An Overview of 802.11e

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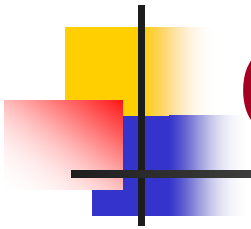
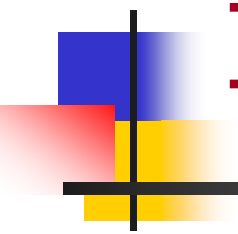


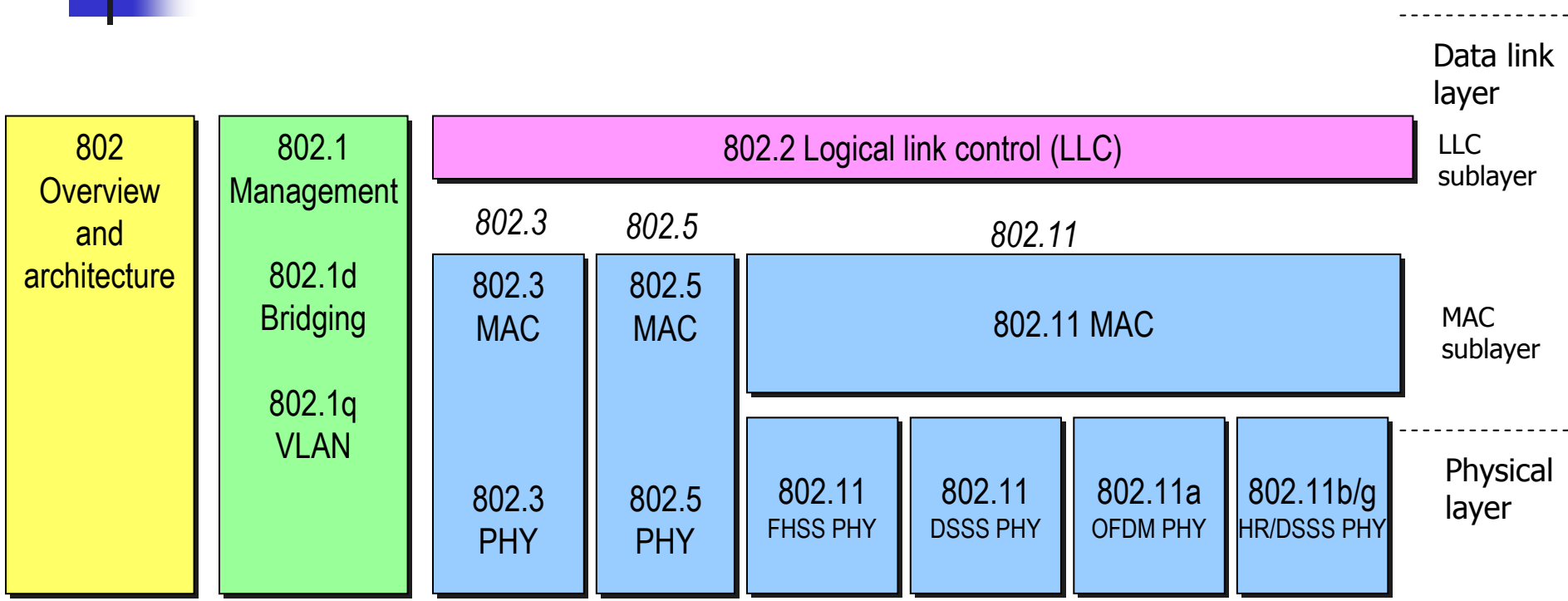
Outlines

- Introduction
- Traffic Differentiation
- Hybrid Coordination Function (HCF)
  - Contention-Based Channel Access – EDCA
  - Controlled Channel Access – HCCA
- Block Acknowledgement
- Direct Link Protocol (DLP)
- Automatic Power-Save Delivery (APSD)
- Performance Evaluation

