# COMPUTER NETWORKS

## - Chapter4 Medium Access Control Sublayer 1

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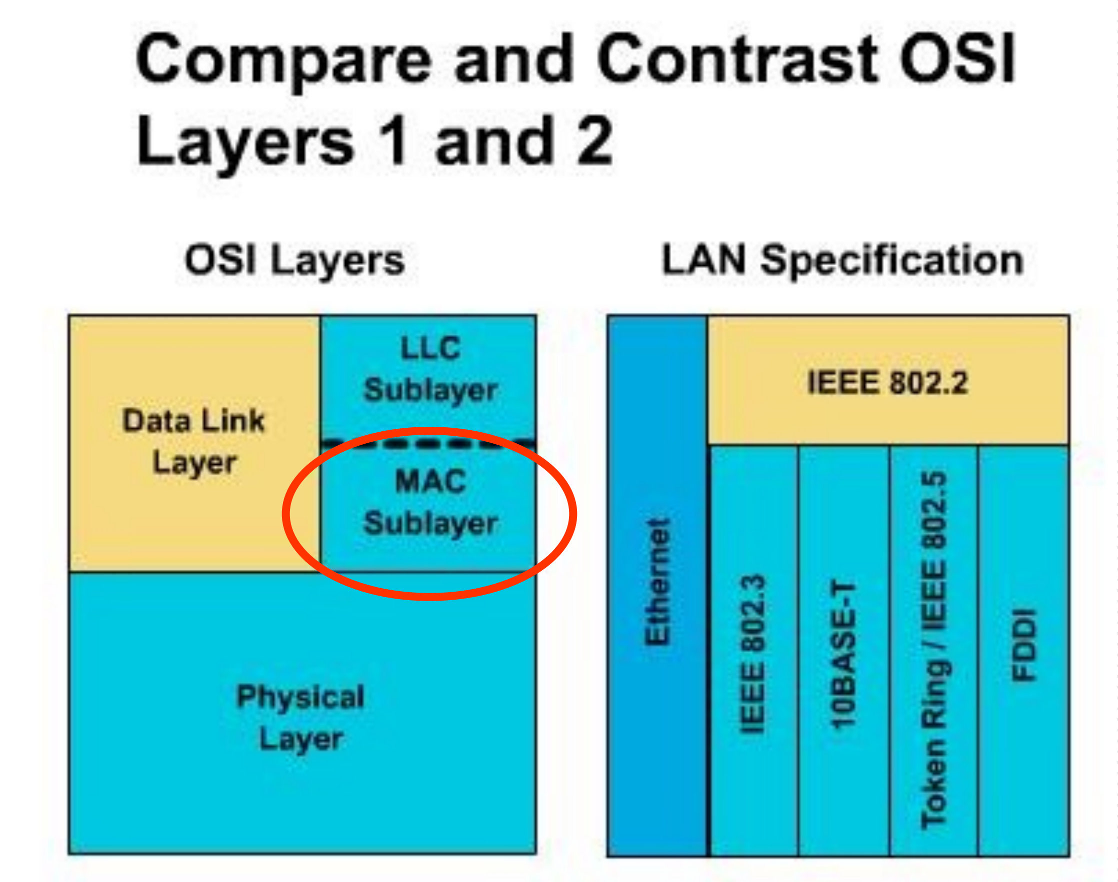
# Position of MAC sublayer

**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

$$T = {}^{1}\!\!\diagup_{\mu C - \lambda}$$

- 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

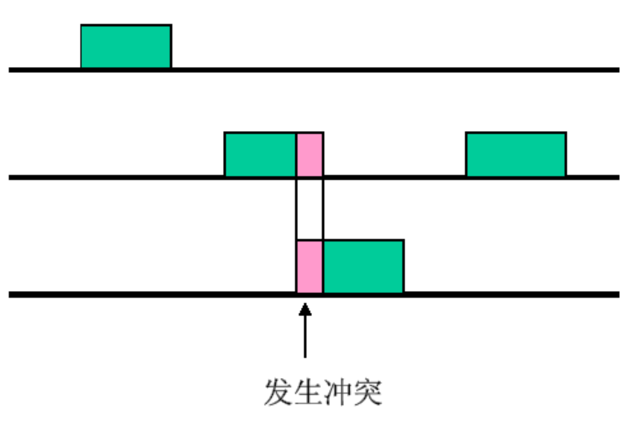
- Random Access Protocol（随机访问协议）
  - Characteristic： compete using channel, maybe result in collision
  - Typical random access protocol
    - ALOHA
      - Pure ALOHA； slotted (分隙,分槽）ALOHA
    - CSMA
    - CSMA/CD（Ethernet）
- 受控访问协议（ Controlled Access ）
  - Characteristic： is allocated channel, no collision

