

# **Service Differentaition and QoS in WLANs (802.11e)**

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# What's the Problem in PCF

- PCF designed to provide QoS to real-time traffic
- What makes QoS in 802.11 difficult?
  1. Unpredictable beacon delay
    - A WSTA stops all timers at TBTT thus it does not initiate a transmission after TBTT; however, it continues on-going transmissions, hence beacon may be delayed
    - The larger the frame size, the longer the delay (up to 4.9 ms)
  2. Unknown transmission duration
  3. Static Polling List



# Quality-of-Service Provisioning: Some Terminology

- **Definition:** A **flow** is a packet stream from a source to a destination, belonging to the same application
- **Definition:** **QoS** is a set of service requirements to be met by the network while transporting a flow
- Typical QoS metrics include: available bandwidth, packet loss rate, estimated delay, packet jitter, hop count and path reliability

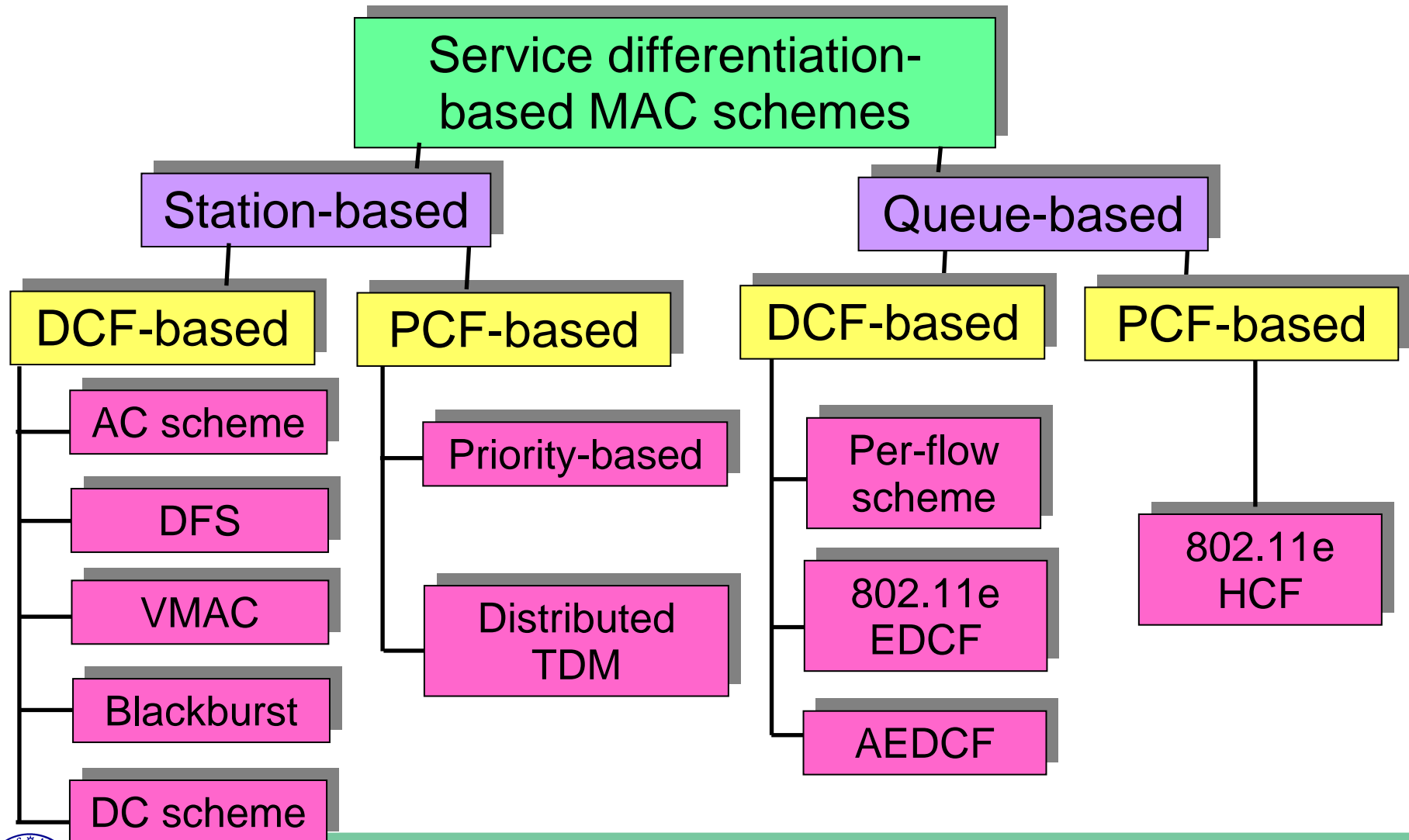


# QoS in Wireless Networks

- QoS schemes in wired networks are NOT suitable for wireless networks
  - e.g., current wired-QoS routing algorithms require accurate link state and topology information
  - time-varying capacity of wireless links, limited resources and node mobility make maintaining accurate information difficult
- Supporting QoS in wireless networks is an even more difficult challenge



# Service Differentiation MAC Schemes that lead to 802.11e



# A QoS Standard for WLANs: IEEE 802.11e

- The IEEE 802.11 TG E was formed in 1999
- The Project Authorization Request (PAR) was approved in March 2000
- **Scopes of the IEEE 802.11 Task Group E**
  - Enhance the current 802.11 MAC to improve and manage QoS
  - Consider efficiency enhancements in the areas of DCF and PCF
  - Provide different classes of service (8 TCs)



