Chapter 4
Local Area network

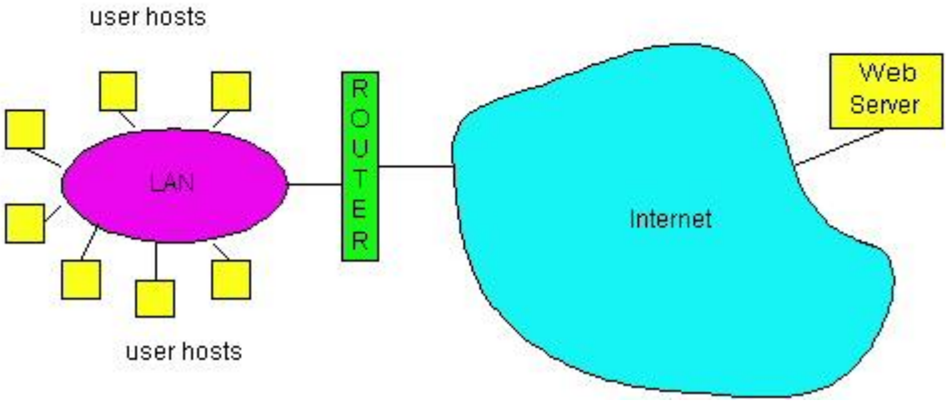
LAN technologies

Data link layer so far:

- services, error detection/correction, multiple access

Next: LAN technologies

- LAN model
- addressing
- Ethernet
- hubs, switches
- 802.11
- 802.15



Keypoints and Difficulties

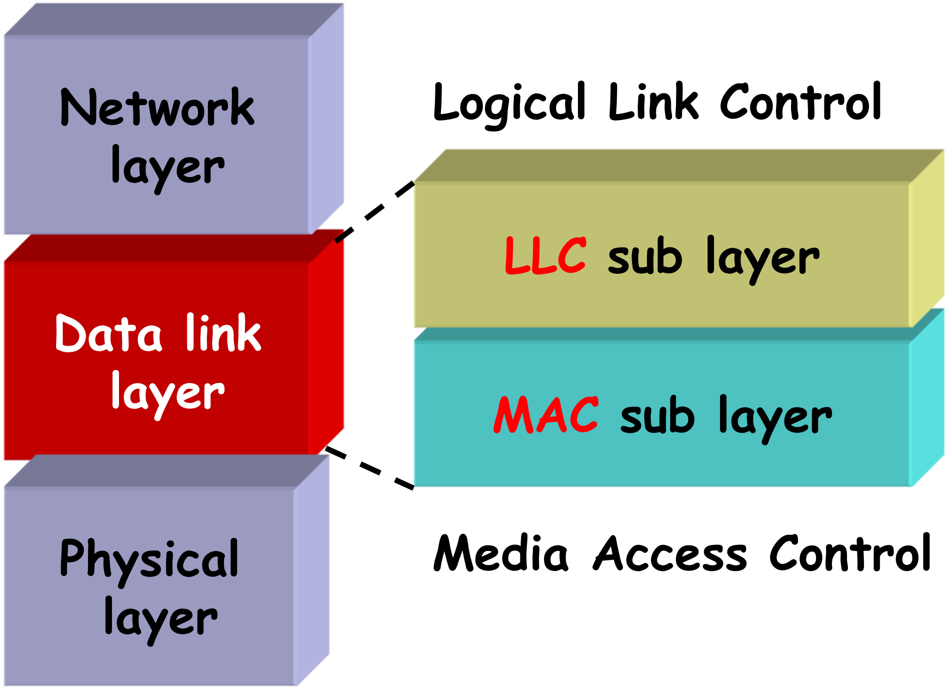
Keypoints:

- LAN model
- Ethernet
- Hubs, switches
- Wireless LAN-IEEE 802.11

Difficulties:

- The minimum frame length
- The exponential Backoff algorithm
- CSMA/CA

LAN model



Network layer

Data link layer

Physical layer

Logical Link Control

LLC sub layer

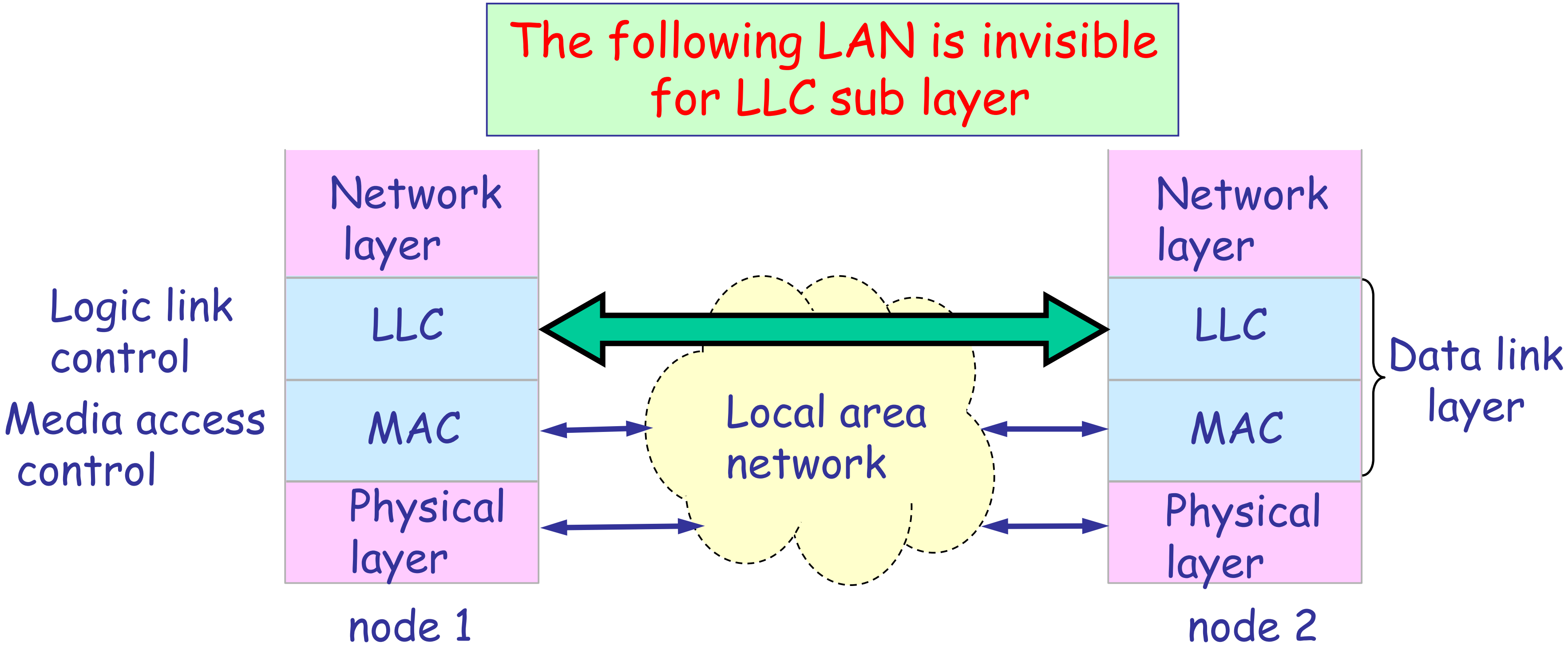
MAC sub layer

Media Access Control

Provide the connection environment to the upper level

Providing media access to the lower layer

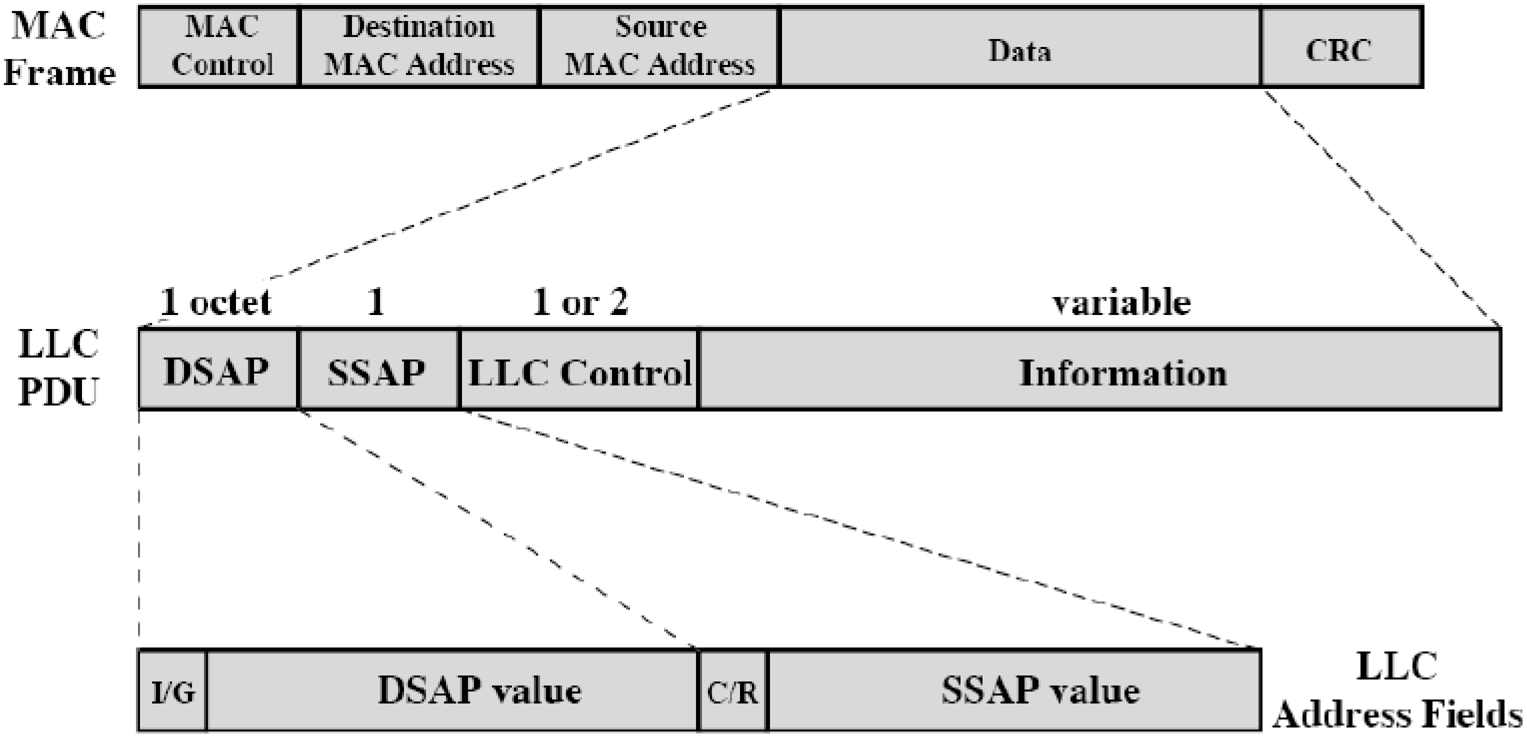
LAN model



For the same LLC, several MAC options may be provided.

LLC and MAC

MAC Frame Format



MAC Frame

MAC Control | Destination MAC Address | Source MAC Address | Data | CRC

LLC PDU

1 octet | 1 | 1 or 2 | variable

DSAP | SSAP | LLC Control | Information

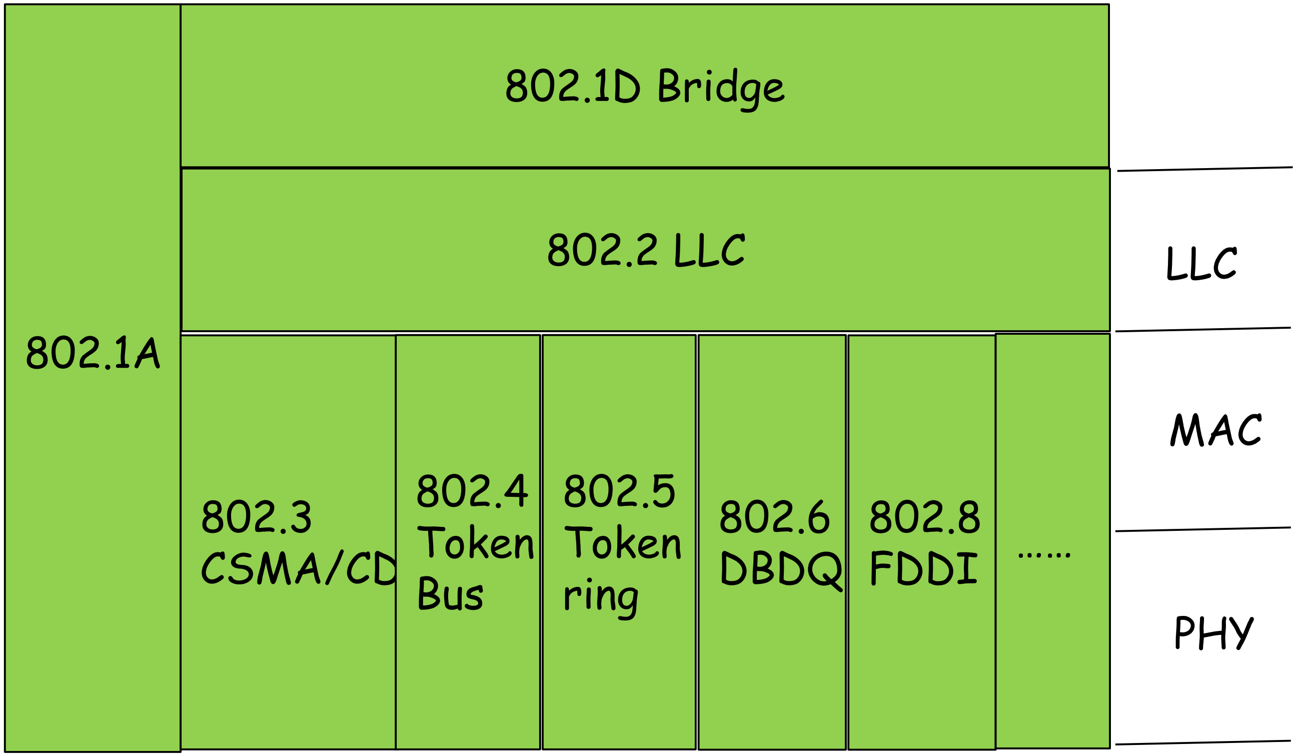
I/G | DSAP value | C/R | SSAP value

LLC Address Fields

I/G = individual/group
C/R = command/response

DSAP = destination service access point
SSAP = source service access point

IEEE 802 working group



802.1D Bridge

802.2 LLC

802.1A

802.3 CSMA/CD

802.4 Token Bus

802.5 Token ring

802.6 DBDQ

802.8 FDDI

……

LLC

MAC

PHY

LAN Addresses

32-bit IP address:

- *network-layer* address
- used to get datagram to destination network

LAN (or MAC or physical) address:

- used to get datagram from one interface to another physically-connected interface (same network)
- 48 bit MAC address (for most LANs) burned in the adapter ROM

LAN Address (more)

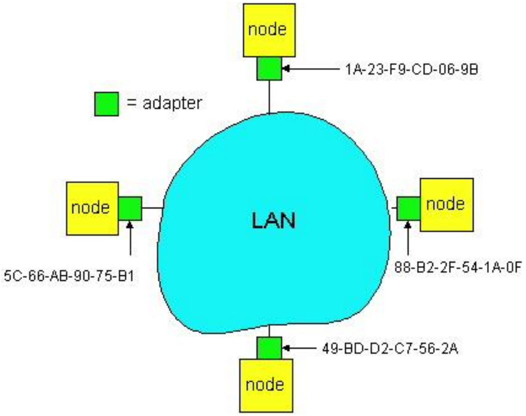
- MAC address allocation administered by IEEE
- manufacturer buys portion of MAC address space (to assure uniqueness)
- Analogy:

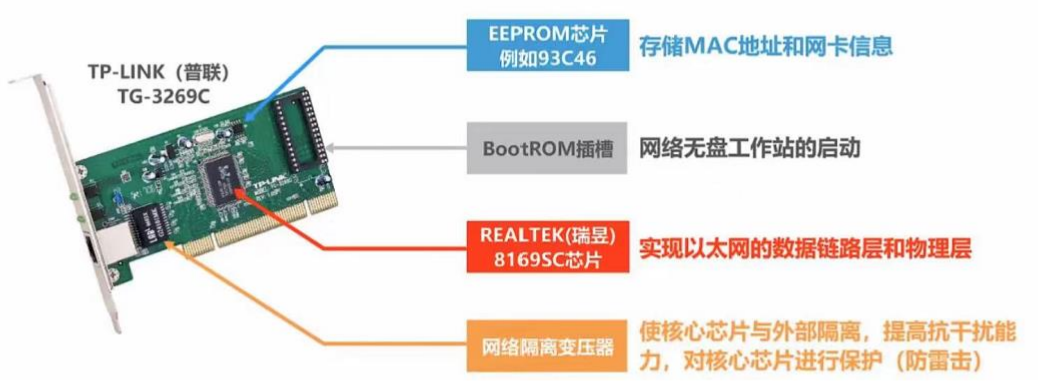
  (a) MAC address: like Social Security Number

  (b) IP address: like postal address
- MAC flat address => portability
  - can move LAN card from one LAN to another
- IP hierarchical address NOT portable
  - depends on network to which one attaches

LAN Address

Each adapter on LAN has unique LAN address





TP-LINK（普联）
TG-3269C

EEPROM芯片
例如93C46

存储MAC地址和网卡信息

BootROM插槽

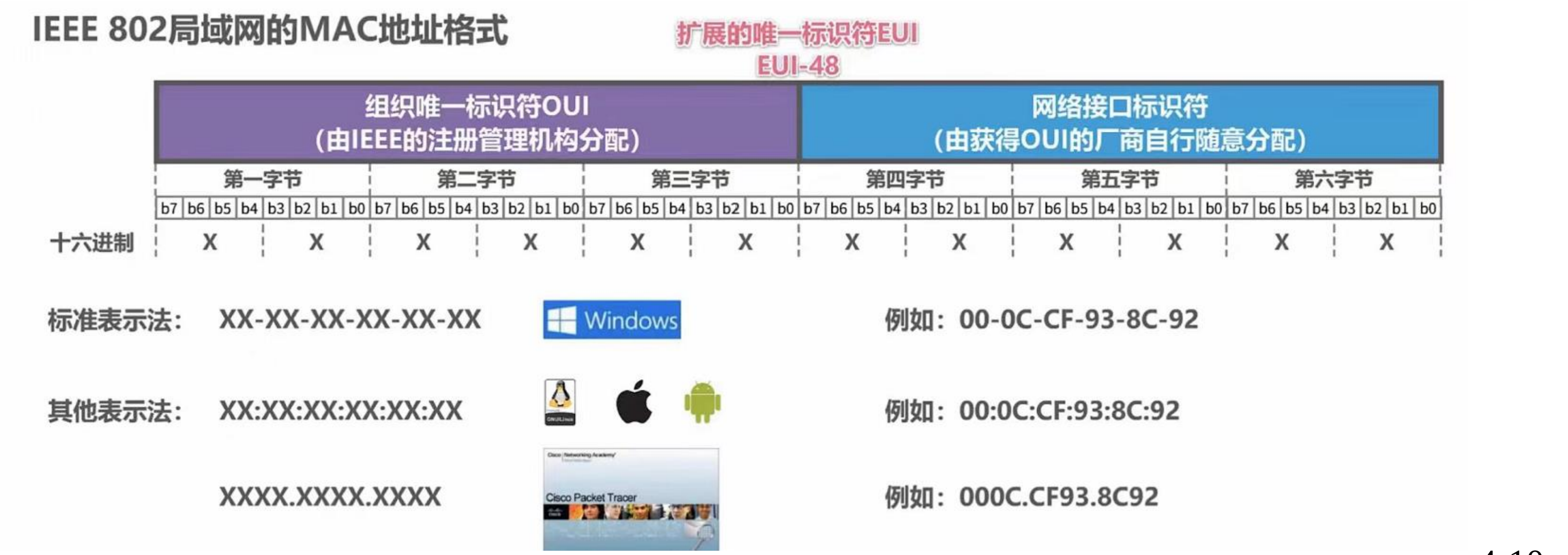
网络无盘工作站的启动

REALTEK(瑞昱)
8169SC芯片

实现以太网的数据链路层和物理层

网络隔离变压器

使核心芯片与外部隔离，提高抗干扰能力，对核心芯片进行保护（防雷击）



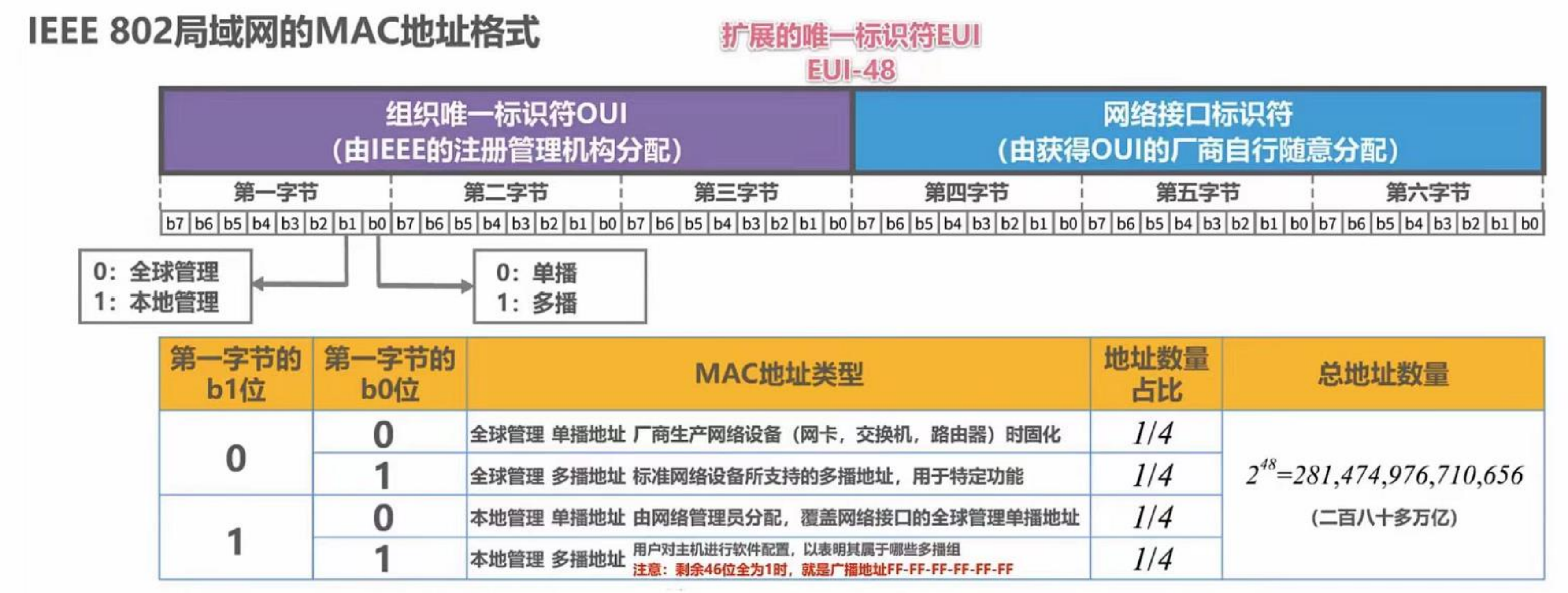
IEEE 802局域网的MAC地址格式

扩展的唯一标识符EUI
EUI-48

	组织唯一标识符OUI （由IEEE的注册管理机构分配）			网络接口标识符 （由获得OUI的厂商自行随意分配）		
	第一字节	第二字节	第三字节	第四字节	第五字节	第六字节
	b7 b6 b5 b4 b3 b2 b1 b0	b7 b6 b5 b4 b3 b2 b1 b0	b7 b6 b5 b4 b3 b2 b1 b0	b7 b6 b5 b4 b3 b2 b1 b0	b7 b6 b5 b4 b3 b2 b1 b0	b7 b6 b5 b4 b3 b2 b1 b0
十六进制	X X	X X	X X	X X	X X	X X