# ALOHA Protocol

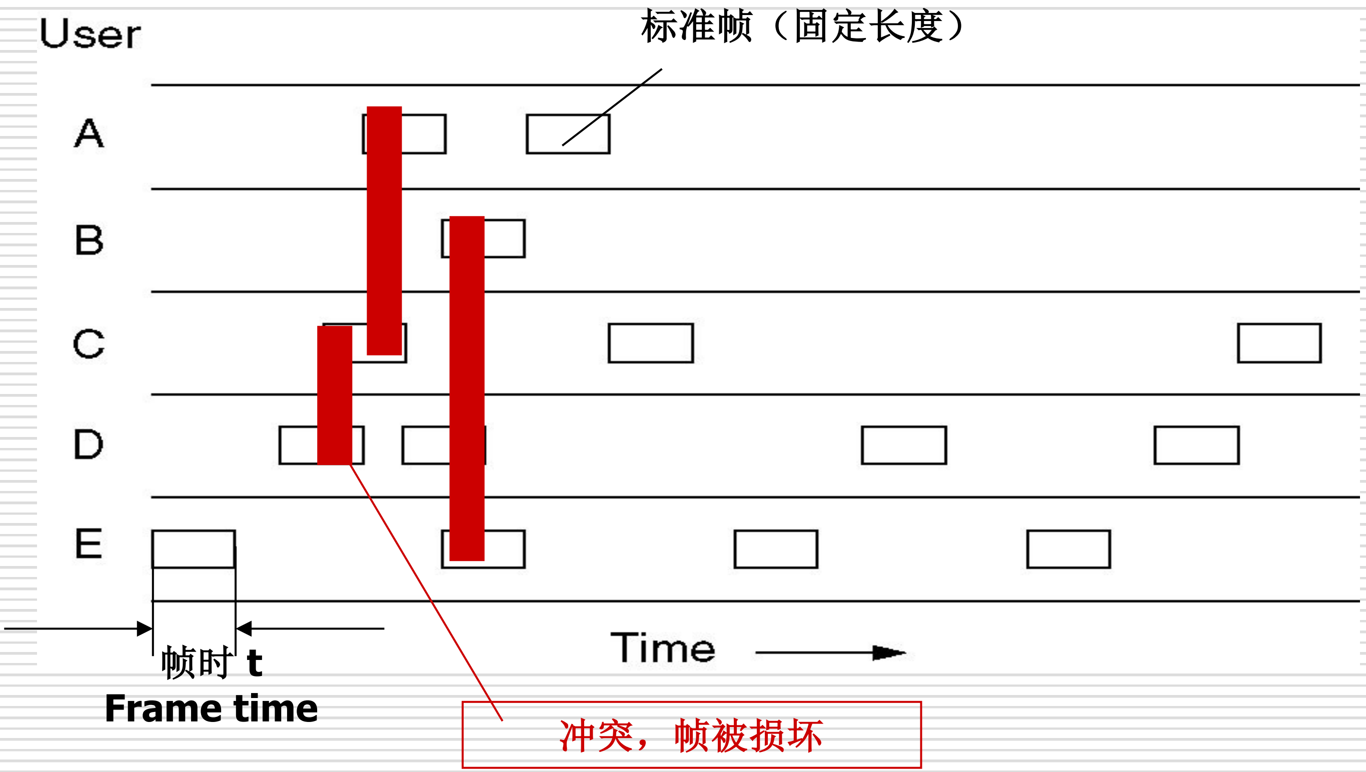
- Norman Abramson and his colleagues at the university of Hawaii devised in the 1970s
- Two version
  - Pure ALOHA
  - Slotted ALOHA (分隙ALOHA协议)

