Introduction to Computer Networks

IEEE 802.11 Wireless LAN

Outline

- Introduction
- Distributed System
- IEEE 802.11 Frame format
- IEEE 802.11 MAC Architecture
- Distributed Coordination Function (DCF)
- Point Coordination Function (PCF)
- IEEE 802.11 Standards

IEEE 802.11

- IEEE 802.11 is designed for a limited geographical area (homes, offices, campuses, stations)
  - The signals propagating through **space** 通过空气传输
- Also known as **Wi-Fi**
- IEEEE 802.11 supports additional features
  - Power management and 电源管理：没有数据要送，就进入睡眠
  - Security mechanisms 因为通过空气传播，所以需要加上加密的功能

IEEE 802.11 Physical layer

- Original 802.11 standard defined two radio-based physical layer standard
  - One using the frequency hopping 跳频
    - Over 791-MHz-wide frequency bandwidths
  - Second using direct sequence
    - Using 11-bit chipping sequence
  - Both standards run in the 2.4-GHz and provide up to 2 Mbps

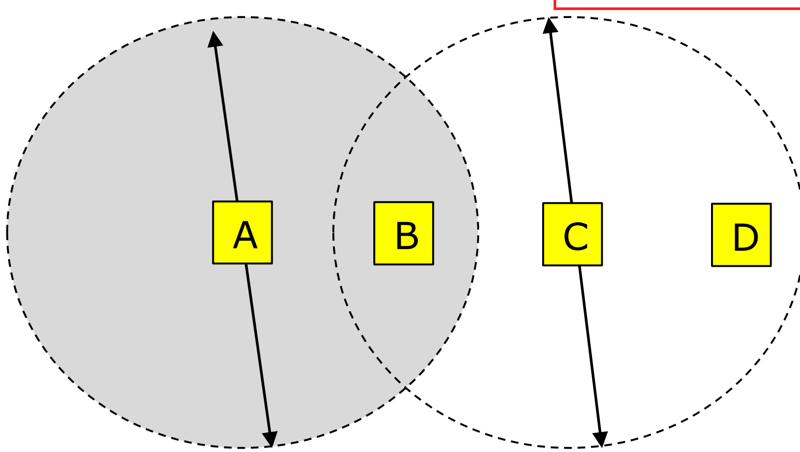
IEEE 802.11 Standards

- Then physical layer standard 802.11b was added
  - Using a variant of direct sequence 802.11b provides up to 11 Mbps
  - Uses license-exempt 2.4-GHz band
- Then came 802.11a which delivers up to 54 Mbps using OFDM
  - 802.11a runs on license-exempt 5-GHz band
- Then came 802.11g which is backward compatible with 802.11b
  - Uses 2.4 GHz band, OFDM and delivers up to 54 Mbps
- Most recent standard is 802.11n which delivers up to 108Mbps, with multiple wireless signals and antennas, called *MIMO* technology.

IEEE 802.11 – Hidden node problem

- Assume each of four nodes is able to send and receive signals that reach just the nodes to its immediate left and right
  - For example, B can exchange frames with A and C, but it cannot reach D
  - C can reach B and D but not A

A和C互相听不到对方，即A和C Hidden

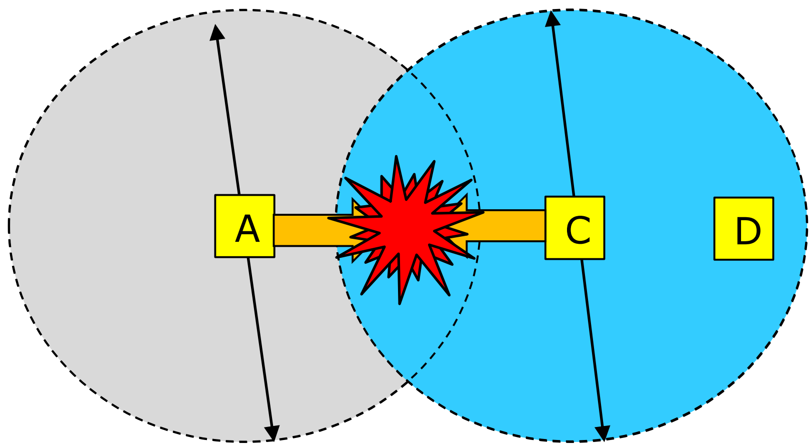


Example of a wireless network

IEEE 802.11 – Hidden node problem

- Suppose both A and C want to communicate with B and so they each send it a frame.
  - A and C are unaware of each other since their signals do not carry that far
  - These two frames collide with each other at B
    - But unlike an Ethernet, neither A nor C is aware of this collision
  - A and C are said to *hidden nodes* with respect to each other

IEEE 802.11 – Hidden node problem



"Hidden Node" Problem

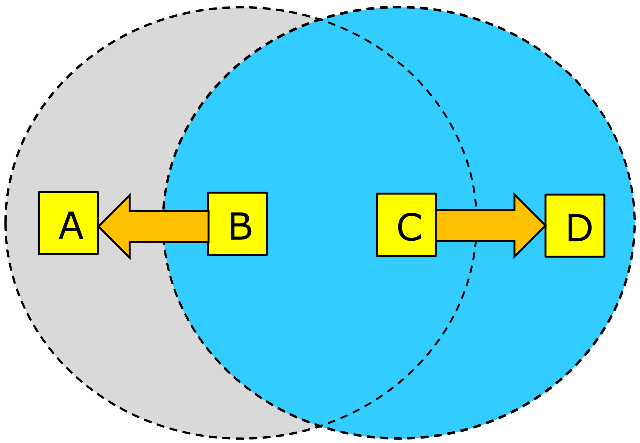
Although A and C are hidden from each other, their signals can collide at B.

雙方雖然聽不到對方的訊號, 但同時傳送給相同的對象會造成衝撞

IEEE 802.11 – Exposed node problem

- *Exposed node* problem
  - Suppose B is sending to A. Node C is aware of this communication because it hears B's transmission.
  - It would be a mistake for C to conclude that it cannot transmit to anyone just because it can hear B's transmission.
  - Suppose C wants to transmit to node D.
  - This is not a problem since C's transmission to D will not interfere with A's ability to receive from B.

IEEE 802.11 – Exposed node problem



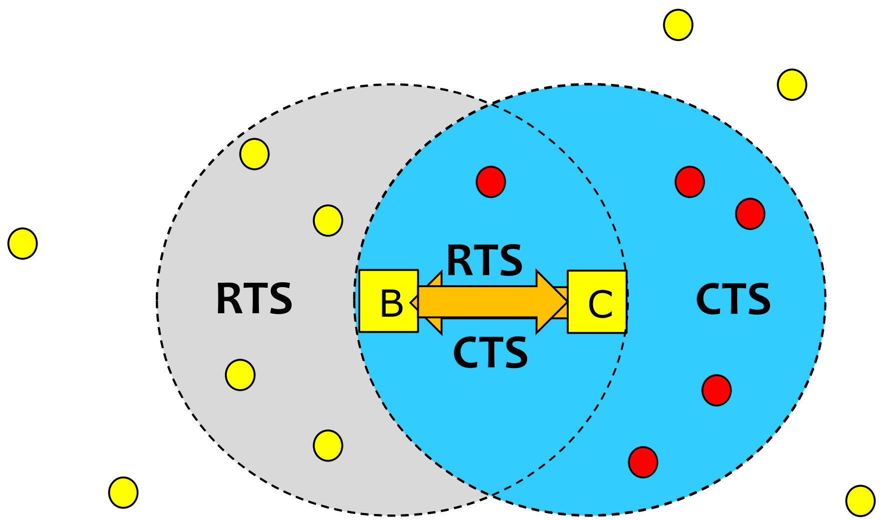
"Exposed Node" Problem

Although B and C are exposed to each other's
signals, there is no interference if B transmits to A while C transmits to D.
雙方雖然聽得到對方的訊號, 但同時可傳送給不同的對象

IEEE 802.11 – CSMA/CA

- 802.11 addresses these two problems with an algorithm called Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA).
- Key Idea
  - Sender and receiver exchange control frames with each other before the sender actually transmits any data.
  - This exchange informs all nearby nodes that a transmission is about to begin
  - Sender transmits a *Request to Send* (RTS) frame to the receiver.
    - The RTS frame includes a field that indicates how long the sender wants to hold the medium
      - Length of the data frame to be transmitted
  - Receiver replies with a *Clear to Send* (CTS) frame
    - This frame echoes this length field back to the sender

IEEE 802.11 – RTS/CTS Frames



802.11 using RTS and CTS frames to reserve the wireless channel for a time period (duration field in the RTS and CTS frames)

IEEE 802.11 – RTS and CTS frames

- Any node that sees the CTS frame
  - it is close to the receiver, therefore
  - cannot transmit for the period of time specified in the CTS frame
- Any node that sees the RTS frame but not the CTS frame
  - is not close enough to the receiver to interfere with it, so is free to transmit

IEEE 802.11 – RTS and CTS frames

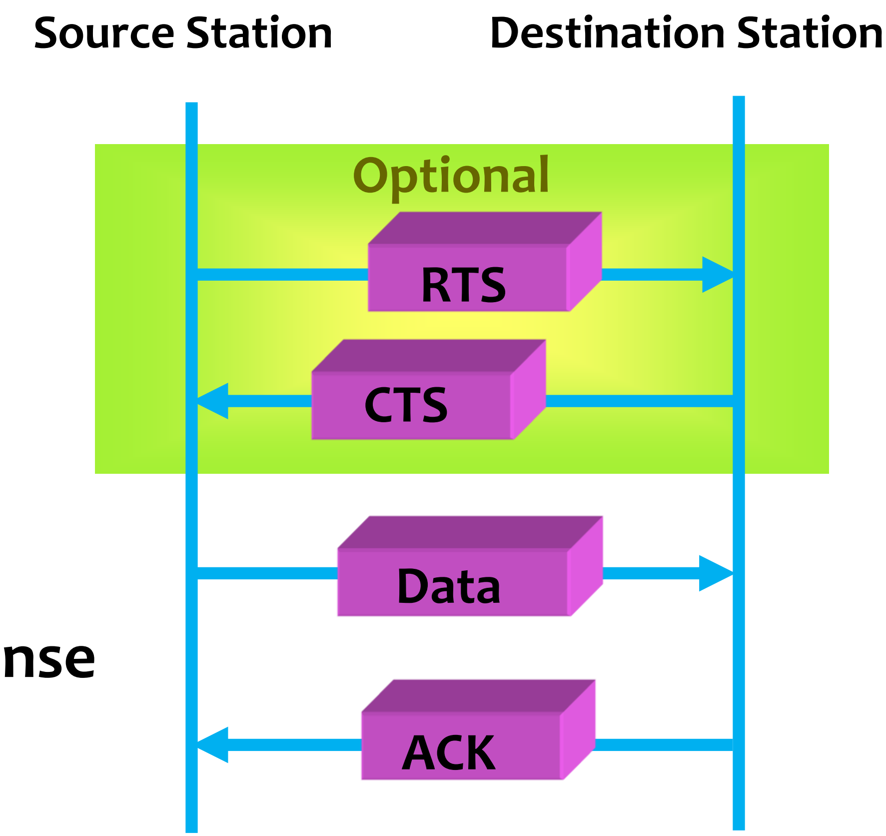
- If two or more nodes detect an idle link and try to transmit an RTS frame at the same time
  - Their RTS frame will collide with each other
- So the senders realize the collision has happened when they do not receive the CTS frame after a period of time
- Each sender waits a random amount of time before trying again.
- The amount of time is defined by the same *exponential backoff* algorithm used on the Ethernet.