标准表示法：	XX-XX-XX-XX-XX-XX	Windows	例如：00-0C-CF-93-8C-92
其他表示法：	XX:XX:XX:XX:XX:XX		例如：00:0C:CF:93:8C:92
	XXXX.XXXX.XXXX	Cisco Packet Tracer	例如：000C.CF93.8C92

MAC Addresses



IEEE 802局域网的MAC地址格式

扩展的唯一标识符EUI
EUI-48

组织唯一标识符OUI
(由IEEE的注册管理机构分配)

网络接口标识符
(由获得OUI的厂商自行随意分配)

第一字节	第二字节	第三字节	第四字节	第五字节	第六字节
b7 b6 b5 b4 b3 b2 b1 b0	b7 b6 b5 b4 b3 b2 b1 b0	b7 b6 b5 b4 b3 b2 b1 b0	b7 b6 b5 b4 b3 b2 b1 b0	b7 b6 b5 b4 b3 b2 b1 b0	b7 b6 b5 b4 b3 b2 b1 b0

0：全球管理
1：本地管理

0：单播
1：多播

第一字节的b1位	第一字节的b0位	MAC地址类型	地址数量占比	总地址数量
0	0	全球管理 单播地址 厂商生产网络设备（网卡，交换机，路由器）时固化	1/4	2^{48}=281,474,976,710,656 (二百八十多万亿)
	1	全球管理 多播地址 标准网络设备所支持的多播地址，用于特定功能	1/4	
1	0	本地管理 单播地址 由网络管理员分配，覆盖网络接口的全球管理单播地址	1/4	
	1	本地管理 多播地址 用户对主机进行软件配置，以表明其属于哪些多播组 注意：剩余46位全为1时，就是广播地址FF-FF-FF-FF-FF-FF	1/4	

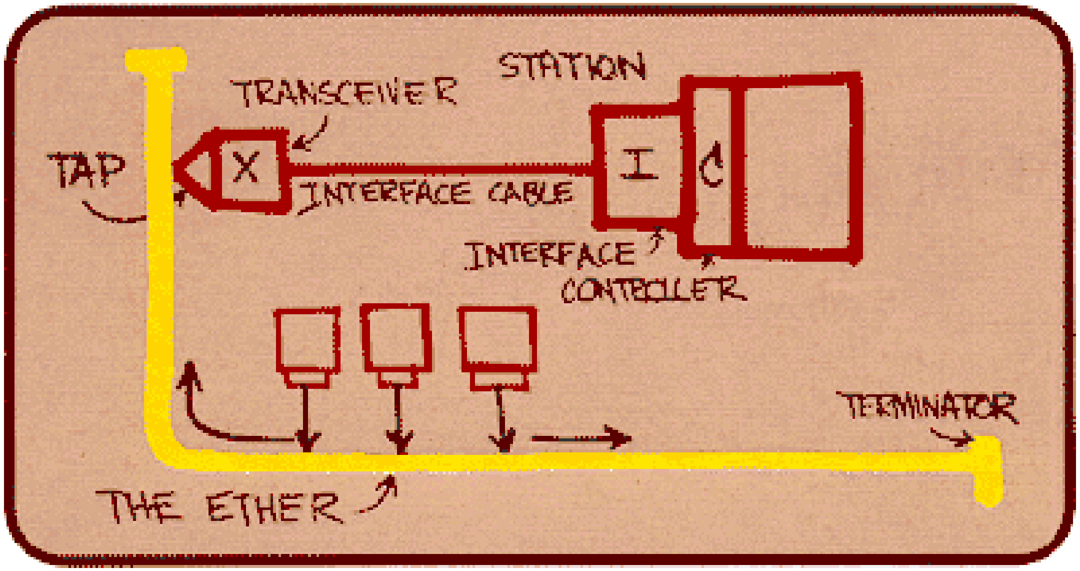
https://standards-oui.ieee.org/oui/oui.txt
MAC地址查询 - https://mac.bmcx.com/

What is the random MAC address technology?

Ethernet

"dominant" LAN technology:

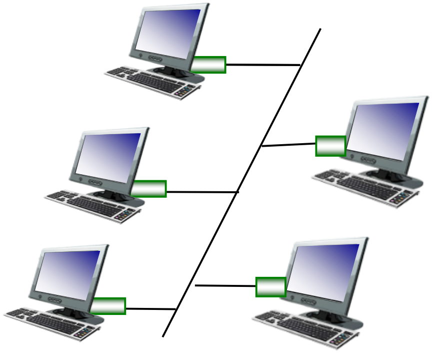
- cheap $20 for 100Mbs!
- first wildey used LAN technology
- Simpler, cheaper than token LANs and ATM
- Kept up with speed race: 10, 100, 1000 Mbps



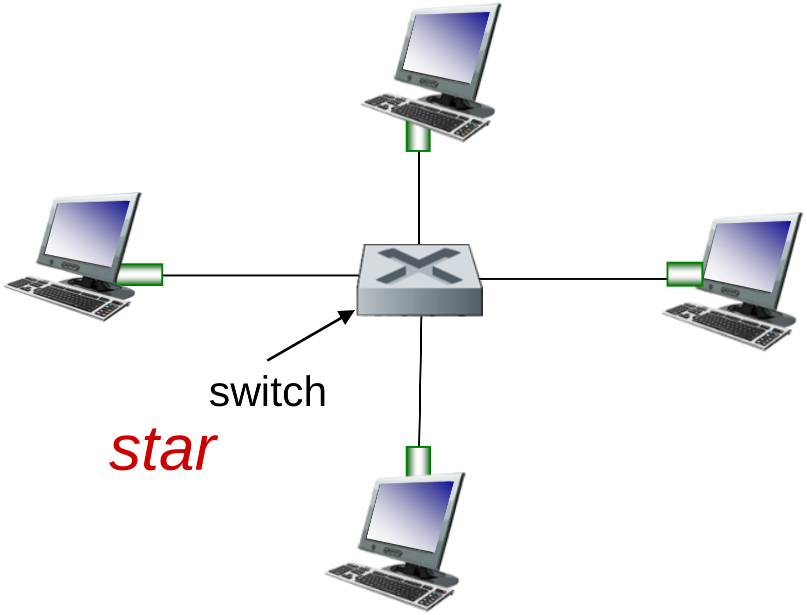
Metcalfe's Etheret sketch

Ethernet: physical topology

- *bus:* popular through mid 90s
  - all nodes in same collision domain (can collide with each other)
- *star:* prevails today
  - active *switch* in center
  - each "spoke" runs a (separate) Ethernet protocol (nodes do not collide with each other)



bus: coaxial cable



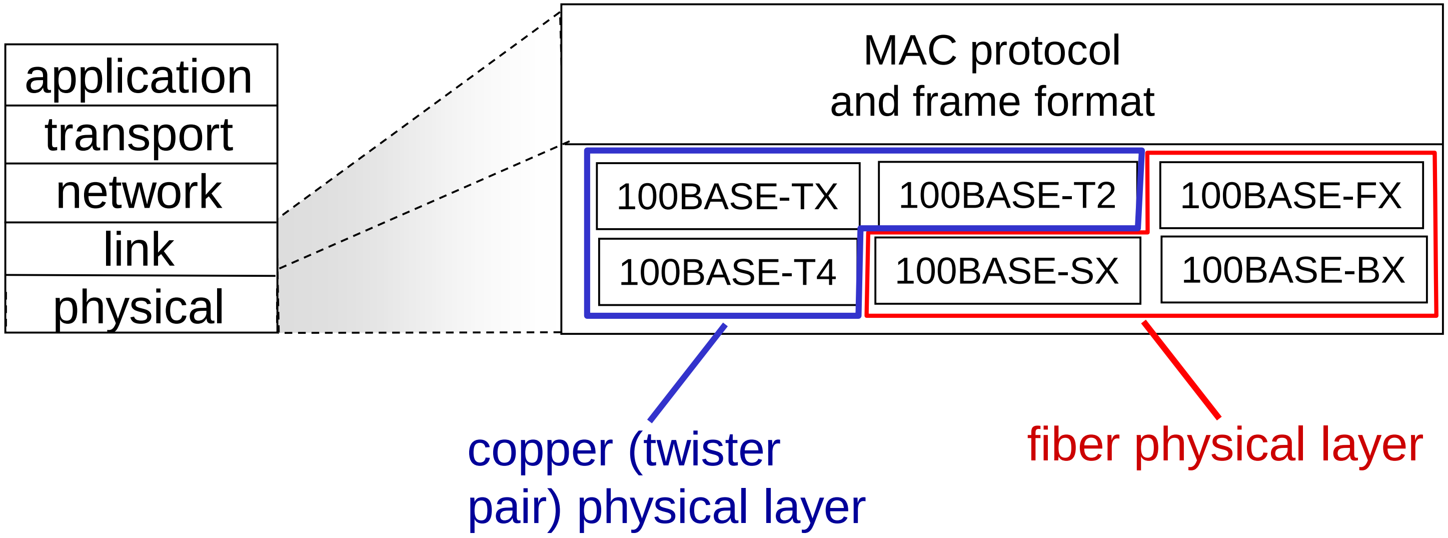
star

Ethernet: unreliable, connectionless

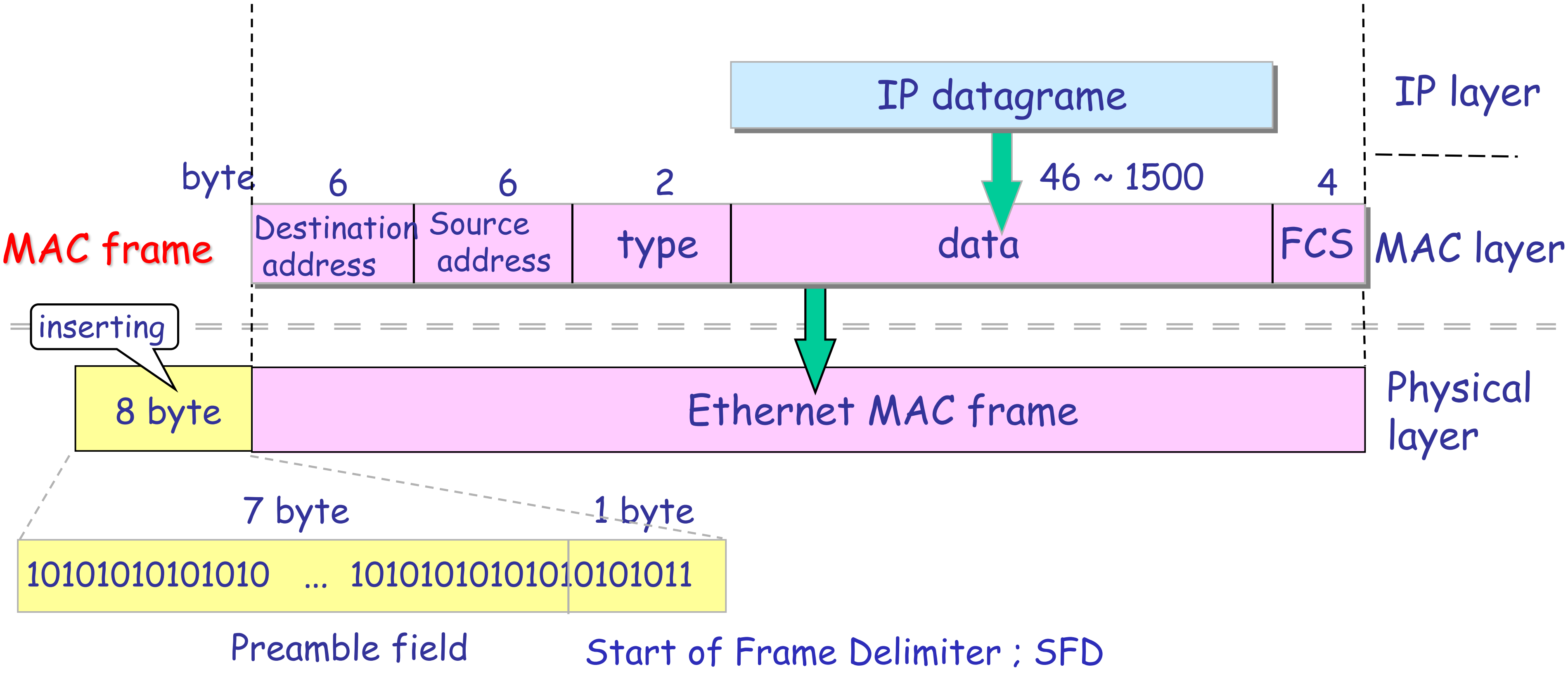
- *connectionless:* no handshaking between sending and receiving NICs
- *unreliable:* receiving NIC doesn't send acks or nacks to sending NIC
  - data in dropped frames recovered only if initial sender uses higher layer rdt (e.g., TCP), otherwise dropped data lost
- Ethernet’s MAC protocol: unslotted *CSMA/CD with binary backoff*

802.3 Ethernet standards: link & physical layers

- *many* different Ethernet standards
  - common MAC protocol and frame format
  - different speeds: 10 Mbps, 100 Mbps, 1Gbps, 10 Gbps, 40 Gbps
  - different physical layer media: fiber, cable



Ethernet Frame Structure



IP datagrame

IP layer

byte 6 6 2 46 ~ 1500 4

MAC frame

Destination address | Source address | type | data | FCS

MAC layer

inserting

8 byte

Ethernet MAC frame

Physical layer

7 byte 1 byte

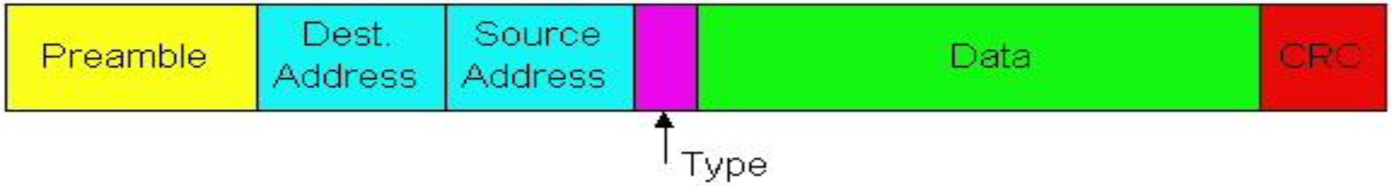
10101010101010 … 10101010101010101011

Preamble field

Start of Frame Delimiter ; SFD

Ethernet Frame Structure

Sending adapter encapsulates IP datagram (or other network layer protocol packet) in Ethernet frame

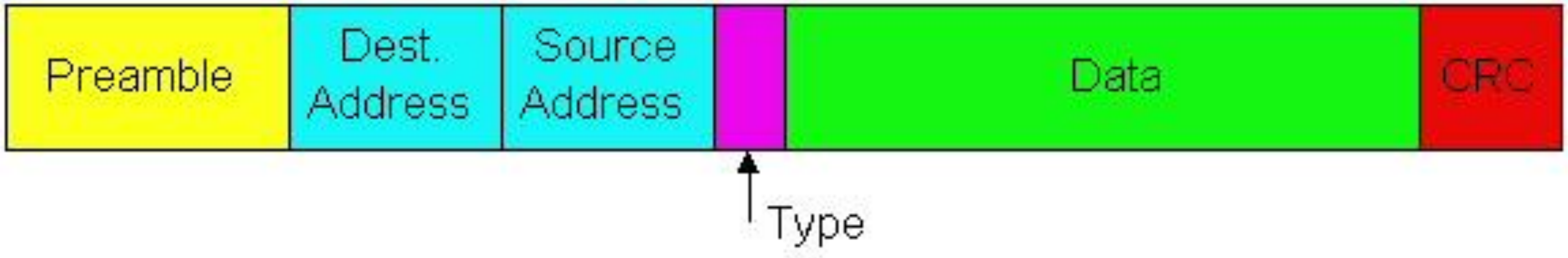


Preamble:

- 7 bytes with pattern 10101010 followed by one byte with pattern 10101011
- used to synchronize receiver, sender clock rates

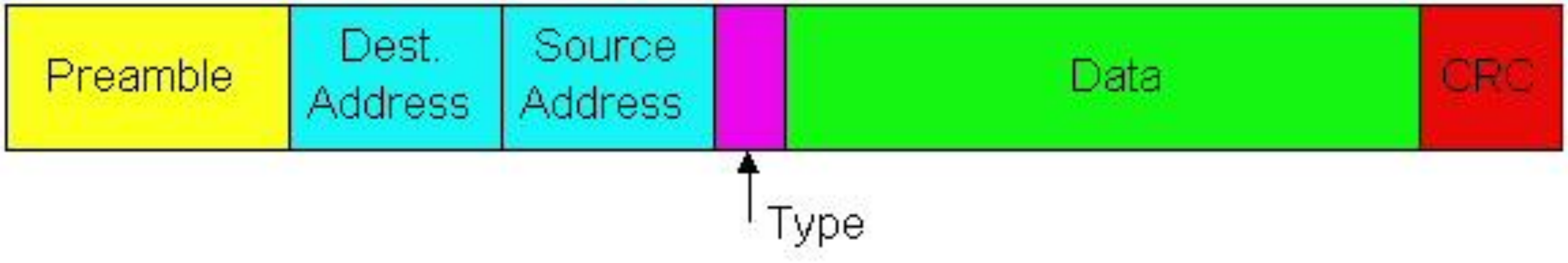
Ethernet Frame Structure (more)

- Addresses: 6 bytes, frame is received by all adapters on a LAN and dropped if address does not match
- Type: 2 bytes, indicates the higher layer protocol, mostly IP but others may be supported such as Novell IPX and AppleTalk)
- CRC: 4 bytes, checked at receiver, if error is detected, the frame is simply dropped



Ethernet Frame Structure (more)

- Data: 46~1500 bytes
- Minimum frame length: 64 bytes, why? (contention period 2τ is 51.2 μs for IEEE 802.3, R=10Mbps)
- Maximum frame length: 1518 bytes, why?



Exercises-1

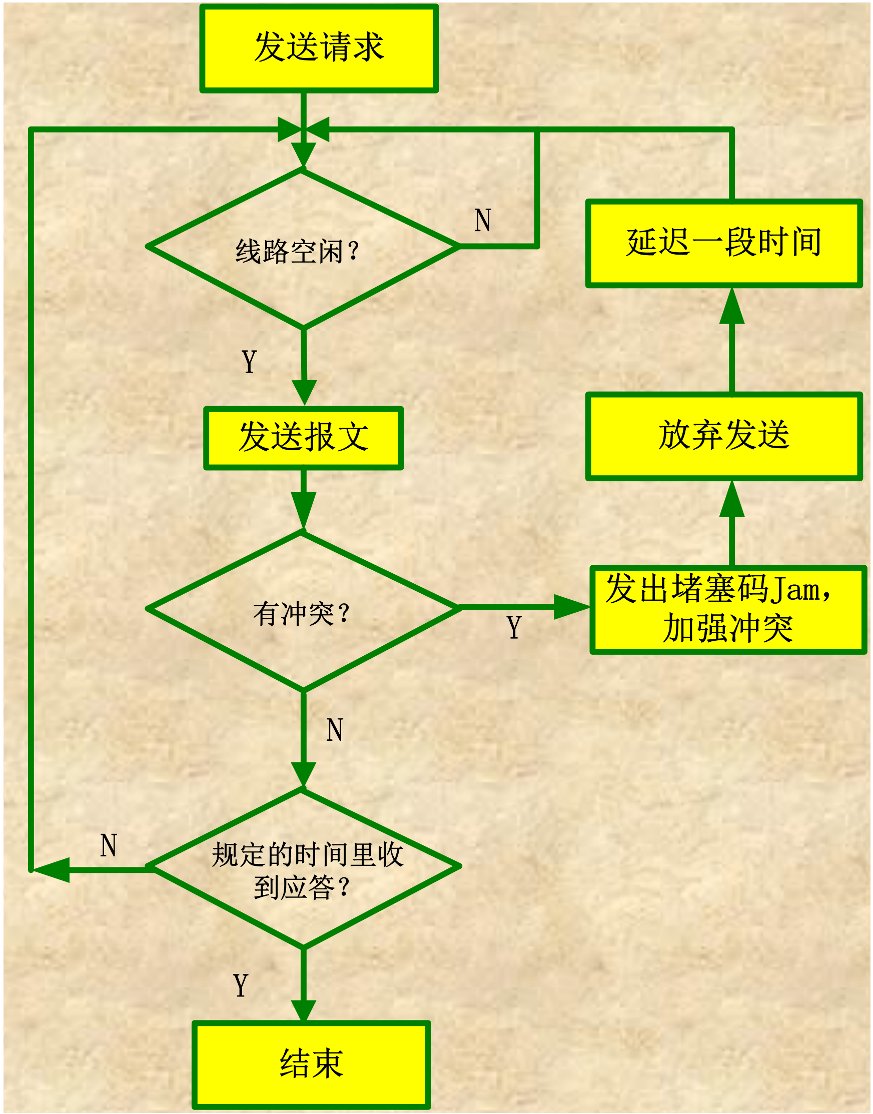
- In a LAN using CSMA / CD protocol, the transmission medium is a complete cable, the transmission rate is 1Gbps, and the signal propagation rate in the cable is 200000 km / s. if the minimum data frame length is reduced by 800 bits, the distance between the farthest two stations needs to be at least

(1) increased by 160m (2) increased by 80m
(3) reduced by 160m (4) reduced by 80m