# 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)

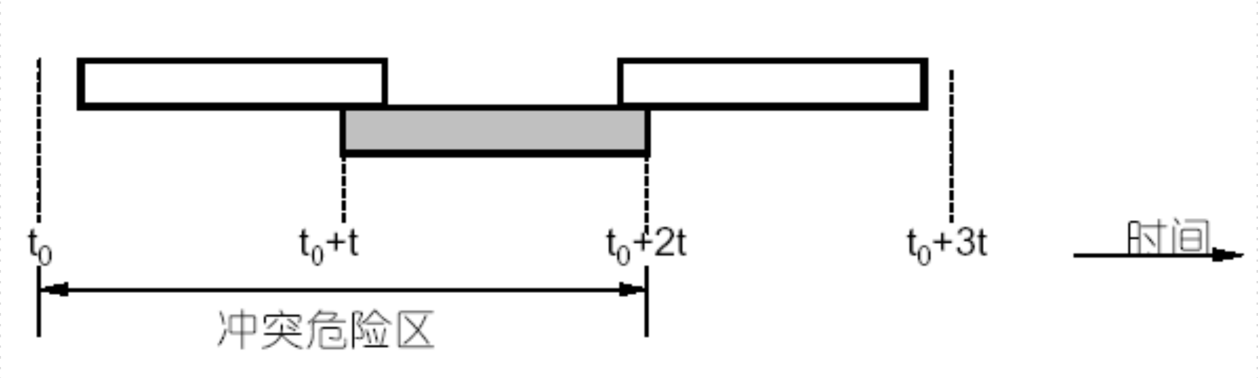
- Carried load(运载负载,网络负载) G
  - The number of the frame generated by all stations (including retransmitted frame )
  - Apparently，  G≧S，
    - G=S, only if no collision
    - G>>1，  collision is occurred frequently
- $P_0$：  $P_0$ is the probability which frame sent successfully (no collision).