IEEE 802.11 – Not Support Collision Detection

- 802.11 does not support collision detection
- How to know the sent frame was received successfully or ?
- We can use CSMA protocol, but the performance is not good enough
- 802.11 using ACK frame in CSMA/CA
- Receiver sends an ACK frame to the sender after successfully receiving a frame
- All nodes must wait for this ACK frame before trying to transmit

802.11 Frame Types

- Class 1 frames
  - Control Frames
    - (1) RTS
    - (2) CTS
    - (3) ACK
    - (4) Poll
  - Management Frames
    - (1) Probe Request/Response
    - (2) Beacon
    - (3) Authentication



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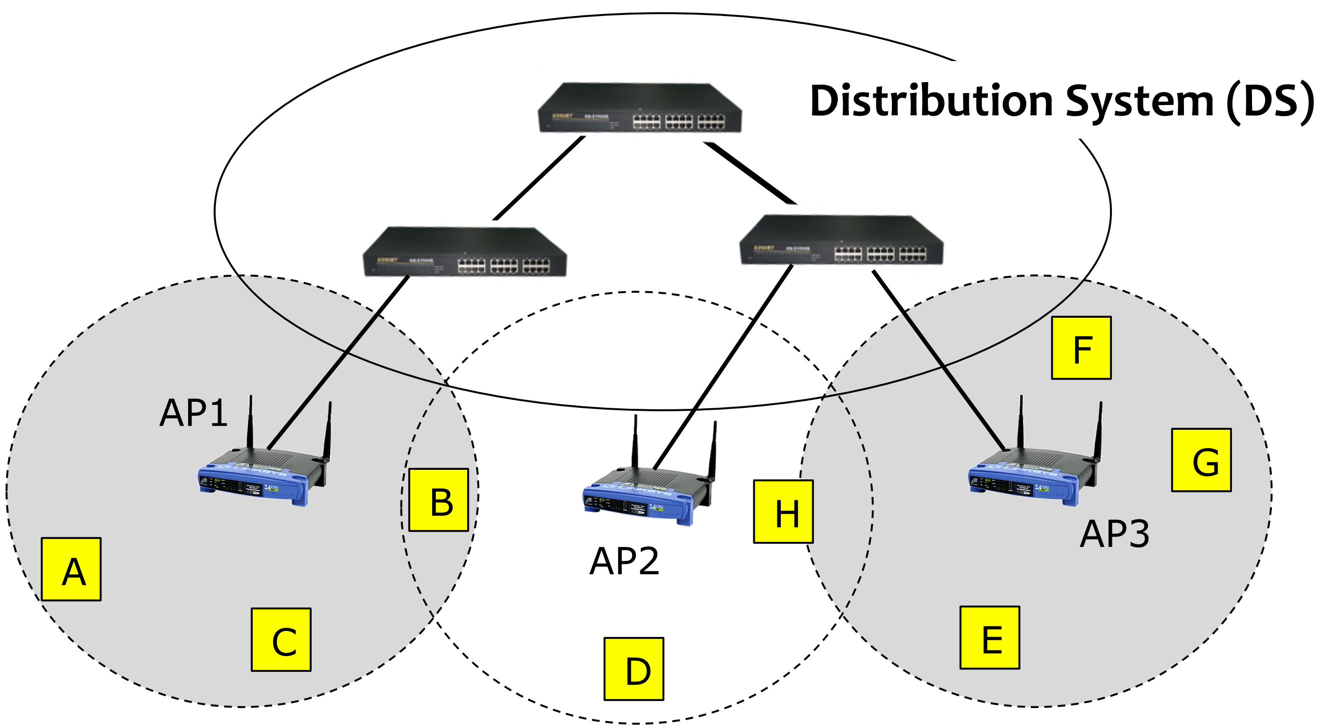
IEEE 802.11 – Distribution System

- Nodes are free to move around
- Directly reachable nodes may change dynamically
- To deal with mobility and partial connectivity,
  - 802.11 defines additional structures on a set of nodes
  - some nodes are allowed to roam
  - some are connected to a wired network infrastructure
    - *Access Points* (AP) and
    - connected to each other by a so-called *distribution system* (DS)

IEEE 802.11 – Distribution System

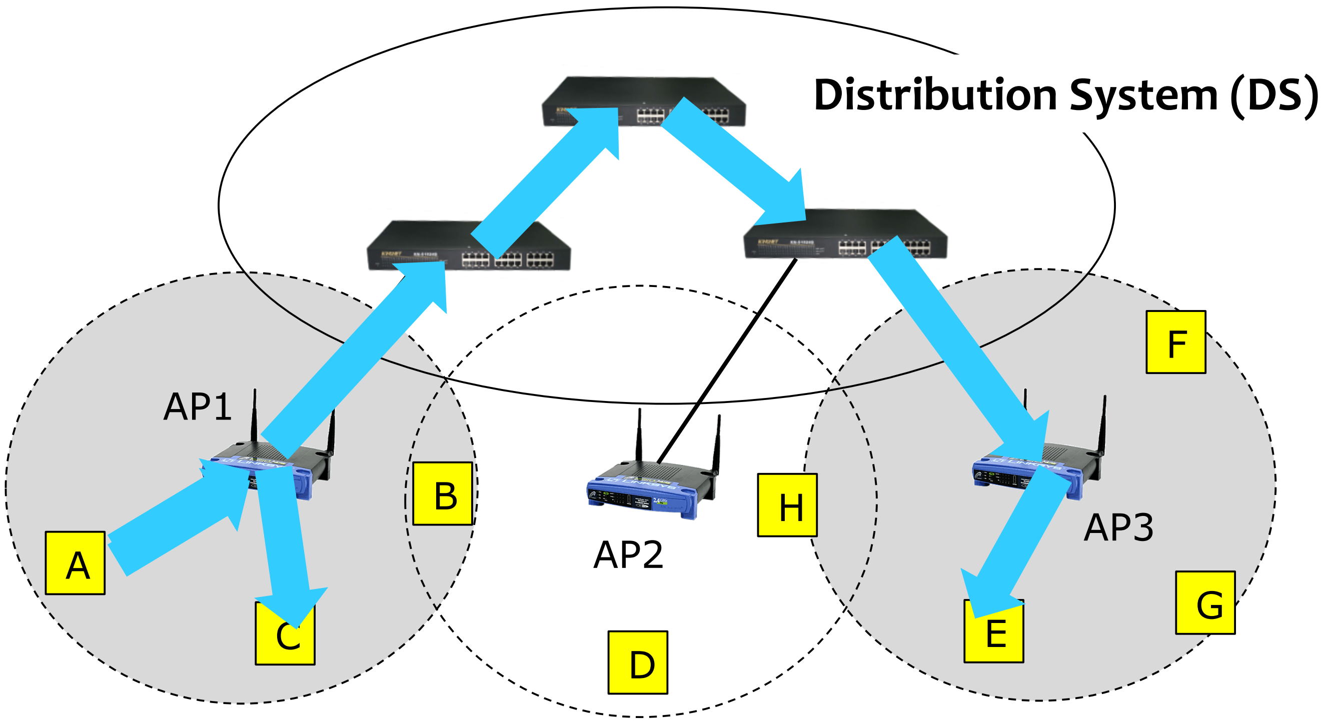
- A distribution system that connects many APs
- The distribution network runs at layer 2 of the ISO architecture



APs connected to a distribution network

IEEE 802.11 – Distribution System

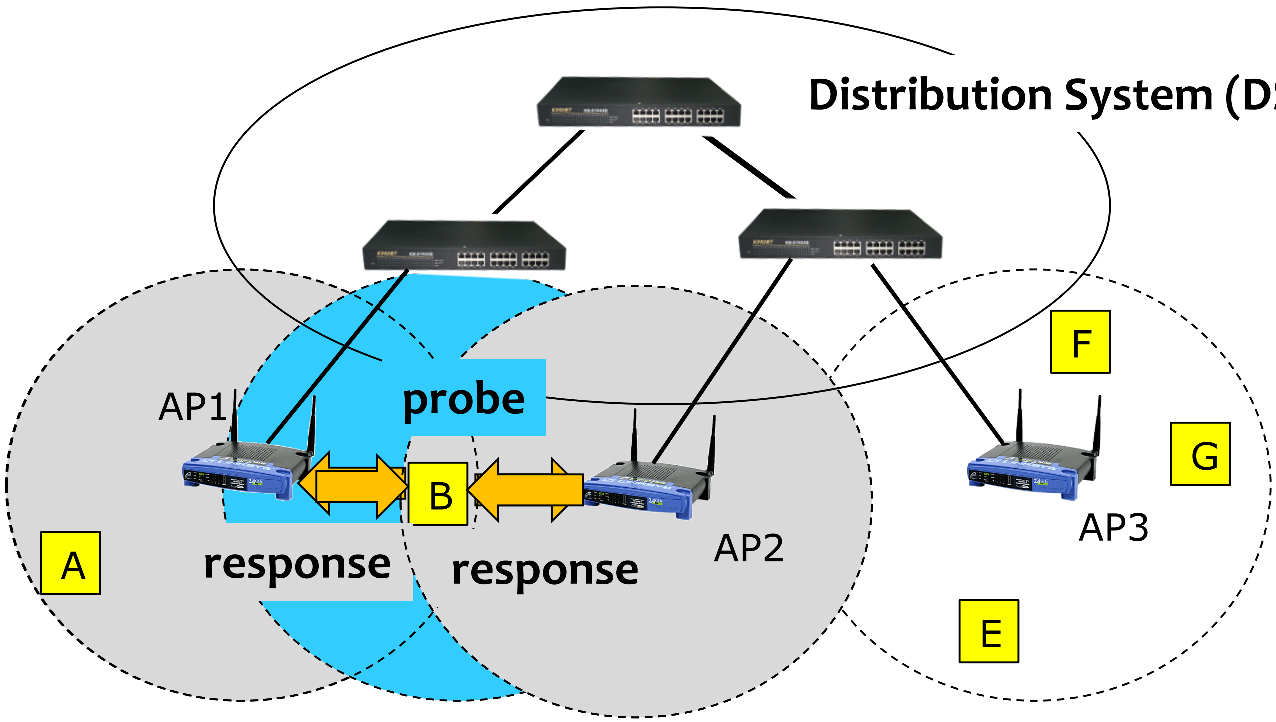
- The idea behind this configuration is
  - Each nodes associates itself with one AP
  - A → C: A → AP1 → C
  - A → E: A → AP1 → DS → AP3 → E



IEEE 802.11 – Distribution System

- How do the nodes select their APs ?
- How does it work when nodes move from one cell to another ?
- The technique for selecting an AP is called *scanning*
  - The node sends a *Probe* frame
  - All APs within reach reply with a *Probe Response* frame
  - The node selects one of the APs and sends that AP an *Association Request* frame
  - The AP replies with an *Association Response* frame
- A node runs this protocol whenever
  - it joins the network, and
  - when it wants to change another AP (better signal)

IEEE 802.11 – Distribution System

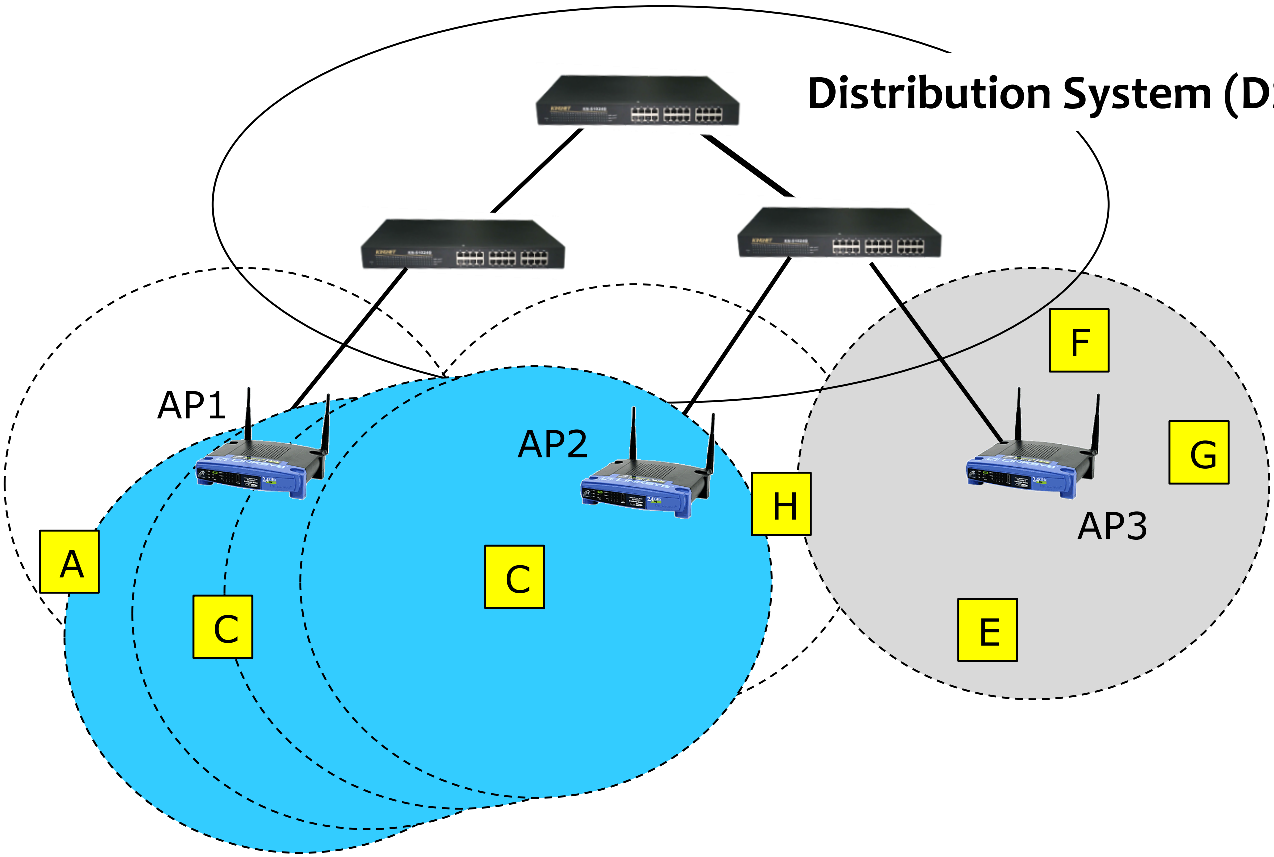


Scanning to select an associated AP
(Probe + Response)