Ethernet: uses CSMA/CD

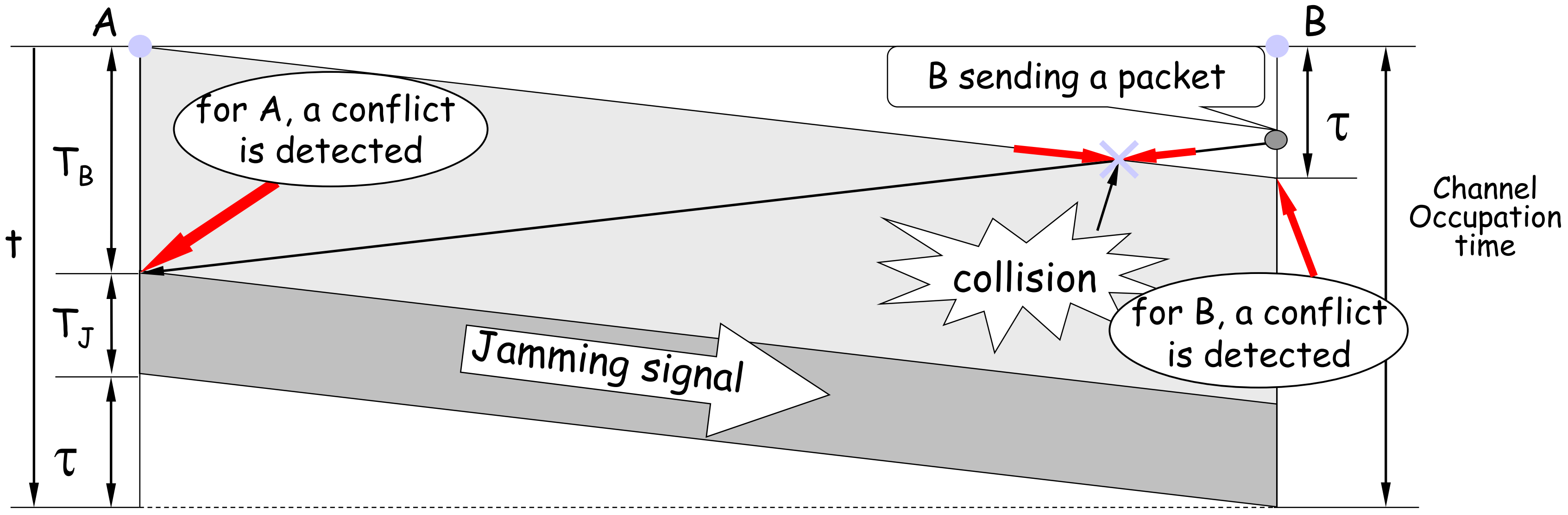
```
A: sense channel, if idle
     then {
              transmit and monitor the channel;
              If detect another transmission
                then {
                   abort and send jam signal;
                   update # collisions;
                   delay as required by exponential backoff algorithm;
                   goto A
                   }
               else {done with the frame; set collisions to zero}
        }
     else {wait until ongoing transmission is over and goto A}
```

Ethernet: uses CSMA/CD



Ethernet's CSMA/CD (more)

Jam Signal: make sure all other transmitters are aware of collision; 48 bits;



Ethernet's CSMA/CD (more)

Exponential Backoff:

- *Goal*: adapt retransmission attemtps to estimated current load
  - heavy load: random wait will be longer
- delay is K x 512 bit transmission times (contention period: 2τ)
- first collision: choose K from {0,1};
- after second collision: choose K from {0,1,2,3}…
- after ten or more collisions, choose K from {0,1,2,3,4,…,1023}
- K=min(n,i),n: # collisions,$n \leq j$(attempt limit);i:back off limit
- For Ethernet, i=10,j=16

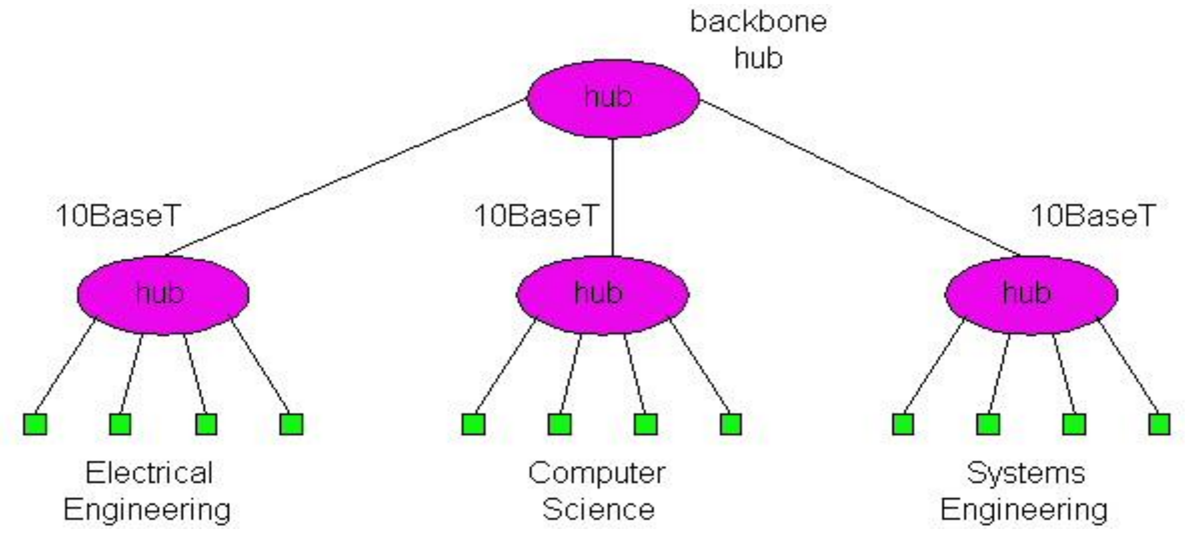
Interconnecting LANs

Q: Why not just one big LAN?

- Limited amount of supportable traffic: on single LAN, all stations must share bandwidth
- limited length: 802.3 specifies maximum cable length
- large "collision domain" (can collide with many stations)

Hubs

- Physical Layer devices: essentially repeaters operating at bit levels: repeat received bits on one interface to all other interfaces
- Hubs can be arranged in a hierarchy (or multi-tier design), with backbone hub at its top



Hubs (more)

- Each connected LAN referred to as LAN **segment**
- Hubs do not isolate collision domains: node may collide with any node residing at any segment in LAN
- Hub Advantages:
  - simple, inexpensive device
  - Multi-tier provides graceful degradation: portions of the LAN continue to operate if one hub malfunctions
  - extends maximum distance between node pairs (100m per Hub)

Hub limitations

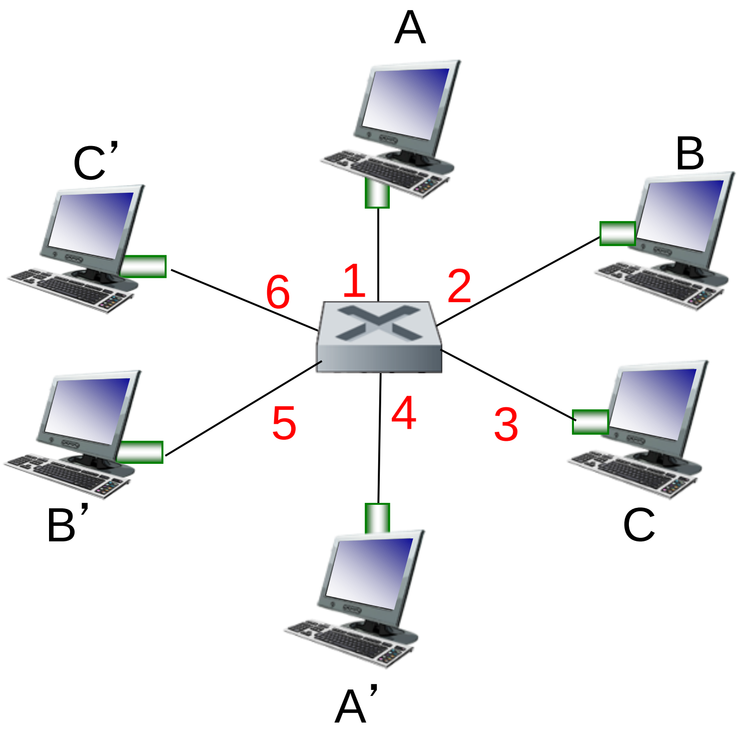
- single collision domain results in no increase in max throughput
  - multi-tier throughput same as single segment throughput
- individual LAN restrictions pose limits on number of nodes in same collision domain and on total allowed geographical coverage
- cannot connect different Ethernet types (e.g., 10BaseT and 100baseT)

Ethernet switch

- link-layer device: takes an *active* role
  - store, forward Ethernet frames
  - examine incoming frame's MAC address, selectively forward frame to one-or-more outgoing links when frame is to be forwarded on segment, uses CSMA/CD to access segment
- *transparent*
  - hosts are unaware of presence of switches
- *plug-and-play, self-learning*
  - switches do not need to be configured

Switch: *multiple* simultaneous transmissions

- hosts have dedicated, direct connection to switch
- switches buffer packets
- Ethernet protocol used on *each* incoming link, but no collisions; full duplex
  - each link is its own collision domain
- *switching:* A-to-A' and B-to-B' can transmit simultaneously, without collisions



switch with six interfaces (1,2,3,4,5,6)

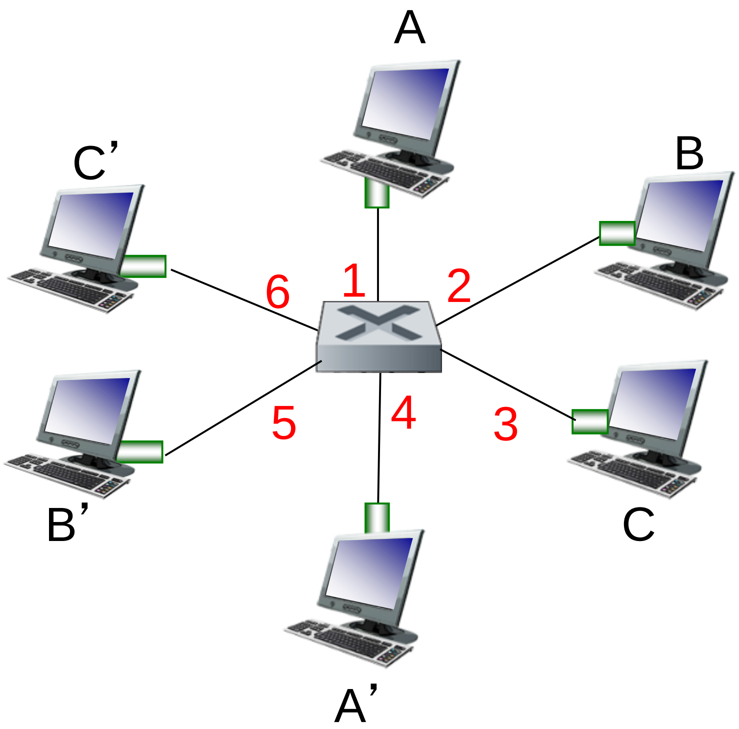
Switch forwarding table

Q: how does switch know A' reachable via interface 4, B' reachable via interface 5?

- A: each switch has a switch table, each entry:
  - (MAC address of host, interface to reach host, time stamp)
  - looks like a routing table!

Q: how are entries created, maintained in switch table?

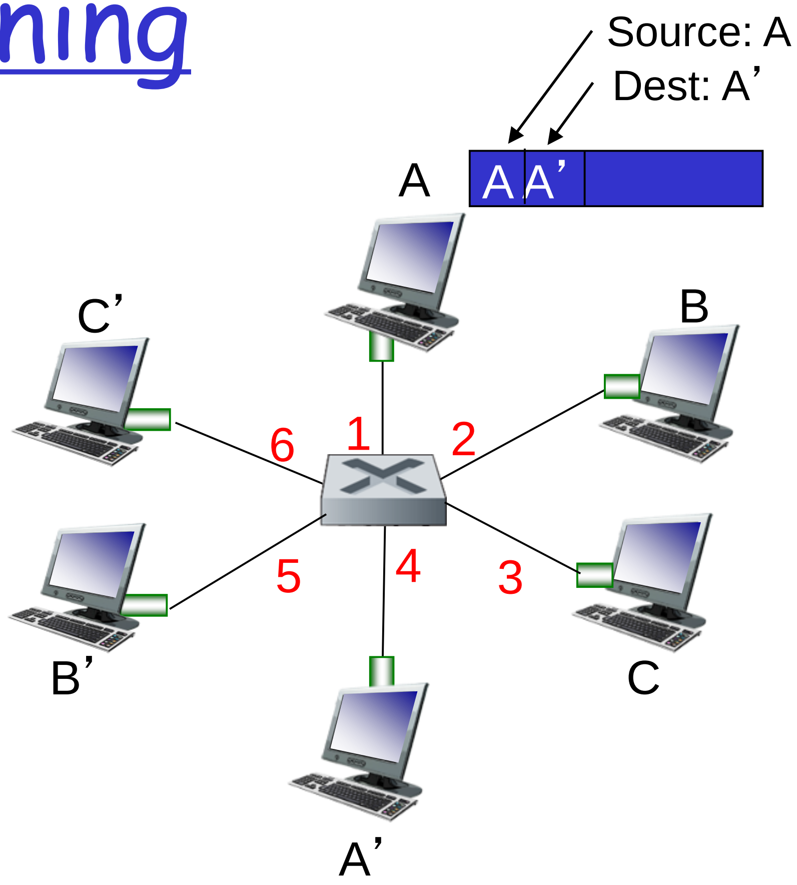
- something like a routing protocol?



switch with six interfaces (1,2,3,4,5,6)

Switch: self-learning

- switch *learns* which hosts can be reached through which interfaces
  - when frame received, switch “learns” location of sender: incoming LAN segment
  - records sender/location pair in switch table



MAC addr	interface	TTL
A	*1*	*60*

Switch table (initially empty)

Switch: frame filtering/forwarding

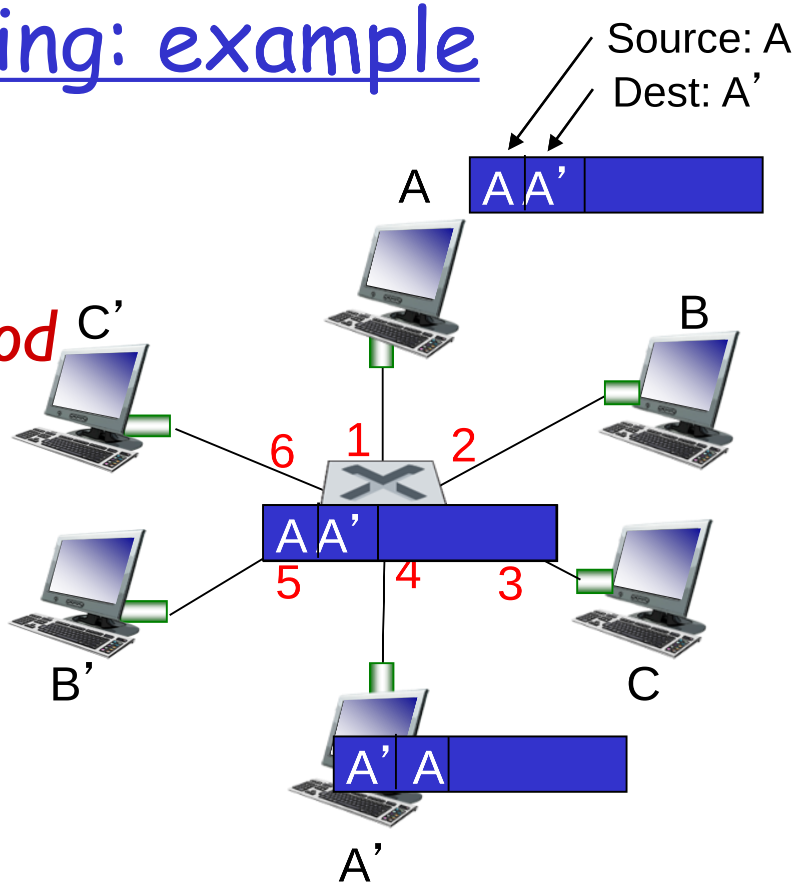
when frame received at switch:

```
1. record incoming link, MAC address of sending host
2. index switch table using MAC destination address
3. if entry found for destination
      then {
       if destination on segment from which frame arrived
          then drop frame
          else forward frame on interface indicated by entry
       }
      else flood /* forward on all interfaces except arriving
                    interface */
```

Self-learning, forwarding: example

- frame destination, A', location unknown: *flood*
- destination A location known:

  selectively send on just one link

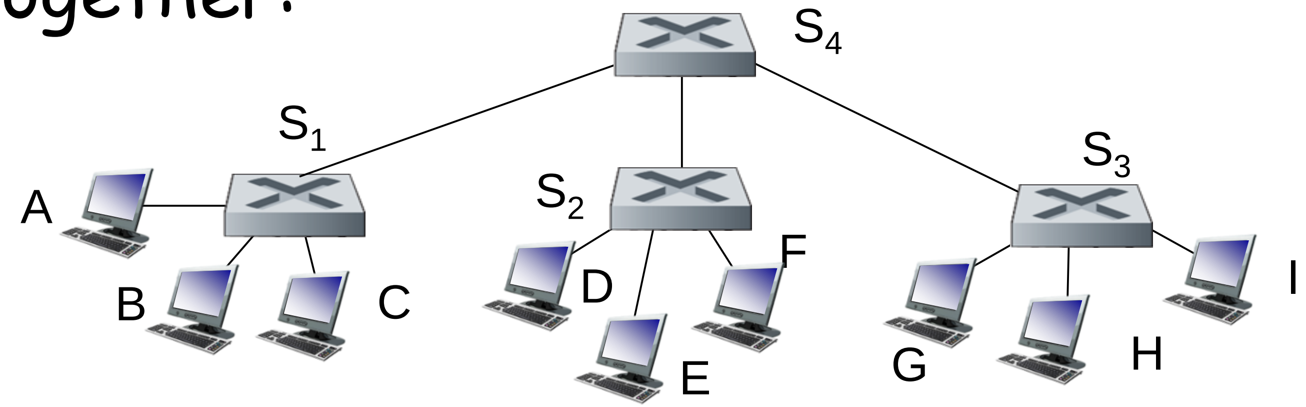


MAC addr	interface	TTL
A *A'*	*1* *4*	*60* *60*

switch table (initially empty)

Interconnecting switches

self-learning switches can be connected together:

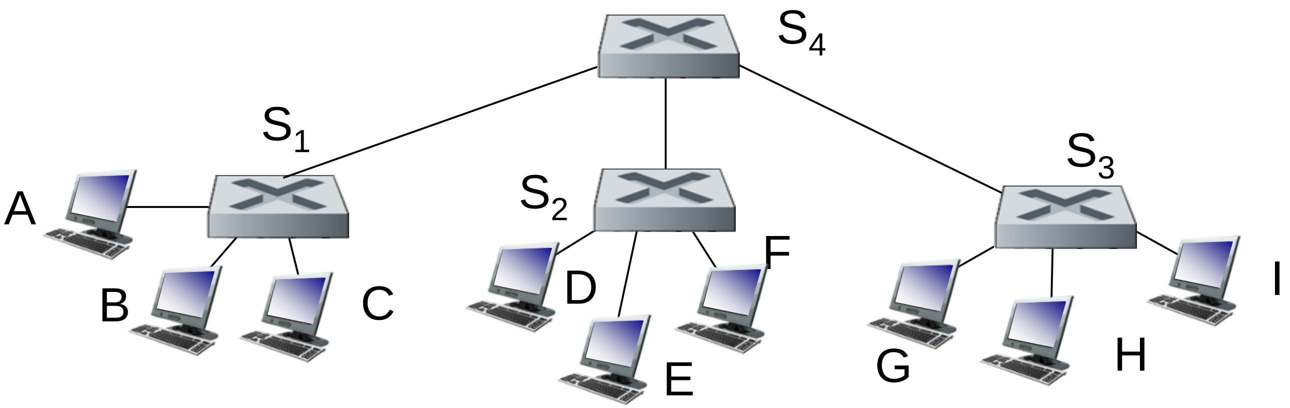


Q: sending from A to G - how does S_1 know to forward frame destined to G via S_4 and S_3?

- A: self learning! (works exactly the same as in single-switch case!)