# 802.11e Standard

- Released last autumn
- PHY unchanged (use a/b/g)
- MAC Enhanced: Goals
  - Traffic Differentiation and Guarantee
  - TSPEC and CAC
  - Interoperation with legacy 802.11



# 802.11e: QSTA, QAP, QBSS, HCF

- A station using 802.11e is called *QoS Enhanced Station (QSTA)*
- An AP using 802.11e is called *QoS Access Point (QAP)*
- QSTA e QAP works within a *QoS Basic Service Set (QBSS)*
- The two coordination functions DCF e PCF are substituted by a single *Hybrid Coordination Function (HCF)*



# TXOPs

- TXOP: Transmission Opportunity
  - Time interval during which a QSTA has the right to transmit
  - It is characterized by a starting time and a maximum duration (TXOP\_Limit)
  - Used in both CP and CFP



# 802.11e Coordination Function

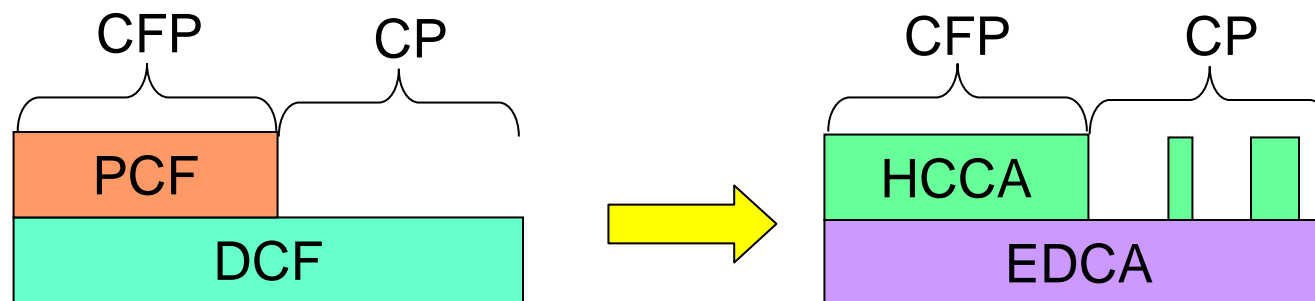
- Hybrid Coordination Function, alternates:
  - EDCA (Enhanced Distributed Channel Access), contention based, conceived to support legacy stations and provide some *stochastic* level of differentiation
  - HCCA (HCF Coordinated Channel Access), polling based, provides collision free periods with guaranteed assignment and *deterministic* differentiation



# 802.11e QoS Mechanisms

802.11e proposes a new access scheme: *Hybrid Coordination Function (HCF)*, composed of two coordination functions

- *Enhanced Distributed Channel Access (EDCA)*
  - A basis layer of 802.11e; operates in CP
- *HCF Controlled Channel Access (HCCA)*
  - HCCA operates in CFP



# 802.11e QoS Mechanisms

- MAC-level FEC (Hybrid I and II)
- Ad hoc features:
  - Direct Communication / Side Traffic
  - WARP: Wireless Address Resolution Protocol
  - AP mobility



# 802.11e: Hybrid Coordinator

- Within a QBSS a centralized controller is needed to coordinate all QSTAs. This is the *Hybrid Coordinator (HC)*, normally implemented within a QAP
- An HC has the role of splitting the transmission superframe in two phases continuously alternating:
  - *Contention Period (CP)*, where QSTAs contend for the channel using EDCA
  - *Contention-Free Period (CFP)*, where HC defines who is going to use the channel and for what time with a collision free polling protocol





# 802.11e: EDCF

- *L'Enhanced Distributed Coordination Function (EDCF)* define a differentiated access scheme based on an improved (yet complex) contention scheme
- It is an evolution of *CSMA/CA DCF*, with the add-on of traffic classes to support QoS and differentiate traffic
- EDCF is designed to support frames with the same 8 priority levels of 802.11d, but mapping them on only 4 access categories
- Every frame passed to the MAC layer from above, must have a priority identifier (from 0 to 7), called *Traffic Category Identification (TCId)*