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

# How to get $P_0$?

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

    $P_0 = e^{-2G}$（why？）



# Performance of pure ALOHA

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

  $S = Ge^{-2G}$

- **Calculate the maximum of S:**

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

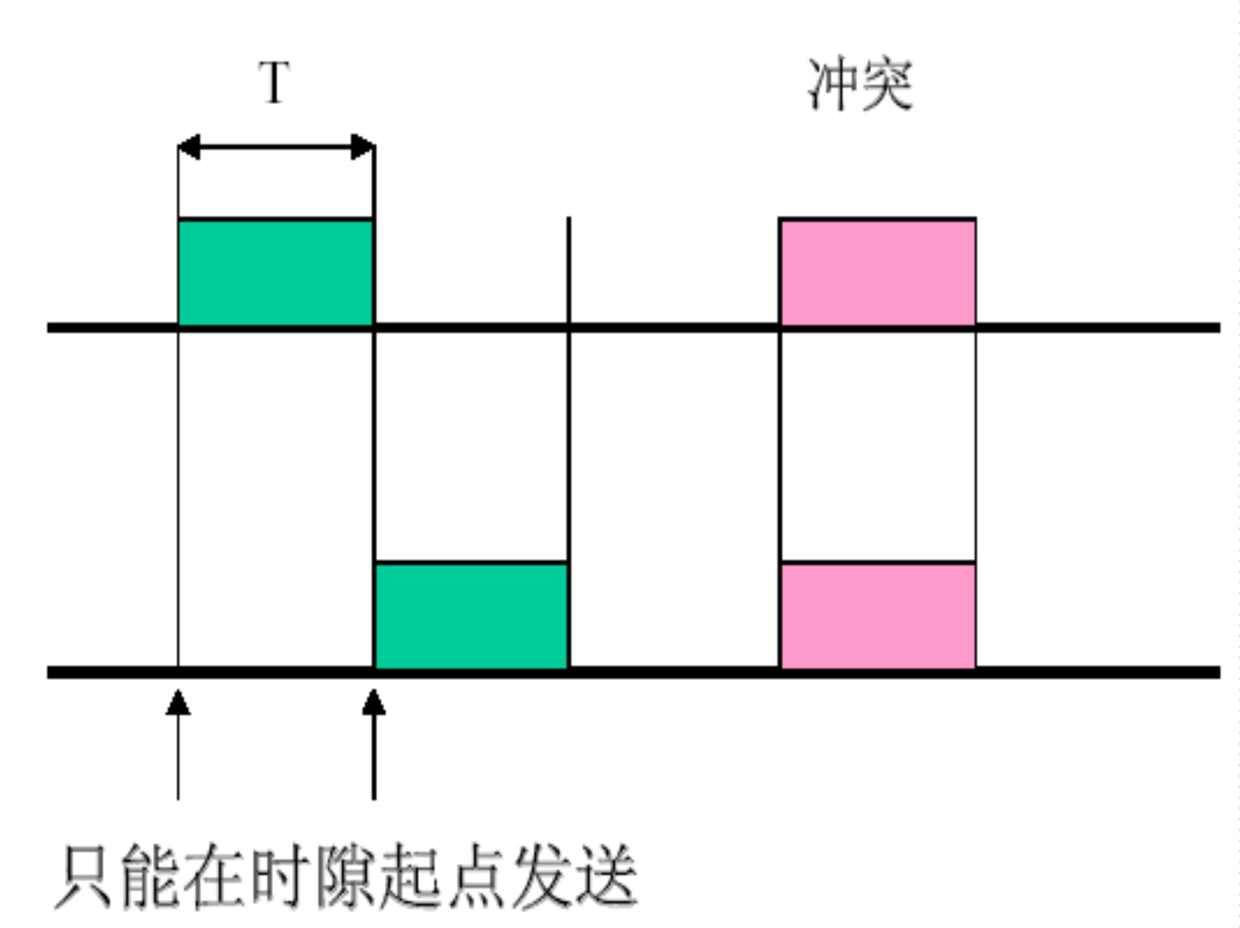
  **When $G = 0.5$，$S \cong 0.184$**

  **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

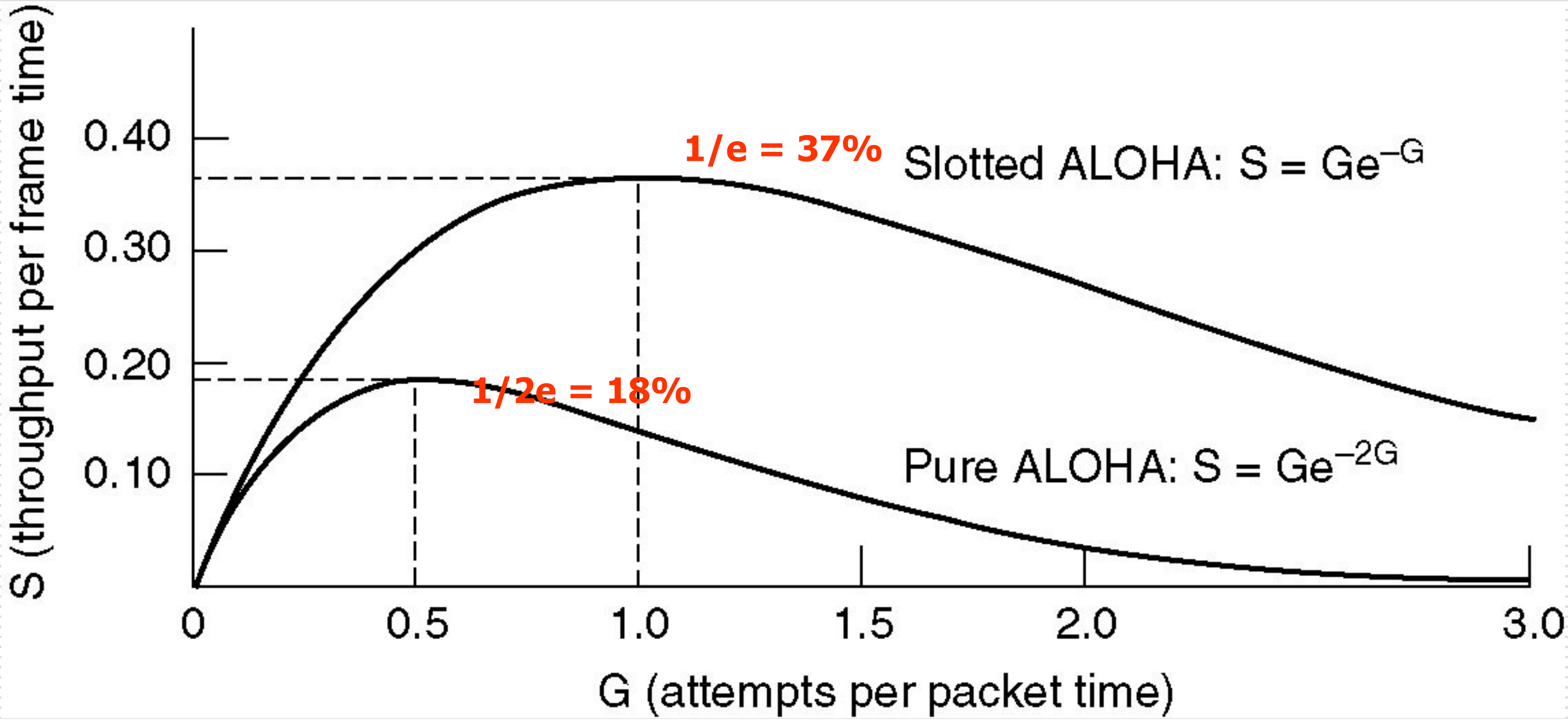
- $P[0] = e^{-G}$
  - $P_0 = P[0] = e^{-G}$（why？）
  - $S = Ge^{-G}$