IEEE 802.11 – Distribution System

- Active Scanning
- When node C moves from the cell serviced by AP-1 to the cell serviced by AP-2.
- As it moves, it sends *Probe* frames, which eventually result in *Probe Responses* from AP-2.
- At some point, C prefers AP-2 over AP-1 , and so it associates with AP-2.
  - This is called *active scanning* since the node is actively searching for an AP

IEEE 802.11 – Distribution System

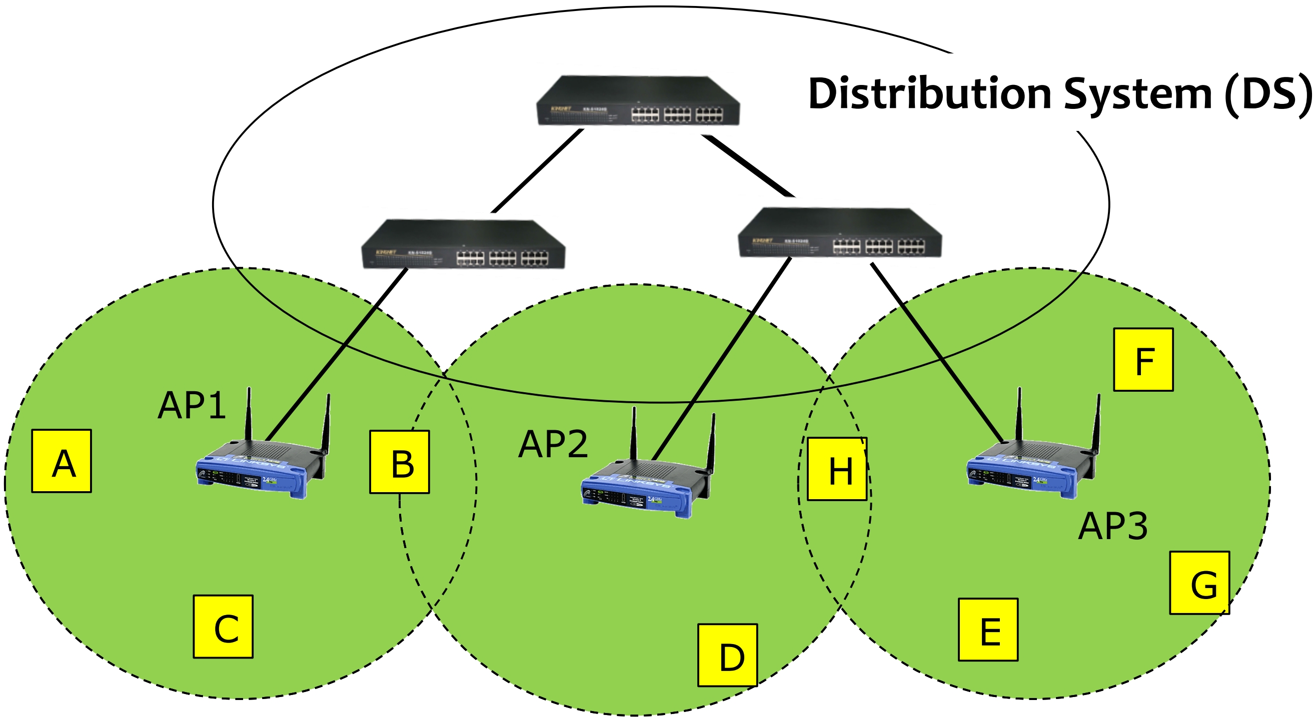


Node Mobility with active scanning
(Probe + Response)

IEEE 802.11 – Distribution System

- Passive Scanning
- APs also periodically send a *Beacon frame* that advertises the capabilities of the AP; these include the transmission rate supported by the AP
  - This is called *passive scanning*
  - A node can change to this AP based on the *Beacon* frame simply by sending it an *Association Request frame* back to the AP.

IEEE 802.11 – Distribution System



Node Mobility with passive scanning (Beacon + Association Request)

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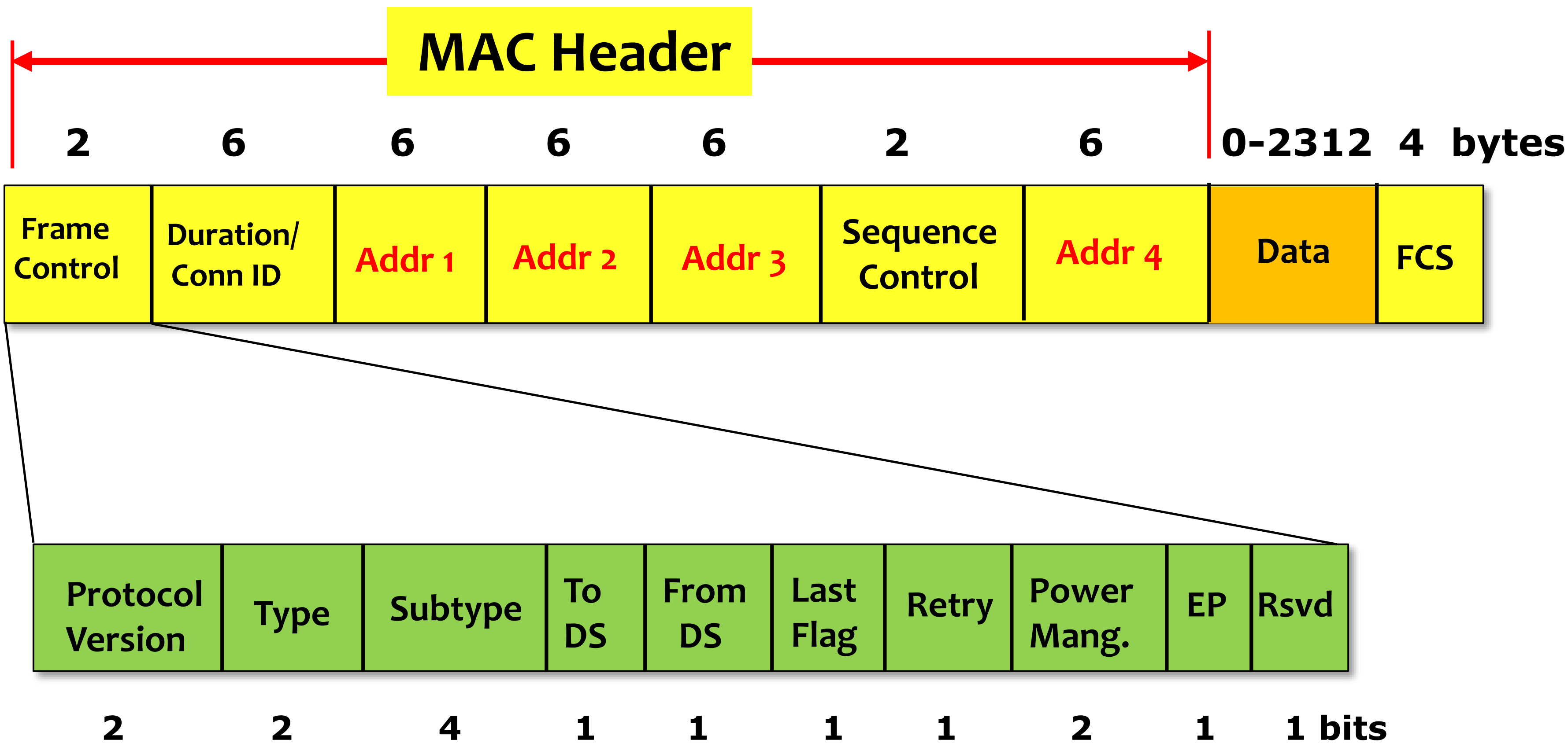
IEEE 802.11 – Frame Format



IEEE 802.11 – Frame Format

- Source and Destination addresses: each 48 bits
- Data: up to 2312 bytes
- CRC: 32 bits
- Control field: 16 bits
  - Contains three subfields (of interest)
    - 6 bit Type field: indicates whether the frame is an RTS or CTS frame or being used by the scanning algorithm
    - A pair of 1 bit fields : called ToDS and FromDS

IEEE 802.11 – Frame Format

- Frame contains four addresses
- How these addresses are interpreted depends on the settings of the ToDS and FromDS bits in the frame's Control field
- This is to account for the possibility that the frame had to be forwarded across the Distribution System
- Simplest case
  - When one node is sending directly to another, both the DS bits are 0, Addr1 identifies the target node, and Addr2 identifies the source node

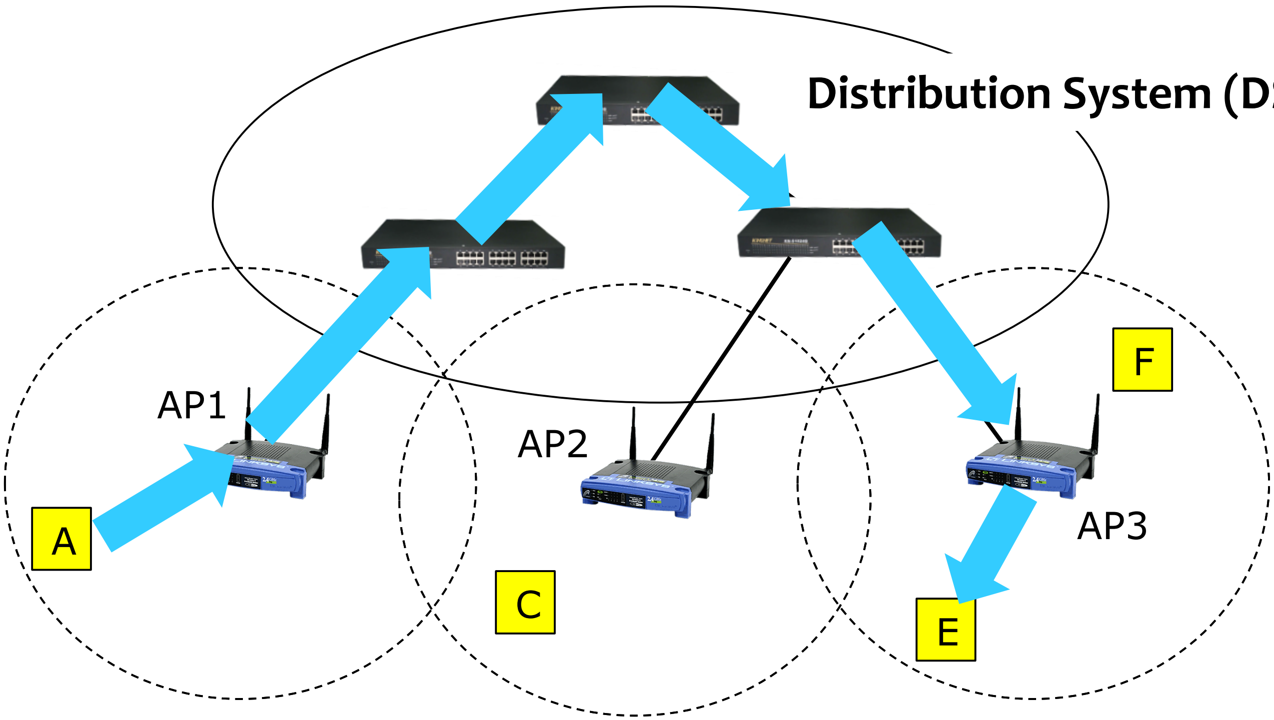
IEEE 802.11 – Frame Format

- Most complex case
  - Both DS bits are set to 1
    - Indicates that the message went from a wireless node → distribution system → another wireless node