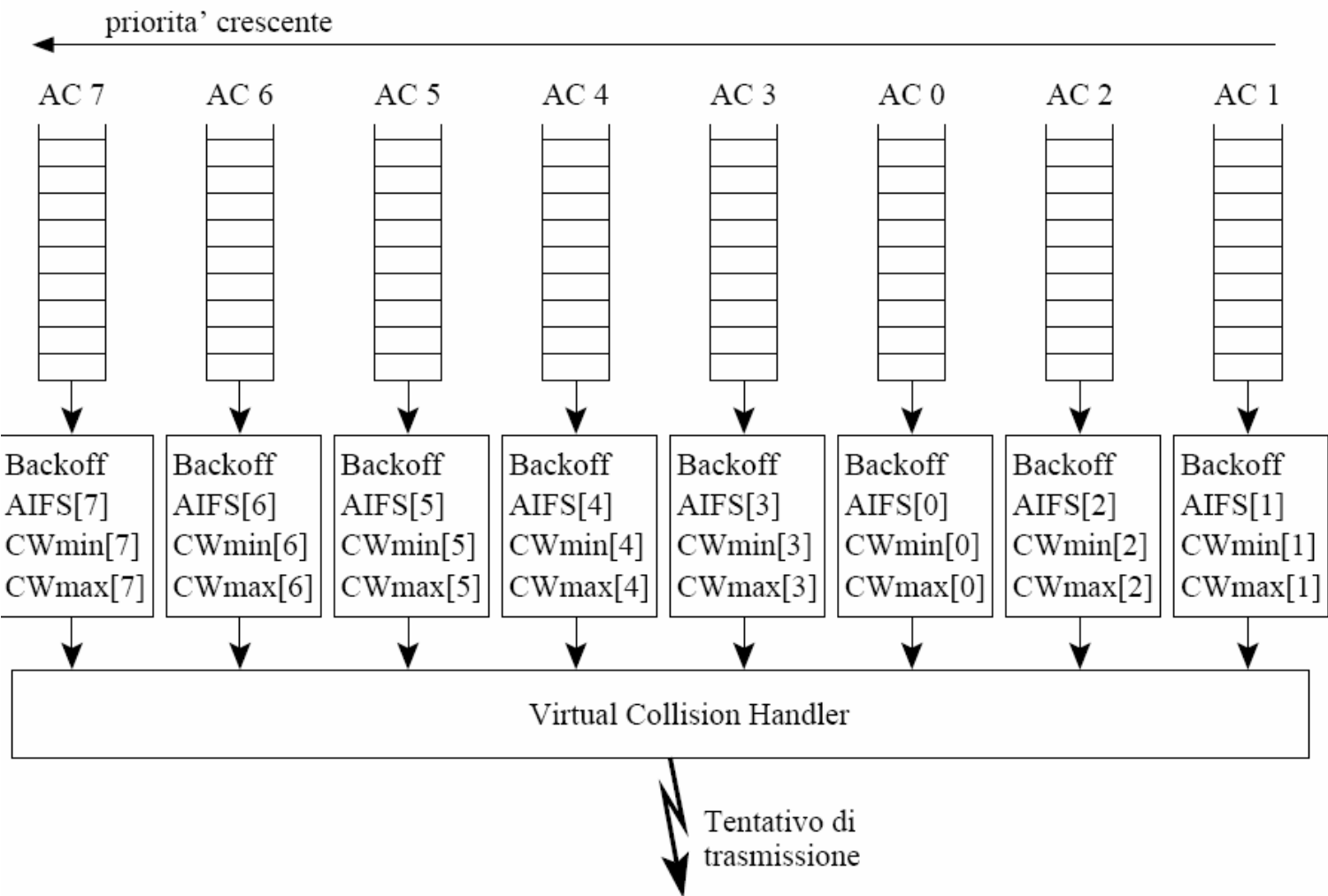


# 802.11e: EDCF

- TCIId is written in one header field of the MAC frame
- Each 802.11e QSTA & QAP MUST have four separated AC queues
- Each AC queue is FIFO and behaves independently from the others as far as the CSMA/CA MAC protocol is concerned



# 802.11e: EDCF



# 802.11e: EDCF

- ACs are differentiated based on their CSMA parameters:
  - **IFS**
  - **CWmin**
  - **CWmax**
  - **Backoff exponent**



# 802.11e: EDCF

- Higher priority ACs are assigned parameters that result in shorter CWs so that a statistical advantage is gained in accessing the channel
- Protocol parameters become vectors
  - $CW_{min}[AC]$
  - $CW_{max}[AC]$
  - $AIFS[AC]$
  - $bck[AC]$
- $CW[AC,t]$  is derived with the usual CSMA/CA rules