  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

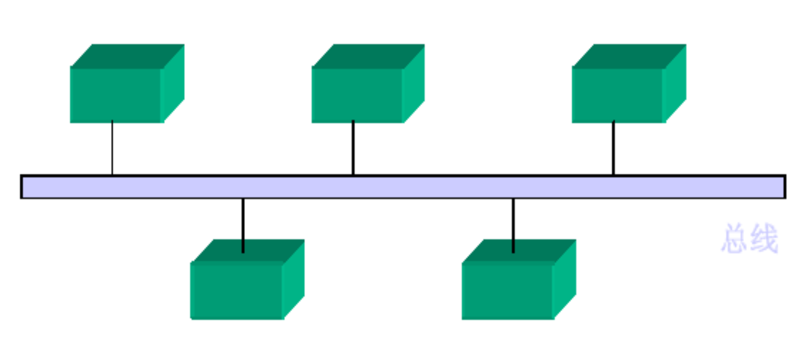
- Pure ALOHA
  - Dangerous period of collision
    - Time length: 2t
    - Generated frame (mean): 2G
    - Probability of no collision: $P_0 = e^{-2G}$
  - Throughput: $S = G\,P_0 = G\,e^{-2G}$
- Slotted ALOHA
  - Frame-time T is discrete interval
  - Dangerous period of collision : t
  - Throughput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