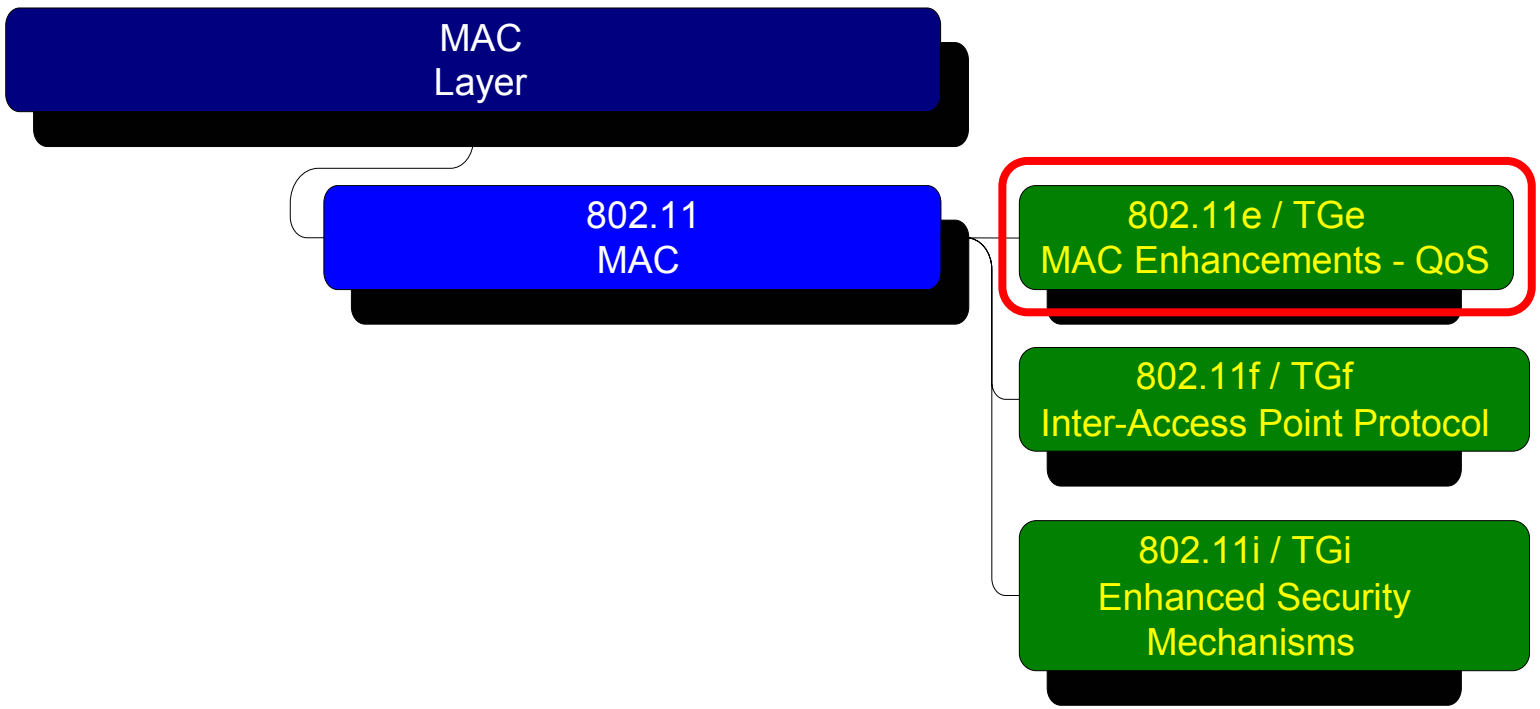


Introduction

IEEE 802 Family



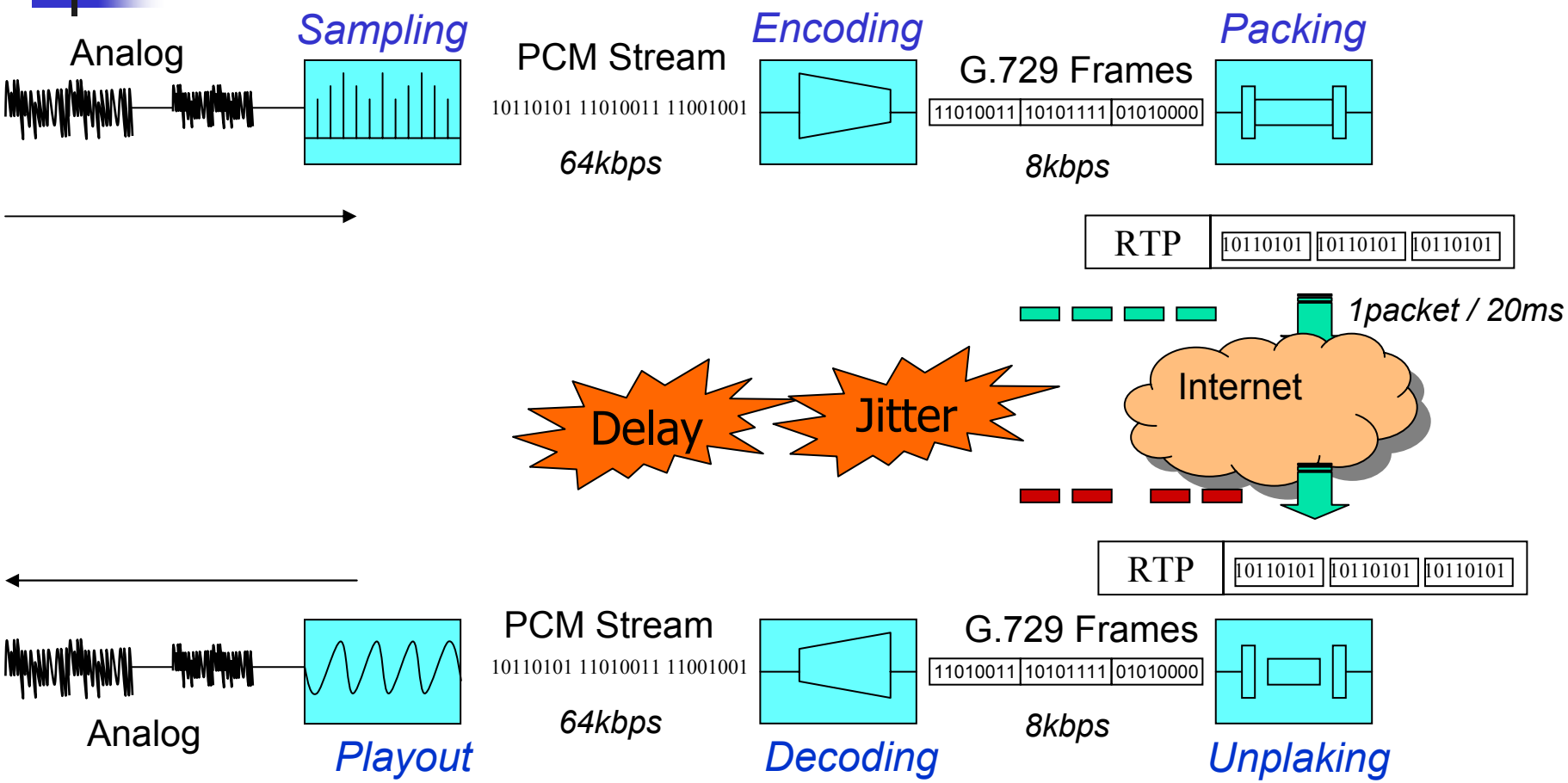
802.11 MAC and Other



Characteristics of Media Streams

- Media Streams
  - Audio
    - Speech
      - Uncompressed – e.g. 64 kbps PCM
      - Compressed: e.g. ITU-T G.723.1, G.729, …
      - Low bit rate & Constant bit rate
    - Music
      - Uncompressed – e.g. CD: 16bit, 44.1khz
      - Compressed: e.g. MP2, MP3, …
      - Medium bit rate & Variable/Constant bit rate
  - Video
      - Compressed – e.g. Mpeg-1, Mpeg-2, Mpeg-4, …
      - High bit rate & Variable/Constant bit rate

Processing of Media Streams



QoS Requirement

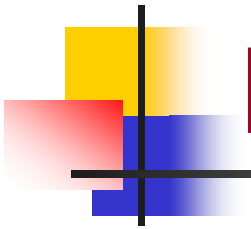
- Parameters of traffic stream
  - Controlled transmission rate
    - Peak rate & Average rate
  - Controlled Service Interval
    - Minimum & Maximum
  - Burst Size on peak rate
- Requirements
  - Bounded Delay ! (→ for real-time & smooth interaction)
  - Bounded Jitter ! (→ for smooth playout)
- Solution in device: Jitter Buffer
- Solution in network: Prioritized Transmission

Two Kinds of QoS

- Parameterized QoS:
  - A strict QoS requirement expressed quantitatively in terms of data rate, delay bound etc. (ex. BW of 10 Mbps, delay bound of 10ms)
- Prioritized QoS:
  - Loose QoS requirement expressed in terms of relative delivery priority

Is 802.11 enough for QoS?

- DCF can not provide QoS trivially
- PCF is not enough
  - Only 1 frame can be sent at each polling
  - *Point Coordinator* (PC) does not know the QoS requirement of traffic
  - Can not guarantee the delay and jitter bound

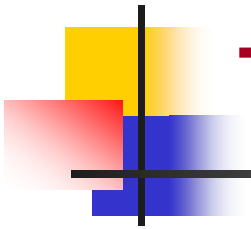


Brief of IEEE 802.11e

- Defined at IEEE 802.11 Task Group E
- Goal: Providing QoS
  - Minimize Latency
  - Maximize throughput
  - Define traffic models for both Ad-hoc and Infrastructure
- Approach: Enhance the MAC (802.11)
- Current Status
  - Draft 11 (Sponsor Ballot is ongoing)
  - Will be finalized this year (???)

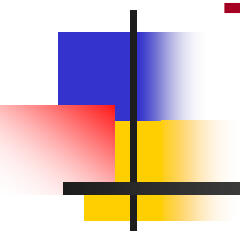
Major Enhancements in 802.11e

- Basic elements for QoS
  - Traffic Differentiation
  - Concept of Transmission Opportunity (TXOP)
- New Contention-based channel access
  - Enhanced Distributed Channel Access (EDCA) (*Contention-Based*)
- New Contention-free channel access
  - HCF Controlled Channel Access (HCCA) (*Contention Free*)
- Other new mechanisms for higher throughput
  - Block Acknowledgement (Block Ack)
  - Direct Link Setup (DLS)
  - Automatic Power-Save Delivery (APSD)



Terms

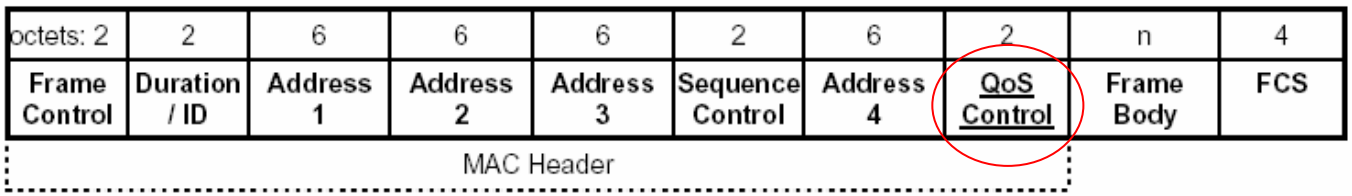
- QoS Facility
  - The mechanisms for QoS defined in 802.11e
- QAP
  - Access Point supporting QoS facility
- QSTA
  - Station supporting QoS facility
- QBSS
- Hybrid Coorinator (HC)
- Access Category (AC)
- User Priority (UP)
- Traffic Category (TC)
- Traffic Specification (TSPEC)
- Traffic Stream (TS)
- Traffic Identifier (TID)



Traffic Differentiation

Classification of QoS Data

- New frame subtype: QoS Data



octets: 2	2	6	6	6	2	6	2	n	4
Frame Control	Duration / ID	Address 1	Address 2	Address 3	Sequence Control	Address 4	QoS Control	Frame Body	FCS
MAC Header									

- Each MSDU of QoS Data is classified as one kind of traffic
  - Identified by TID field in frame header
- Two types of traffic classification
  - By **User Priority (UP)**
    - (for prioritized QoS)
  - By **Traffic Specification (TSPEC)**
    - (for parameterized QoS)

User Priority

- 8 User Priorities:
  - Identical to IEEE 802.1D priority tags

Priority	User Priority (same as 802.1D user priority	802.1D Designation	Access category (AC)	Designation (Informative)
Lowest	1	BK	AC_BK	Background
	2	-	AC_BK	Background
	0	BE	AC_BE	Best Effort
	3	EE	AC_BE	Video
	4	CL	AC_VI	Video
	5	VI	AC_VI	Video
highest	6	VO	AC_VO	Voice
	7	NC	AC_VO	Voice

User Priority (cont.)