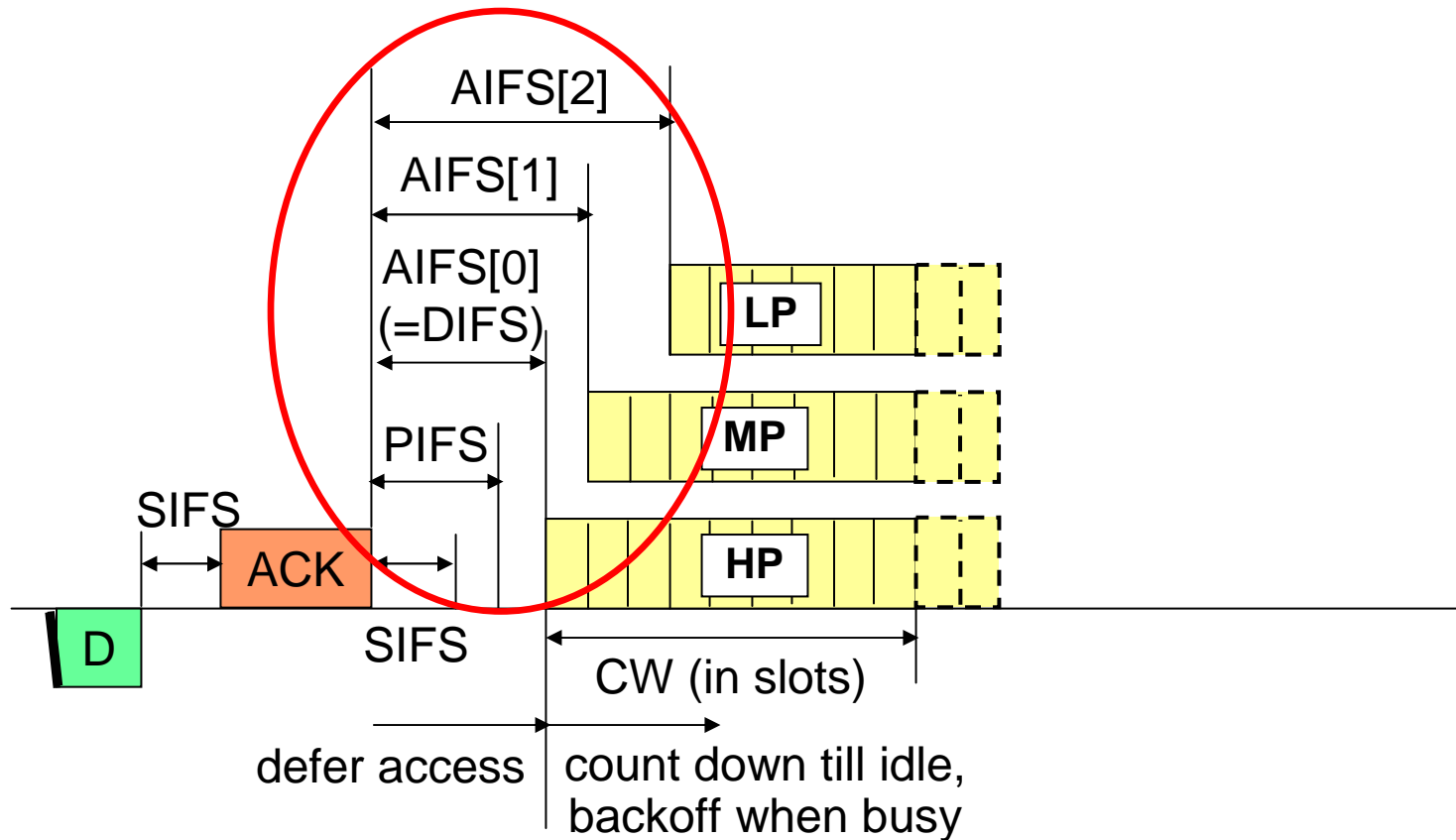


# 802.11e: EDCF

- Arbitration InterFrame Space (AIFS) substitute the common DIFS
- Each AIFS is at least DIFS long
- Befor entering the backoff procedure each *Virtual Station* will have to wait AIFS[AC], instead of DIFS



# Arbitration IFS (AIFS)



802.11a: slot=9  $\mu$ s, SIFS=16  $\mu$ s, PIFS=25  $\mu$ s, DIFS=34  $\mu$ s, AIFS  $\geq$ 34  $\mu$ s



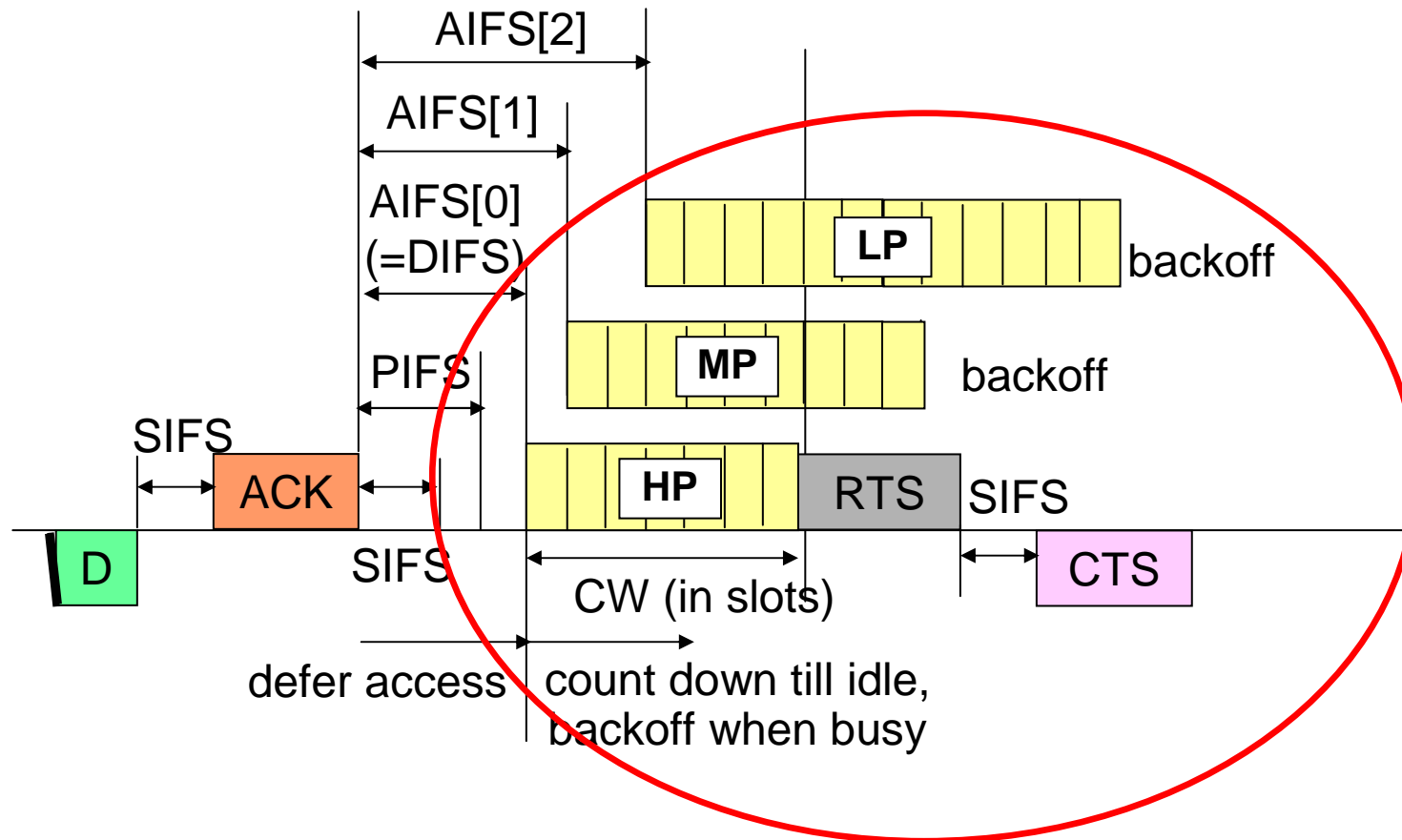
# Contention Window

- $CW_{\min}[AC]$  and  $CW_{\max}[AC]$
- Contention Window update:

$$CW_{new}[AC] = (CW_{old}[AC] + 1) \cdot bck - 1$$



# Backoff



802.11a: slot=9  $\mu$ s, SIFS=16  $\mu$ s, PIFS=25  $\mu$ s, DIFS=34  $\mu$ s, AIFS  $\geq$ 34  $\mu$ s



