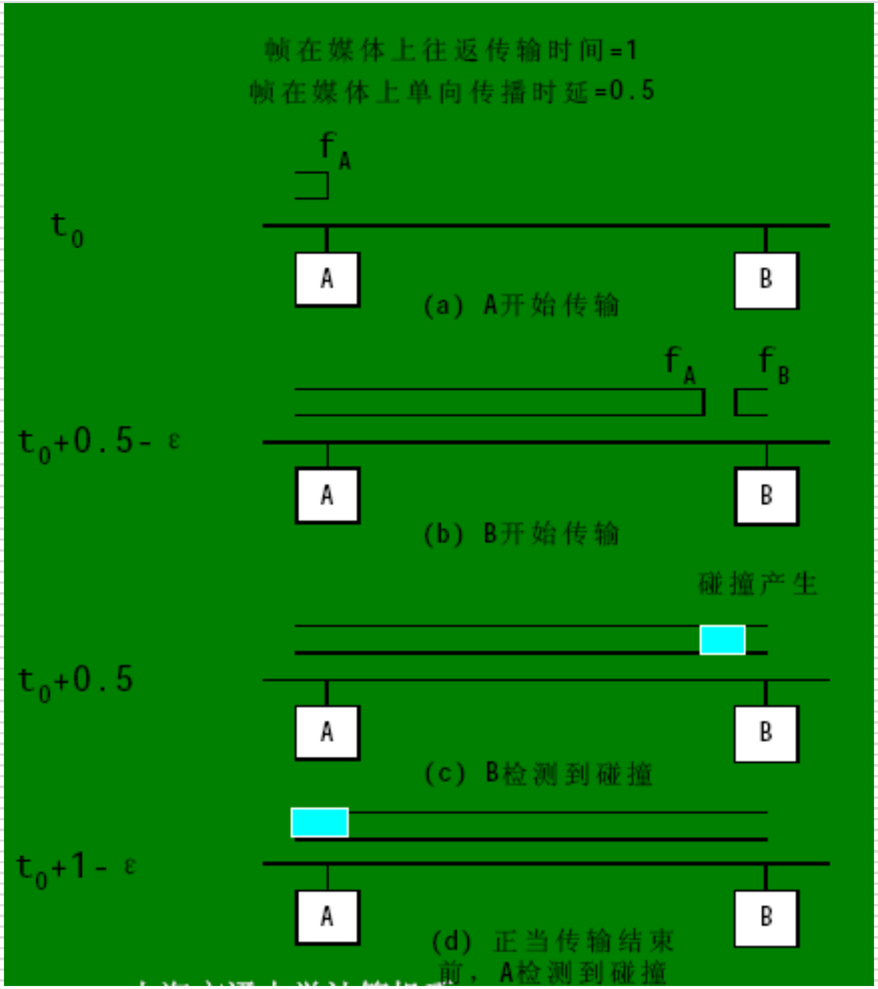
- Key: yes!
  - Cause：
    - 2 or more stations send data at the same time
    - Propagation (传播延迟时间)
      - Propagation-speed is 0.65C, about 200m/μs

Influence of propagation



Collision window(冲突窗口)

- 发生冲突时间的上限，即发送站发出帧后能检测到碰撞的最长时间，数值上等于最远两站传播时间的两倍，即2τ



How to compute collision window

- Assume： signal's propagation speed v is about: $v = 200m\ /\mu s$， NIC delay is t_{PHY}， then：

  $t= S/v$，

  Collision window (slot time)= $2t + 2t_{PHY}$，

- If repeater is used, assume delay caused by repeater is $t_{中继器}$, then:

  Collision window (slot time)= $2*(t + t_{PHY}+ N\times t_{中继})$

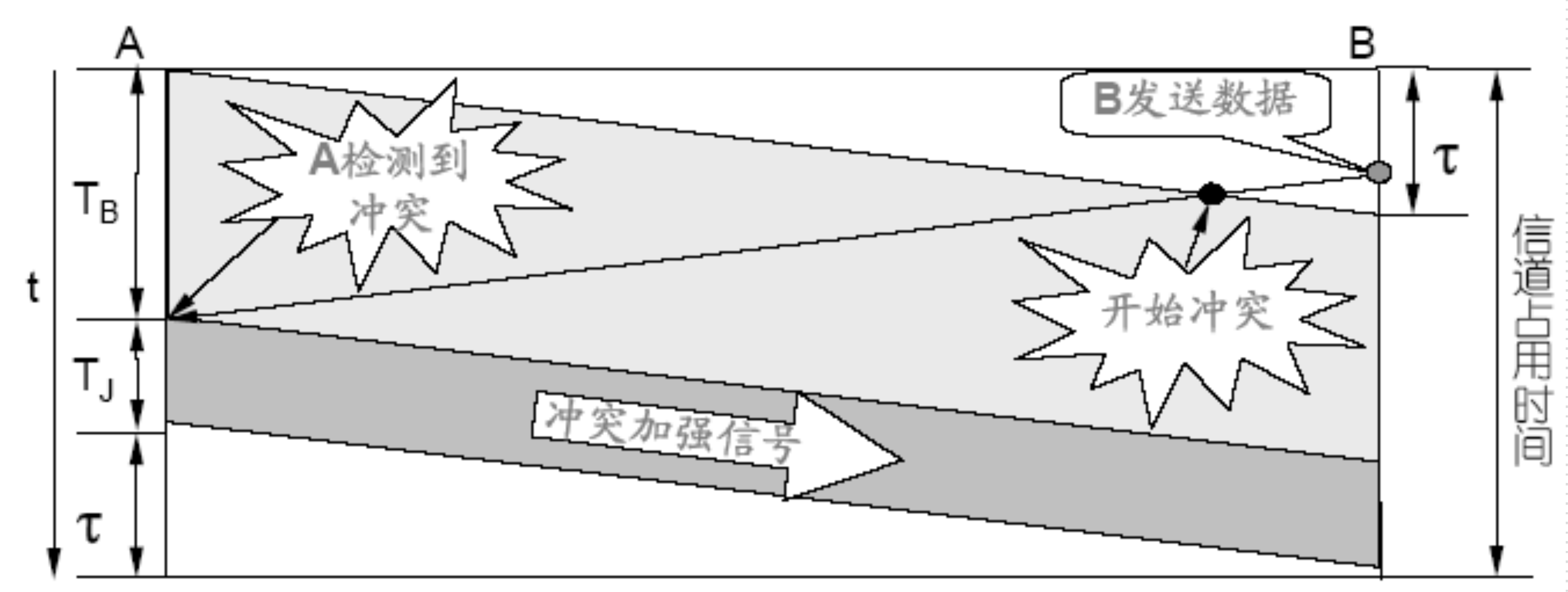
CSMA/CD

- **CSMA with Collision Detection (Carrier Sense Multiple Access with Collision Detection)**
- “先听后发、边发边听”
- **Basic idea:**
  - **① A station sense channel, if no one else is sending, then it begin sending.**
  - **② If channel is busy, the station waits and sense it continually, once the channel becomes idle, send data at once.**
  - **③If collision is occurred, aborts its transmission, and waits a random time and repeat①。**