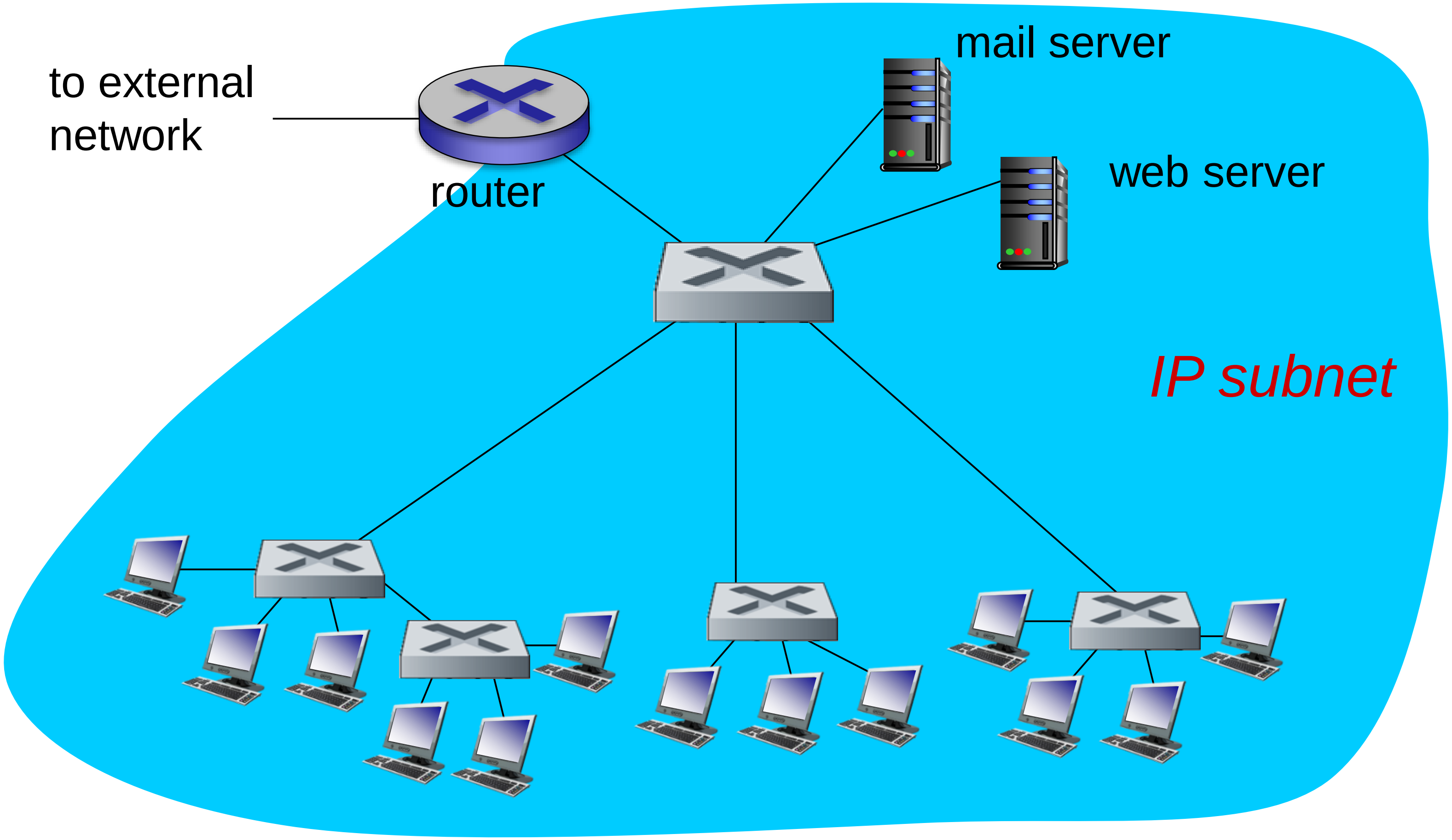
Self-learning multi-switch example

Suppose C sends frame to I, I responds to C



- Q: show switch tables and packet forwarding in S_1, S_2, S_3, S_4

Institutional network



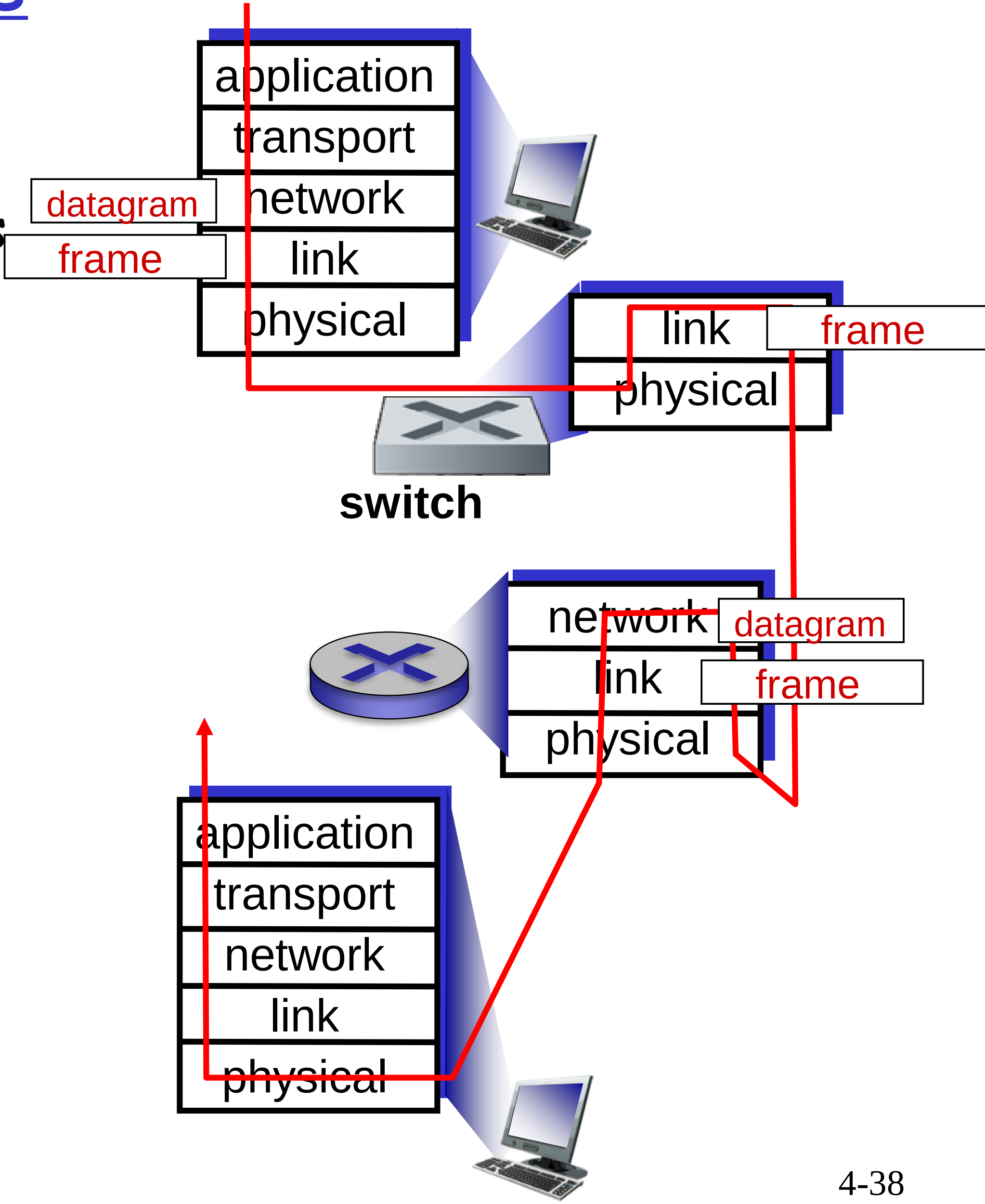
Switches vs. routers

both are store-and-forward:

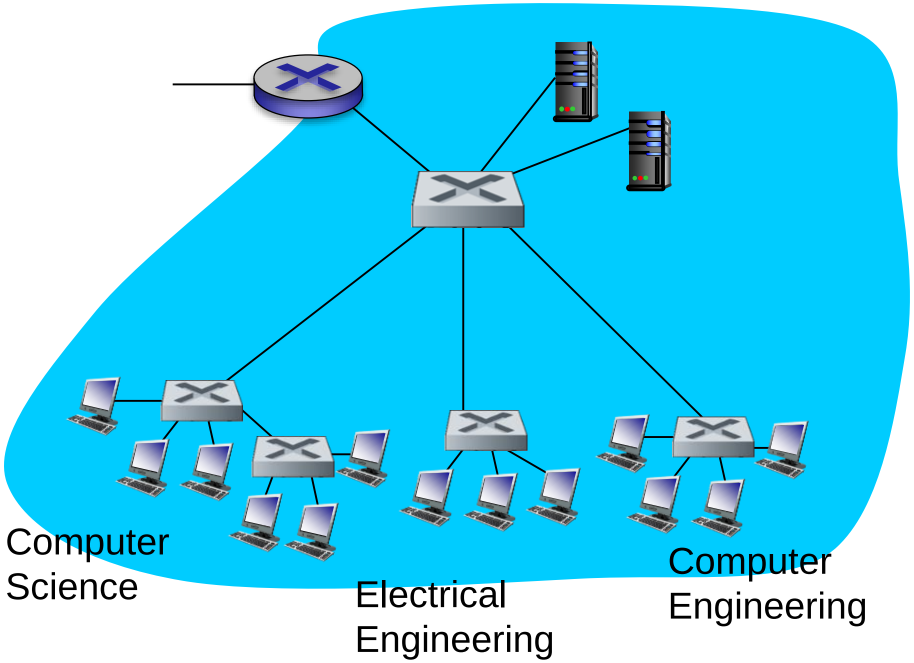
- *routers:* network-layer devices (examine network-layer headers)
- *switches*: link-layer devices (examine link-layer headers)

both have forwarding tables:

- *routers:* compute tables using routing algorithms, IP addresses
- *switches:* learn forwarding table using flooding, learning, MAC addresses



VLANs: motivation



consider:

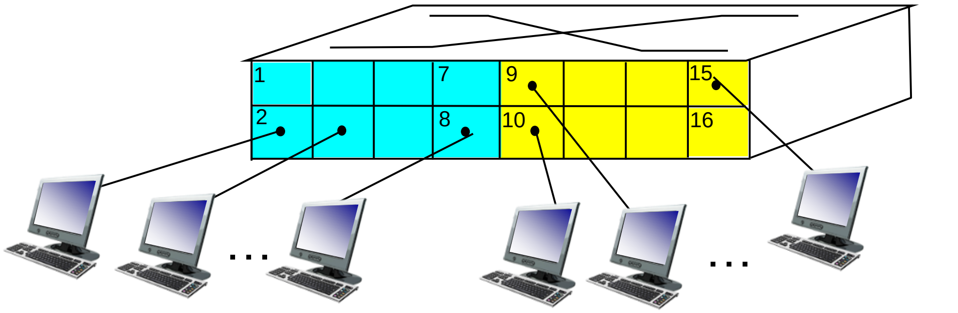
- CS user moves office to EE, but wants connect to CS switch?
- single broadcast domain:
  - all layer-2 broadcast traffic (ARP, DHCP, unknown location of destination MAC address) must cross entire LAN
  - security/privacy, efficiency issues

VLANs

port-based VLAN: switch ports grouped (by switch management software) so that *single* physical switch ……

Virtual Local Area Network

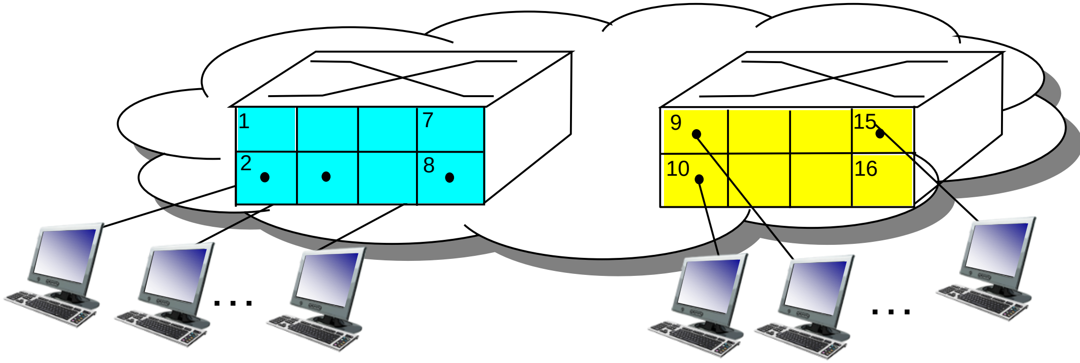
switch(es) supporting VLAN capabilities can be configured to define multiple ***virtual*** LANS over single physical LAN infrastructure.



Electrical Engineering
(VLAN ports 1-8)

Computer Science
(VLAN ports 9-15)

… operates as multiple virtual switches

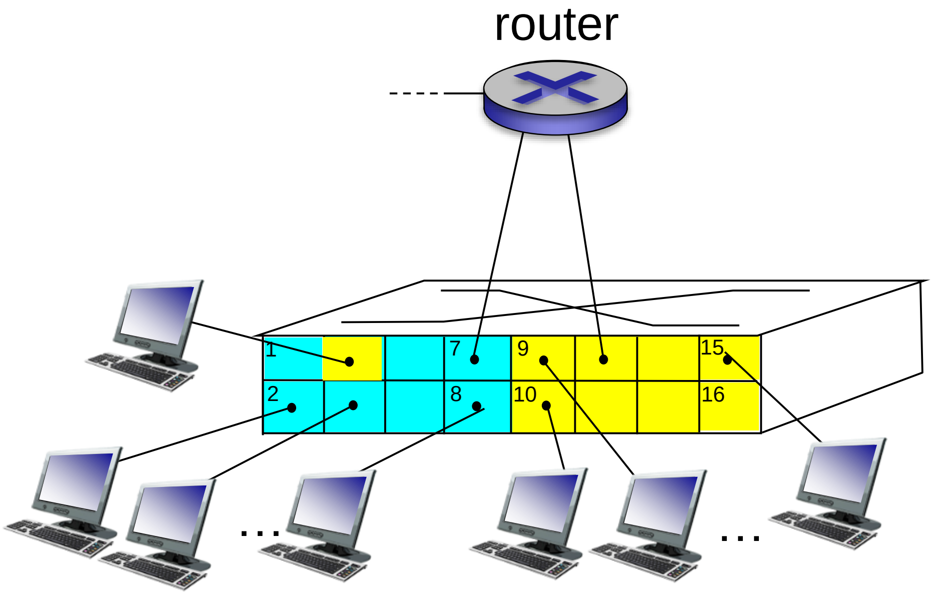


Electrical Engineering
(VLAN ports 1-8)

Computer Science
(VLAN ports 9-16)

Port-based VLAN

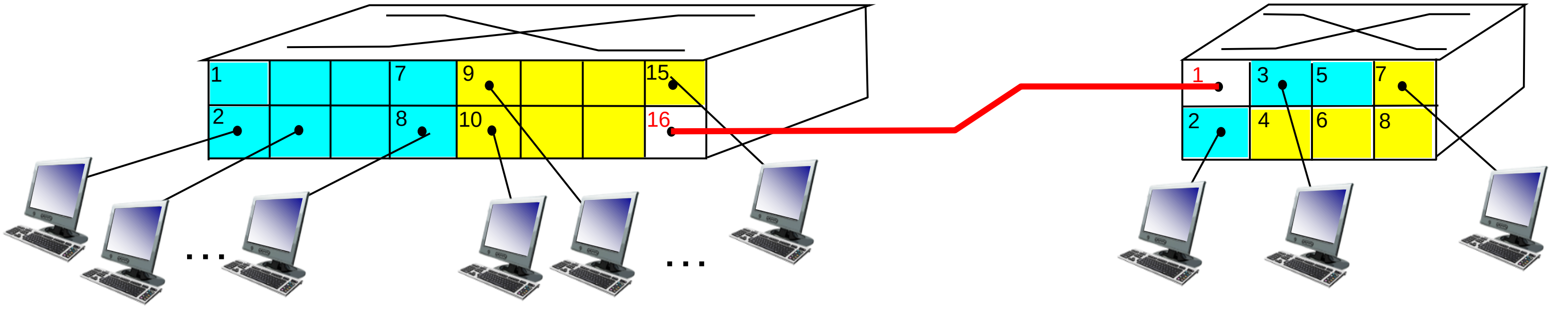
- *traffic isolation:* frames to/from ports 1-8 can *only* reach ports 1-8
  - can also define VLAN based on MAC addresses of endpoints, rather than switch port
- dynamic membership: ports can be dynamically assigned among VLANs
- forwarding between VLANS: done via routing (just as with separate switches)
  - in practice vendors sell combined switches plus routers



Electrical Engineering
(VLAN ports 1-8)

Computer Science
(VLAN ports 9-15)

VLANS spanning multiple switches



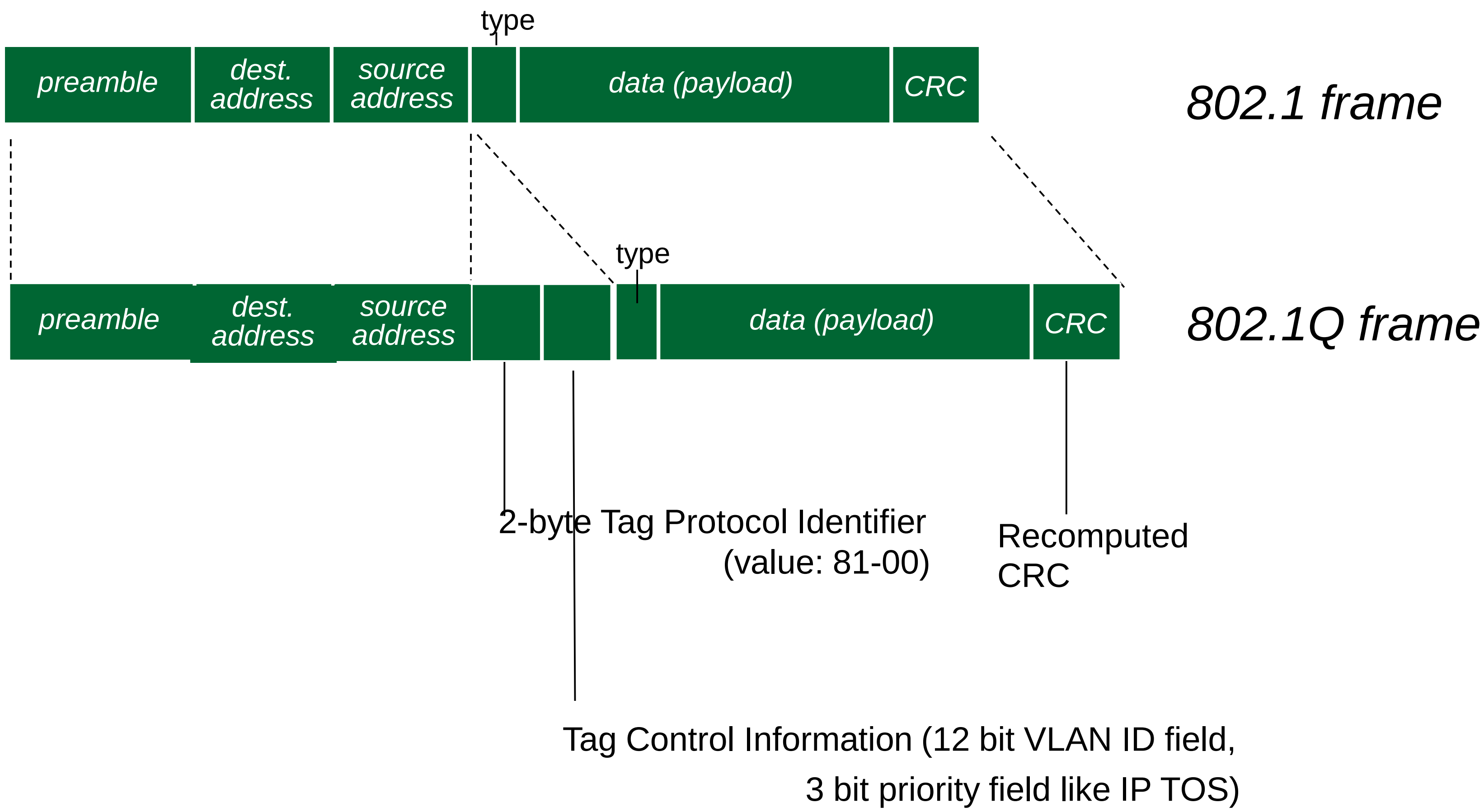
Electrical Engineering
(VLAN ports 1-8)

Computer Science
(VLAN ports 9-15)

Ports 2,3,5 belong to EE VLAN
Ports 4,6,7,8 belong to CS VLAN

- ***trunk port:*** carries frames between VLANS defined over multiple physical switches
  - frames forwarded within VLAN between switches can't be vanilla 802.1 frames (must carry VLAN ID info)
  - 802.1q protocol adds/removed additional header fields for frames forwarded between trunk ports

802.1Q VLAN frame format



2-byte Tag Protocol Identifier
(value: 81-00)

Recomputed
CRC

Tag Control Information (12 bit VLAN ID field,
3 bit priority field like IP TOS)

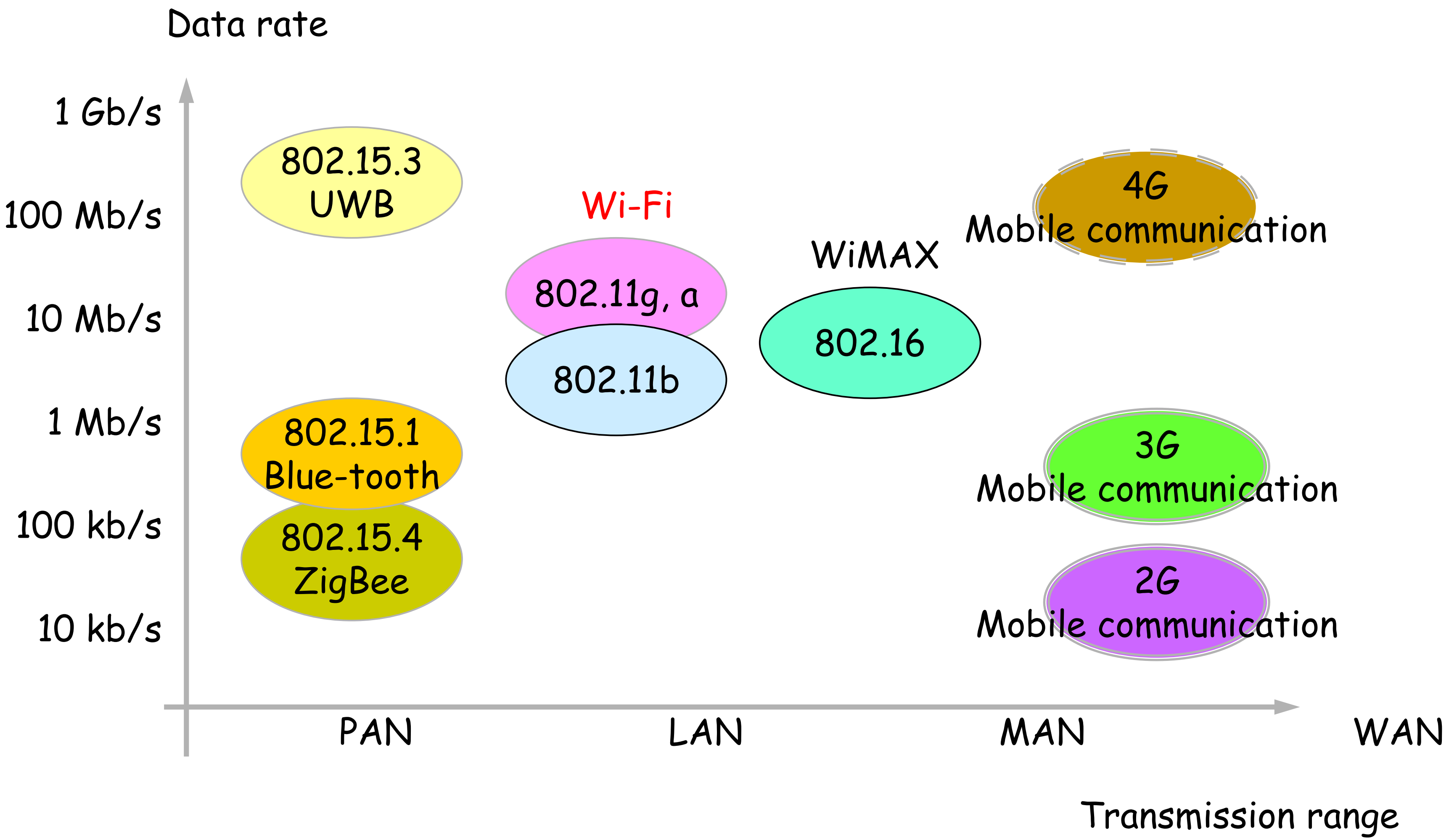
Wireless communications

- the challenges of wireless communications
- wireless communication standards
- IEEE 802.11
- IEEE 802.15.4
- 5G?

the challenges of Wireless communications

- fading: path loss, multipath effect, shadow effect, Doppler effect
- interference: from other wireless communications
- hidden terminal problem
- security
- mobility