- Priority Determination of MSDU
  - Directly:
    - provided at MAC SAP by upper-layer software
  - Indirectly:
    - defined in TSPEC's

Access Category (AC)

- Rules
  - One UP belongs to one AC
  - Each AC contains two UP
  - Traffic of higher UP will be transmitted first in one AC
- In EDCA, media access is based on the AC of MSDU
- 4 AC's are defined
  - AC_BK (background)
  - AC_BE (best-effort)
  - AC_VI (Video)
  - AC_VO (Voice)
- In EDCA, the size of Contention-Window (CW) and Inter-frame space (IFS) is dependent on AC

Traffic Specification

- Traffic Specification (TSPEC)
  - Characteristics of traffic streams created by negotiation between QSTA and HC
  - HC can schedule the polling within CFP and the data transmission of the TS accordingly
  - At most 8 TSPEC can be registered
  - Identified by TSID (0~7)
- TSPEC Setup & Delete
  - Use Management Frame with new subtype Action
    - ADDTS request & ADDTS response: for TSPEC setup
    - DELTS: for TSPEC delete

MAC Frame Formats

MAC frame format (QoS Data):

octets: 2	2	6	6	6	2	6	2	n	4
Frame Control	Duration / ID	Address 1	Address 2	Address 3	Sequence Control	Address 4	QoS Control	Frame Body	FCS
				MAC Header					

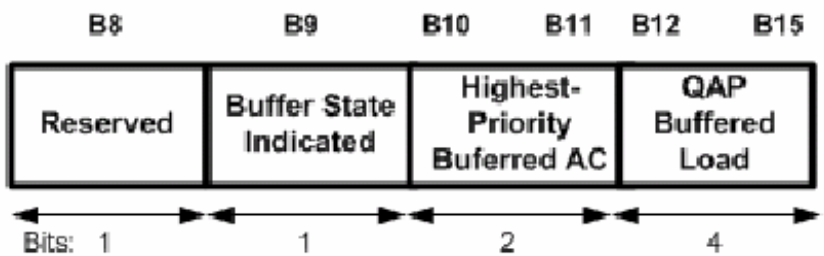
QoS Control Field:

Applicable Frame (sub) Types	Bits 0-3	Bit 4	Bit 5-6	Bit 7	Bits 8-15
QoS (+)CF-Poll frames sent by HC	TID	EOSP	Ack Policy	Reserved	TXOP limit
QoS Data, QoS Null, and QoS Data+CF-Ack frames sent by HC	TID	EOSP	Ack Policy	Reserved	QAP PS Buffer State
QoS data type frames sent by non-AP QSTAs	TID	0	Ack Policy	Reserved	TXOP duration requested
	TID	1	Ack Policy	Reserved	Queue size

(Source: Draft11)

Frame Formats (cont.)

- In QoS control field,
  - TID: Traffic Identifier
  - EOSP: End of Service Period
    - Service period is ended after successful transmission of this frame
    - Used with APSD
  - QAP PS Buffer State



Traffic Identified (TID)

- Distinguish MSDUs of different traffic types
- Range: 0-15

Bits 0-3	Usage
0-7	UP for prioritized QoS (TC)
8-15	TSID for parameterized QoS (TS)

Action Frames: ADDTS request & ADDTS response

Frame Body:

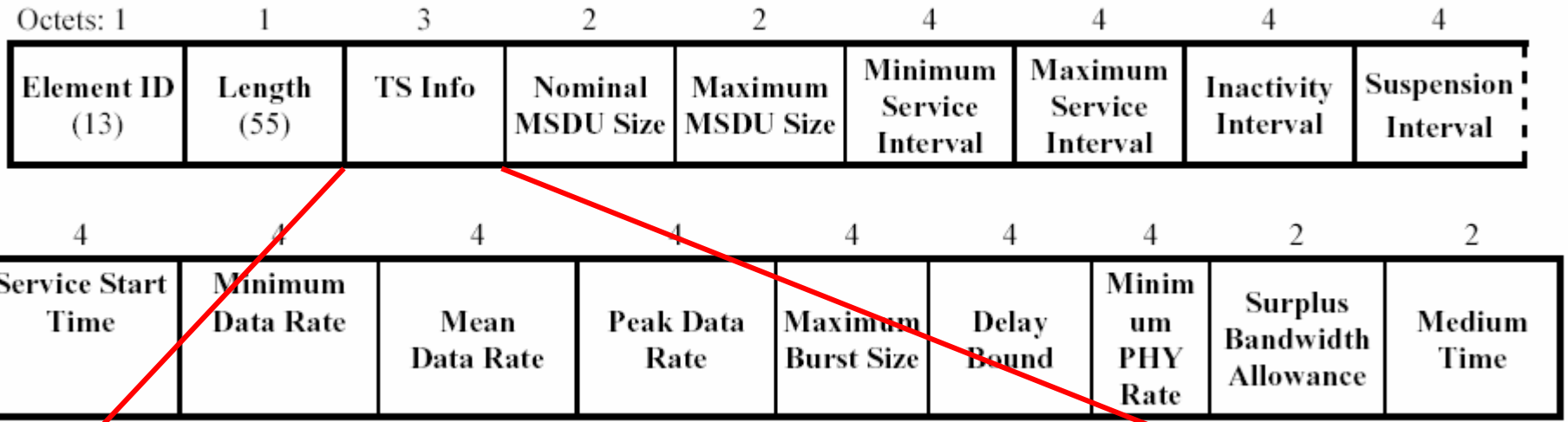
ADDTS Request

Order	Information
1	Category
2	Action
3	Dialog Token
4	TSPEC
5 - n	TCLAS (optional)
n + 1	TCLAS Processing (optional)

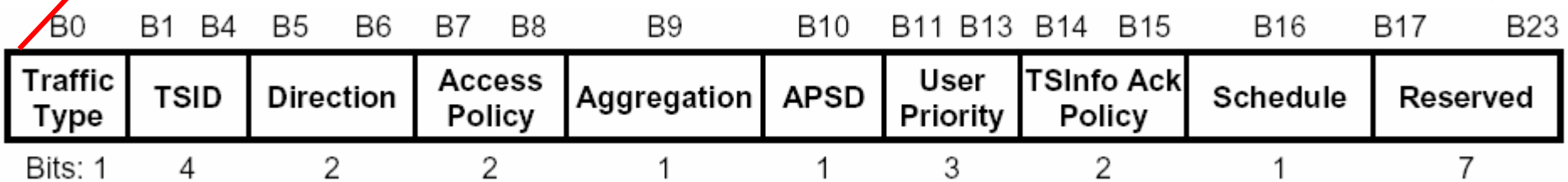
ADDTS Response

Order	Information
1	Category
2	Action
3	Dialog Token
4	Status Code
5	TS Delay
6	TSPEC
7 – n	TCLAS (optional)
n + 1	TCLAS Processing (optional)
n + 2	Schedule

TSPEC Element Format



TS Info:

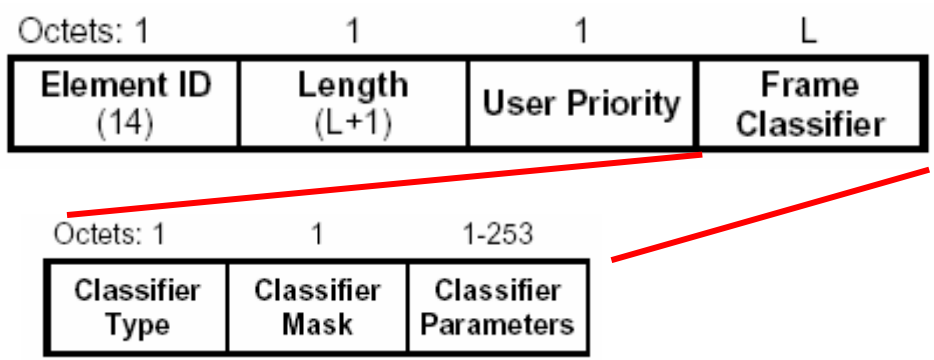


Fields in TS Info

在802.11e中的名稱	中文名稱	欄位大小（位元）	意義
Traffic Type	資料流型態	1	1表示這是週期性的資料流；0則表示非週期性的資料流。
TSID	資料流辨識碼	3	為上層軟體設定給該資料流的辨識碼，範圍是十進位的0~7。
Direction	傳送方向	2	標示出該資料流的傳送方向： I)Uplink（上行）：由工作站流向存取點。 II)Downlink（下行）：由存取點流向工作站。 III)Direct link（直接連線）：直接傳到另一個工作站。 IV)Bi-directional link（雙向）：同時有上行與下行的資料流。
Access Policy	存取策略	2	標示出此資料流要在何種通道存取模式下傳送：競爭模式（EDCA）、免競爭模式（HCCA）、或兩者皆可。
Aggregation	集成式排程	1	標示出此資料流在存取點轉送時是否要使用集成式的排程方式，而非個別排程。 802.11e規定：當資料流指定使用省電模式自動傳送（APSD）時，則非得要使用集成式排程不可。
APSD	省電模式自動傳送	1	標示出此資料流是否要使用省電模式自動傳送。
User Priority	使用者優先權	3	標示出此資料流所對應的使用者優先權（應用於EDCA模式中競爭通道存取權）。
TSInfo Ack Policy	回應方式	2	標示出在傳送此資料流的訊框時所採用的回應傳送方式：原始802.11的回應方式、不回應、或是整批回應方式。
Schedule	是否排程	1	若此資料流指定的存取策略（也就是Access Policy欄位）包含EDCA模式時，此欄位即用來標示是否需要存取點依據TSPEC的各項QoS需求進行排程，以分配通道傳輸權供此資料流傳送。或是若APSD欄位設定為1，則表示在省電模式自動傳送時，是要使用不排程的方式或是有排程的方式來作資料傳送。

Traffic Classification (TCLAS) Element

- For identifying the TS to which the incoming MSDUs belong



Traffic Classification (TCLAS) Element

Classifier Type	Classifier Parameters
0	Ethernet parameters
1	TCP/UDP IP parameters
2	IEEE 802.1D/Q Parameters
3 – 255	Reserved

Type 0

Octets: 1	1	6	6	2
Classifier Type (0)	Classifier Mask	Source Address	Destination Address	Type

Type 1 (IPv4)

Octets: 1	1	1	4	4	2	2	1	1	1
Classifier Type (1)	Classifier Mask	Version	Source IP Address	Destination IP Address	Source Port	Destination Port	DSCP	Protocol	Reserved

Type 1 (IPv6)

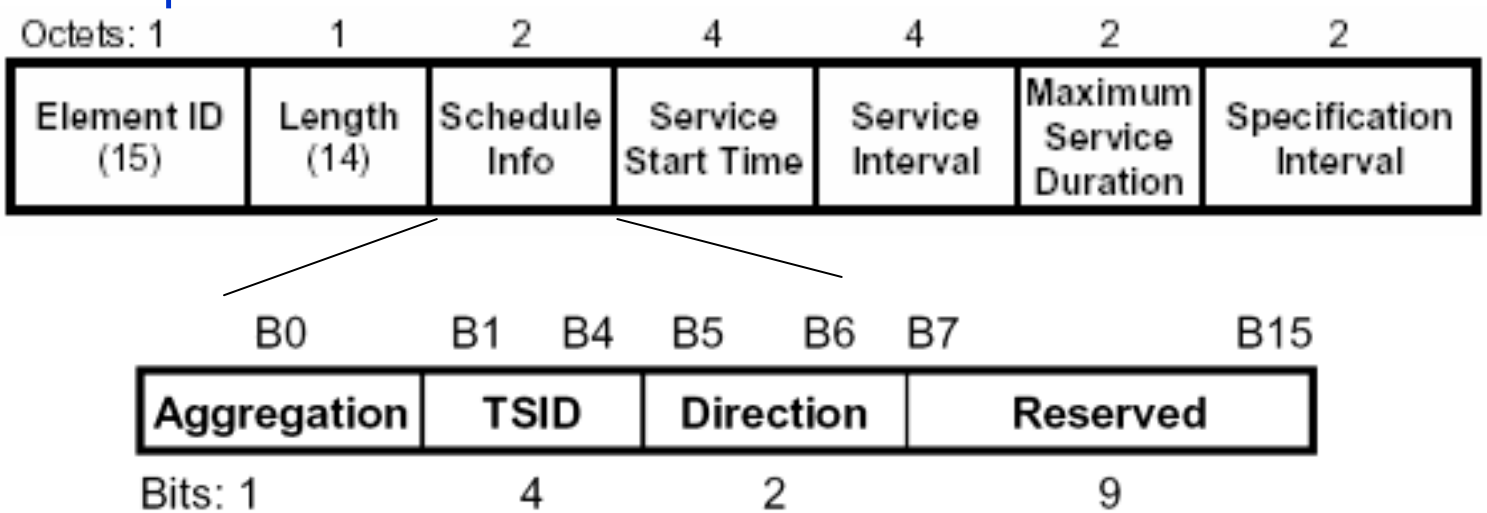
Octets: 1	1	1	16	16	2	2	3
Classifier Type (1)	Classifier Mask	Version	Source IP Address	Destination IP Address	Source Port	Destination Port	Flow Label

Type 2

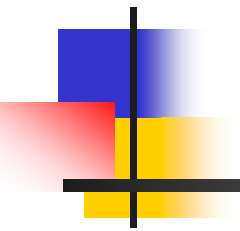
Octets: 1	1	2
Classifier Type (2)	Classifier Mask	802.1Q Tag Type

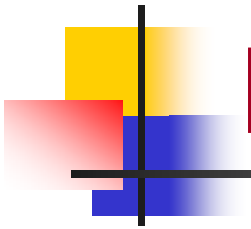
Schedule Element

- HC contains Schedule element in ADDTS response if incoming ADDTS request's TS_INFO.Schedule = 1.
- If TS_Info.Access_Policy includes EDCA, the schedule element indicate the polling schedule for this TS in HCF
- If TS_Info.APSD = 1, the schedule element indicate the wake-up schedule for transmission



Hybrid Coordination Function (HCF)