To DS	From DS	Addr 1	Addr 2	Addr 3	Addr 4
0	0	DA	SA	BSSID	N/A
0	1	DA	BSSID	SA	N/A
1	0	BSSID	SA	DA	N/A
1	1	DA	TA	RA	SA

- BSSID: MAC address of an AP
- SA: Original Source address
- DA: Final Destination address
- TA: Transmitter address
- RA: Receiver address

IEEE 802.11 – Frame Format



Frame Control	Duration/ Conn ID	E	AP3	A	Sequence Control	NA	Data	FCS

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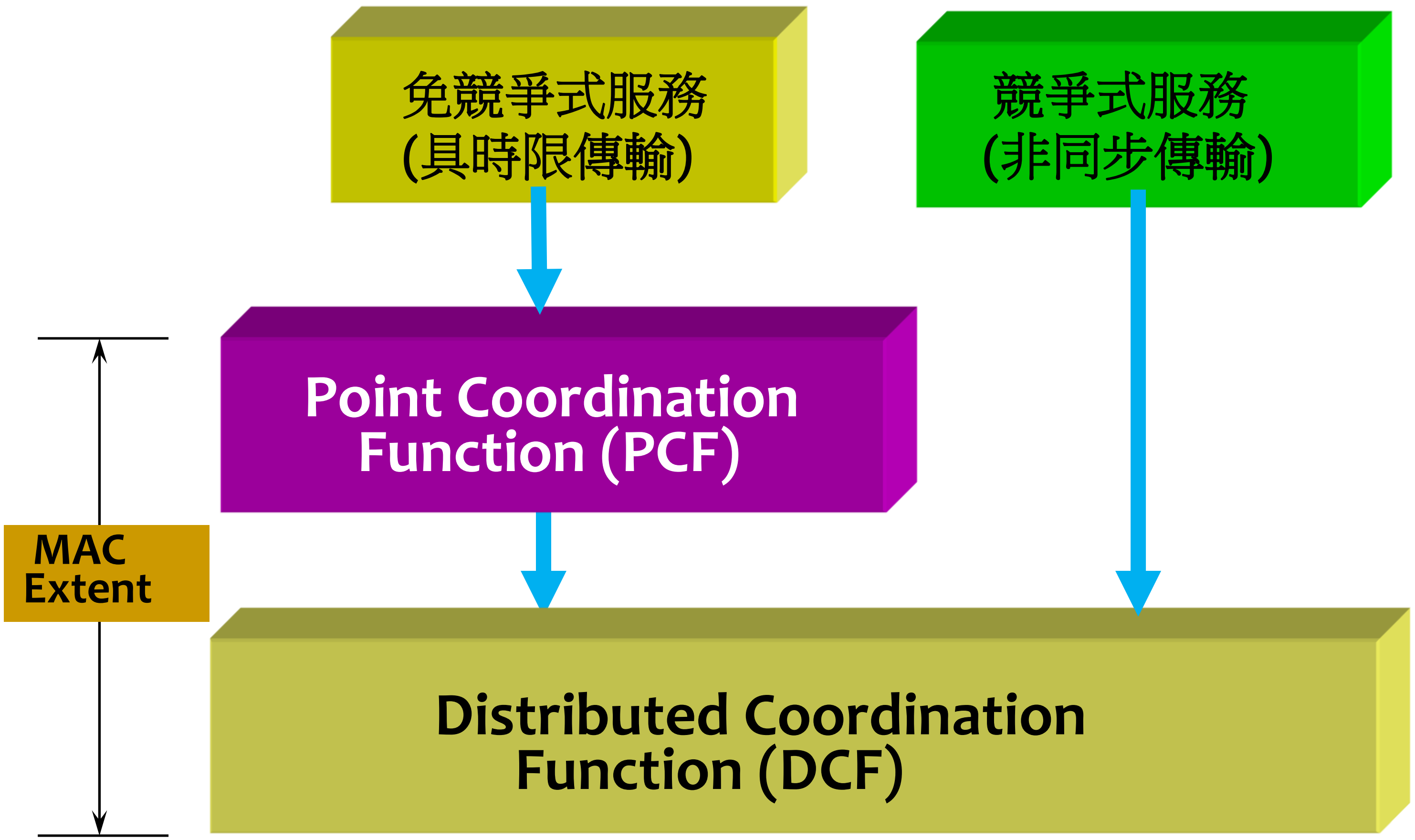
IEEE 802.11 MAC Architecture



IEEE 802.11 MAC Architecture

- Distributed Coordination Function (DCF)
  - The fundamental access method for the 802.11 MAC, known as Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA).
  - Shall be implemented in all stations and APs.
  - Used within both configurations:
    - Ad hoc
    - Infrastructured

IEEE 802.11 MAC Architecture

- Point Coordination Function (PCF)
  - An alternative access method
  - Shall be implemented on top of the DCF
  - A point coordinator (polling master) is used to determine which station currently has the right to transmit.
  - Shall be built up from the DCF through the use of an access priority mechanism.
  - Different accesses of traffic can be defined through the use of different values of IFS (Inter-Frame Space).

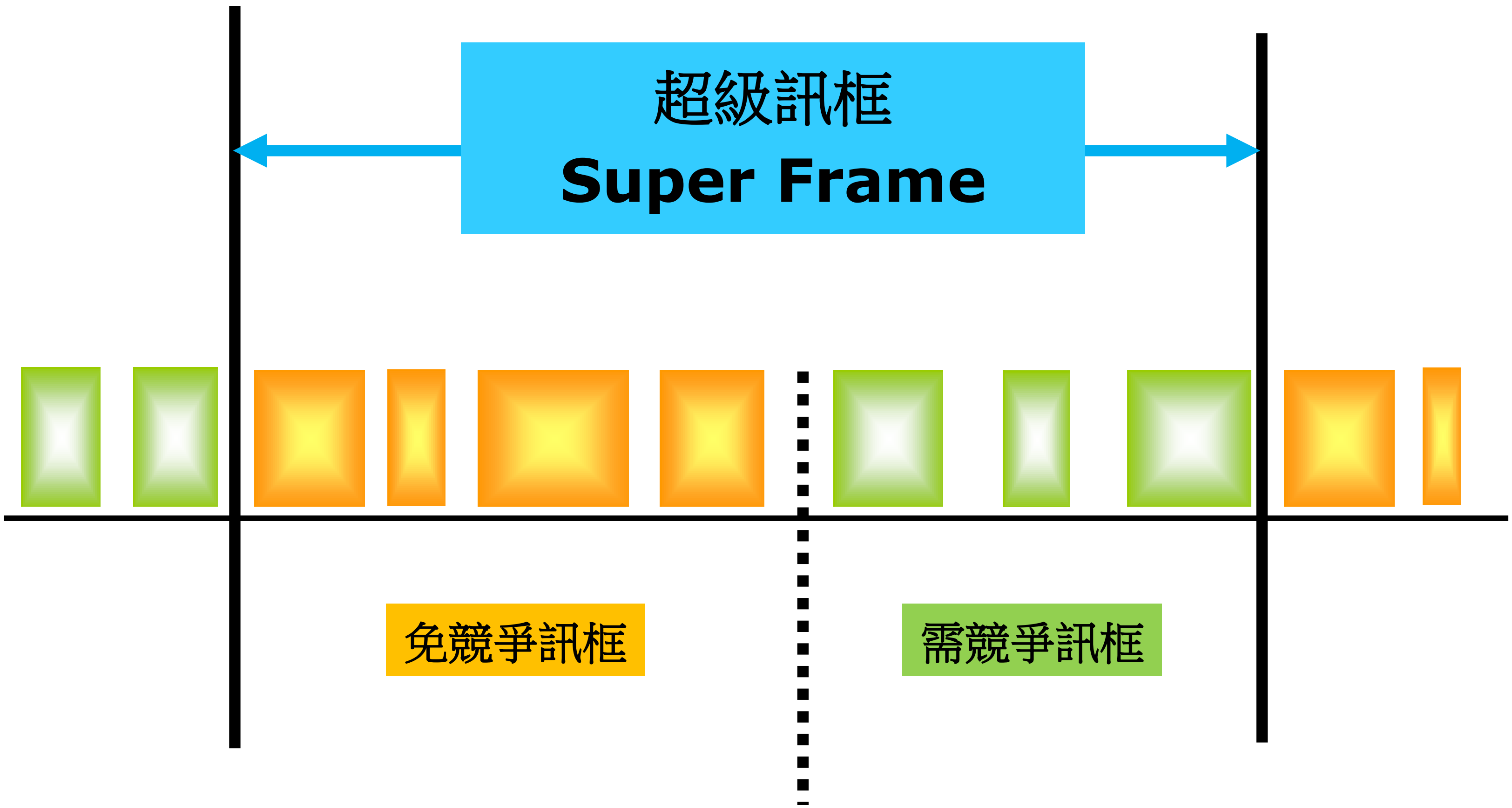
IEEE 802.11 MAC Architecture

- Shall use a Point IFS (PIFS) < Distributed IFS (DIFS)
- Point coordinated traffic shall have higher priority to access the medium, which may be used to provide a *contention-free* access method.
- The priority access of the PIFS allows the point coordinator to seize control of the medium away from the other stations.

IEEE 802.11 MAC Architecture

- **Coexistence of DCF and PCF**
  - **Both the DCF and PCF shall coexist without interference.**
  - **Superframe : A contention-free burst occurs at the beginning, followed by a contention period.**

IEEE 802.11 MAC Architecture



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Distributed Coordination Function

- Allows for automatic medium sharing between PHYs through the use of CSMA/CA and a random backoff time following a busy medium condition.
- All directed traffic uses immediate positive ACK frame
- Retransmission is scheduled by the sender if no ACK is received.
- Carrier Sense shall be performed both through *physical* and *virtual* mechanisms.

Distributed Coordination Function

- The **Virtual Carrier Sense mechanism** is achieved by distributing **medium busy reservation** information through an exchange of RTS and CTS frames (contain a **duration field**) prior to the actual data frame.
- Unicast only, not used in multicast/broadcast.
- The use of RTS/CTS is under control of **RTS_Threshold** (payload length, under which without any RTS/CTS prefix).

Distributed Coordination Function

- **Physical Carrier Sense Mechanism**
  - A physical carrier sense mechanism shall be provided by the PHY.
- **Virtual Carrier Sense Mechanism**
  - Provided by the MAC, named Net Allocation Vector (NAV), which maintains a prediction of future traffic based on duration information announced in RTS/CTS frames.

Distributed Coordination Function

- MAC-Level Ack (Positive Acknowledgment)
  - To allow detection of a lost or errored frame an ACK frame shall be returned immediately following a successfully received frame.
  - The gap between the received frame and ACK frame shall be SIFS.
  - The frame types should be acknowledged with an ACK frame:
    - Data
    - Poll
    - Request
    - Response
  - The lack of an ACK frame means that an error has occurred.

DCF -- Inter-Frame Space (IFS)

- **Priority levels:** Three different IFS's are defined.
- **Short-IFS (SIFS)**
  - Used for
    - an ACK frame,
    - a CTS frame,
    - by a station responding to any polling
  - Any STA intending to send only these frame types is allowed to transmit after the SIFS time has elapsed following a busy medium.