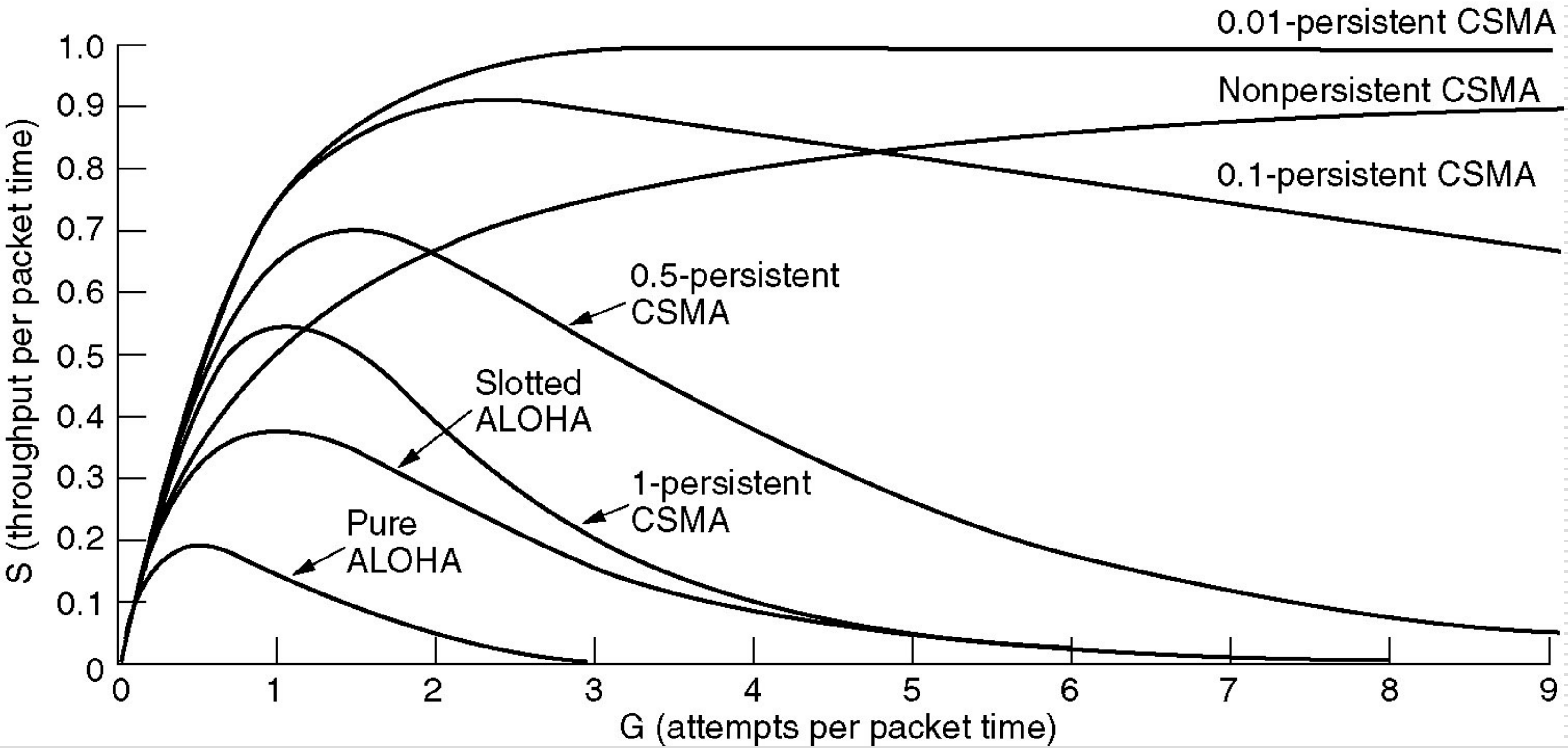
Characteristic of CSMA/CD

- **All station receive signal of itself while sending, so, the station detects a collision if signals are different.**
- **Aborts its transmission at once it detect a collision, and send a jam signal in order to notify other stations when there is a collision; All stations need a random time to retransmit again.**
- **Be widely used on LANs in the MAC sublayer**