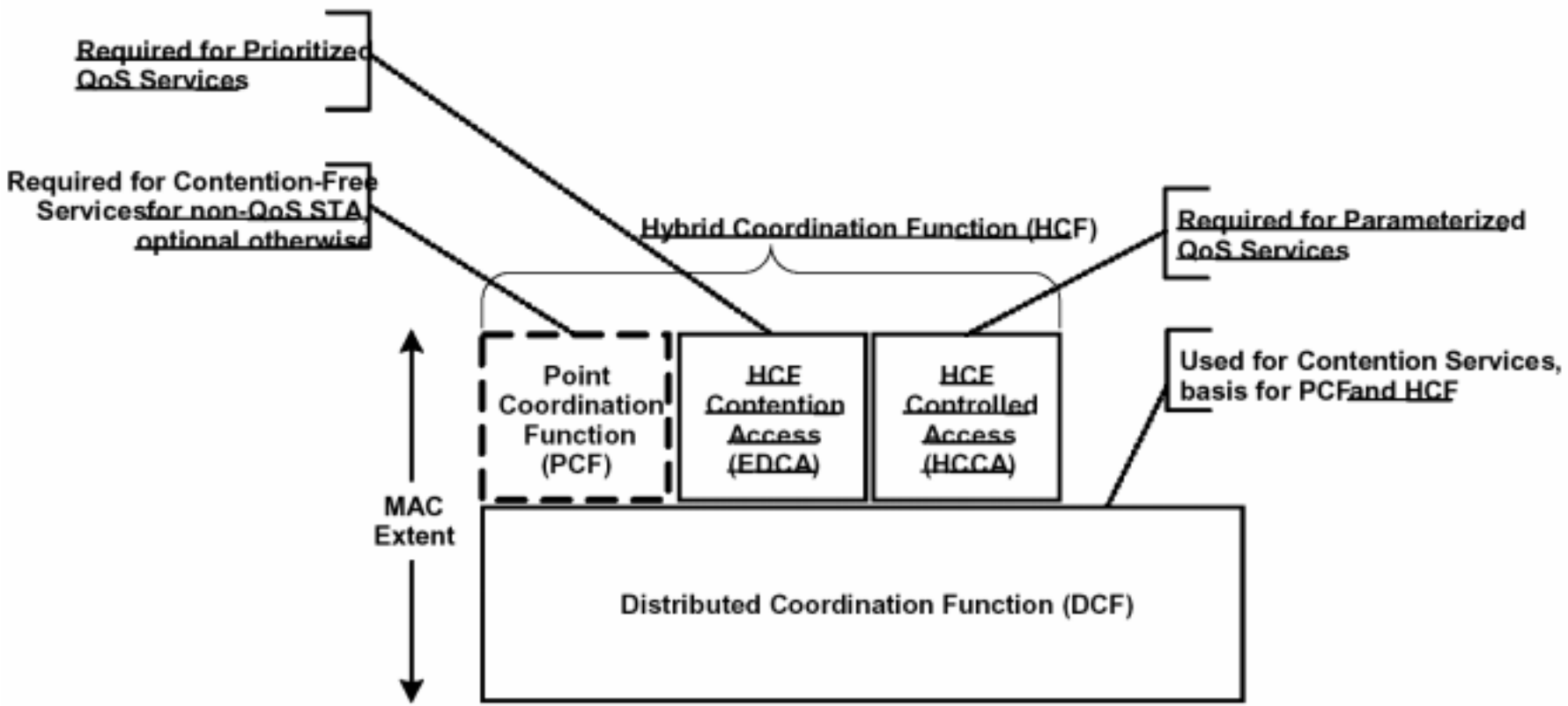


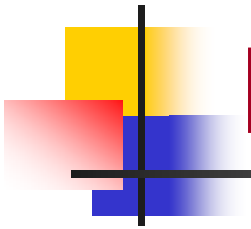


HCF Brief

- In 802.11, two access methods are
  - Distributed Coordination Function (DCF)
  - Point Coordination Function (PCF)
- In 802.11e, HCF access method is added, including
  - Contention-Based channel access– EDCA
    - Combined with DCF
  - Controlled channel access – HCCA
    - Similar to PCF but with enhancement