# Virtual Stations

- Each AC queue behaves like a different **virtual station** (independent sensing and backoff)
- If the backoff counters of two or more parallel ACs in the same QSTA reach 0 at the same time, a scheduler inside the QSTA avoids virtual collision by **granting the TXOP** to the AC with the highest UP
- The lowest priority colliding behaves as if there were an external collision



# 802.11e: EDCF – Beacon Frames

- Values of  $AIFS[AC]$ ,  $CWmin[AC]$  e  $CWmax[AC]$  are determined by the QAP and transmitted within beacon frames (normally every 100 msec)
- QSTAs must abide to the received parameters
- QSTAs may use these parameters to chose the QAP the prefer to connect to (estimate of the expected performance)

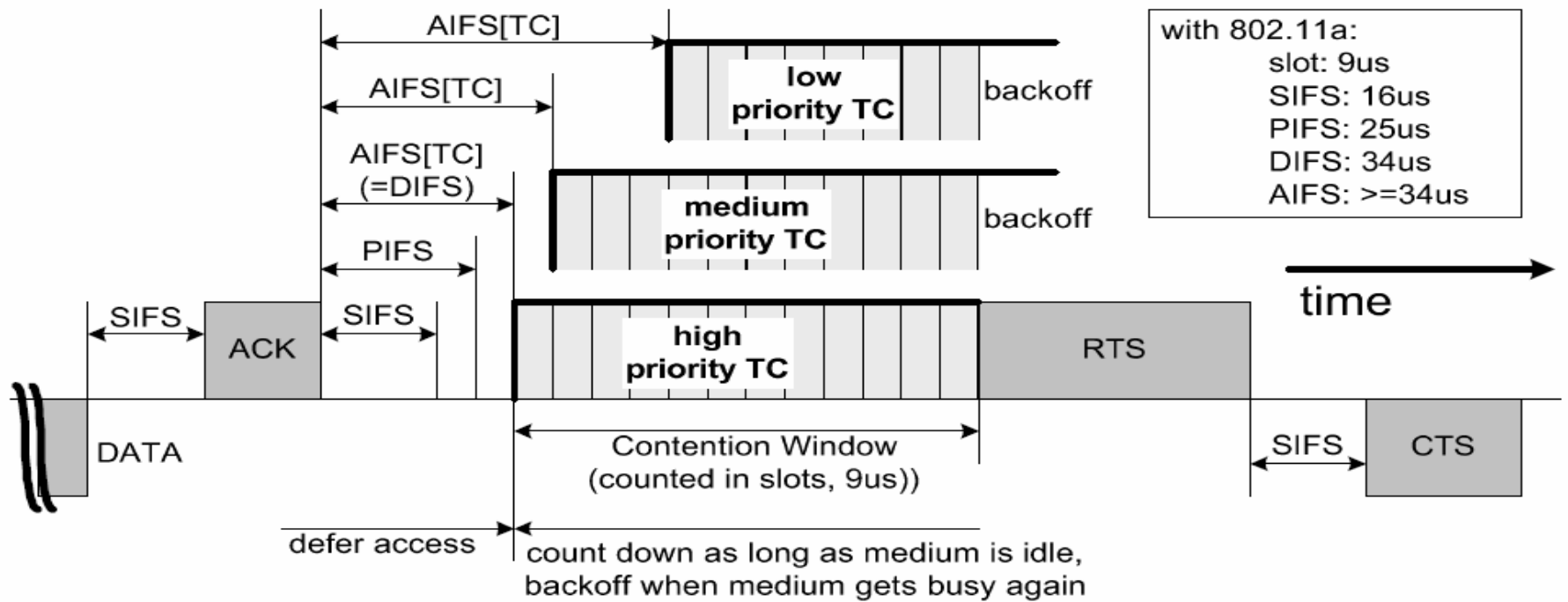


# 802.11e: EDCF – Virtual Collisions

- Every AC within a QSTA behaves as if it were an independent station, with its own MAC parameters  $AIFS[AC]$  e  $CW[AC]$
- So Virtual Stations (AC queues) within a QSTA contend for the channel
- Internal collisions between different ACs are solved virtually, without loss of resources
- The TXOP goes to the highest priority AC and the others behave as if there was a real collision



# 802.11e: EDCF – Collisioni Virtuali



# 802.11e: TXOP

- TXOP is the time interval in which a STA may use the channel
- It's an initial time plus a duration, indeed the negotiation is no more for a PDU, but can be for many aggregated PDUs (this part is not well defined in the standard)
- $CW[AC]$  is managed with usual rules of increment (after collisions/failures) and devrement (during idle cahnnel):

$$\text{NewCW}[AC] = ((\text{OldCW}[AC] + 1) * 2) - 1$$



# 802.11e: EDCF

- Sample allocation of TCID to ACs:

TCID	CA	Traffic description
0	0	Best Effort
1	0	Best Effort
2	0	Best Effort
3	1	Video Probe
4	2	Video
5	2	Video
6	3	Voice
7	3	Voice



# EDCA Bursting

- Once the station has gained access to the medium, it can be allowed to send **more than one frame** without contending again
- The station cannot transmit longer than **TXOP\_Limit**
- **ACK frame by frame or Burst ACK**
- **SIFS** is used between packets (to avoid collisions)



# EDCA Bursting: Pros / Cons

- **Pros**

- Reduces network **overhead**
- **Increases throughput** (SIFS and burst ACKs)
- **Better fairness** among the same priority queues:  
independently of the frame size, a QSTA gets a TXOP  
every time it wins a contention
  - E.g., STA A uses 500 B frame; STA B uses 1K B frame. Thus B would get higher throughput in 802.11, while in 802.11e both can get approximately same throughput



# EDCA Bursting: Pros / Cons

- **Cons**
  - Possible increasing of **delay jitter**
  - TXOP\_Limit should not be longer than the time required for transmitting the largest data frame
- In any case EDCA does not solve the downlink/uplink unfairness problem



# 802.11e: HCF

- HC may allocate TXOPs to himself (QAP) or to other QSTAs
- Self allocation is done to transmit MSDUs, allocation of resources may solve the uplink/downlink unfairness
- Allocation to AP can be done after a Point coordination InterFrame Space (PIFS) con  $PIFS < DIFS$
- HC (QAP) has priority over other stations and may interrupt a CP to start a CFP transmitting a Poll frame