Principle show of CSMA/CD

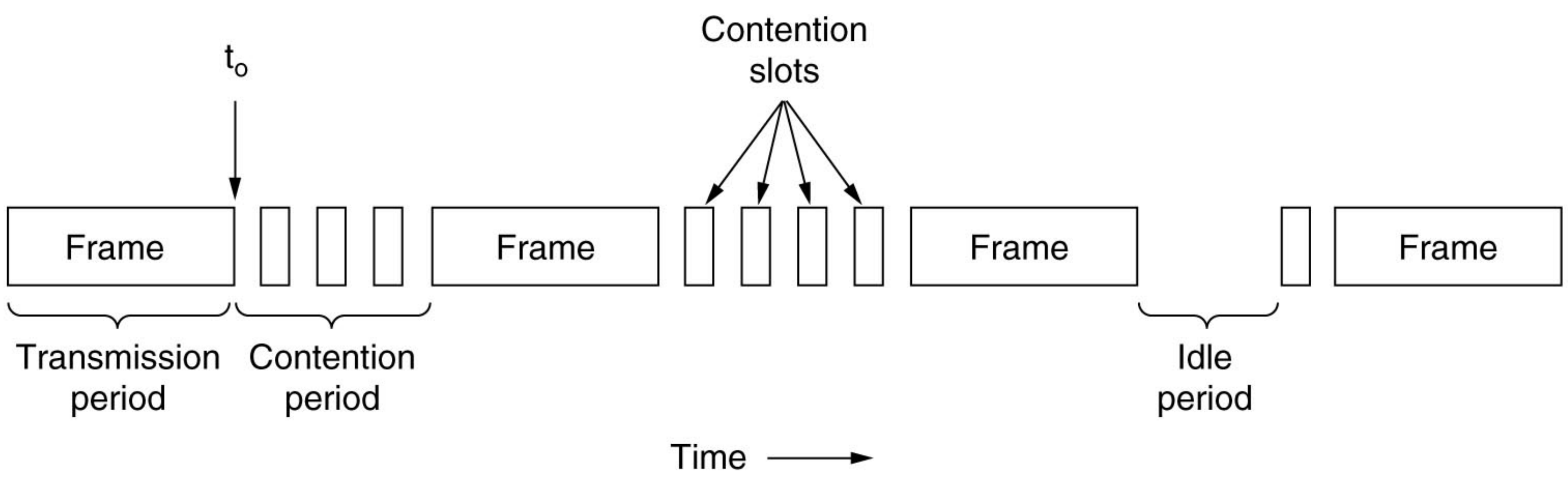


Comparison of performance



Conceptual model of CSMA/CD

- CSMA/CD channel can be in one of three states
  - Contention
  - Transmission
  - idle



Collision detection and processing

- Assume the length of time for data to propagate between the two furthest terminals is τ.
- If a second terminal begins to transmit at $\tau - \varepsilon$, then the maximum amount of time it will take for the sender to notice the collision is $2\tau - \varepsilon$.
- The minimum amount of time is when both start transmitting at the same time, making the minimum amount simply τ.

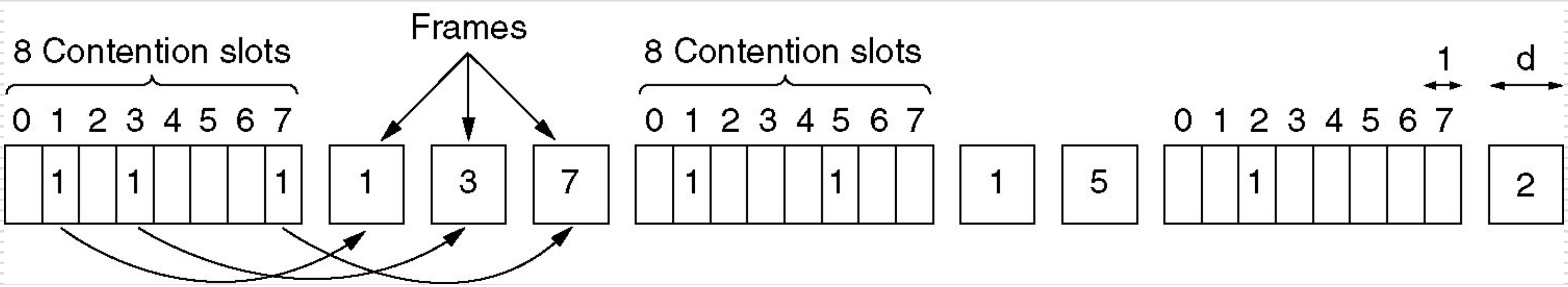
Other Multiple Access Protocol

- Collision-Free protocol (无冲突的协议)
  - A Bit-Map protocol(位图协议,预留协议)
  - Binary Countdown protocol (二进制倒计数协议)
- Limited-Contention protocol (有限竞争协议)
- WDMA（波分多路访问协议）
- MACAW（无线局域网协议）
  - MACA：Multiple Access with Collision Avoidance
  - MACAW：MACA for wirless

A Bit-Map Protocol

- One assumption: there are N stations, each with a unique address from 0 to N –1 ``wired'' into it.
  - Which station gets the channel after a successful transmission ?
- A basic bit-map protocol:
  - Each contention period consists of exactly N slots, with one slot time being at least 2τ.
  - If station i (0<= i <= N -1) has a frame to send, it transmits 1 bit during the ith slot; otherwise, it transmits 0 bit during the ith slot.
  - After all slots have passed by, stations begin transmitting in numerical order.
  - After the last ready station has transmitted its frame, another N-bit contention period is begun.