MAC Architecture

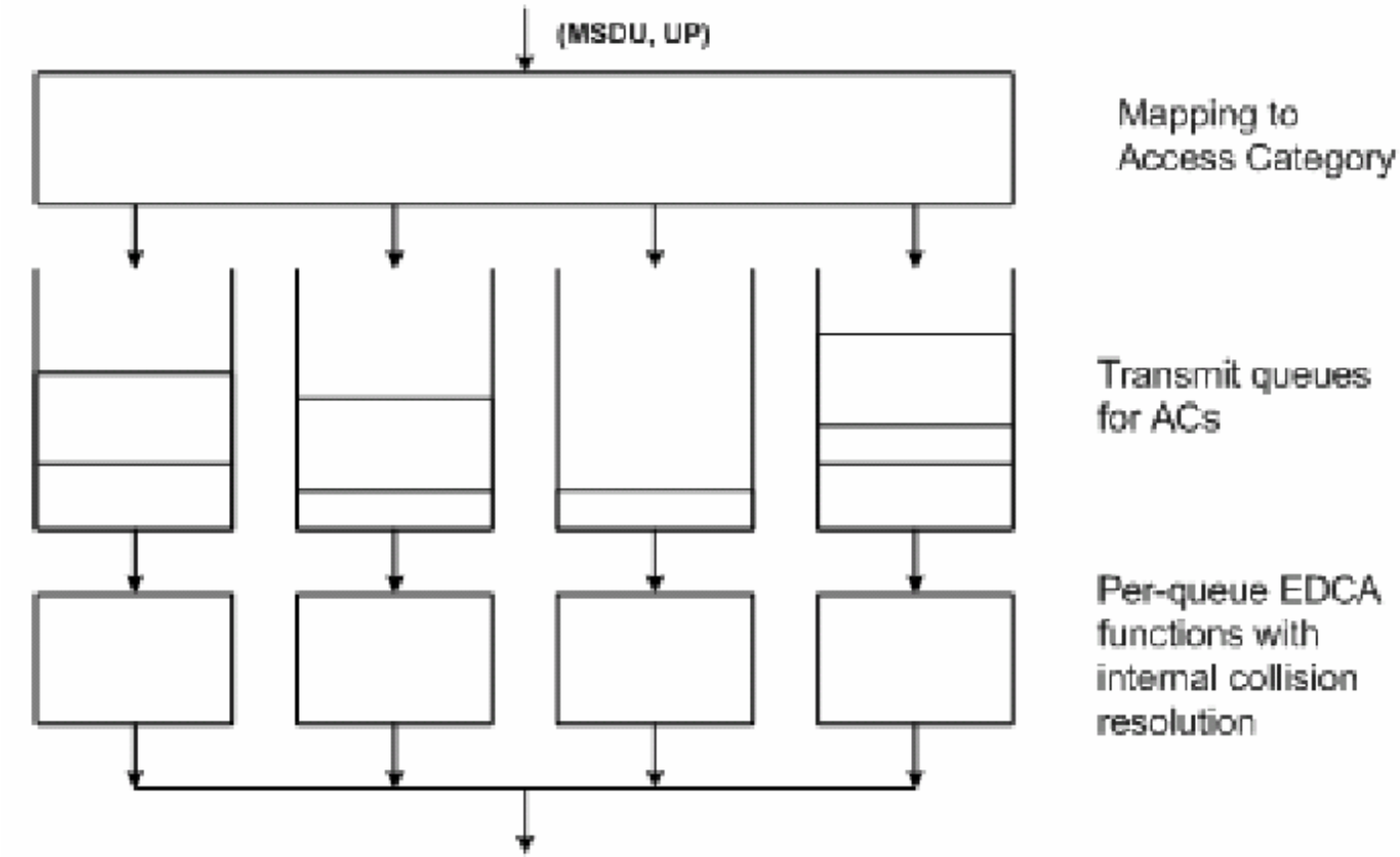




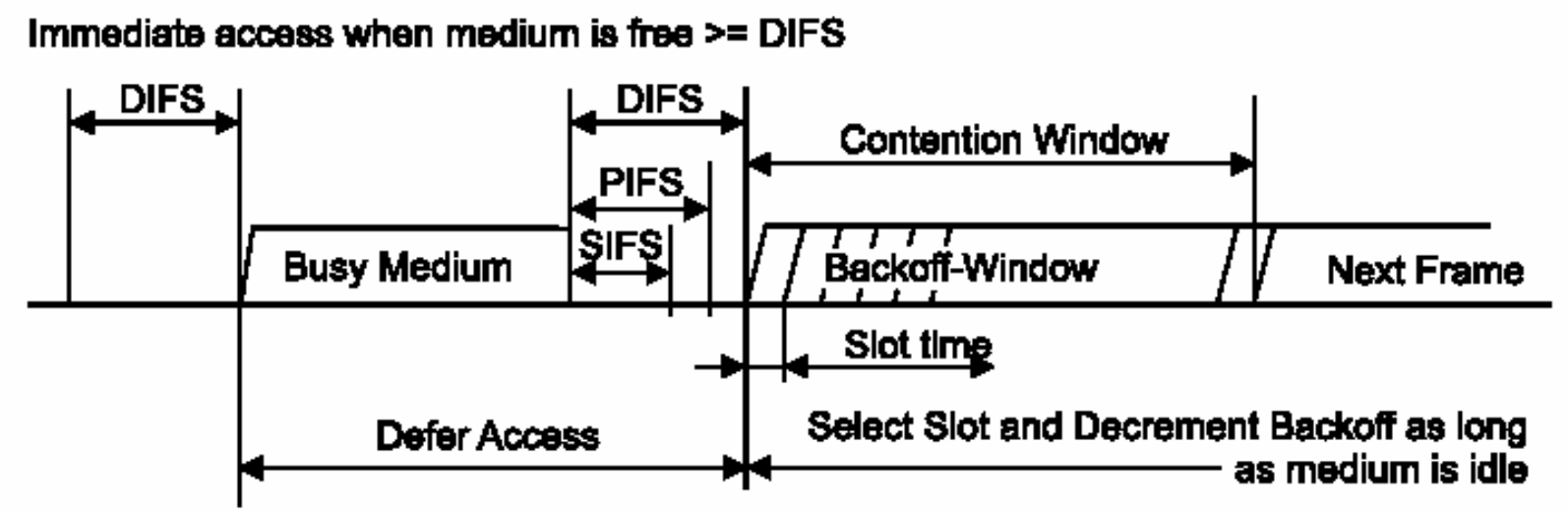
EDCA

- Difference from original DCF
  - Contention between ACs (Not STAs)
  - AC Contends for Transmission Opportunity (TXOP) in unit of 32 microseconds.
  - New Inter-frame Space (IFS) for each AC: Arbitration Interframe Space (AIFS)

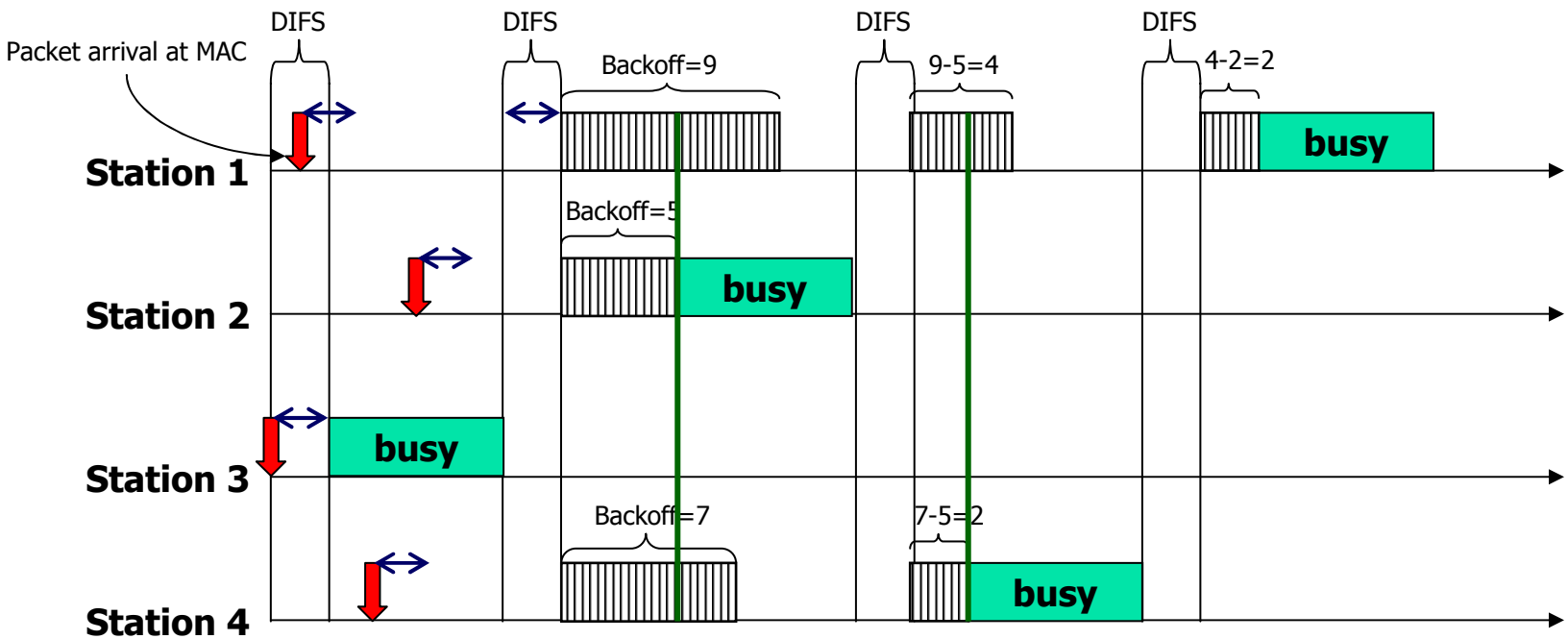
Reference Implementation



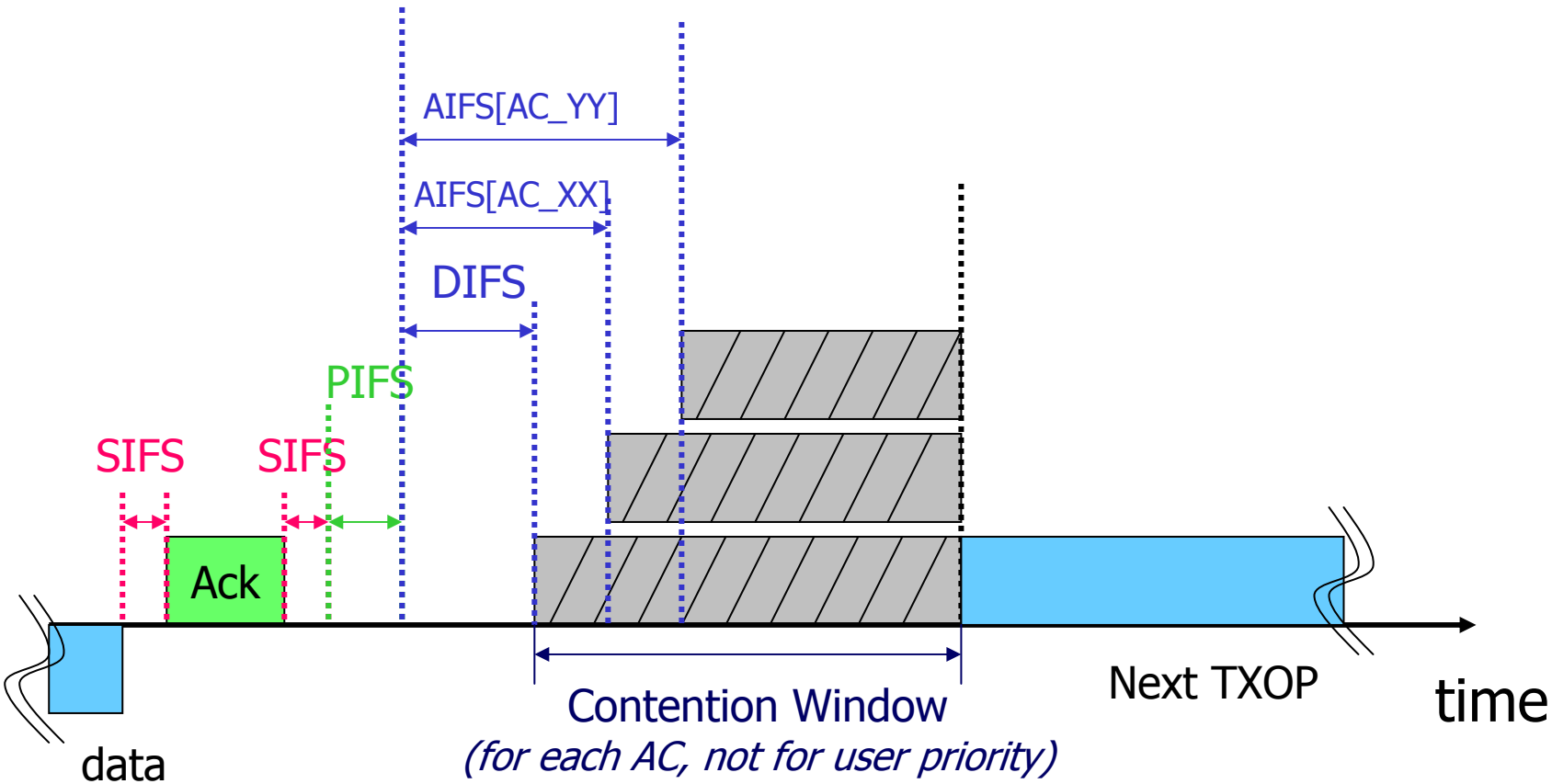
IFS in 802.11 DCF: Contention between STAs