# 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

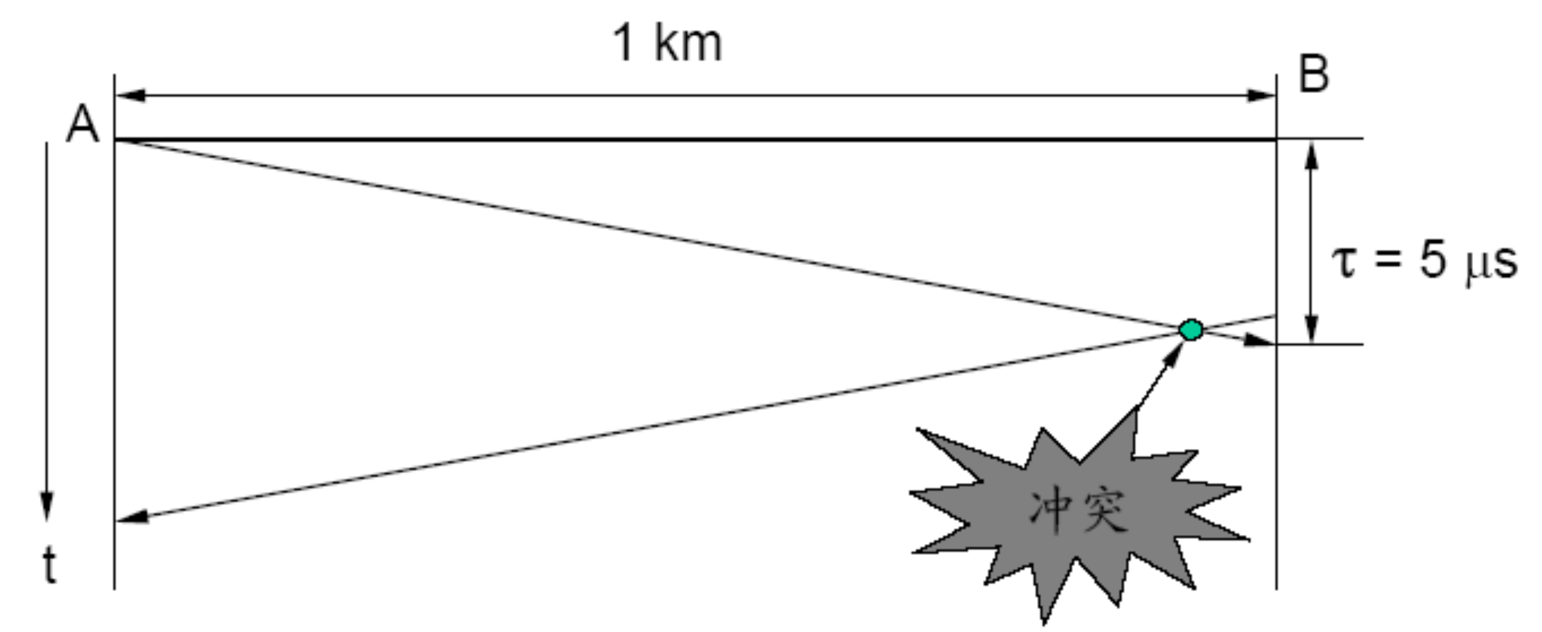
# Question

- 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

这里A的最大窗口是10μs



# 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)= $2*(t + t_{PHY} + N \times t_{中继})$**

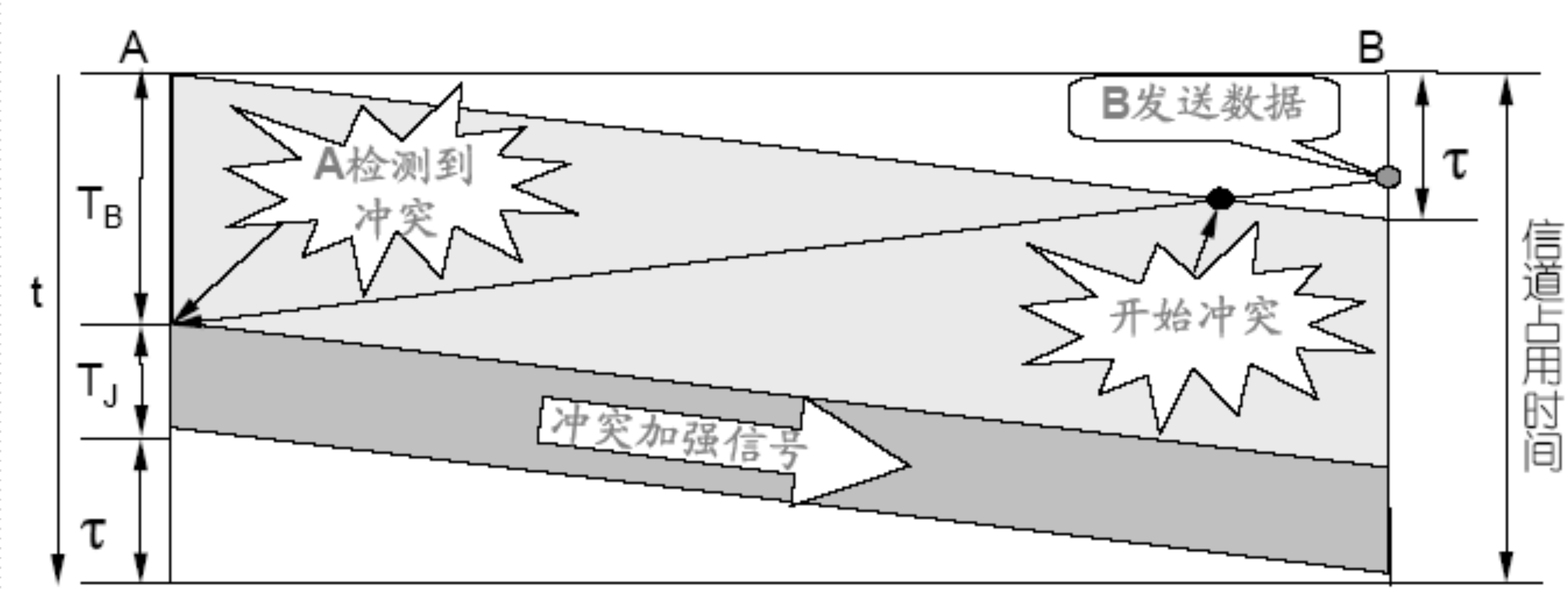
# CSMA/CD

- 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。