DCF -- Inter-Frame Space (IFS)

- **PCF-IFS (PIFS)**
  - **Used only by the PCF to send any of the Contention Free Period frames.**
  - **The PCF shall be allowed to transmit after it detects the medium free for the period PIFS.**
- **DCF-IFS (DIFS)**
  - **Used by the DCF to transmit asynchronous MPDUs.**
  - **A STA using the DCF is allowed to transmit after it detects the medium free for the period DIFS, as long as it is not in a backoff period.**

DCF -- Random Backoff Time

- **Before transmitting asynchronous MPDUs, a STA shall determine the medium state.**
- **If busy, the STA shall defer until after a DIFS gap is detected, and then generate a random backoff period for an additional deferral time (resolve contention).**

Backoff time = INT(CW * Random()) * Slot time

DCF -- Random Backoff Time

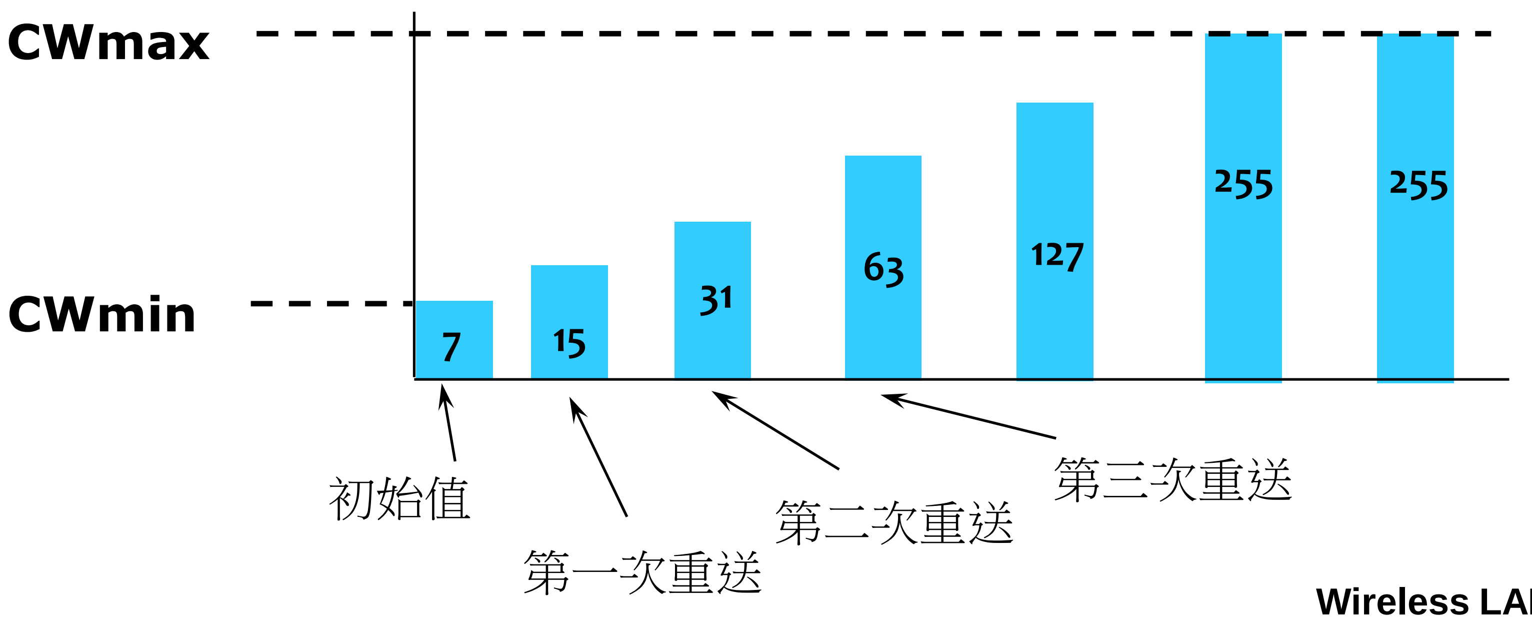
Where CW = An integer between CWmin and CWmax

Random() = a random number

Slot Time = Transmitter turn-on delay +

medium propagation delay +

medium busy detect response time

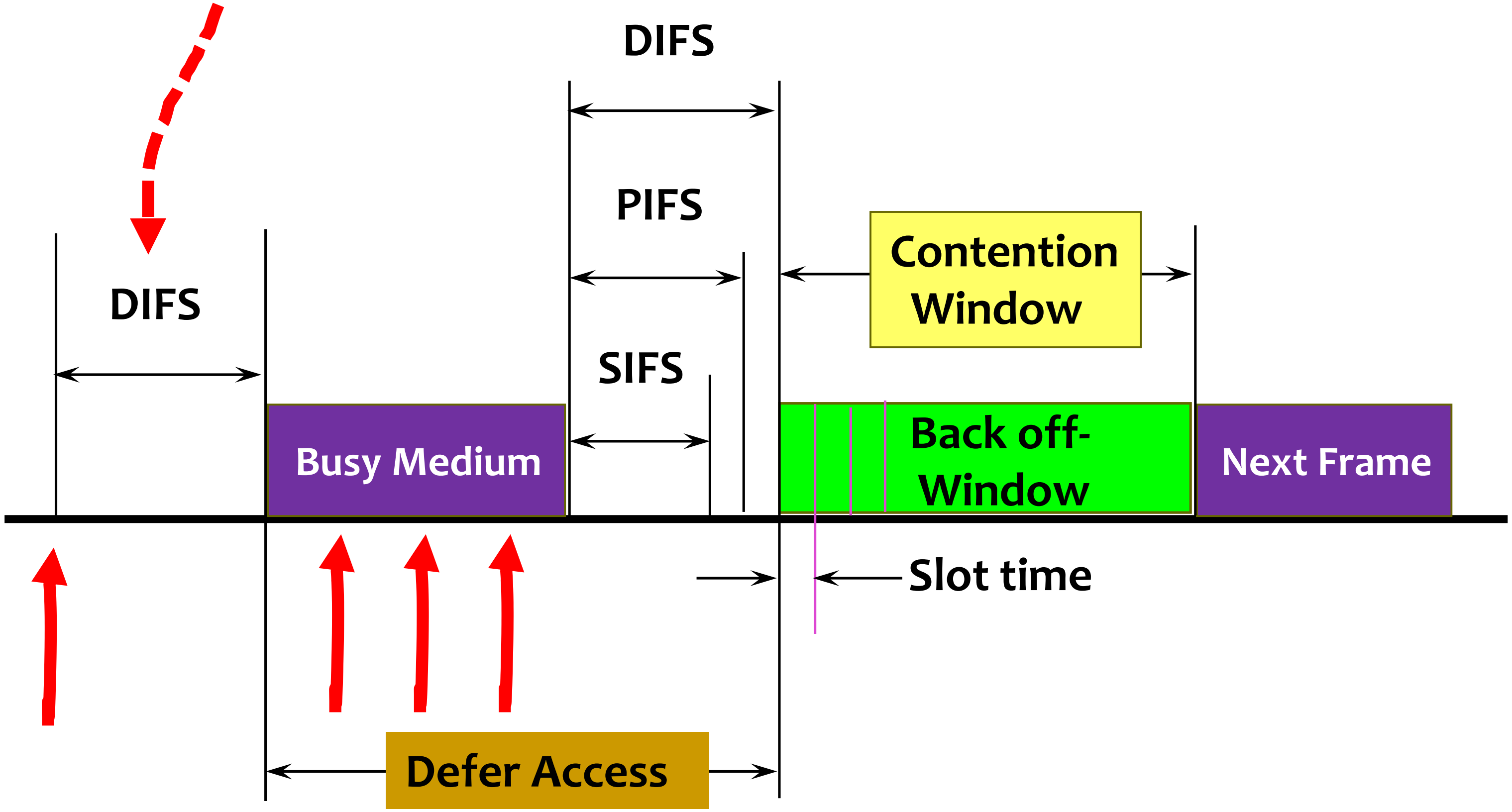


DCF Access Procedure

- CSMA/CA Protocol
- Used when there is no PCF detected and when in the Contention Period of a Superframe when using a PCF.
- Basic Access
  - A STA with a pending MPDU may transmit when it detects a free medium for greater than or equal to a DIFS time.
  - If the medium is busy when a STA desires to initiate a Data, Poll, Request, or Response MPDU transfer, and only a DCF is being used (or a Contention Period portion of a Superframe is active), the Random Backoff Time algorithm shall be followed.

DCF Access Procedure

Immediate access when medium is free >= DIFS

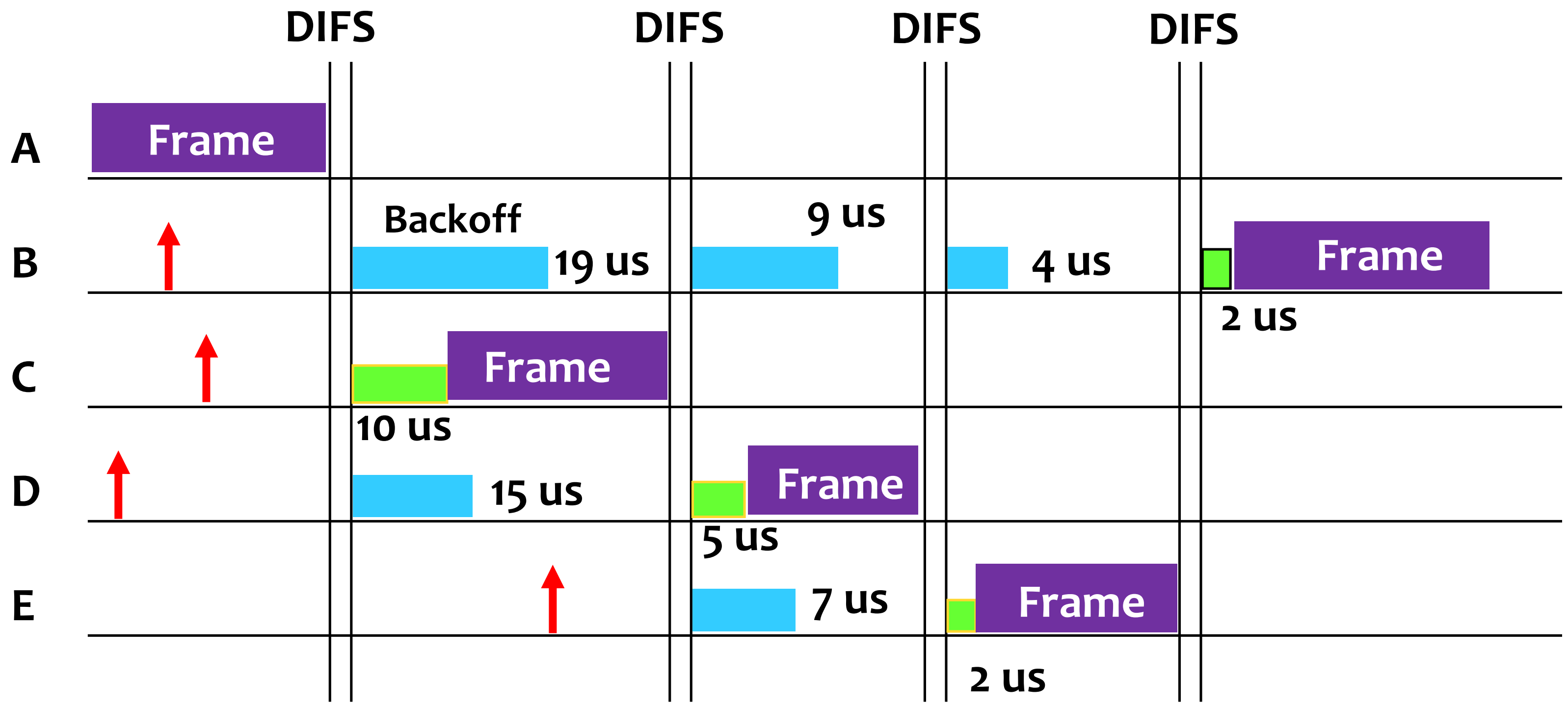


DCF Access Procedure

Backoff Procedure

- A backoff time is selected first.
- The Backoff Timer shall be frozen while the medium is sensed busy and shall decrement only when the medium is free (resume whenever free period > DIFS).
- Transmission shall commence whenever the Backoff Timer reaches zero.
- A STA that has just transmitted a frame and has another frame ready to transmit (queued), shall perform the backoff procedure (fairness concern).
- Tends toward fair access on a FCFS basis.