Wireless communication technology

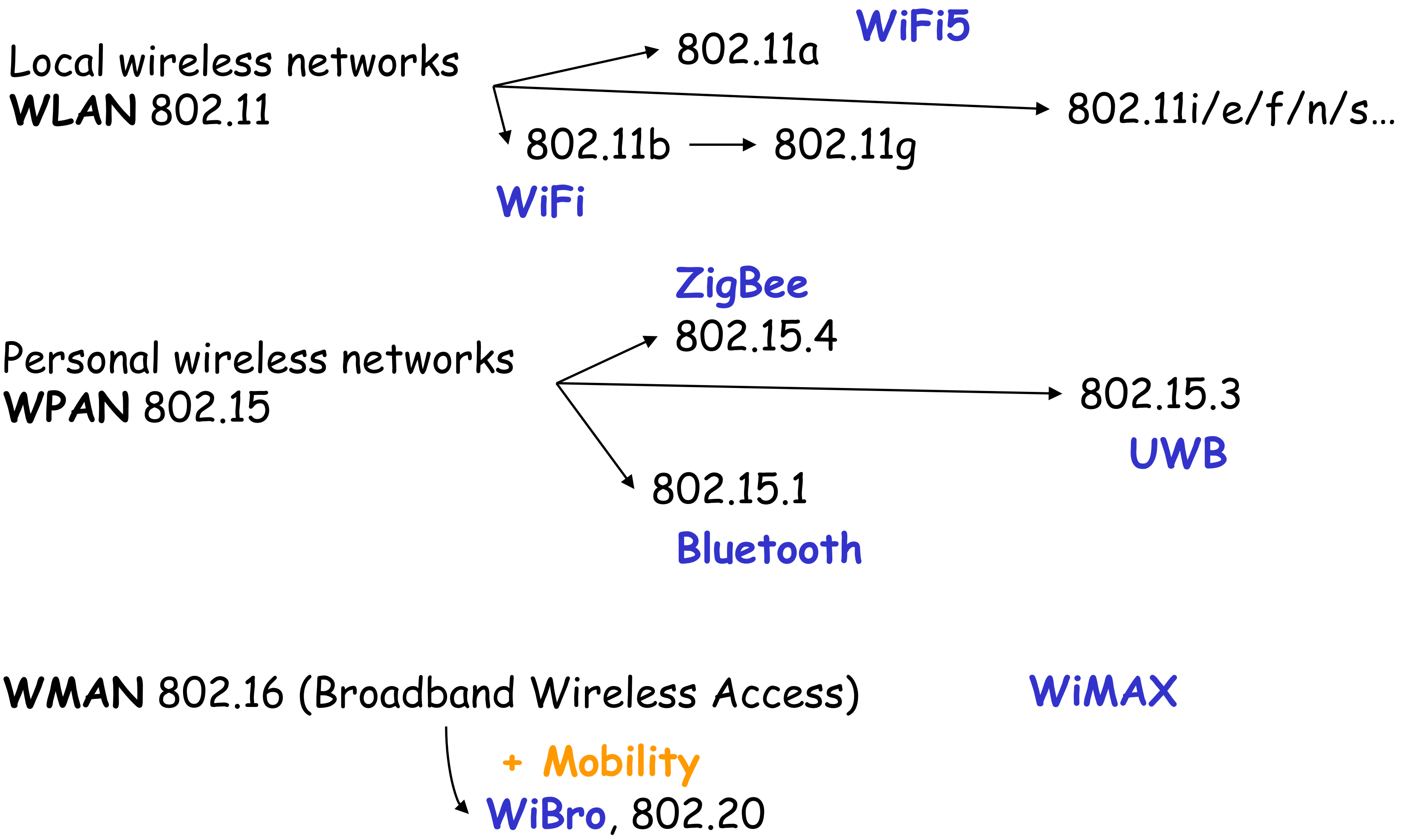


Wireless communication technology

从一片空白到世界领先，中国通信翻身逆袭史_CSDN 程序人生的博客-CSDN博客

中国通讯发展史（六）1G到5G - 知乎 (zhihu.com)

IEEE Wireless Technology



Local wireless networks
WLAN 802.11

802.11a WiFi5

802.11i/e/f/n/s…

802.11b → 802.11g

WiFi

ZigBee
802.15.4

Personal wireless networks
WPAN 802.15

802.15.3
UWB

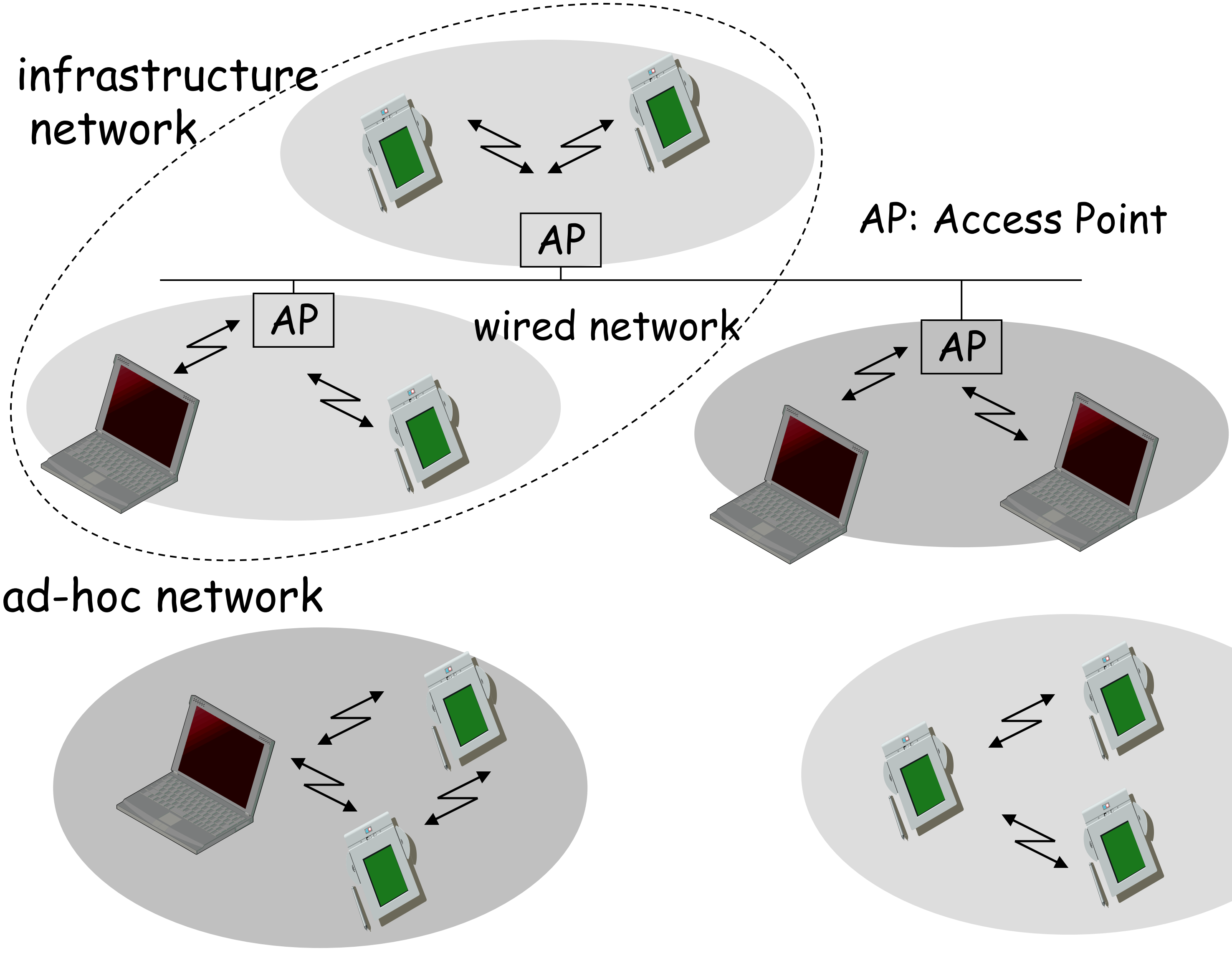
802.15.1
Bluetooth

WMAN 802.16 (Broadband Wireless Access) WiMAX

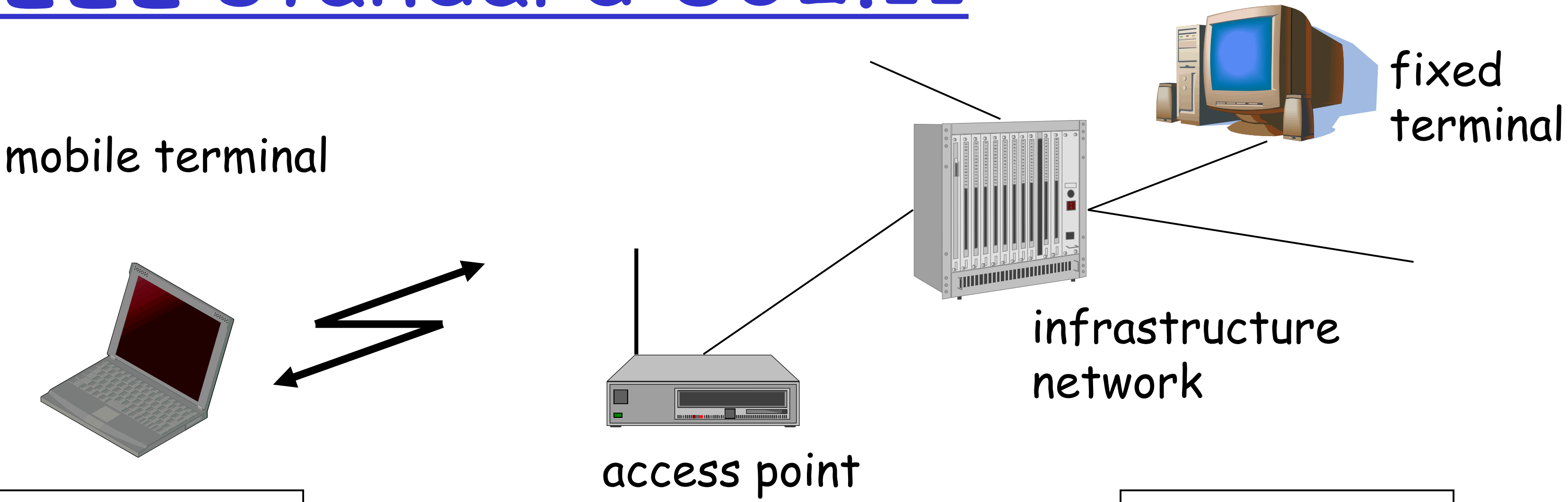
+ Mobility

WiBro, 802.20

infrastructure vs. ad-hoc networks

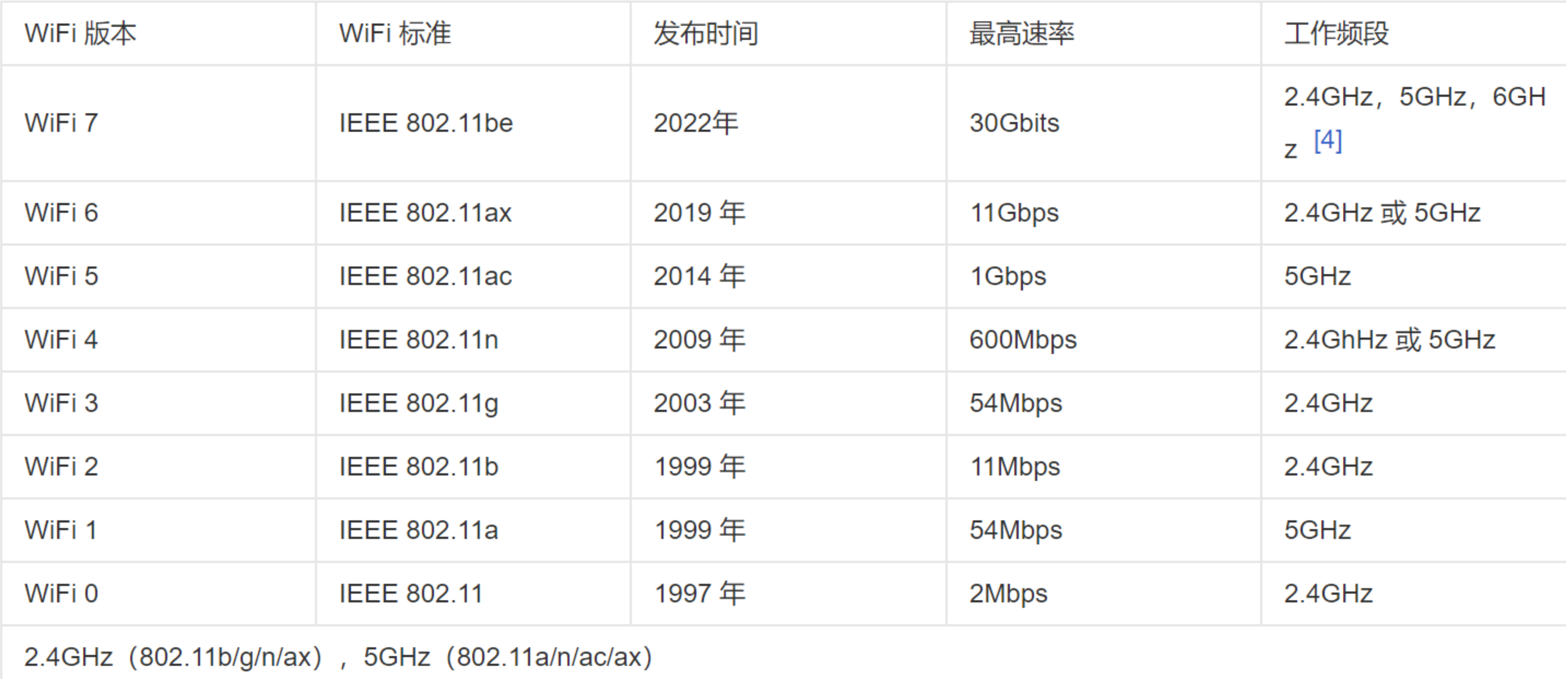


IEEE standard 802.11



application			application
TCP			TCP
IP			IP
LLC	LLC		LLC
802.11 MAC	802.11 MAC	802.3 MAC	802.3 MAC
802.11 PHY	802.11 PHY	802.3 PHY	802.3 PHY

IEEE 802.11 physical layer

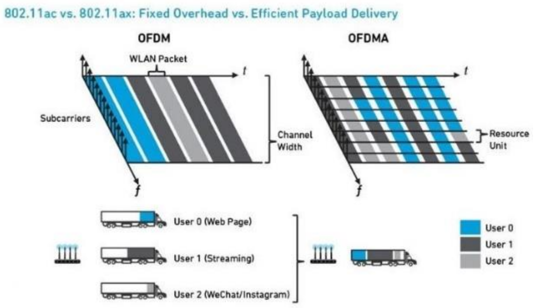


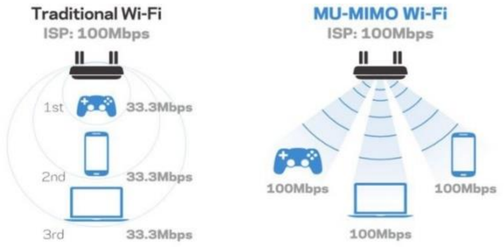
WiFi 版本	WiFi 标准	发布时间	最高速率	工作频段
WiFi 7	IEEE 802.11be	2022年	30Gbits	2.4GHz，5GHz，6GHz [4]
WiFi 6	IEEE 802.11ax	2019 年	11Gbps	2.4GHz 或 5GHz
WiFi 5	IEEE 802.11ac	2014 年	1Gbps	5GHz
WiFi 4	IEEE 802.11n	2009 年	600Mbps	2.4GhHz 或 5GHz
WiFi 3	IEEE 802.11g	2003 年	54Mbps	2.4GHz
WiFi 2	IEEE 802.11b	1999 年	11Mbps	2.4GHz
WiFi 1	IEEE 802.11a	1999 年	54Mbps	5GHz
WiFi 0	IEEE 802.11	1997 年	2Mbps	2.4GHz

2.4GHz（802.11b/g/n/ax），5GHz（802.11a/n/ac/ax）

WiFi 6

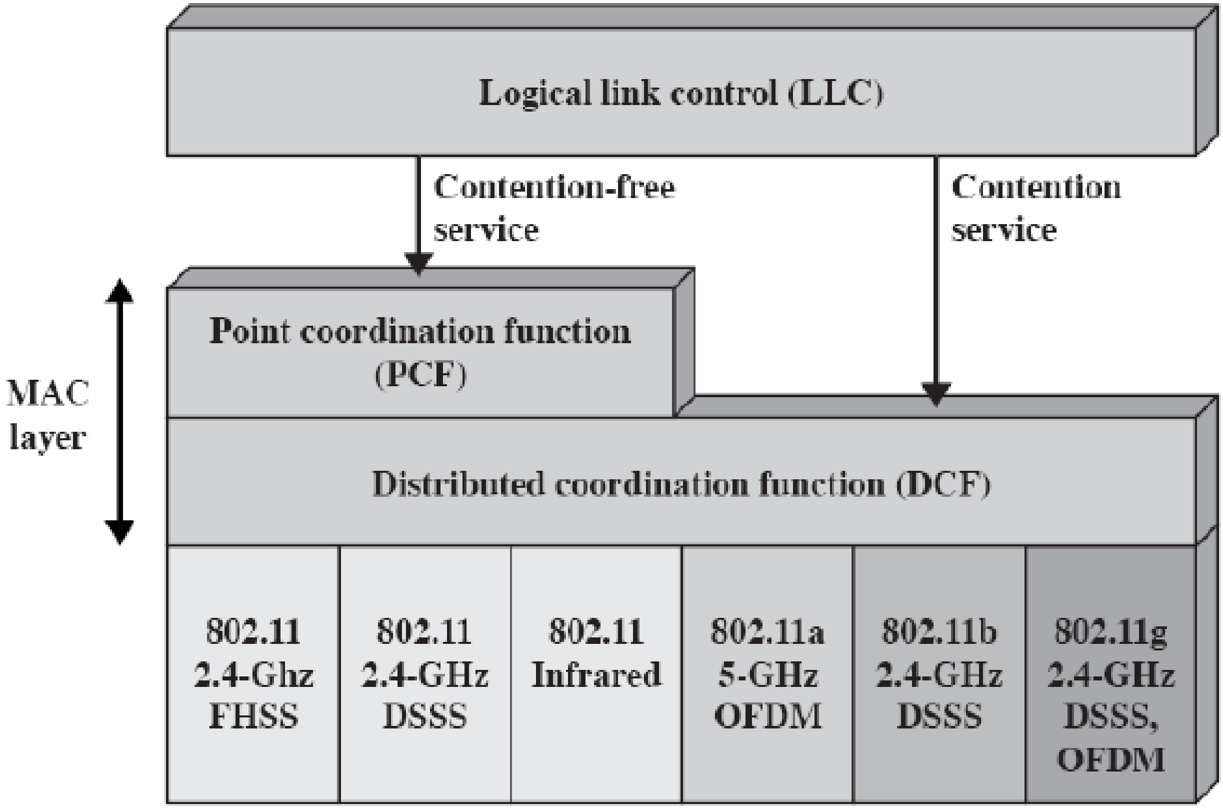
- ❐ OFDMA
- ❐ MU-MIMO
- ❐ 1024-QAM
- ❐ Spatial Reuse & BBS Coloring





IEEE 802.11 protocol architecture

IEEE 802.11 Architecture



Logical link control (LLC)

Contention-free service

Contention service

MAC layer

Point coordination function (PCF)

Distributed coordination function (DCF)

802.11 2.4-Ghz FHSS	802.11 2.4-GHz DSSS	802.11 Infrared	802.11a 5-GHz OFDM	802.11b 2.4-GHz DSSS	802.11g 2.4-GHz DSSS, OFDM

IEEE 802.11 Protocol Architecture

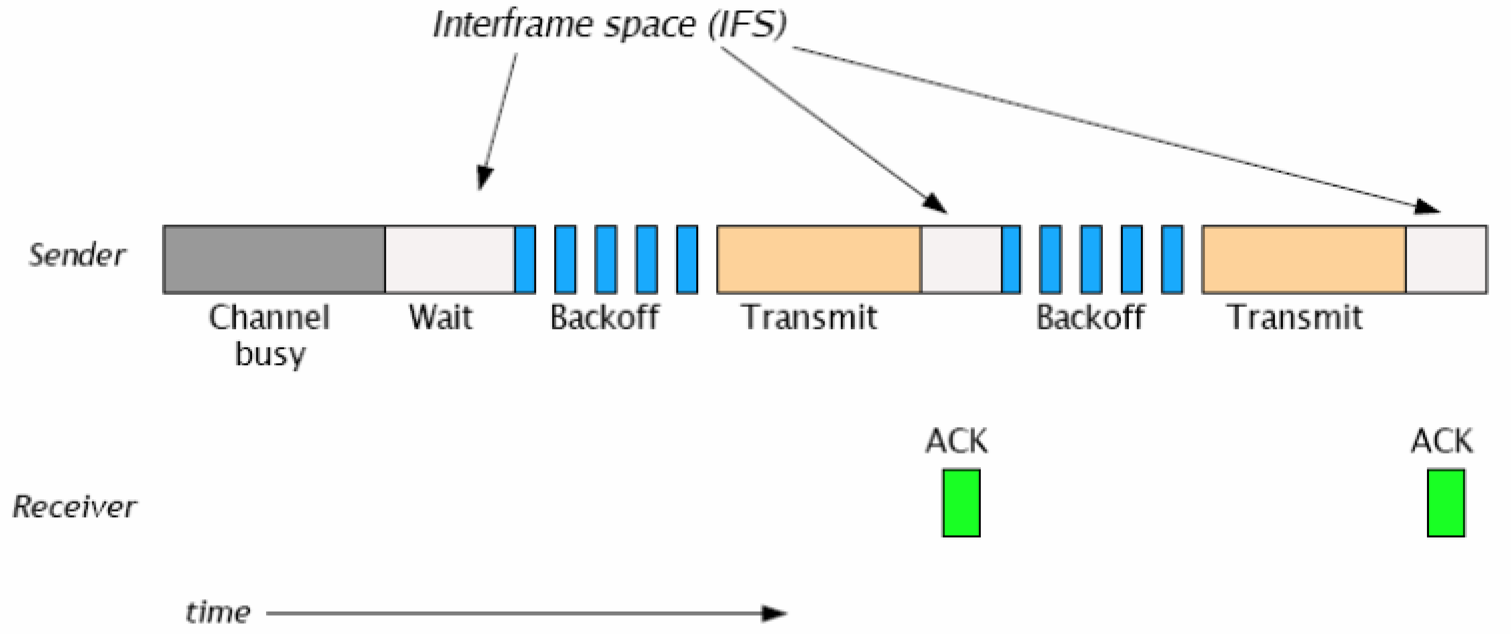
802.11 - MAC layer

- Traffic services
  - Asynchronous Data Service (mandatory)
    - implemented using DCF (Distributed Coordination Function)
  - Time-Bounded Service (optional)
    - implemented using PCF (Point Coordination Function)
- Access methods
  - DCF CSMA/CA (mandatory)
    - Distributed Wireless MAC
    - collision avoidance via randomized „back-off" mechanism
    - minimum distance between consecutive packets
    - ACK packet for acknowledgements (not for broadcasts)
  - DCF w/ RTS/CTS (optional)
    - avoids hidden terminal problem
  - PCF (optional)
    - access point polls terminals
    - Contention free

802.11 MAC functions

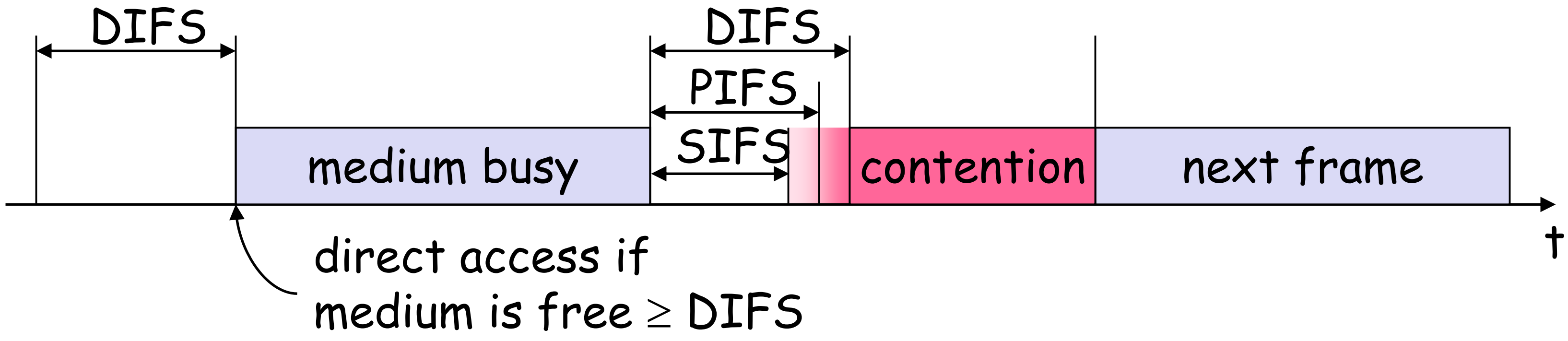
- MAC layer covers three functional areas:
  - Reliable data delivery
    - ACK-based scheme for reliability (receiver sends ACK after each successful transmission)
  - Medium access control
    - CSMA/CA; collision avoidance, not collision detection, Why? How?
  - Security
    - Wired Equivalent Privacy (WEP),WEP relies on a secret key being shared by end hosts and APs