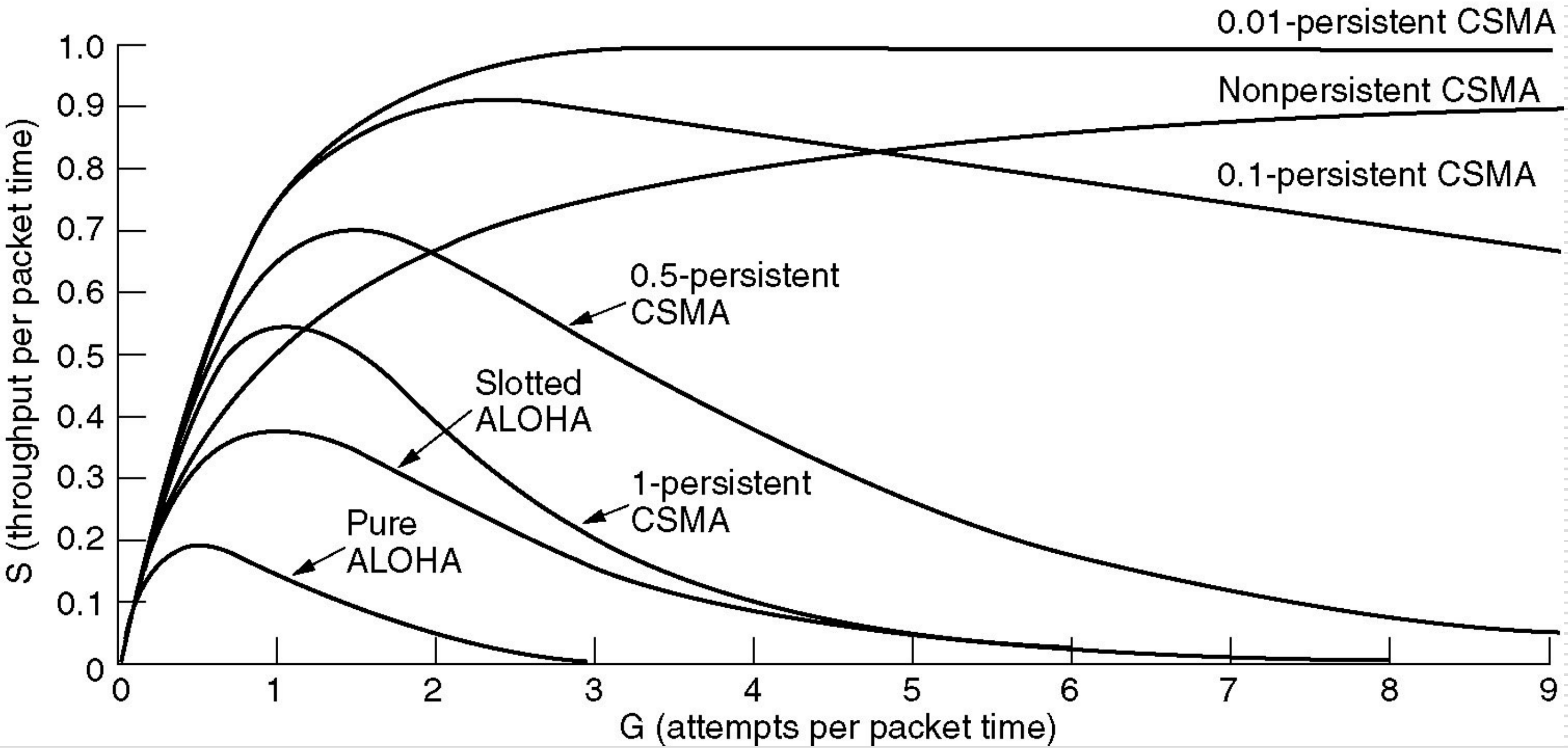
# Characteristic of CSMA/CD

- 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

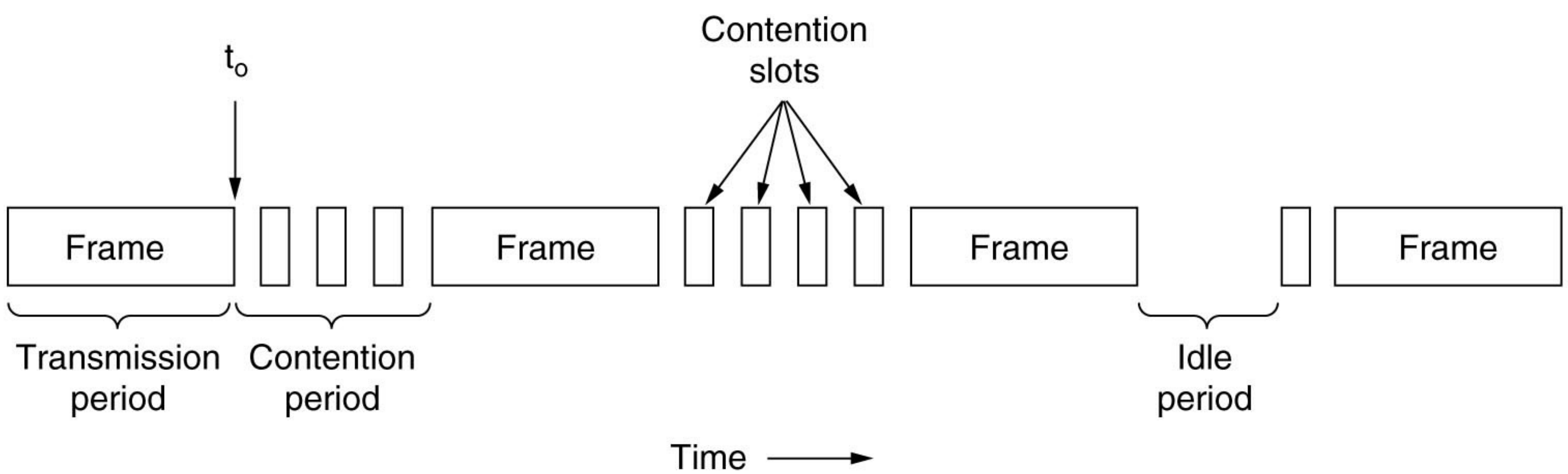


# Comparison of performance



# 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 $\tau$.
- 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 $\tau$.