DCF Example


Packet arrival at MAC
DIFS
DIFS
DIFS
DIFS
Backoff=9
9-5=4
4-2=2
busy
Station 1
Backoff=5
busy
Station 2
busy
Station 3
Backoff=7
7-5=2
busy
Station 4

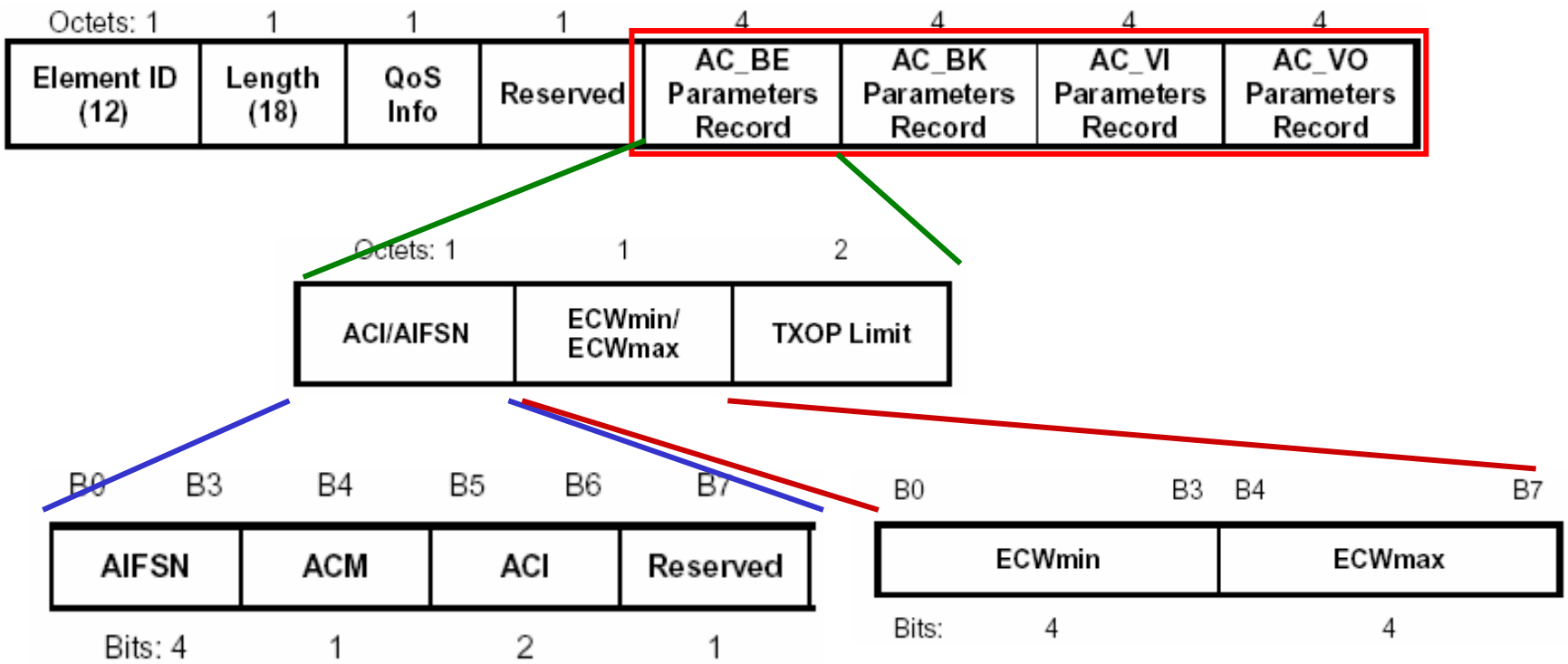
IFS in EDCF: Contention between **ACs**



Arbitration Interframe Space (AIFS)

- QSTA use AIFS to defer the contention window or transmission for each AC
- AIF[AC] = AIFSN[AC] x aSlotTime + aSIFTime
  - *AIFSN* for each AC is broadcast via beacon frame containing 'EDCA Parameter Set' element
- (DIFS = 2 x aSlotTime + aSIFTime)

EDCA Parameter Set Element



ACI: AC Index
ACM: Admission Control Mandatory

$CWmin = 2^{ECWmin} - 1$
$CWmax = 2^{ECWmax} - 1$

Default EDCA Parameter Set

For QSTA

AC	CWmin	CWmax	AIFSN	TXOP Limit		
				DS-CCK[8]	Extended Rate /OFDM[9]	Other PHYs
AC_BK	aCWmin	aCWmax	7	0	0	0
AC_BE	aCWmin	aCWmax	3	0	0	0
AC_VI	(aCWmin+1)/2 – 1	aCWmin	2 1	6.016ms	3.008ms	0
AC_VO	(aCWmin+1)/4 – 1	(aCWmin+1)/2 - 1	2 1	3.264ms	1.504ms	0