DCF CSMA/CA Illustrated

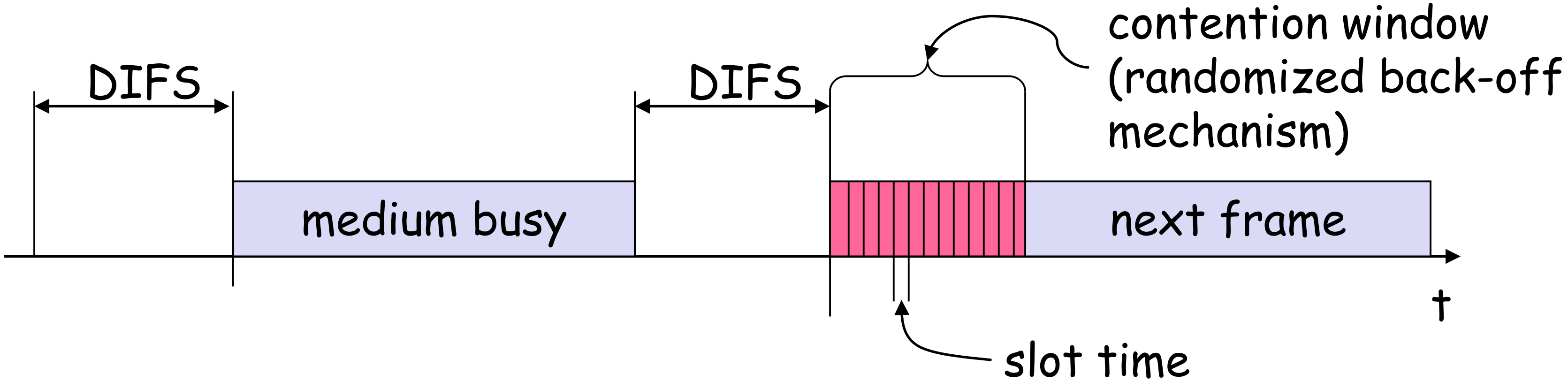


802.11 - MAC

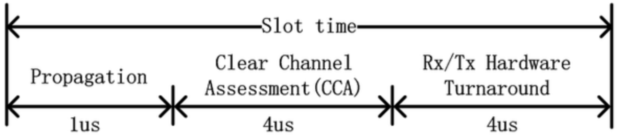
- Priorities
  - defined through different inter frame spaces
  - SIFS (Short Inter Frame Spacing) :
    - 10µs (802.11b/g), 16 µs (802.11a)
    - High priority, for ACK, CTS, polling response
  - PIFS (PCF IFS) :
    - PIFS = SIFS + Slot time, which is 20 µs 802.11b, 9 µs 802.11a/g
    - medium priority, for time-bounded service using PCF
  - DIFS (DCF IFS):
    - DIFS = PIFS + Slot time
    - lowest priority, for asynchronous data service



CSMA/CA access method



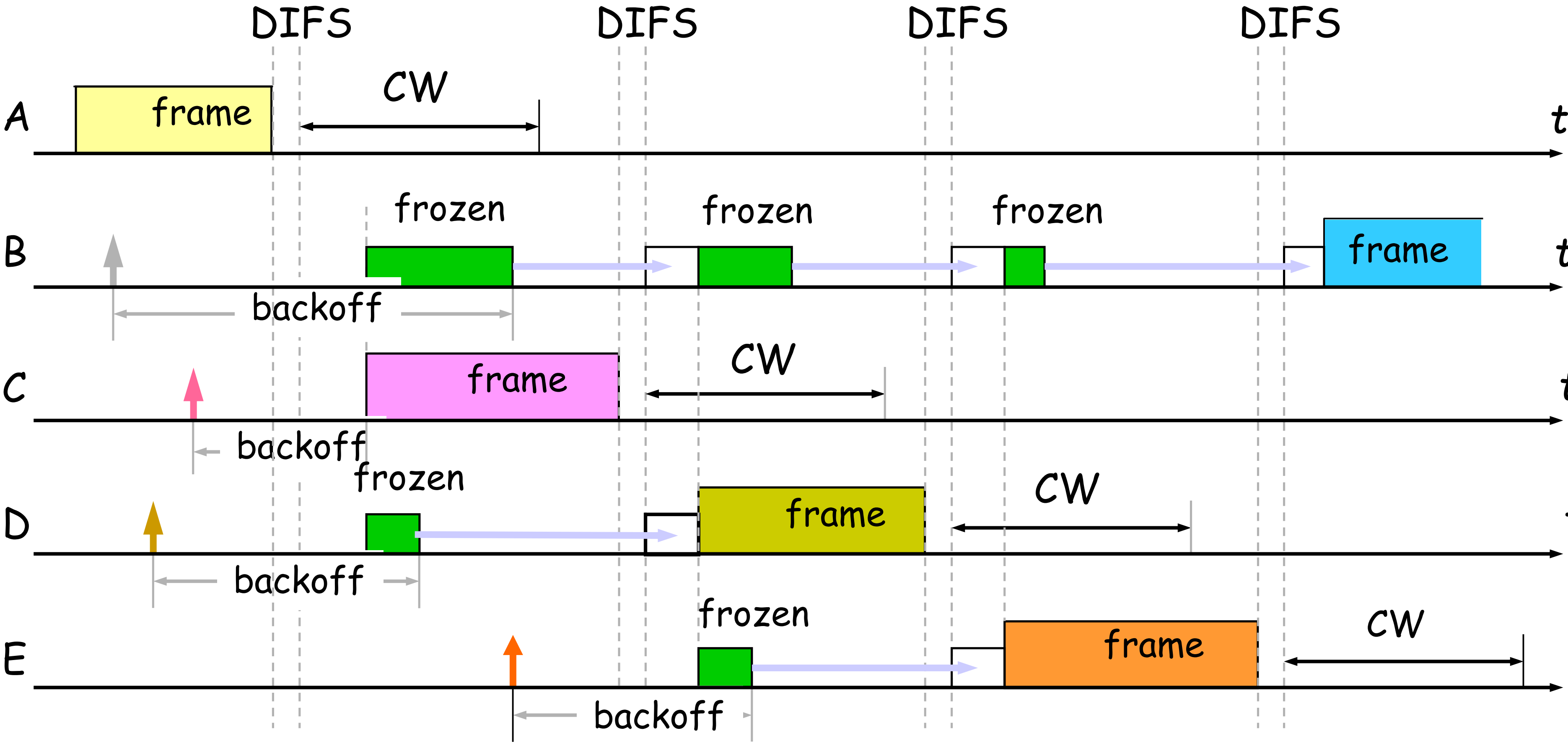
- station ready to send starts sensing the medium (Carrier Sense based on CCA, Clear Channel Assessment)
- if the medium is free for the duration of an Inter-Frame Space (IFS), the station can start sending (IFS depends on service type)
- if the medium is busy, the station has to wait for a free IFS, then the station must additionally wait a random back-off time (collision avoidance, multiple of slot-time)
  - Slot time = 20 µs for 802.11b, 9 µs in 802.11a/g
  - CW_min = 16 for 802.11a, 32 for 802.11b
  - CW_max = 1024



CSMA/CA access method (Continued)

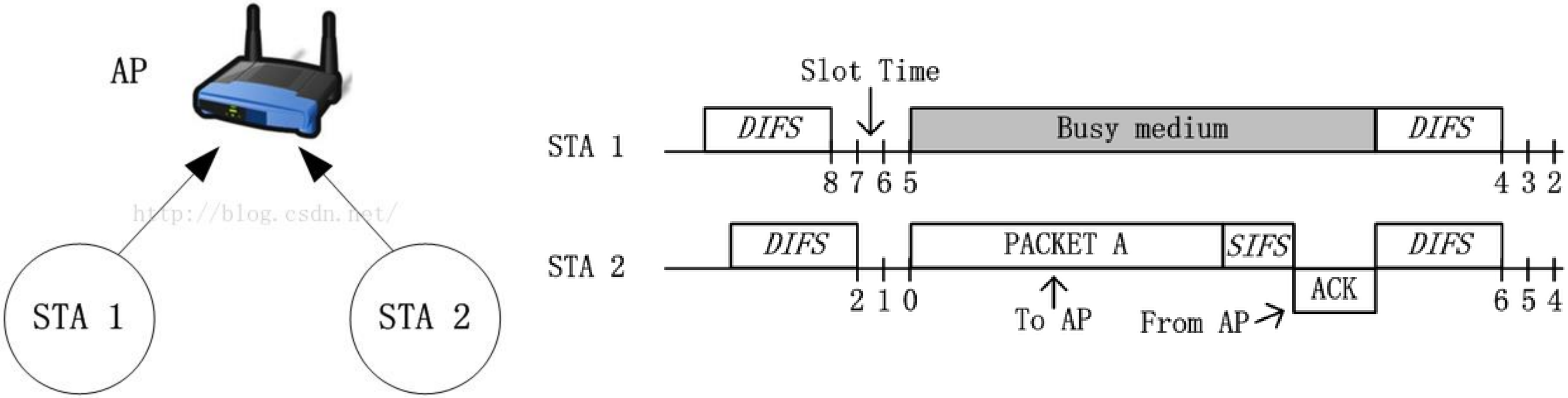
- If another station occupies the medium during the back-off time of the station, the back-off timer stops (fairness)
- When back-off timer reaches zero, start transmission
  - If more than one nodes decrement to zero at the same time, a collision will occur.
- If a collision occurs (missing ACK), the corresponding nodes double the CW size and choose their back-off time from the increase CW
- After successful transmission, CW size is reset to its min value.

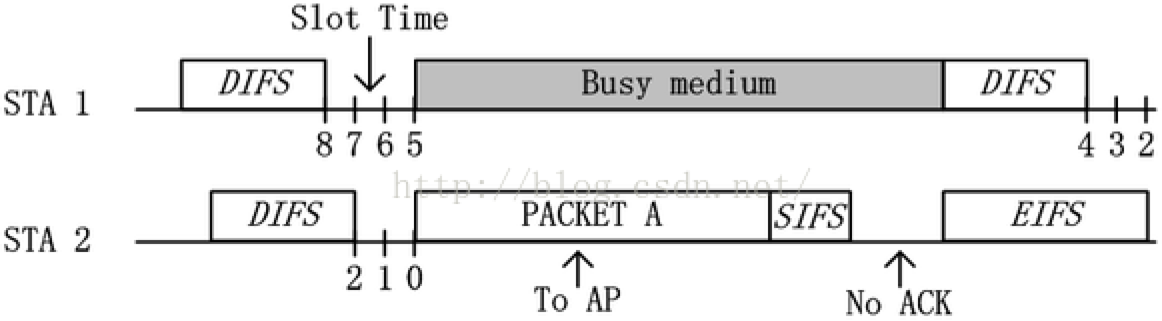
A simplified example



🟩 frozen residual backoff time

CSMA/CA example

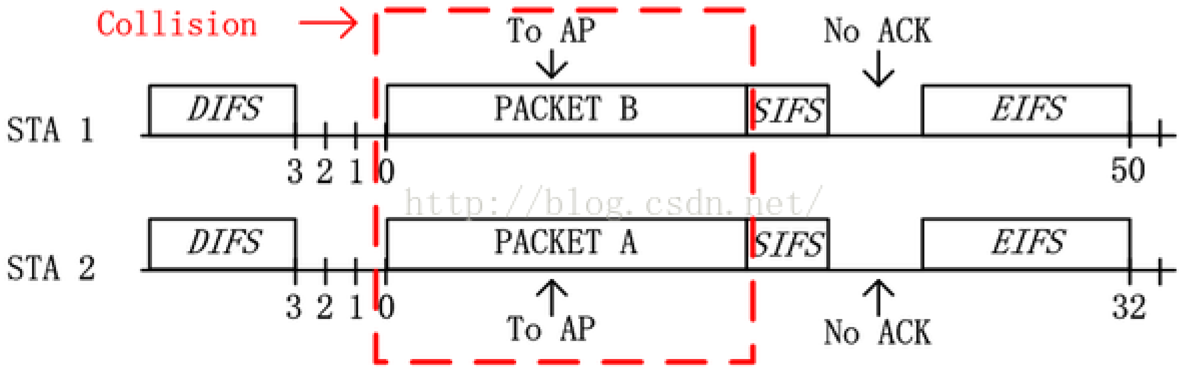




802.11协议精读2：DCF与CSMA/CA_adr5970的博客-CSDN博客

https://www.zhihu.com/column/dot11

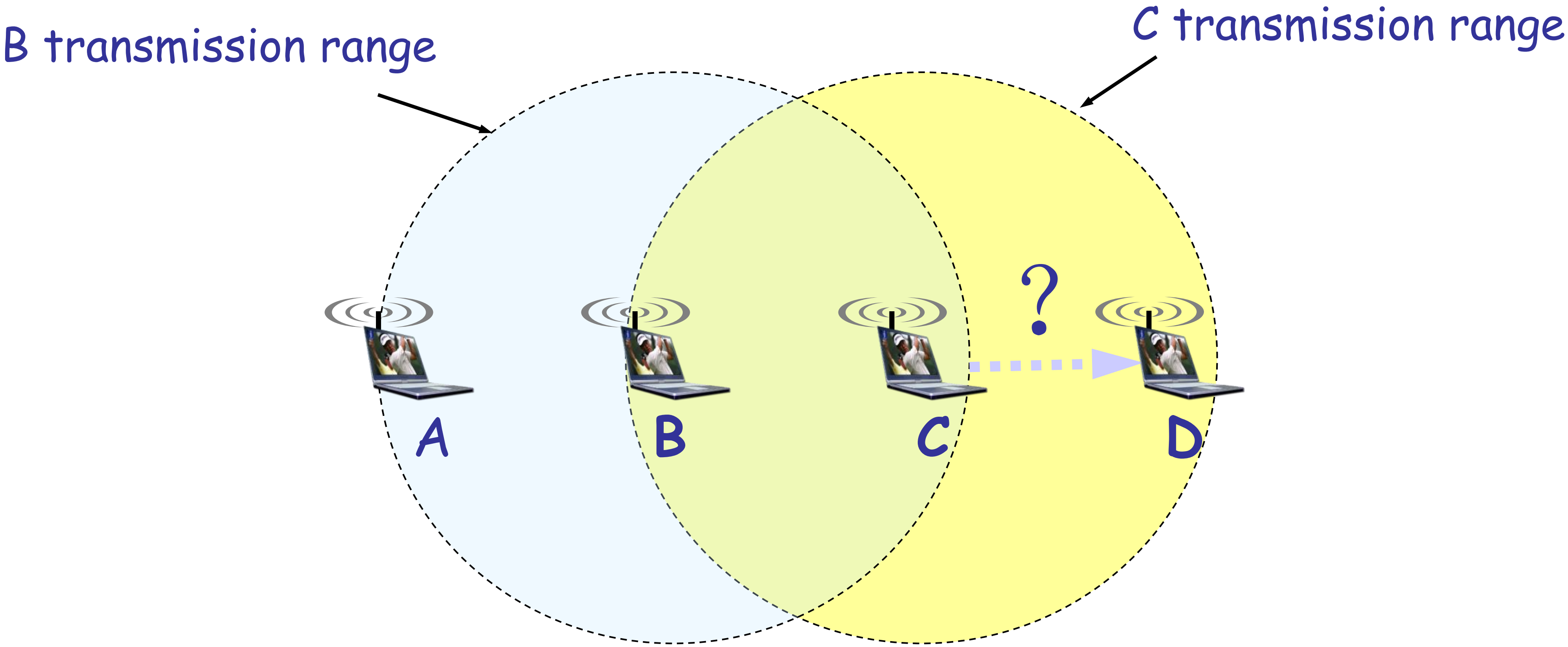
CSMA/CA example



在 "**等待**" DIFS后，STA 1与STA 2从各自的竞争窗体CW中选择一个随机数。只是碰巧的是，两者随机到了一样的数值，如图中，STA 1与STA 2都是随机到了3作为随机回退计数值。在经过3个slot time之后，因为两者同一时候倒数至0。那么意味着两者会同一时候发送数据。如图中的红色虚线框表示，在AP处因为两者信号互相干扰，从而都无法正确解码，从而CRC校验错误。即发生冲突。在冲突之后，即若AP处CRC校验失败，则不会给随意节点反馈ACK数据包。故两节点在ACK timeout之后，则等待EIFS之后，准备进入下一次竞争。

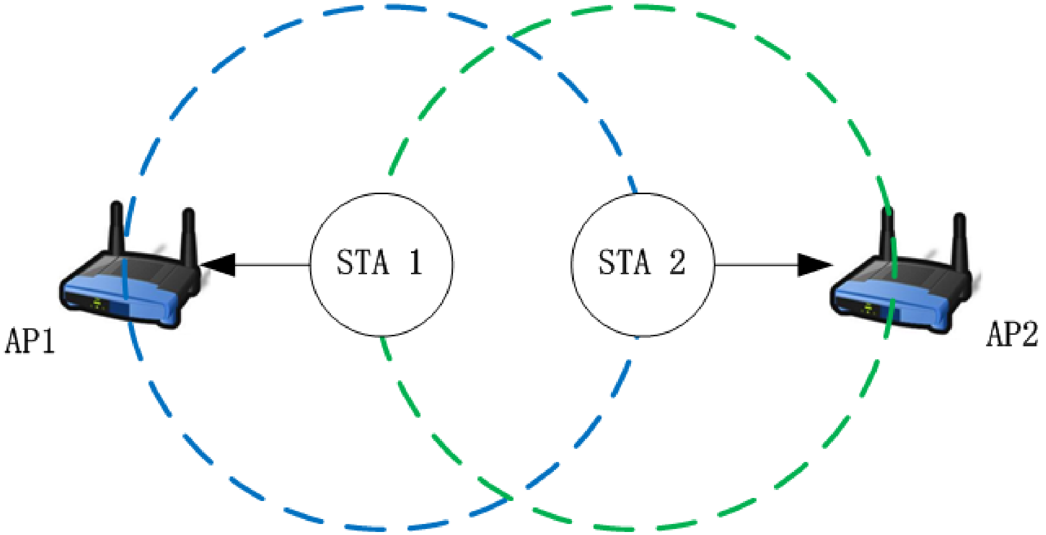
802.11协议精读2：DCF与CSMA/CA_adr5970的博客-CSDN博客

LAN exposed terminal problem



B is sending data to A. At the same time, C hopes to communication with D. But C senses a signal in the medium and dare not send the data.

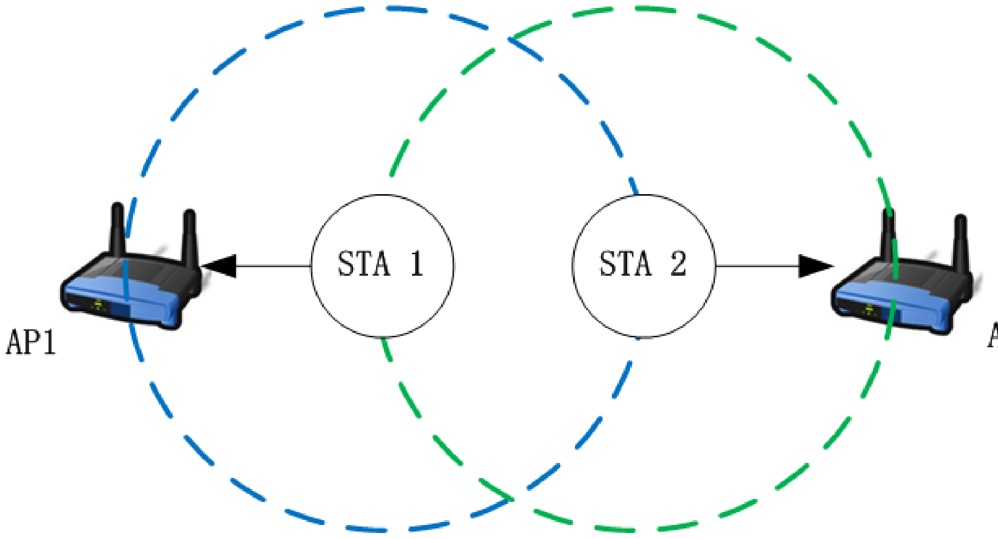
LAN exposed terminal problem



AP1处于STA 1的覆盖范围内，而不再STA 2的覆盖范围内。AP2处于STA 2的覆盖范围，而不在STA 1的覆盖范围内。换言之，AP1只能接受到STA 1的数据，AP2也只能接收到STA 2的数据。当STA 1与STA 2同时发送时，接受节点AP1或者AP2处均不会发生冲突，故其是可以同时传输的。但是由于这样的拓扑特殊性以及DCF中CSMA/CA的工作机制，造成STA 1与STA 2无法同时传输，该问题则是暴露终端问题。

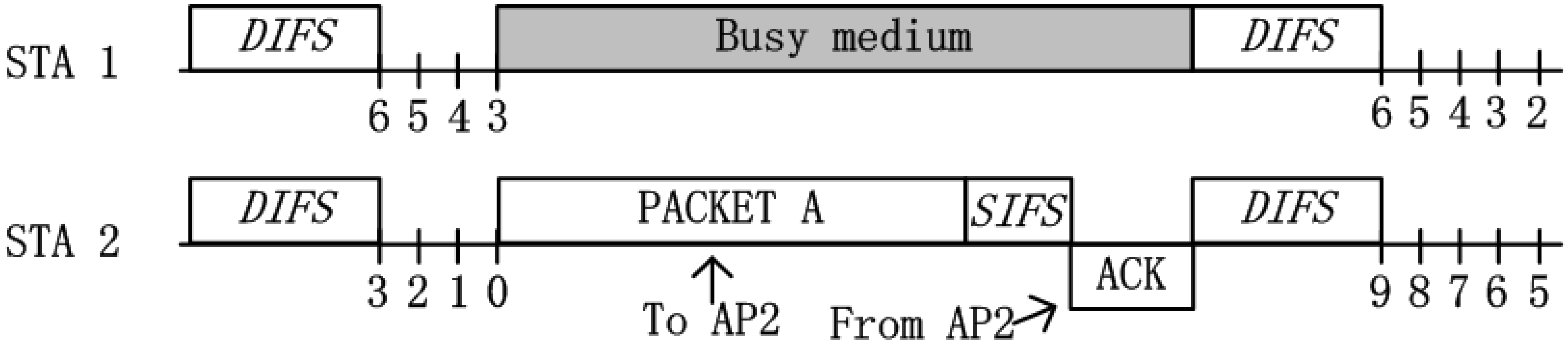
802.11协议精读5：隐藏终端和暴露终端 - 知乎 (zhihu.com)