DCF Access Procedure



CWindow = Contention Window

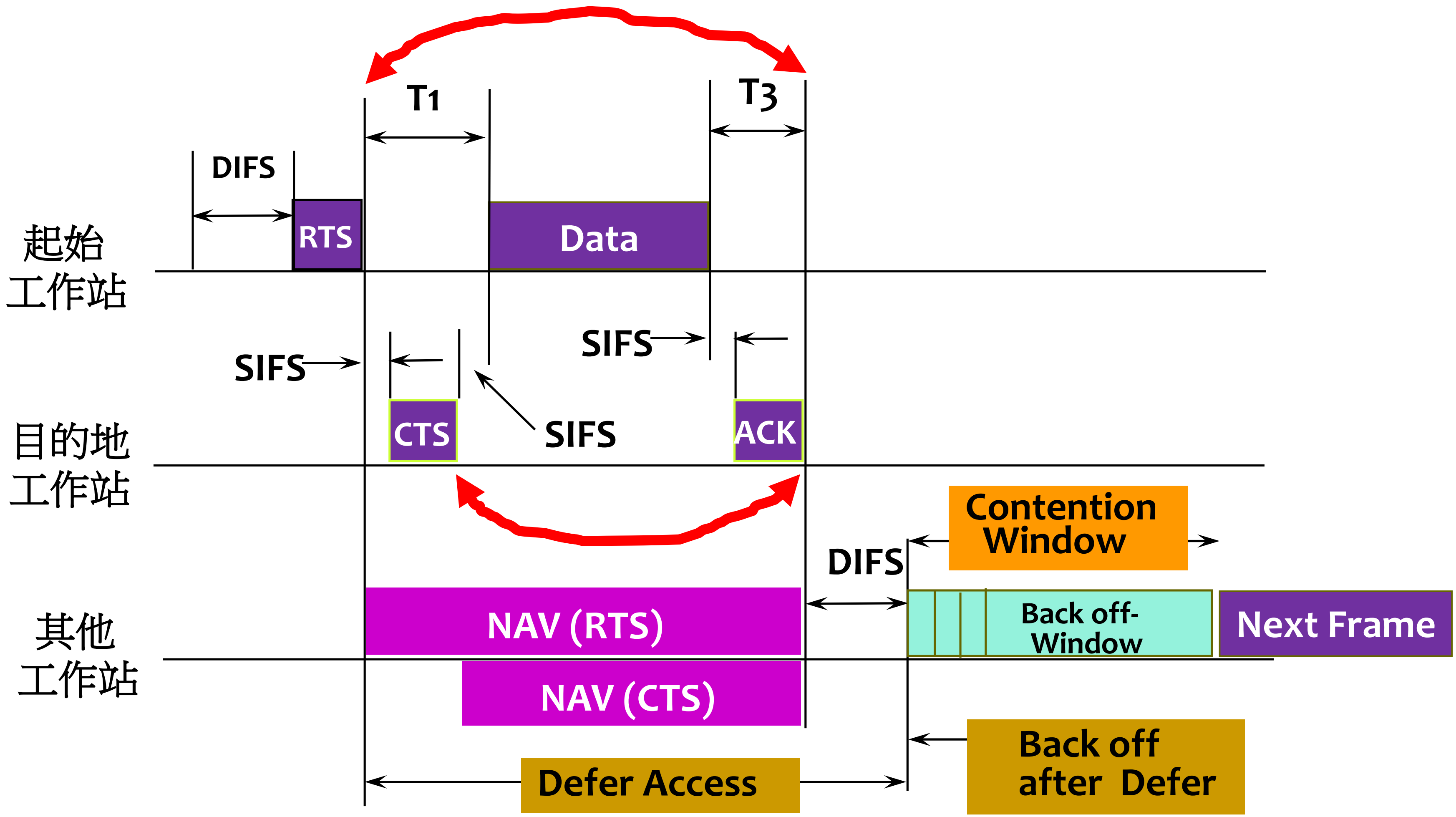
= Backoff (後退)

= Remaining Backoff (持續後退)

DCF Access Procedure

- Setting the NAV Through Use of RTS/CTS Frames
  - RTS and CTS frames contain a Duration field based on the medium occupancy time of the MPDU from the end of the RTS or CTS frame until the end of the ACK frame.

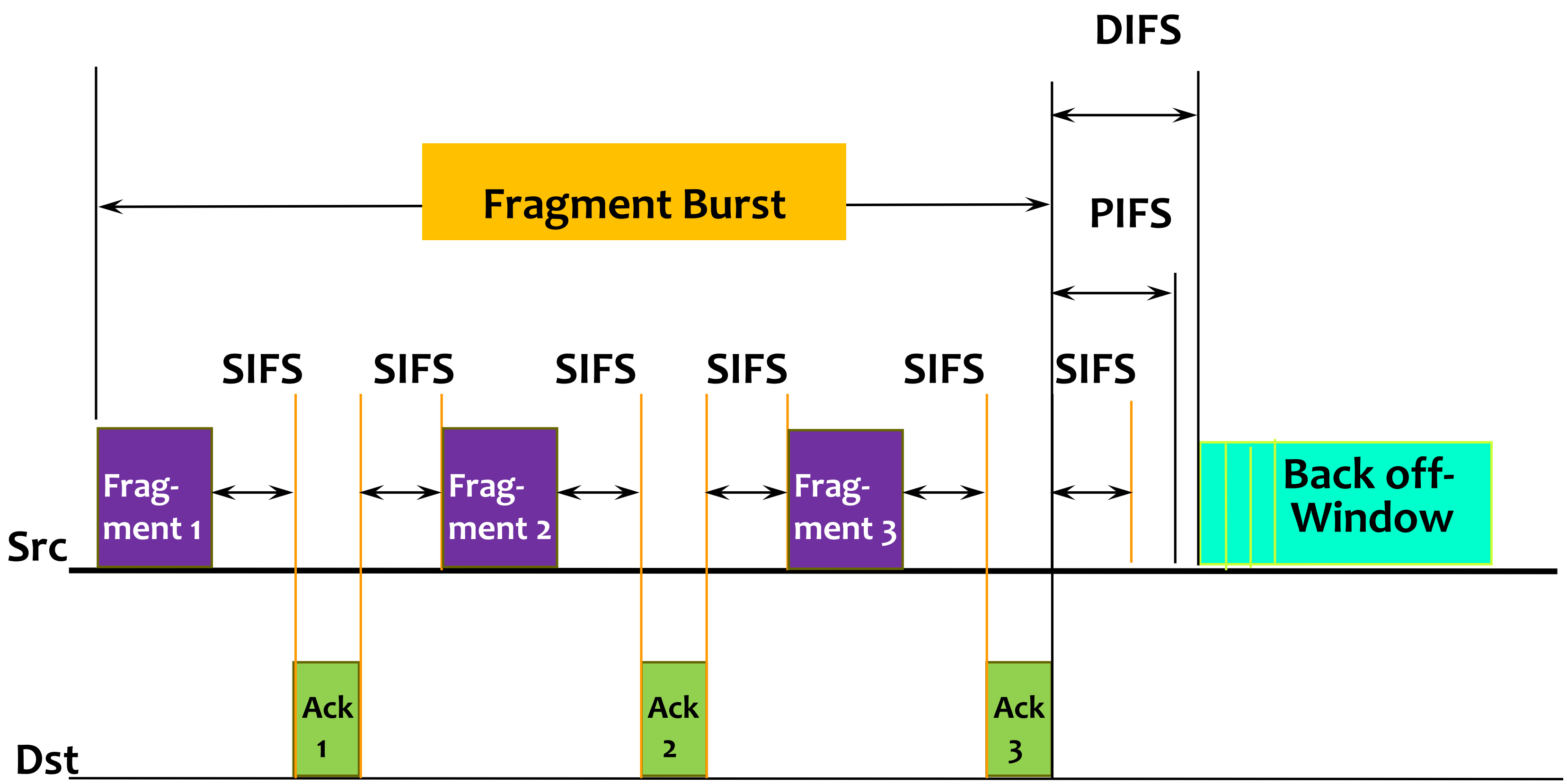
DCF Access Procedure



DCF Access Procedure

- **Control of the Channel**
  - **The IFS is used to provide an efficient MSDU delivery mechanism.**
  - **Once a station has contended for the channel, it will continue to send fragments until either**
    - **all fragments of a MSDU have been sent,**
    - **an ack is not received, or**
    - **the station can not send any additional fragments due to a dwell time boundary.**

DCF Access Procedure



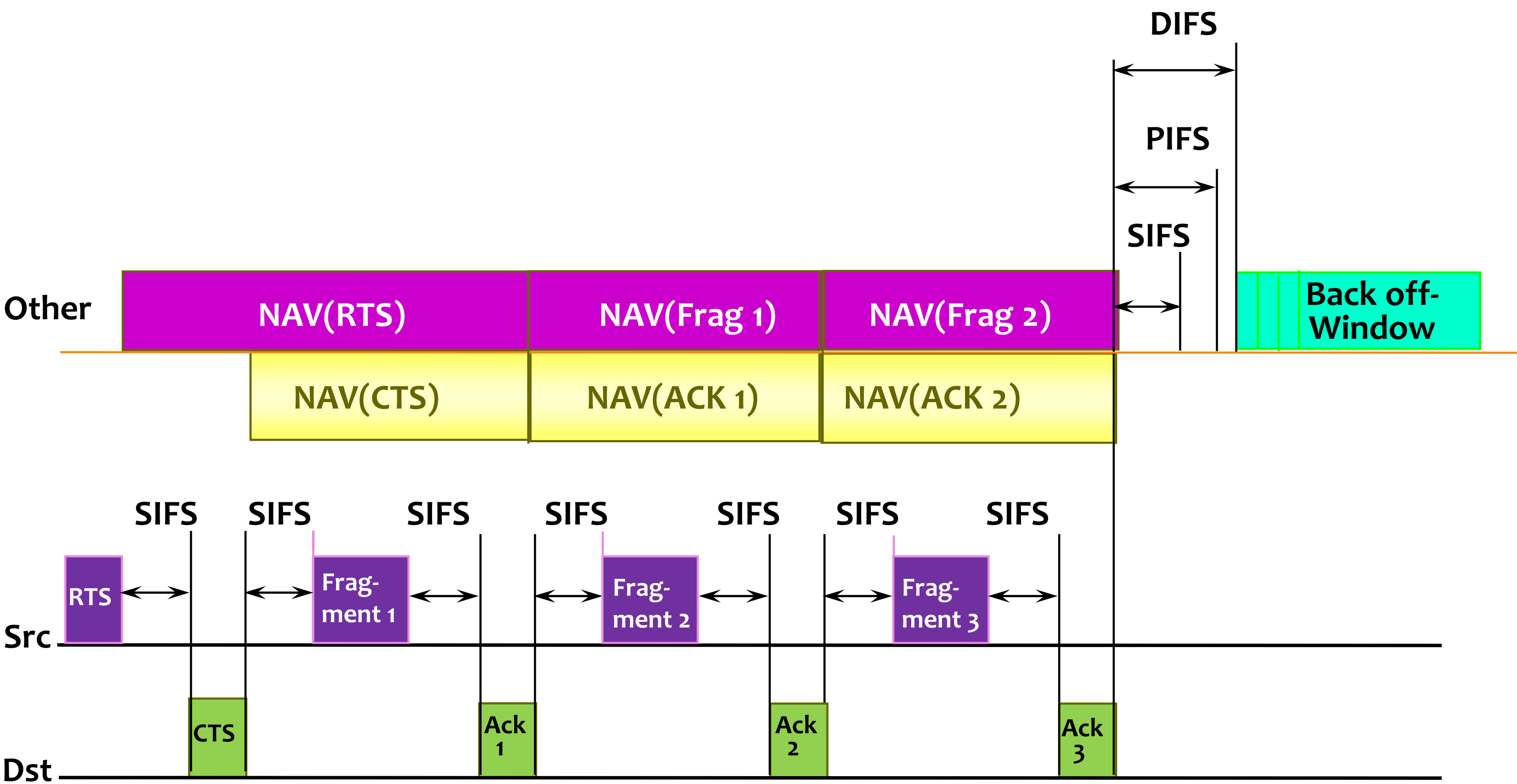
DCF Access Procedure

- Control of the Channel
  - If the source station does not receive an ack frame, it will attempt to retransmit the fragment at a later time (according to the backoff algorithm).
  - When the time arrives to retransmit the fragment, the source station will contend for access in the contention window.