A Bit-Map Protocol (cont'd)



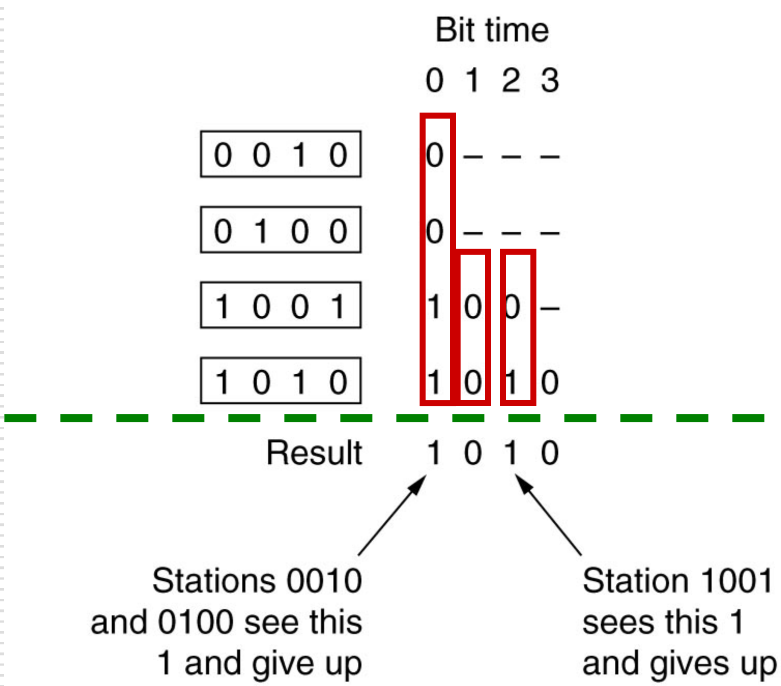
Performance analysis

- Assume: time unit is contention bit slot, data frames consisting of d time units and N is the number of stations or slots.
  - low load: d/(N+d)
  - high load: d/(d+1)
- Mean frame delay (high load): N(d+1)/2
- Disadvantage: no priority

Binary Countdown (二进制倒数)

- Each station has a binary address. All addresses are the same length.
- To transmit, a station broadcasts its address as a binary bit string, starting with high-order bit.
- The bits in each address position from different stations are BOOLEAN ORed together (so called Binary countdown).
- As soon as a station sees that a high-order bit position that is 0 in its address has been overwritten with a 1, it gives up.
- After the winning station has transmitted its frame, there is no information available telling how many other stations to send, so the algorithm begins all over with the next frame.

Binary Countdown (cont'd)



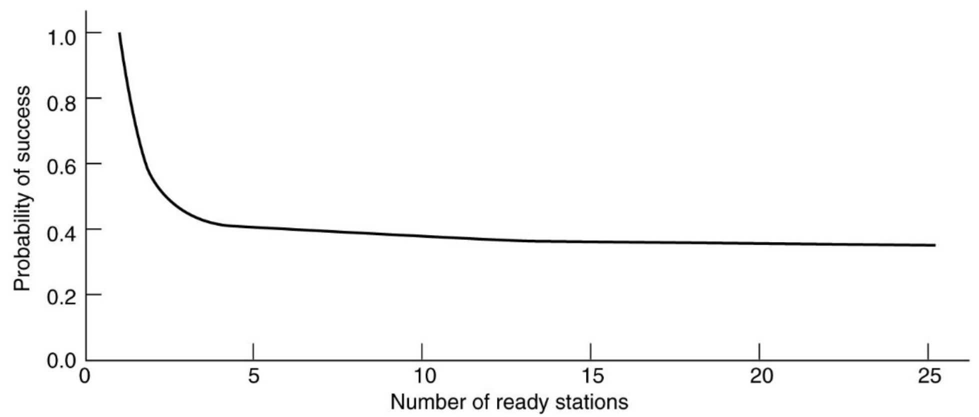
Improvement: prevent lower-station from silence long

Efficiency analysis

- Bits which N stations address need is $\log_2 N$
- Efficiency is: $d/(d+\log_2 N)$
- If first field of frame is address, then efficiency is 100%

Limited-Contention Protocol

- When low load, use contention, can reduce delay
- When high load， use contention-free, can get high line-utility (efficiency)



Summary

- Learn random access protocol(随机访问协议)
- Master pure ALOHA and slotted ALOHA
- Master the characteristics of each CSMA
  - 1-P CSMA
  - CSMA/CD
- Learn collision-free protocol (无冲突的协议)
  - A Bit-Map protocol
  - Binary Countdown
- other

Thanks!