LAN exposed terminal problem



物理载波监听引起的暴露终端

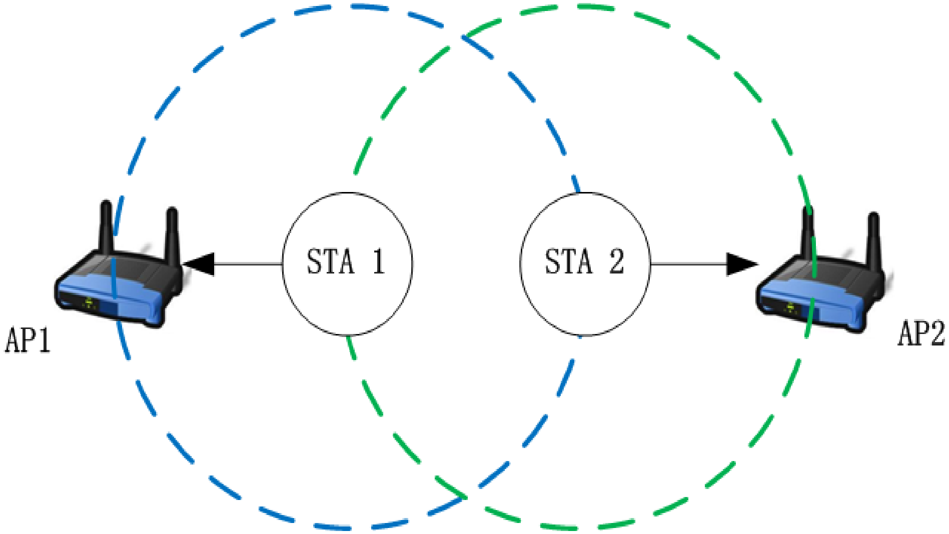
由于STA 1与STA 2可以互相监听。由于STA 2选择了较小的随机数进行倒数，从而其最先倒数至0，并进行发送。当STA 2首先发送数据包给STA 2后，STA 1监听信道为忙状态，从而无法发送信息。故根据拓扑而言，STA 1是可以传数据给AP1的，但是由于监听STA 2正在传输，导致信道忙，故STA1悬挂随机倒数计数器，无法继续倒数，从而无法传输。



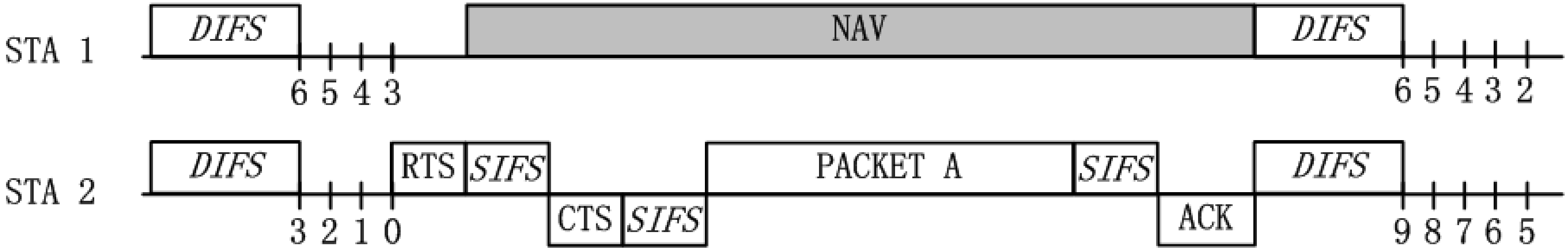
802.11协议精读5：隐藏终端和暴露终端 - 知乎 (zhihu.com)

LAN exposed terminal problem

虚拟载波监听引起的暴露终端

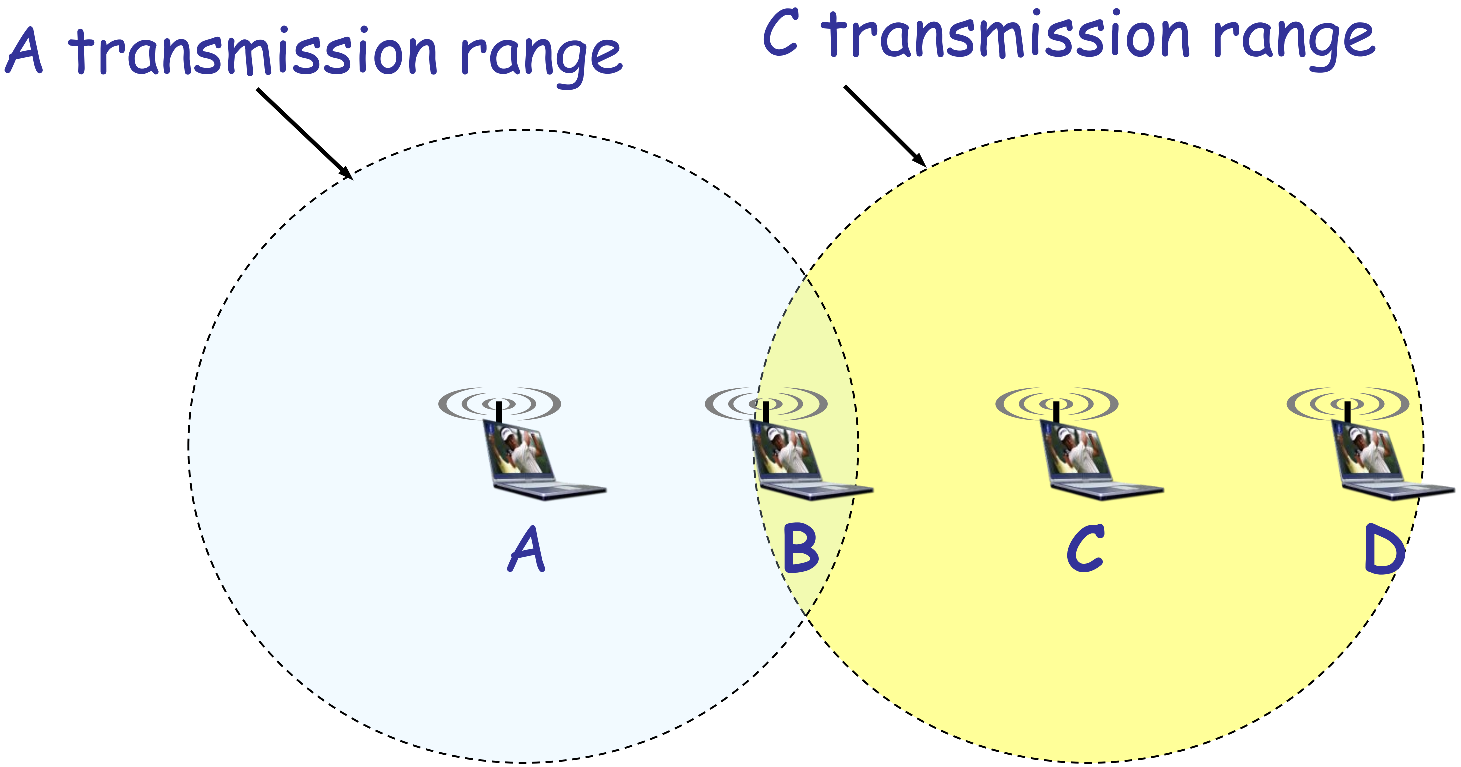


在暴露终端场景中，若STA 2不仅选择了较小的随机数进行优先倒数，并且其发送的数据包是RTS数据包。当STA 1识别到该RTS数据包后，其就会被设置为NAV状态，无法在后面的过程主动竞争信道，进而无法传输。与之前描述用RTS/CTS解决隐藏终端问题时不同，在解决隐藏终端问题中，NAV是由AP所反馈的CTS帧所进行保护。而这里由于STA 1与STA 2能够互相监听，换言之，在暴露终端情况下，STA 1的NAV是被STA 2所发送的RTS帧进行保护的。在STA 1被NAV保护后，其也无法传输，最终导致暴露终端问题。



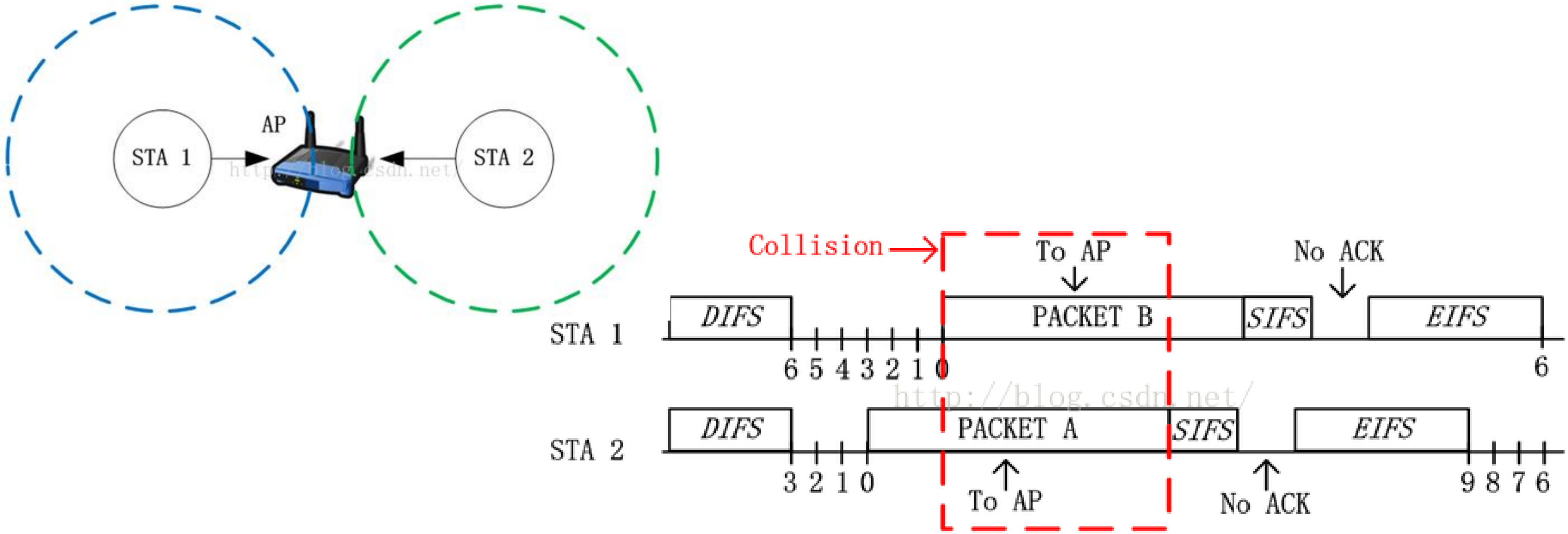
802.11协议精读5：隐藏终端和暴露终端 - 知乎 (zhihu.com)

LAN hidden terminal problem



A and C cannot hear each other and think B is idle, then, they both send data to B. A collision appears at the destination, B.

LAN hidden terminal problem



因为STA 1与STA 2无法互相监听，即STA 2发送数据后，STA 1还继续进行backoff过程，从而继续倒数。当STA 1的随机回退计数值倒数至0时。STA 1也会发送数据。

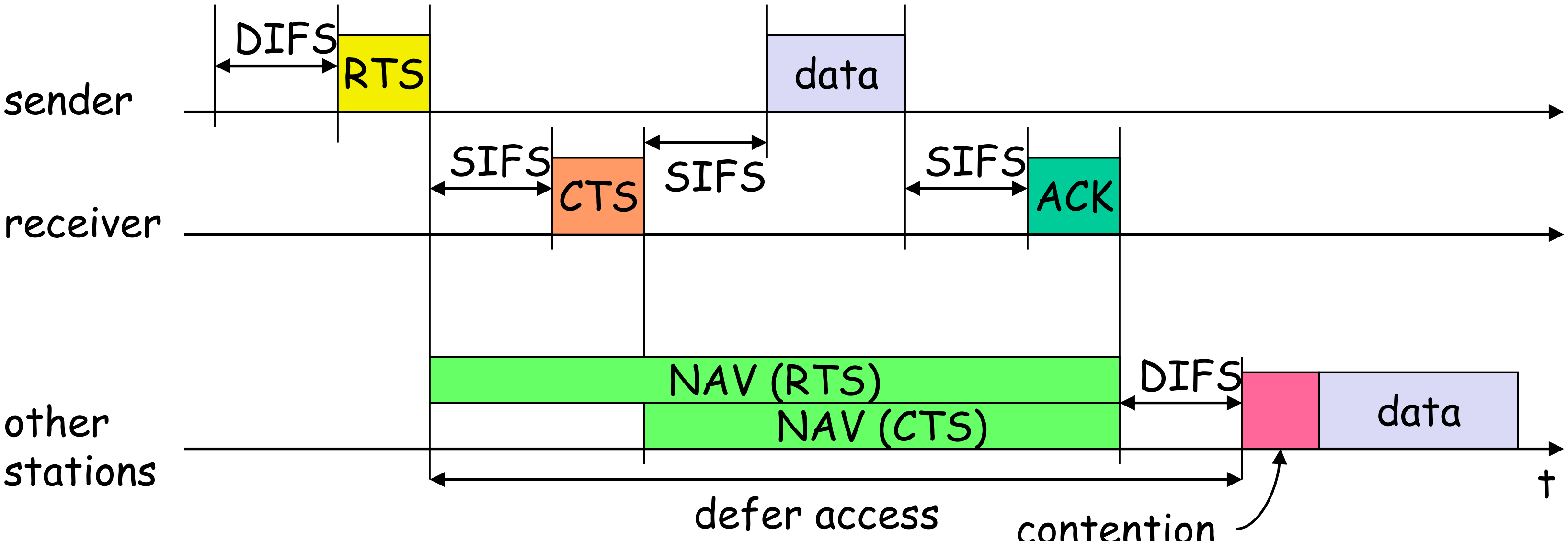
因为STA 1与STA 2的发送存在重叠区域，即也是发生了冲突，AP无法正确接收数据。即不会反馈ACK，终于这一轮传输失败。这一轮失败之后，STA 1与STA 2采用BEB算法又一次选择随机数进行回退，可是因为两者没有办法互相监听，所以非常容易再次出现同一时候传输的现象。

所以在隐藏终端的情况下，网络性能最差时是无法传递数据包的，换言之。STA 1与STA 2的吞吐量都趋近于0。

RTS/CTS

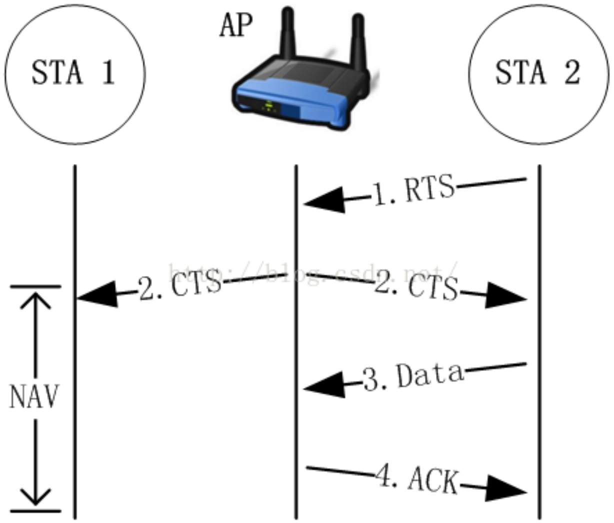
802.11 CSMA/CA WITH Hidden Terminals (pearsoncmg.com)

- Sending unicast packets
  - station can send RTS with reservation parameter after waiting for DIFS (reservation determines amount of time the data packet needs the medium)
  - acknowledgement via CTS after SIFS by receiver (if ready to receive)
  - other stations store medium reservations distributed via RTS and CTS
  - Two (potentially different) NAV groups

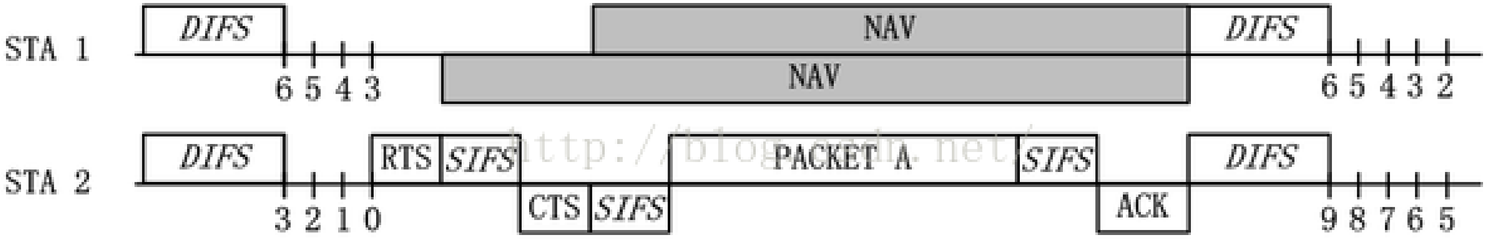


RTS/CTS

•当STA 1接收到CTS之后，该CTS不是我所请求所获得的，或者说，该CTS不是相应发给我的CTS。从而STA 1会将CTS数据帧的duration给提出。并设置在自己本地的NAV（Network Allocation Vector）上。若NAV没有倒数到0，那么其会主动悬挂其随机回退计数值，在NAV没有倒数到0之前，其随机回退计数值不再继续倒数。

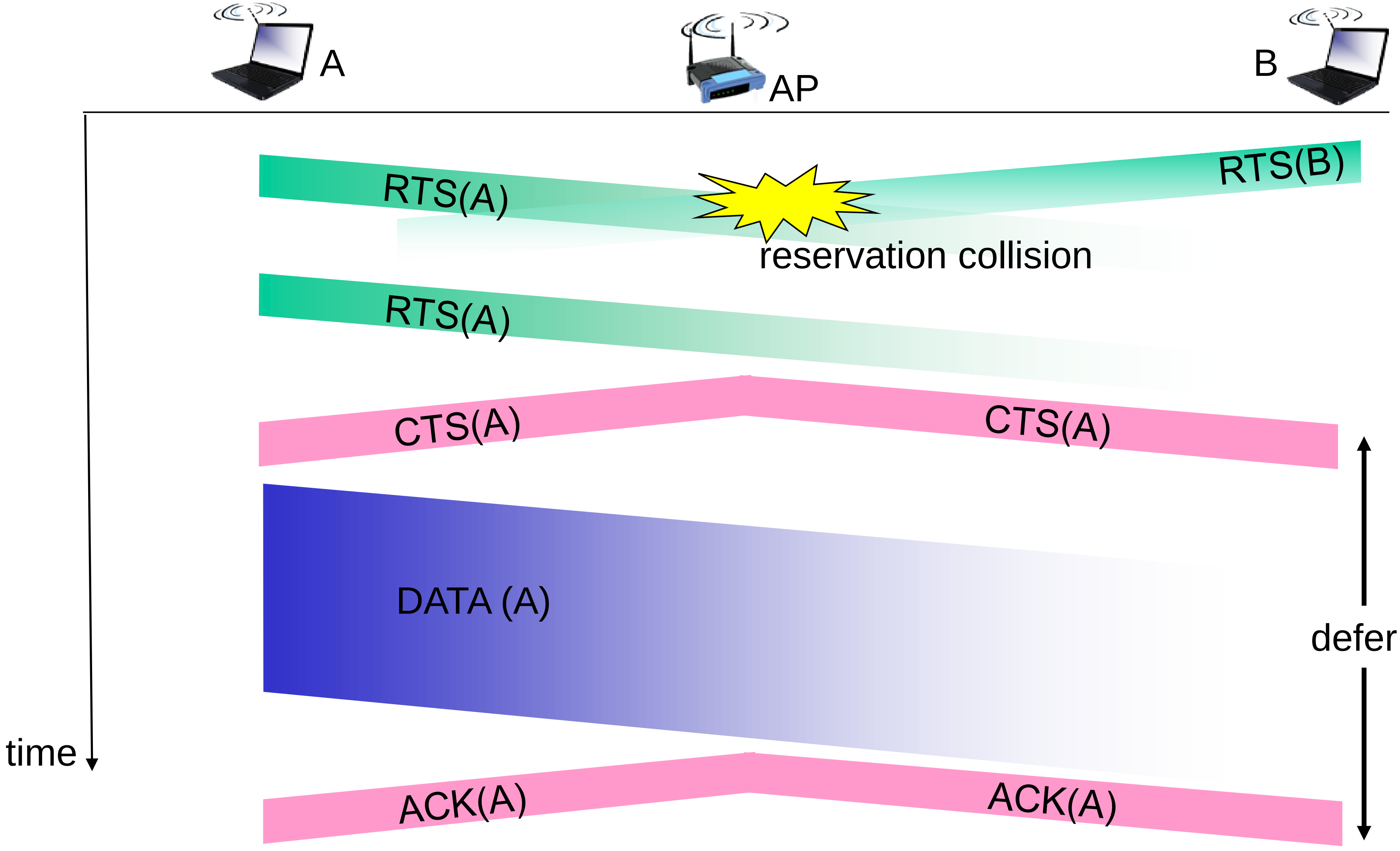


当STA 2接收到CTS后。其发现该其是之前发送RTS的反馈。故节点已知信道空暇，在等待SIFS后，STA 2发送数据。当传输数据完毕之后，AP向STA 2反馈ACK，从而终于完毕一次传输。