DCF Access Procedure

- RTS/CTS Usage with Fragmentation
  - The RTS/CTS frames defines the duration of the first frame and ack.
  - The duration field in the data and ack frames specifies the total duration of the next fragment and ack.
  - The last Fragment and ACK will have the duration set to zero.

RTS/CTS Usage with Fragmentation



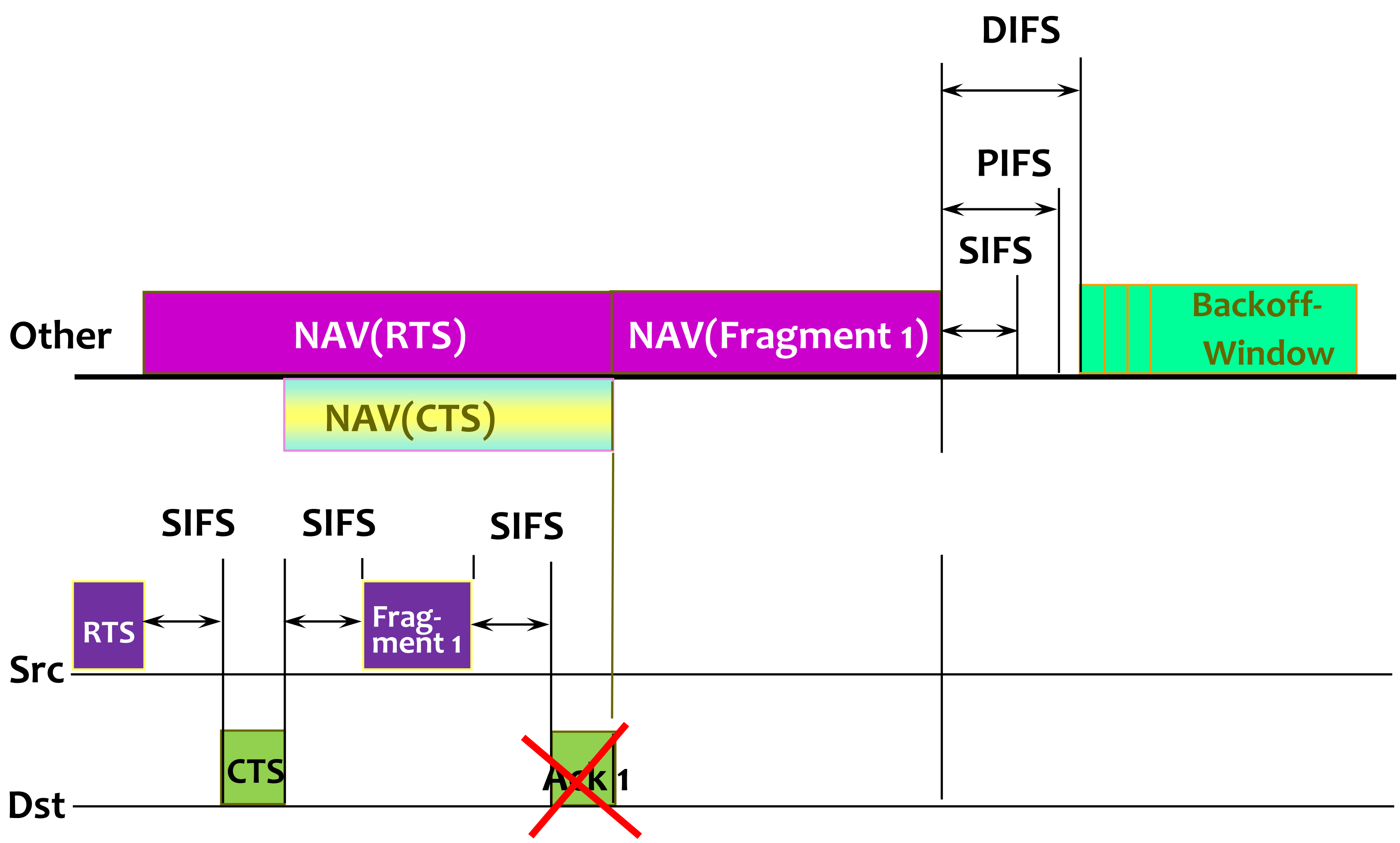
DCF Access Procedure

- **RTS/CTS Usage with Fragmentation**
  - Each Fragment and ACK acts as a virtual RTS and CTS.
  - In the case where an ack is not received by the source station, the NAV will be marked busy for next frame exchange. This is the worst case situation.

DCF Access Procedure

- **RTS/CTS Usage with Fragmentation**
  - If the ack is not sent by the destination, stations that can only hear the destination will not update their NAV and be free to access the channel.
  - All stations will be free to access the channel after the NAV from Fragment 1 has expired.
  - The source must wait until the NAV (Fragment 1) expires before attempting to contend for the channel after not receiving the ack.

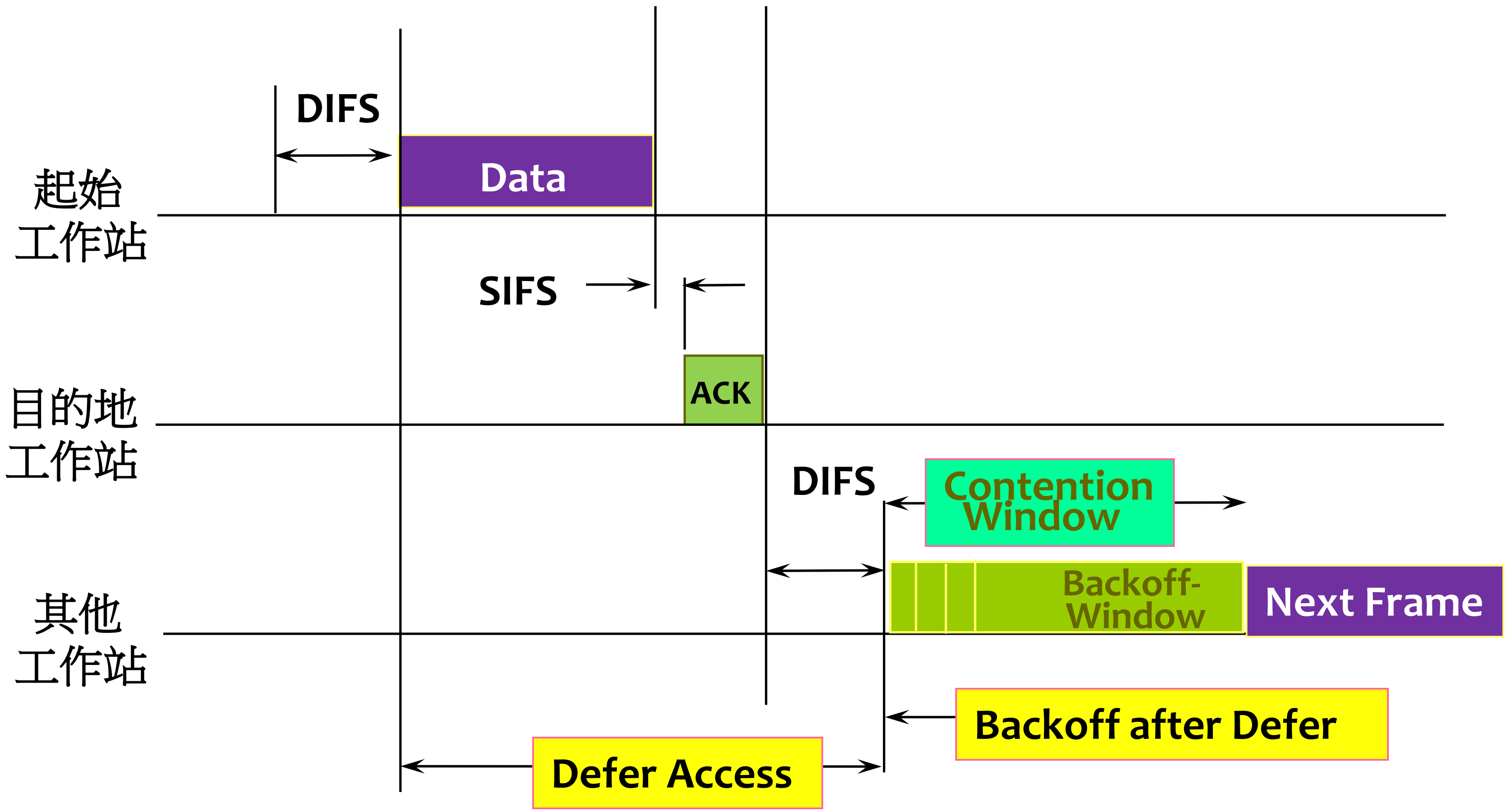
RTS/CTS Usage with Fragmentation



DCF Access Procedure

- Directed MPDU Transfer Procedure Using RTS/CTS
  - STA shall use an RTS/CTS exchange for directed frames only when the length of the MPDU is greater than the RTS_Threshold.
- Directed MPDU Transfer Procedure Without RTS/CTS

DCF Access Procedure



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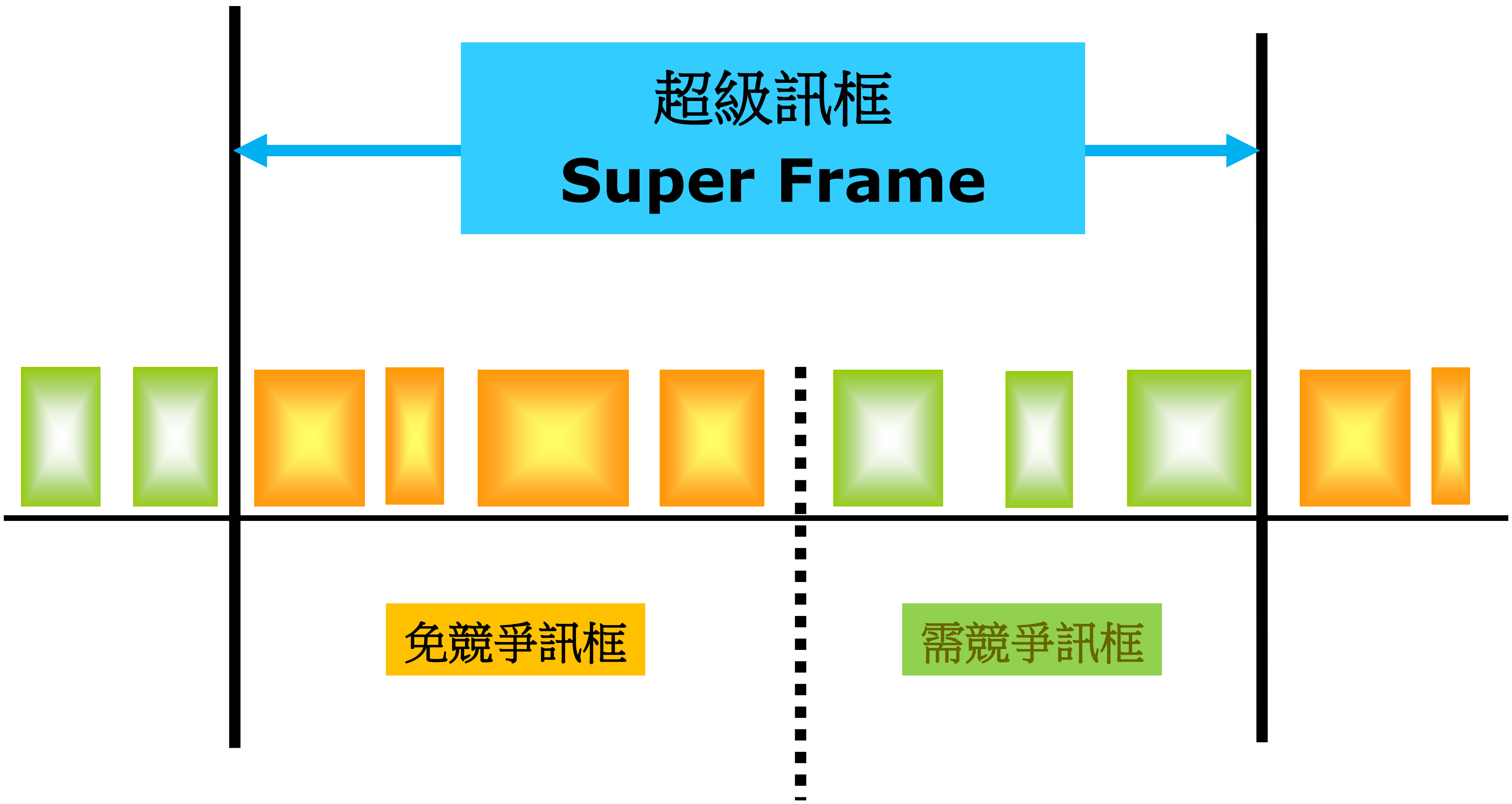
Point Coordination Function (PCF)

- The PCF provides contention free services.
- It is an option for a station to become the Point Coordinator (PC), which generates the Superframe (SF).
- Not all stations must be capable of becoming the PC and transmitting PCF data frames.
- The Superframe consists of a Contention Free (CF) period and a Contention Period.
- The length of a Superframe is a manageable parameter and that of the CF period may be variable on a per SF basis.