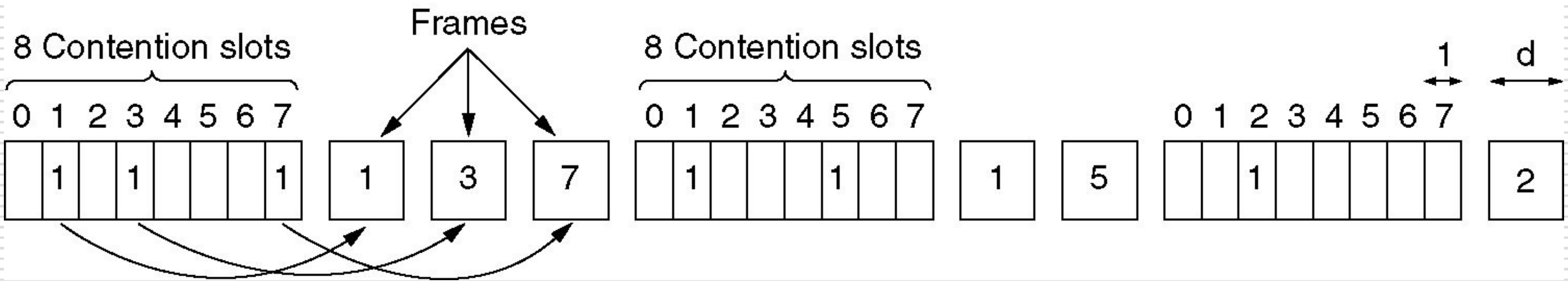
# Other Multiple Access Protocol

- Collision-Free protocol (无冲突的协议) 考试不用考
  - 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 $2\tau$.
  - 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)



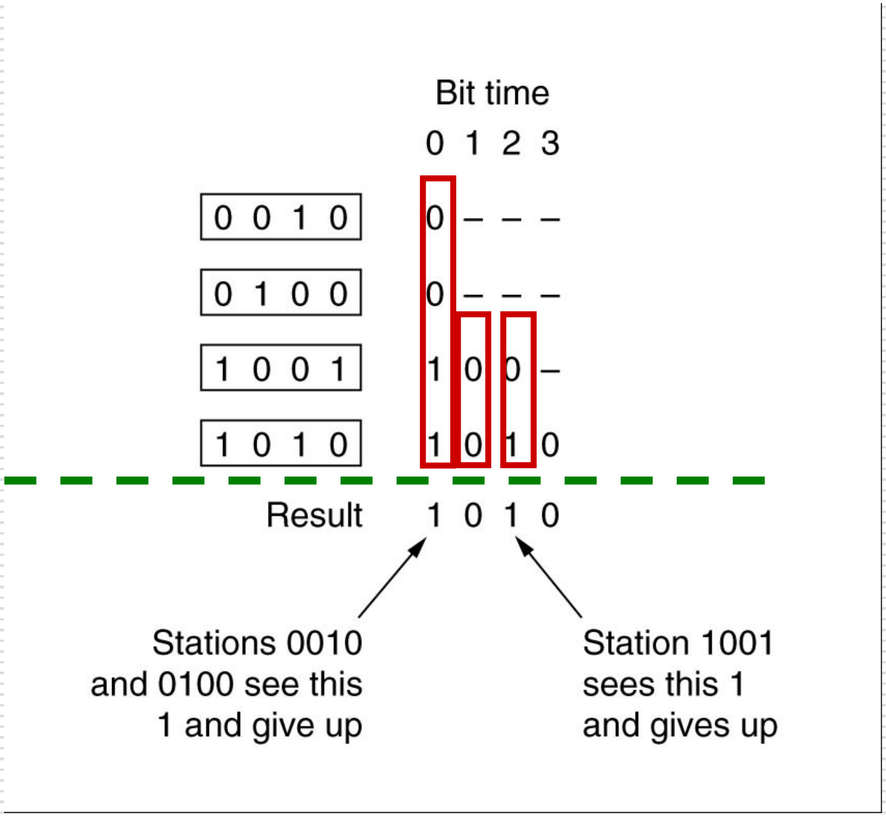
# Performance analysis

- 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%**

# 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!