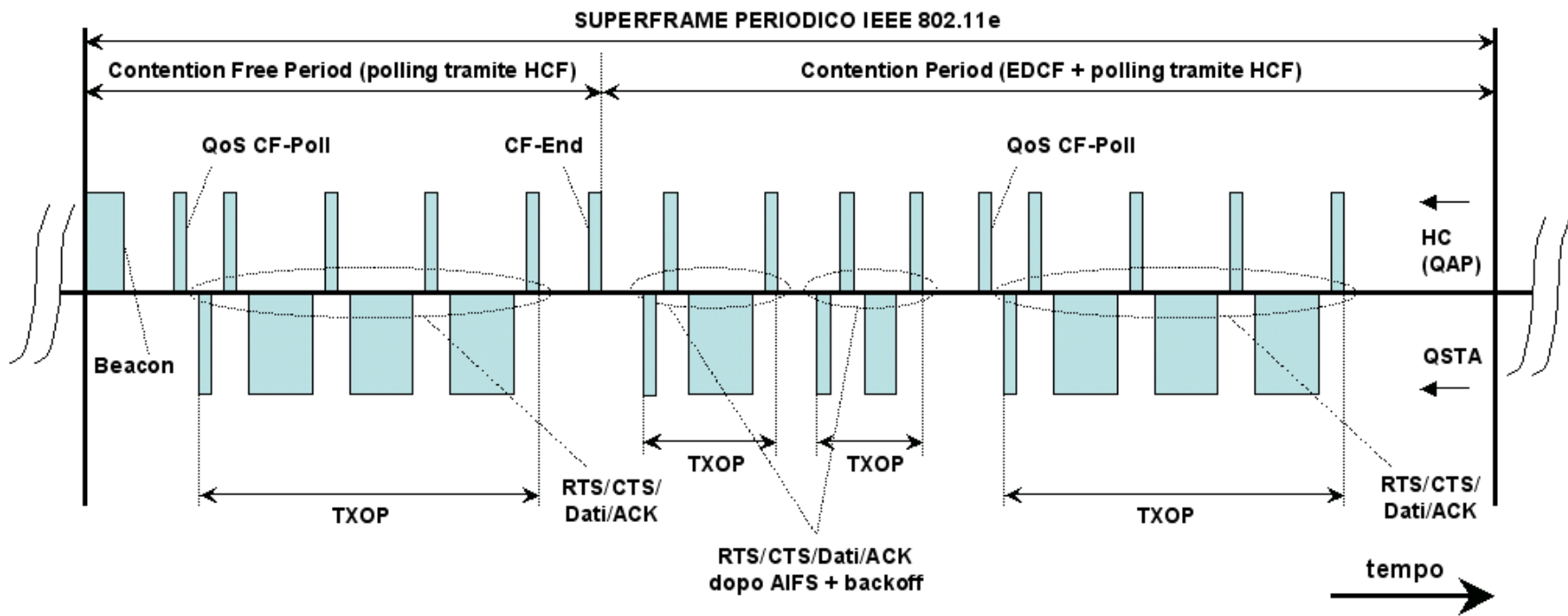


# 802.11e: HCF

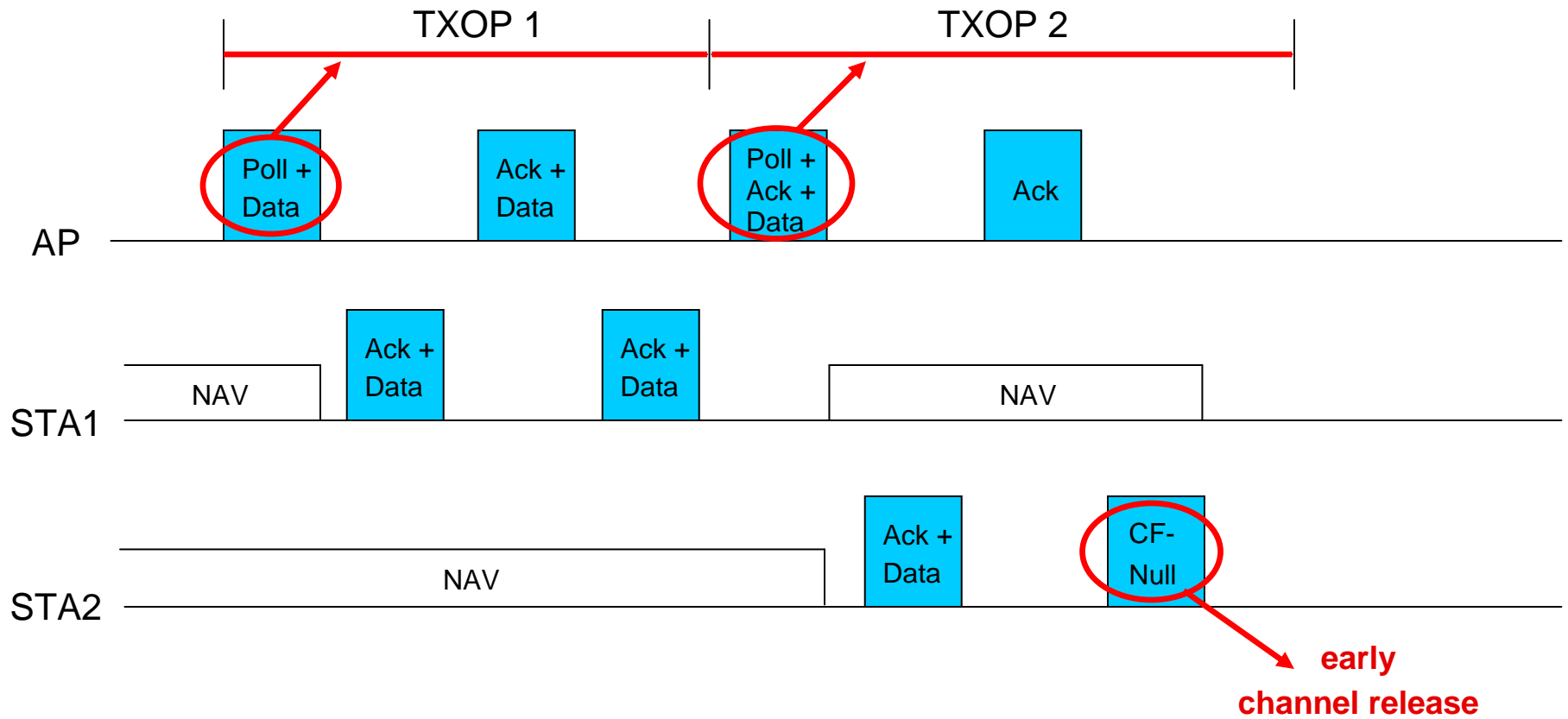
- Time is divided between contention free periods (CFP) and contention periods (CP), that are alternated roughly cyclically
- A sequence CFP + CP defines a Periodic Superframe of 802.11e
- The CP can be interrupted by other contention free periods called CAPs



# 802.11e: HCF



# MAC 802.11e: HCCA



# 802.11e: HCF – QoS CFPoll Frame

- Within a CP, TXOP is determined either:
  - Through EDCF rules (free channel + AIFS + BO + TXtime)
  - Through a poll frame, called QoS CFPoll, sent by HC to a station
- QoS CFPoll is sent after PIFS, so with priority wrt any other traffic
- Indeed there is not a big difference between a CFP and CAPs as defined above.



# 802.11e: HCF – QoS CFPoll Frame

- During CFP, TXOPs are again determined by HC and QoS CFPoll can be piggybacked with data and ACKs if needed
- Stations not polled set NAV and cannot access the channel
- The CFP must terminate within a time specified within the beacons and it is terminated by the CF-End frame sent by HC



# 802.11e: HCF – QoS CFPoll Frame

- QoS CF-Poll frame was introduced with the 802.11e amendment, for backward compatibility it contains a NAV field the legacy stations can use to avoid interfering
- NAV specify the whole TXOP duration
- Legacy stations in HCF can only use the CP period



# 802.11e: HCF – Controlled Content.

- Is a mix between polling and contention based
- Should guarantee better performances than contention during congestions periods
- The *Controlled Contention* mechanism is mandatory for QAP and optional for QSTA:
  - QSTA notify QAP some allocation requests, QAP will allocate the necessary TXOPs via polling
  - Different from standard polling, because it'



# 802.11e: HCF – Controlled Content.

- QAP defines if there are resources to satisfy requests:
  - ❑ If available schedules the channel (IEEE 802.11e does not specify scheduling algorithms, these are open for research and competitive implementation)
  - ❑ The answer to stations can be acceptance, rejections or a proposal to use resources with a lower priority



# HCCA

- HCCA effectively provides policing and deterministic channel access by controlling the channel through the HC
- It is backward compatible with basic DCF/PCF
- Based on polling of QSTAs by the HC



# HCCA

## Crucial features of HCCA

- HCCA operates in CP and CFP
- Uses TXOPs which are granted through HC (in HCCA!)
  - HC allocates TXOPs by using QoS CF-Poll frames
  - In CPs, the time interval during which TXOPs are polled by HC is called CAP (Controlled Access Period)
  - 8 Traffic Categories (TCs)