Point Coordination Function(PCF)



PCF Access Procedure

- The PCF protocol is based on a polling scheme controlled by one special STA called the Point Coordinator (PC).
- The PC gains control of the medium at the beginning of the SuperFrame and maintains control for the entire CF period by waiting a shorter time between transmissions (PIFS).
- CF-Down Frames and CF-UP Frames.

PCF Access Procedure

- At the beginning of the SF, the PC shall sense the medium.
- If it is free the PC shall wait a PIFS time and transmit
  - a Data frame with the CF-Poll Subtype bit set, to the next station on the polling list, or
  - a CF-End frame, if a null CF period is desired.

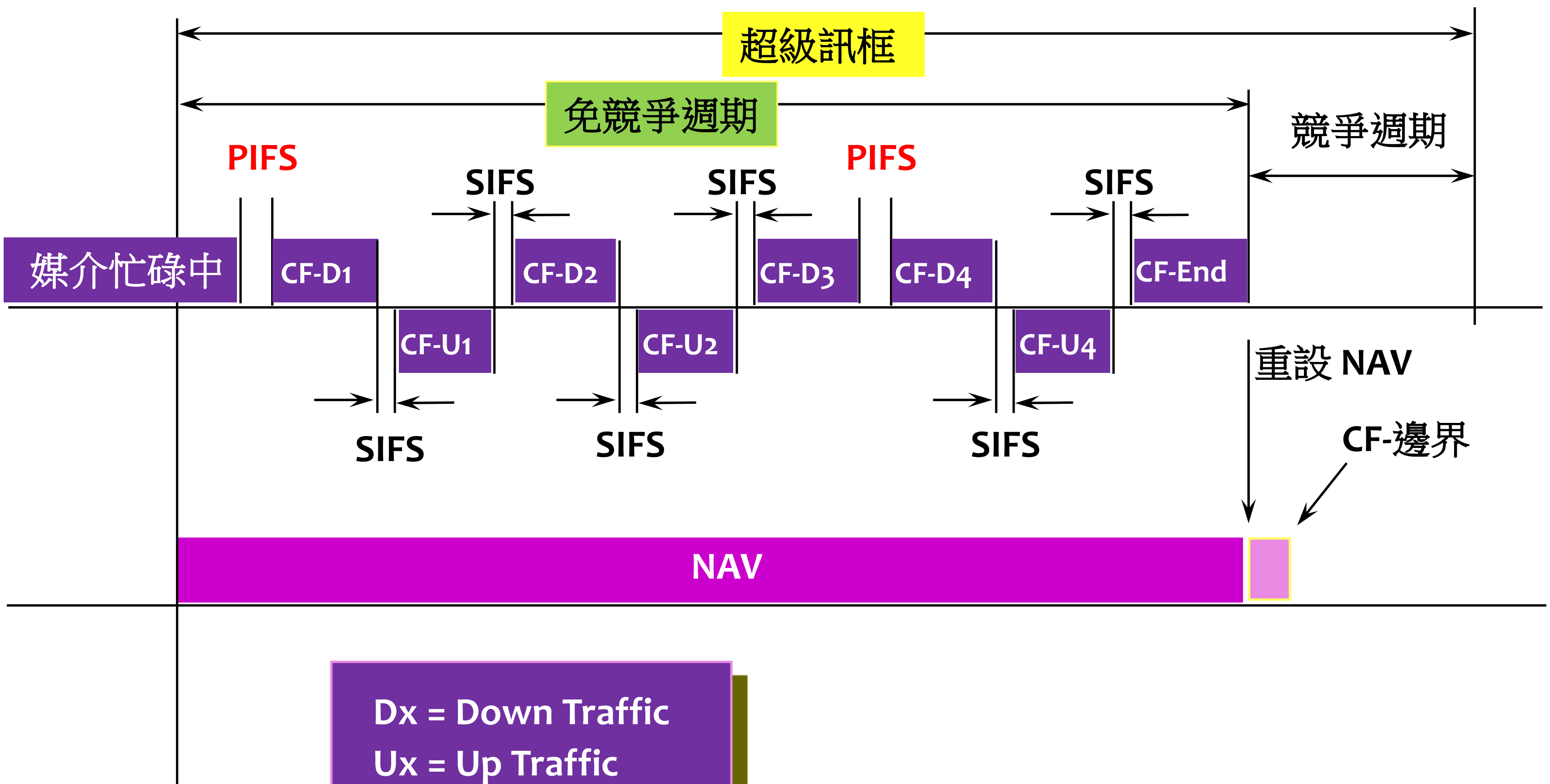
PCF Access Procedure

- The PCF uses the PCF **priority level** of the CSMA/CA protocol.
- The **shorter PIFS gap** causes a burst traffic with inter-frame gaps that are shorter than the DIFS gap needed by stations using the Contention period.
- Each station, except the station with the PCF, shall preset it's **NAV to the maximum CF-Period length** at the beginning of every SF.
- The PCF shall transmit a **CF-End frame**, at the end of the CF-Period, to **reset the NAV** of all stations in the BSS.

PCF Transfer Procedure

- When the PCF Station is Transmitter or Recipient
  - Stations shall respond to the CF-Poll immediately when a frame is queued, by sending this frame after an SIFS gap.
  - This results in a burst of Contention Free traffic (CF-Burst).
  - For services that require MAC level ack, the ack is preferably done through the CF-Ack bit in the Subtype field of the responding CF-Up frame.

PCF Transfer Procedure

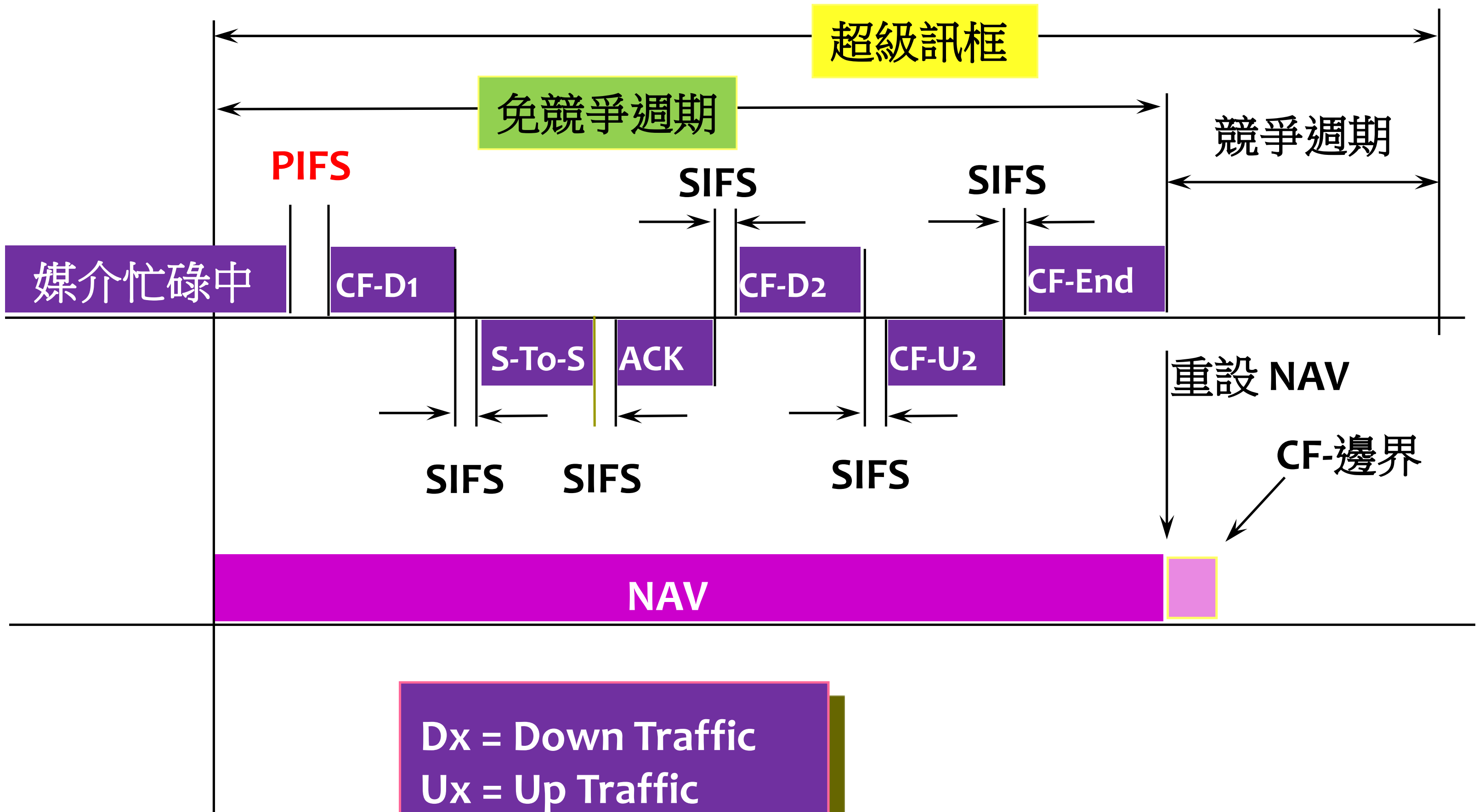


Dx = Down Traffic
Ux = Up Traffic

PCF Transfer Procedure

- **When the PCF Station is Neither Transmitter nor Recipient**
  - A CF-aware station, when polled by the PCF, may send a Data frame to any station an SIFS period after receiving the CF-Poll.
  - If the recipient of this transmission is not the PCF station, the Data frame is received and acknowledged in the same manner as a contention-based Data frame.
  - The PCF resumes (CF-Down) transmissions an SIFS period after the ACK frame. If not acknowledged, a PIFS period is employed.

PCF Transfer Procedure



Dx = Down Traffic
Ux = Up Traffic

Outline

- Introduction
- Distributed System
- IEEE 802.11 Frame format
- IEEE 802.11 MAC Architecture
- Distributed Coordination Function (DCF)
- Point Coordination Function (PCF)
- IEEE 802.11 Standards

IEEE 802.11 Standards

- IEEE 802.11, 2Mbps
- IEEE 802.11b, 11Mbps
- IEEE 802.11a, 54 Mbps
- IEEE 802.11g, 54Mbps
- IEEE 802.11n, 108Mbps

Summary

- Hidden node problem
  - 雙方雖然聽不到對方的訊號, 但同時傳送給相同的對象會造成衝撞
- Exposed node problem
  - 雙方雖然聽得到對方的訊號, 但同時可傳送給不同的對象
- IEEE 802.11 wireless communication no collision detection
- Use RTS/CTS frames to reserve the channel for large frames
  - A duration field in the RTS/CTS frames
- Use ACK frame to confirm the correct frame
- Two ways to sense the carrier
  - Physical
  - Virtual (NAV) – duration field

Summary

- CSMA/CA (Collision Avoidance), sense the carrier
  - Idle, wait a DIFS then transmit
  - Busy, wait channel to idle + wait a DIFS + wait random backoff time, then transmit
- Three Priority levels
  - SIFS < PIFS < DIFS
- Superframe : A contention-free burst occurs at the beginning, followed by a contention period.
- The PCF protocol is based on a polling scheme controlled by the Point Coordinator.