802.11协议精读2：DCF与CSMA/CA_adr5970的博客-CSDN博客

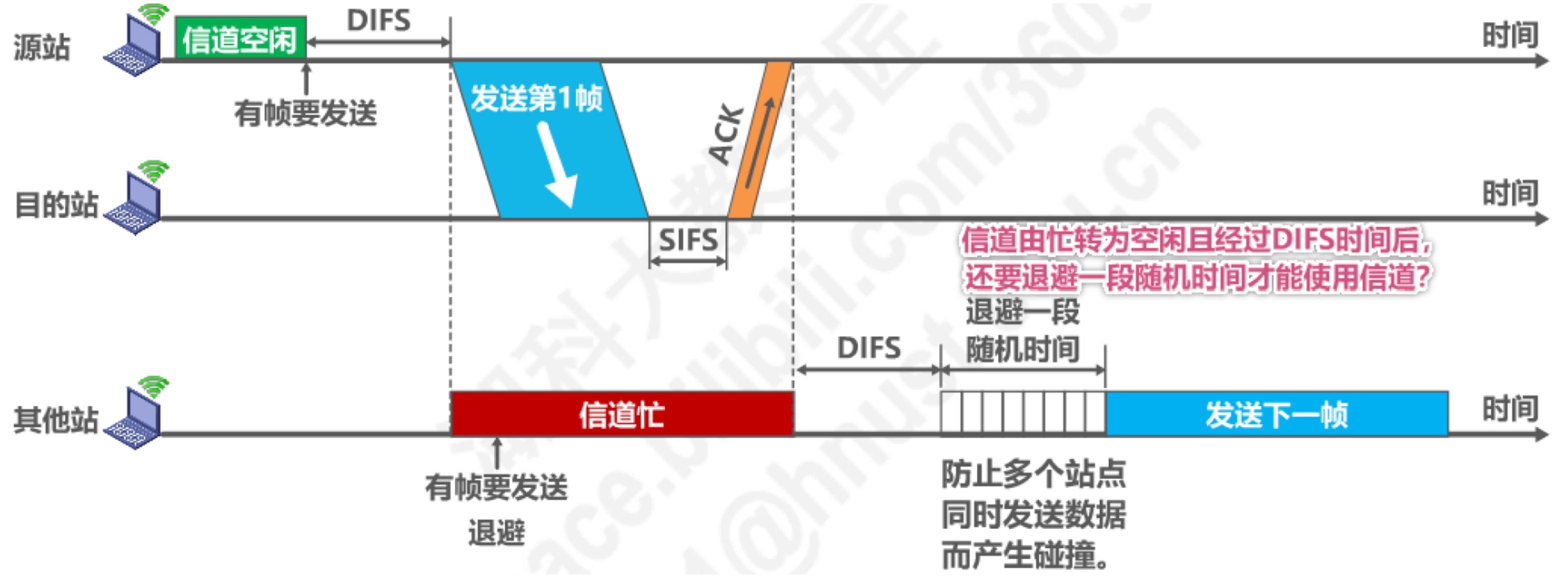
Collision Avoidance: RTS-CTS exchange

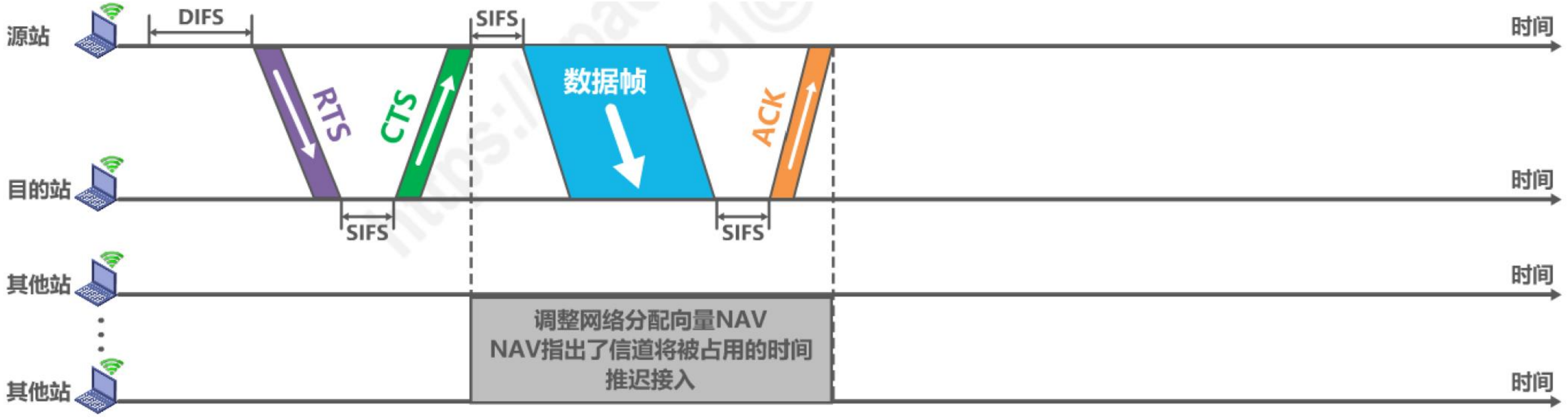


RTS/CTS (Continued)

- Avoid hidden terminal problems
- Also, reduce bandwidth waste by collisions
  - Data frame can be as large as 2300bytes
  - RTS = 20bytes, CTS = 14bytes
  - The bigger is the data frame, the more advantageous
- Price : extended delay and more resource consumption!
- RTS threshold
  - Enable RTS/CTS for frames which are bigger than RTS threshold
  - Each node's decision

CSMA/CA access method





802.11 CSMA/CA WITHOUT Hidden Terminals (pearsoncmg.com)

802.11 CSMA/CA WITH Hidden Terminals (pearsoncmg.com)

802.11 - MAC frame format

- Type/subtype
  - control frames(01), management frames(00), data frames(10)
  - E.g., data frame: type=10,subtype=0000
    beacon: type=00,subtype=1000
    RTS: type= 01,subtype=1011
- Sequence numbers
  - important against duplicated frames due to lost ACKs
- Addresses
  - receiver, transmitter (physical), BSS identifier, sender (logical)
- Miscellaneous
  - duration, checksum, frame control, data

bytes	2	2	6	6	6	2	6	0-2312	4
	Frame Control	Duration/ ID	Address 1	Address 2	Address 3	Sequence Control	Address 4	Data	CRC

bits	2	2	4	1	1	1	1	1	1	1	1
	Protocol version	Type	Subtype	To DS	From DS	More Frag	Retry	Power Mgmt	More Data	WEP	Order

MAC address format

scenario	to DS	from DS	address 1	address 2	address 3	address 4
ad-hoc network	0	0	DA	SA	BSSID	-
infrastructure network, from AP	0	1	DA	BSSID	SA	-
infrastructure network, to AP	1	0	BSSID	SA	DA	-
infrastructure network, within DS	1	1	RA	TA	DA	SA

DS: Distribution System
AP: Access Point
DA: Destination Address
SA: Source Address
BSSID: Basic Service Set Identifier – MAC address of AP, cf: (E)SSID
RA: Receiver Address (AP)
TA: Transmitter Address (AP)

Special Frames: ACK, RTS, CTS

- Acknowledgement

ACK

bytes	2	2	6	4
	Frame Control	Duration	Receiver Address	CRC

- Request To Send

RTS

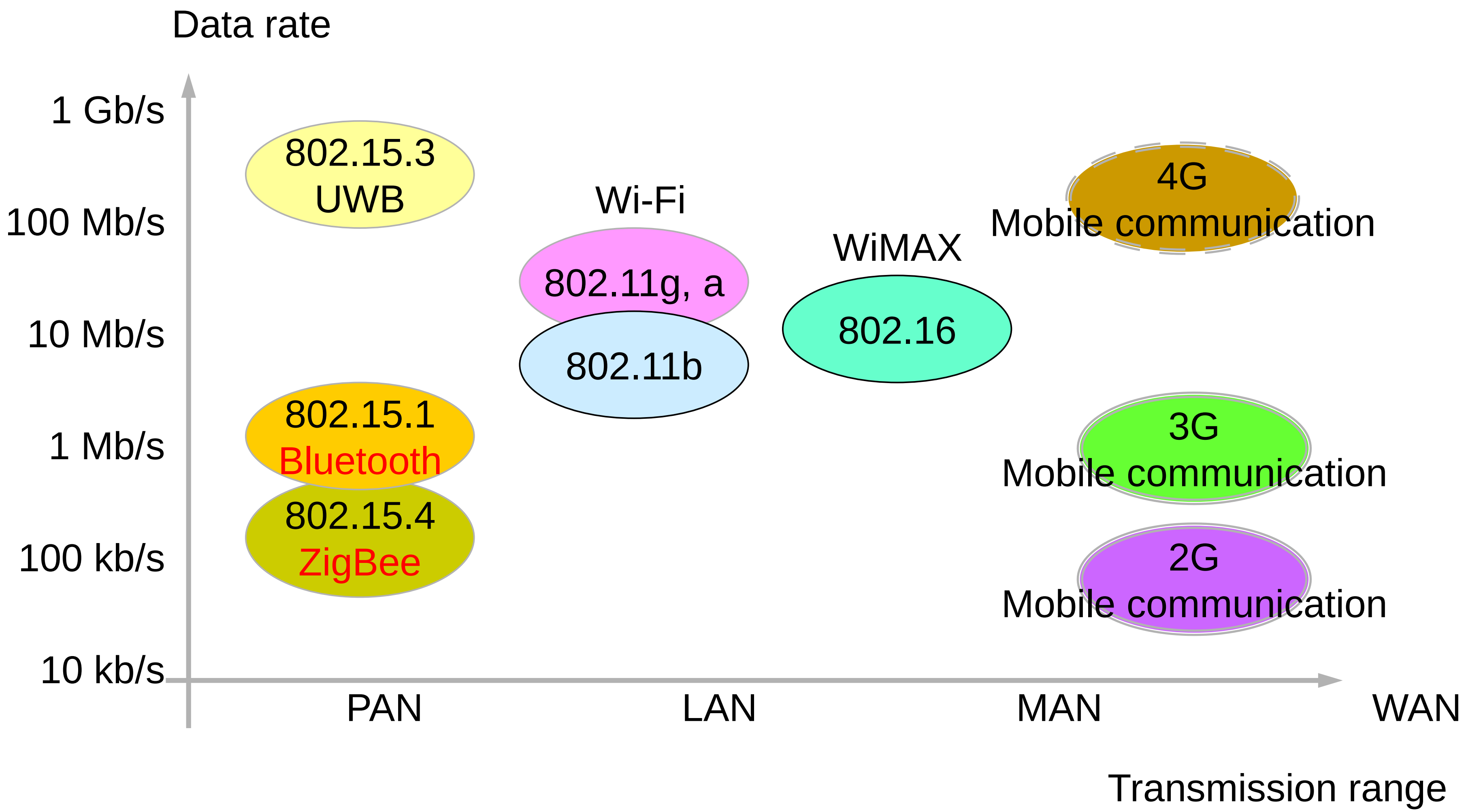
bytes	2	2	6	6	4
	Frame Control	Duration	Receiver Address	Transmitter Address	CRC

- Clear To Send

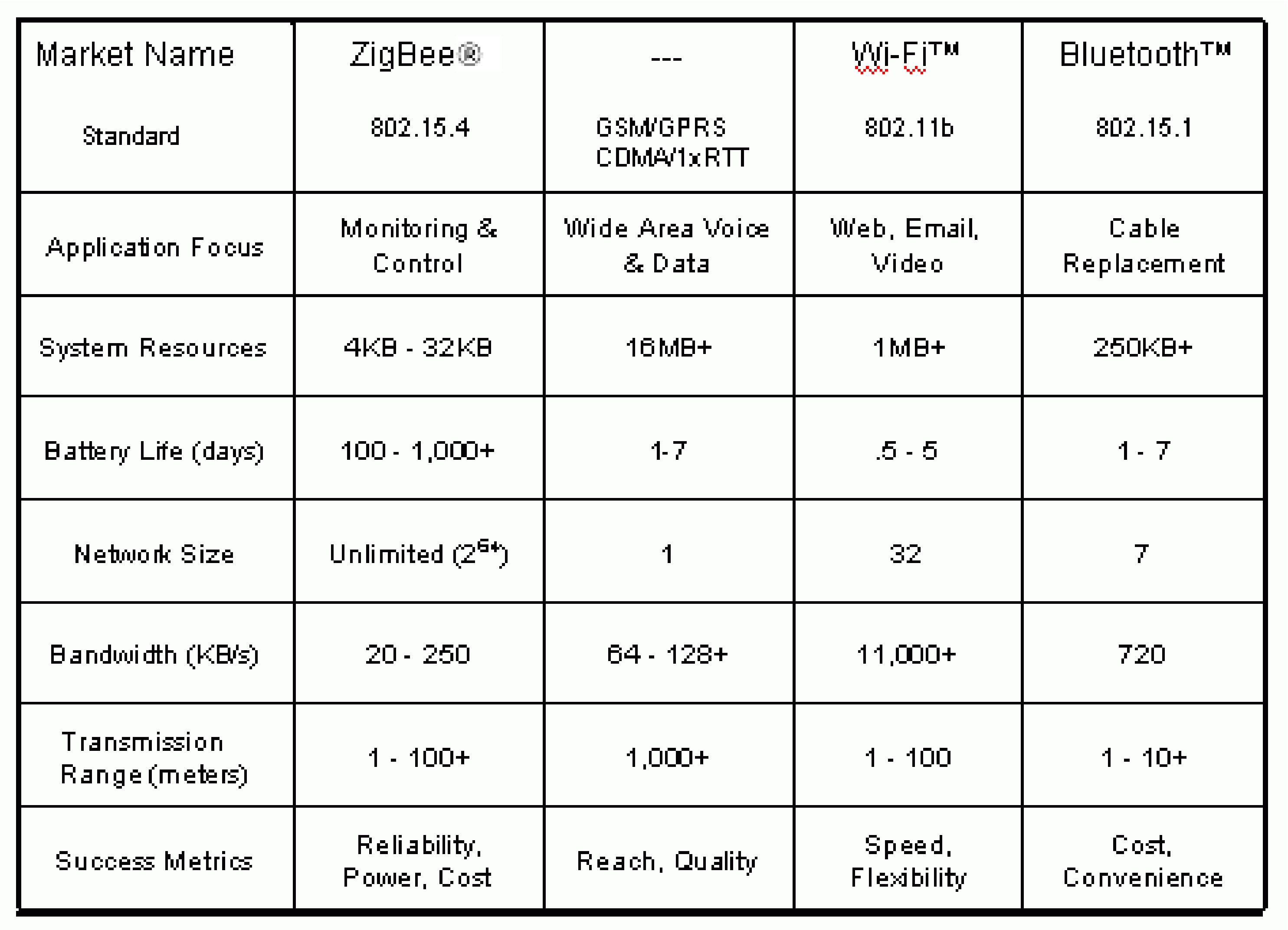
CTS

bytes	2	2	6	4
	Frame Control	Duration	Receiver Address	CRC

Wireless communication technology



Wireless standards



Market Name Standard	ZigBee® 802.15.4	--- GSM/GPRS CDMA/1xRTT	Wi-Fi™ 802.11b	Bluetooth™ 802.15.1
Application Focus	Monitoring & Control	Wide Area Voice & Data	Web, Email, Video	Cable Replacement
System Resources	4KB - 32KB	16MB+	1MB+	250KB+
Battery Life (days)	100 - 1,000+	1-7	.5 - 5	1 - 7
Network Size	Unlimited (2^{64})	1	32	7
Bandwidth (KB/s)	20 - 250	64 - 128+	11,000+	720
Transmission Range (meters)	1 - 100+	1,000+	1 - 100	1 - 10+
Success Metrics	Reliability, Power, Cost	Reach, Quality	Speed, Flexibility	Cost, Convenience

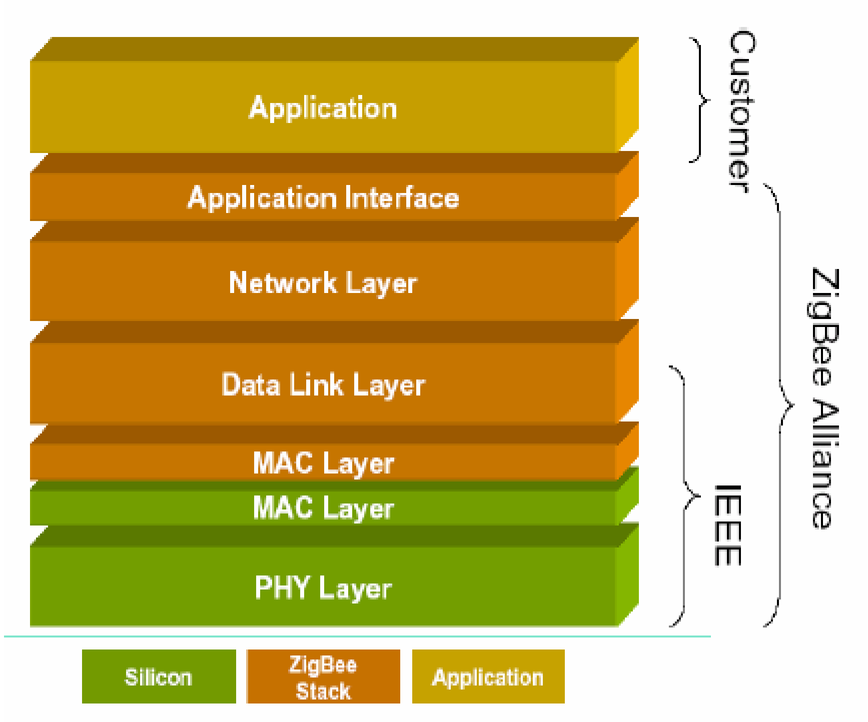
IEEE 802.15.4 and ZigBee

- IEEE 802.15.4 Working Group

  Defining lower layers of protocol stack: MAC and PHY

- ZigBee Alliance

  Defining upper layers of protocol stack from network to application

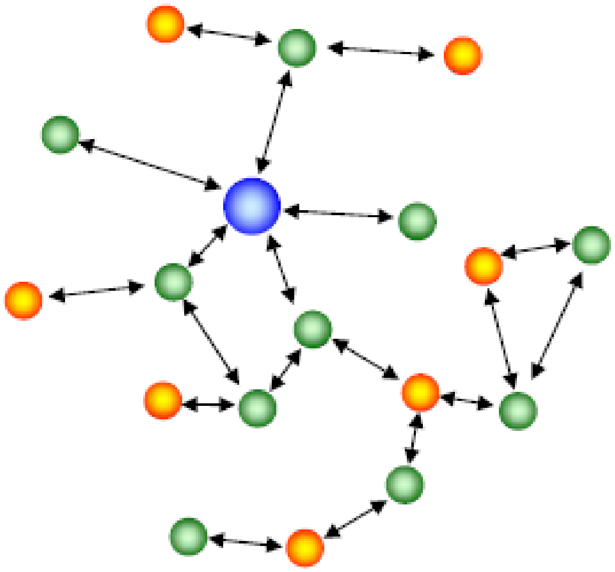


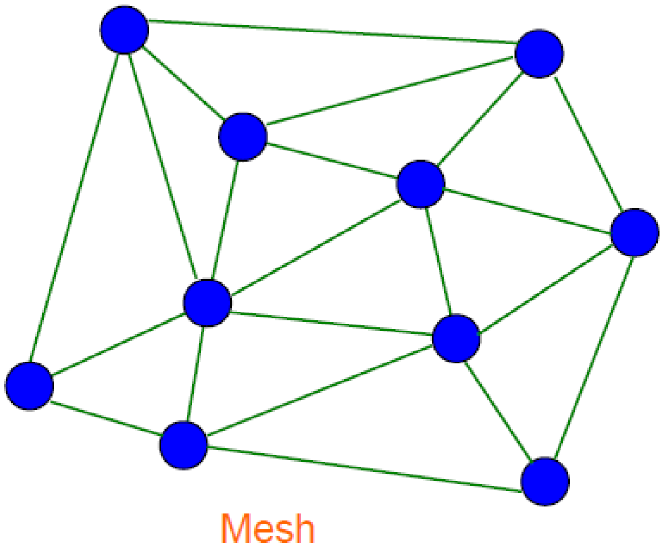
ZigBee overview

- ZigBee was created to address the market need for a cost-effective, standards based wireless networking solution that supports low data-rates, low-power consumption, security, and reliability.
- ZigBee is the only standards-based technology that addresses the unique needs of most remote monitoring and control and sensory network applications.
- The initial markets for the ZigBee Alliance include Home Automation, Building Automation and Industrial Automation.

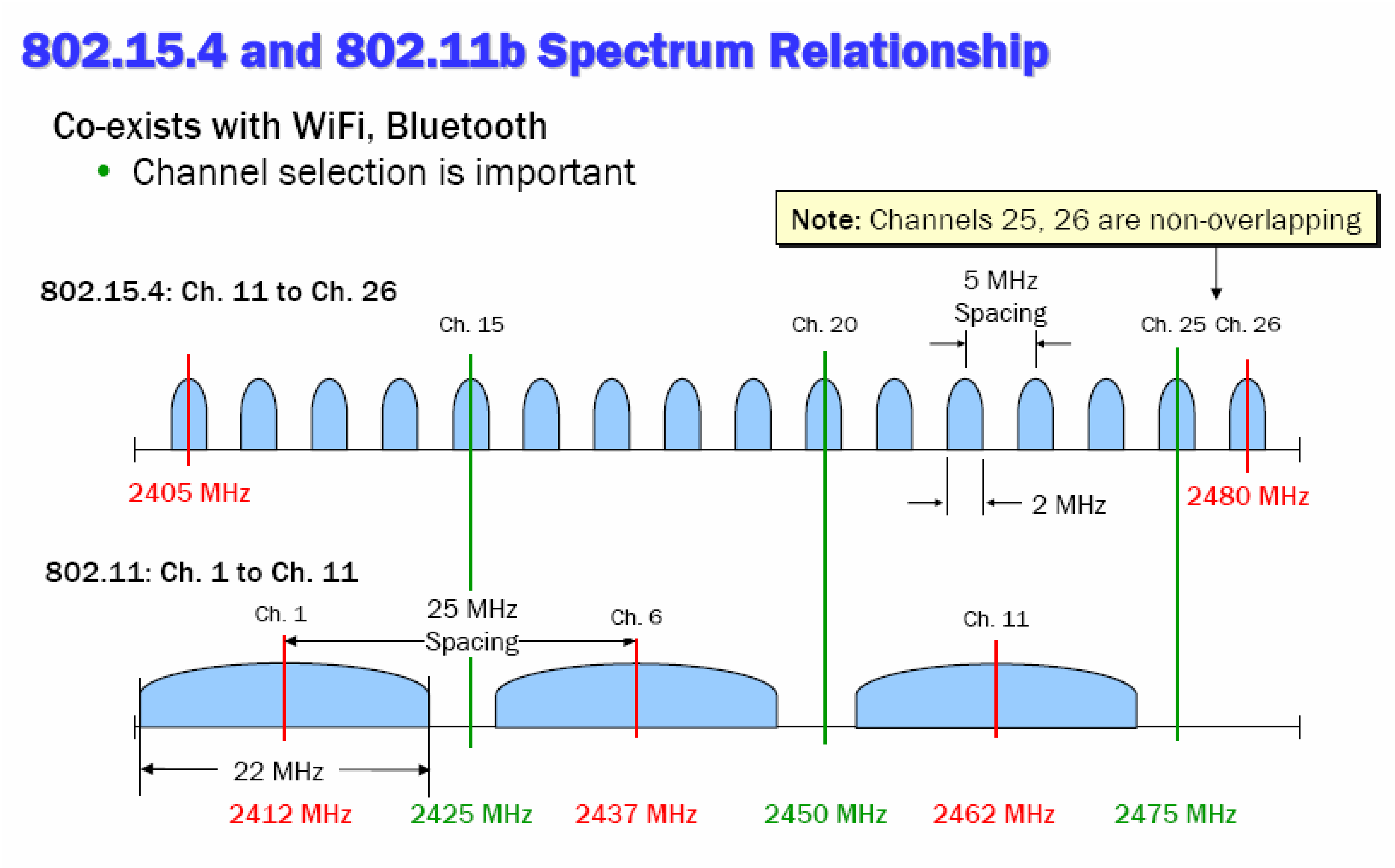
How to achieve low power consumption?

- The duty cycle of battery is designed to be very low, resulting in very low average power consumption.
- Once associated with a network, a ZigBee node can wake up and communicate with other devices and return to sleep.
- Short range operation.
- Simple but flexible protocol.





Interference and Coexistence in the 2.4GHz Band



802.15.4 and 802.11b Spectrum Relationship

Co-exists with WiFi, Bluetooth

- Channel selection is important

Note: Channels 25, 26 are non-overlapping

Chapter 4:Local area network Summary

- various link layer technologies
  - LAN model
  - Ethernet
  - hubs, switches
  - VLAN
  - IEEE 802.11
  - IEEE 802.15

802.11协议精读3：CSMA/CD与CSMA/CA
https://zhuanlan.zhihu.com/p/20731045