# HC Behavior in HCCA

- According to HCCA:
  - HC may allocate TXOPs to itself to transmit MSDUs whenever it wants, however only after having sensed the channel idle for PIFS
  - In CP, the HC can send the CF-Poll frame after a PIFS idle period, thus starting a CAP
  - In CFP, only the HC can grant TXOPs to QSTAs by sending the CF-Poll frame
  - The CFP ends after the time announced by HC in the beacon frame or by the CF-End frame from HC

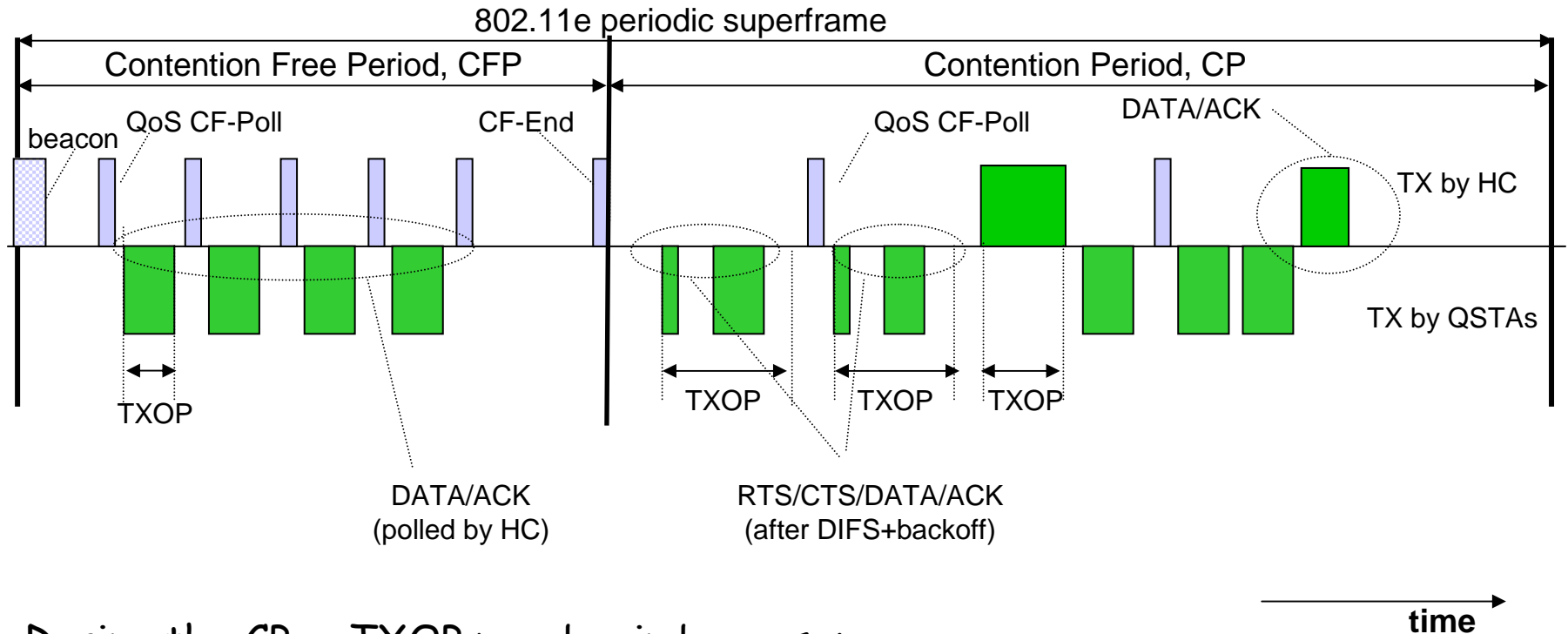


# QSTA Behavior in HCCA

- A QSTA behaves as follows
  - In CP QSTAs can gain a TXOP thanks to a CF-Poll frame issued by HC during CAPs, otherwise they can use EDCA
  - In CFP, QSTAs do not attempt accessing the channel on their own but wait for a CF-Poll frame from the HC
- The HC indicates the TXOP duration to be used in the CF-Poll frame (QoS-control field)
  - Legacy stations kept silent by NAV whenever they detect a CF-Poll frame



# 802.11e Superframe



During the CP, a TXOP may begin because:

- The medium is determined to be available under EDCA rules (EDCA-TXOP)
- The STA receives a special polling frame from HC (polled-TXOP)



# Polling in HCCA

- Polling list is a crucial key in HCCA
  - Traffic scheduling (i.e., how QSTAs are polled) is not specified
  - QSTAs can send updates to the HC on their queue size as well as on the desired TXOP, (through the QoS control field in data frames)
  - QSTAs can send ADDTS requests to initiate a new traffic stream



# Traffic Signaling

- Two types of signaling traffic are supported:
  - Connectionless queue state indicator
    - E.g., Arrival rate measurement: notification and not negotiation between *peer entities* is used
  - TSPEC (Traffic Specification) between HC and QSTAs
    - E.g., service negotiation and resource reservation



# Traffic Signaling

- TSPEC are the base for CAC
- QoS without CAC is impossible
- QoS is granted to flows not to packets
- Flows are persistent (normally)
- Flows can be predicted (sometimes)



# Resource Scheduling

- Not essential to backward compatibility
  - The standard has just a reference impl. (SS)
- HCF is implemented in the AP
  - HCCA scheduling is a function of HCF
- Requirements of traffic flows are contained in the *Traffic Specifications* (TSPEC):
  - Maximum, minimum and mean data rate
  - Maximum and nominal size of the MSDUs
  - Maximum Service Interval and *Delay Bound*
  - Inactivity Interval
  - ...