CW size is smaller than DCF's

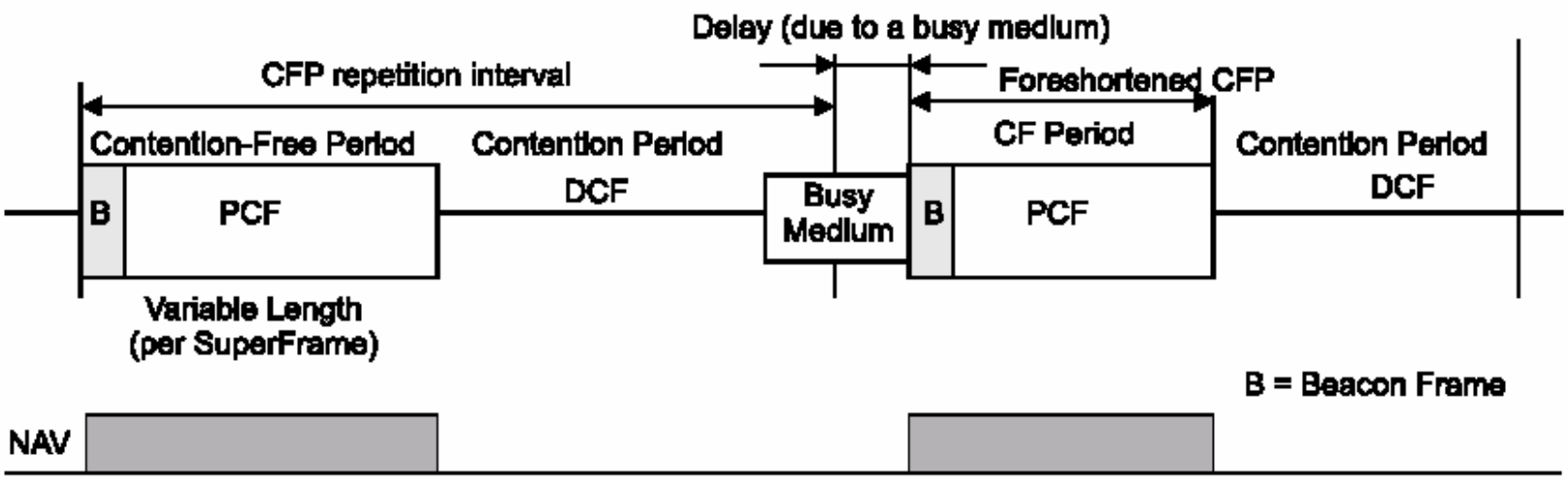
For QSTA: AIFS=DIFS

For QAP: AIFS<DIFS

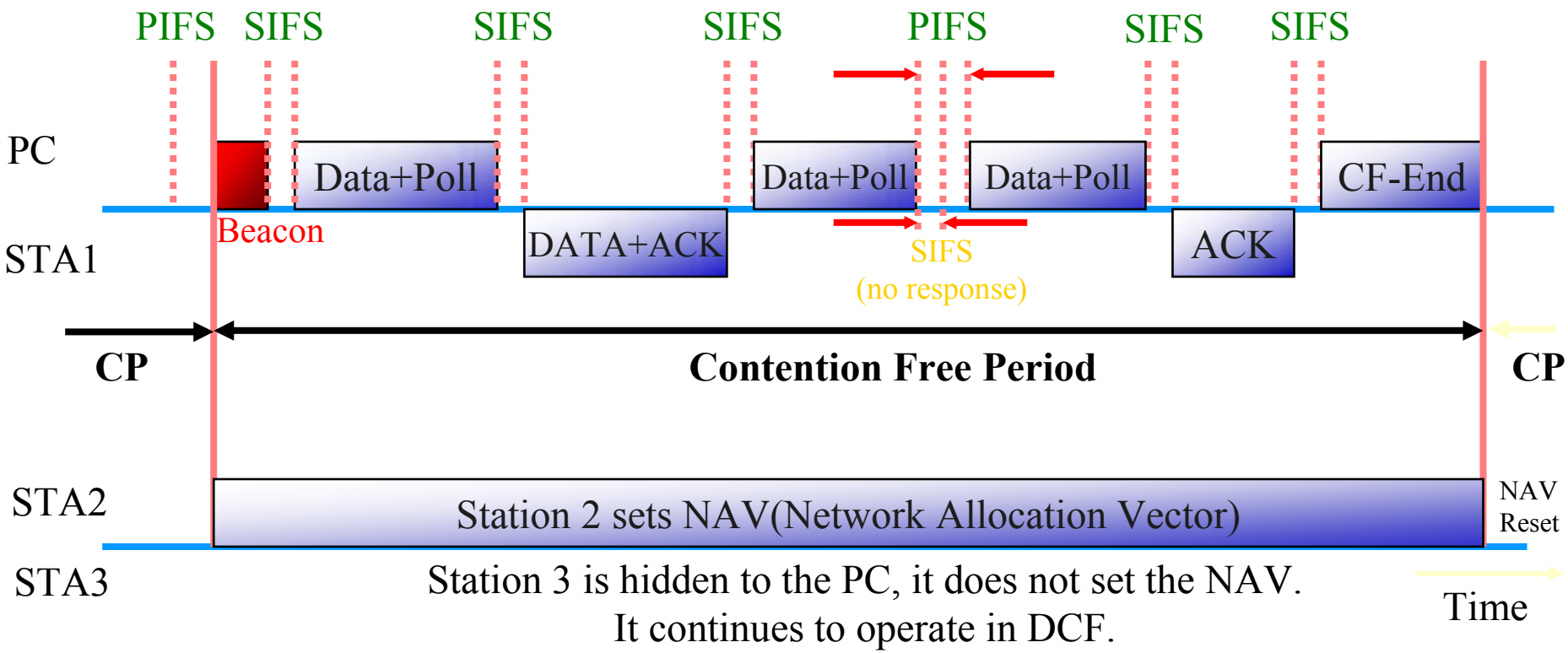
HCF Controlled Channel Access (HCCA)

- The procedure is similar to PCF
- Hybrid Coordinator (HC)
  - Operate at QAP
  - Control the iteration of CFP and CP
    - By using beacon and CF-End frame and NAV Mechanism (Same as PCF)
  - Use polling Scheme to assign TXOP to QSTA
    - Issue Qos (+) CF-poll frame to poll QSTA
    - Polling can be issued in both CFP & CP
    - Polling schedule in HC can be calculated according to TSPECs

Iteration of CFP and CP

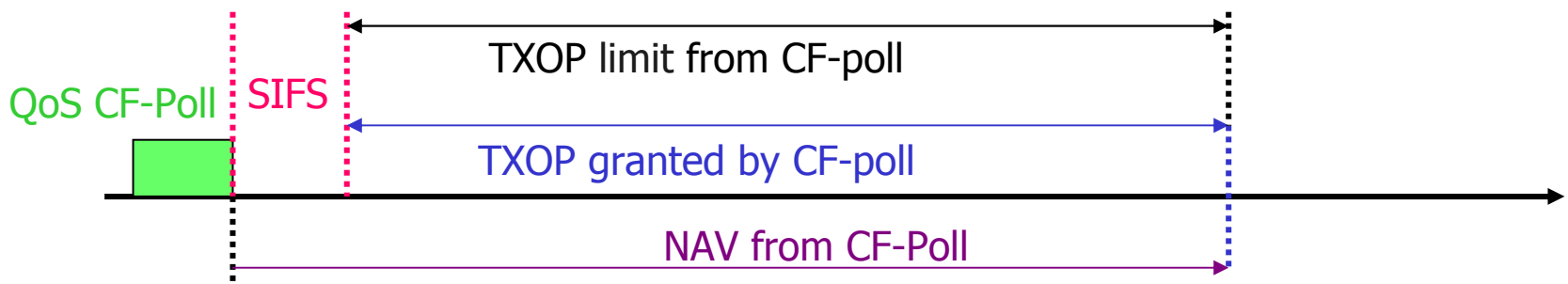


PCF


PIFS
SIFS
SIFS
SIFS
PIFS
SIFS
SIFS
PC
Data+Poll
Data+Poll
Data+Poll
CF-End
Beacon
STA1
DATA+ACK
SIFS
(no response)
ACK
CP
Contention Free Period
CP
STA2
Station 2 sets NAV(Network Allocation Vector)
NAV
Reset
STA3
Station 3 is hidden to the PC, it does not set the NAV.
It continues to operate in DCF.
Time

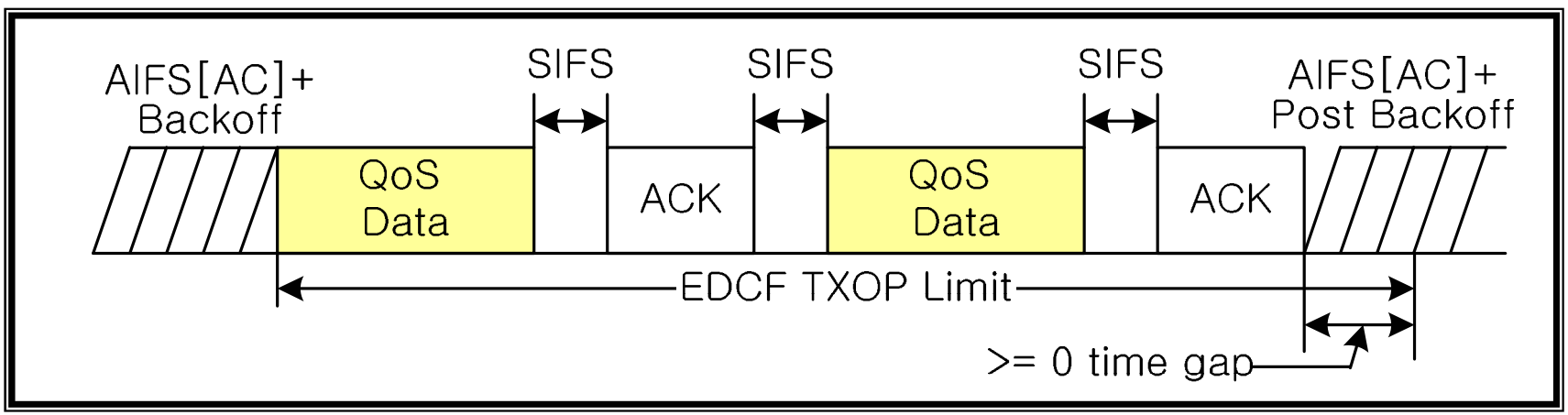
Transmission Opportunity (TXOP)

- TXOP: the duration of a QSTA to transmit frame(s)
- When will a QSTA get a TXOP ?
  - Win a contention in EDCA during CP
  - Receive a QoS (+)CF-poll (→"polled TXOP")



Transmission Opportunity (TXOP) (cont.)

- In TXOP, frames exchange sequences are separated by SIFS

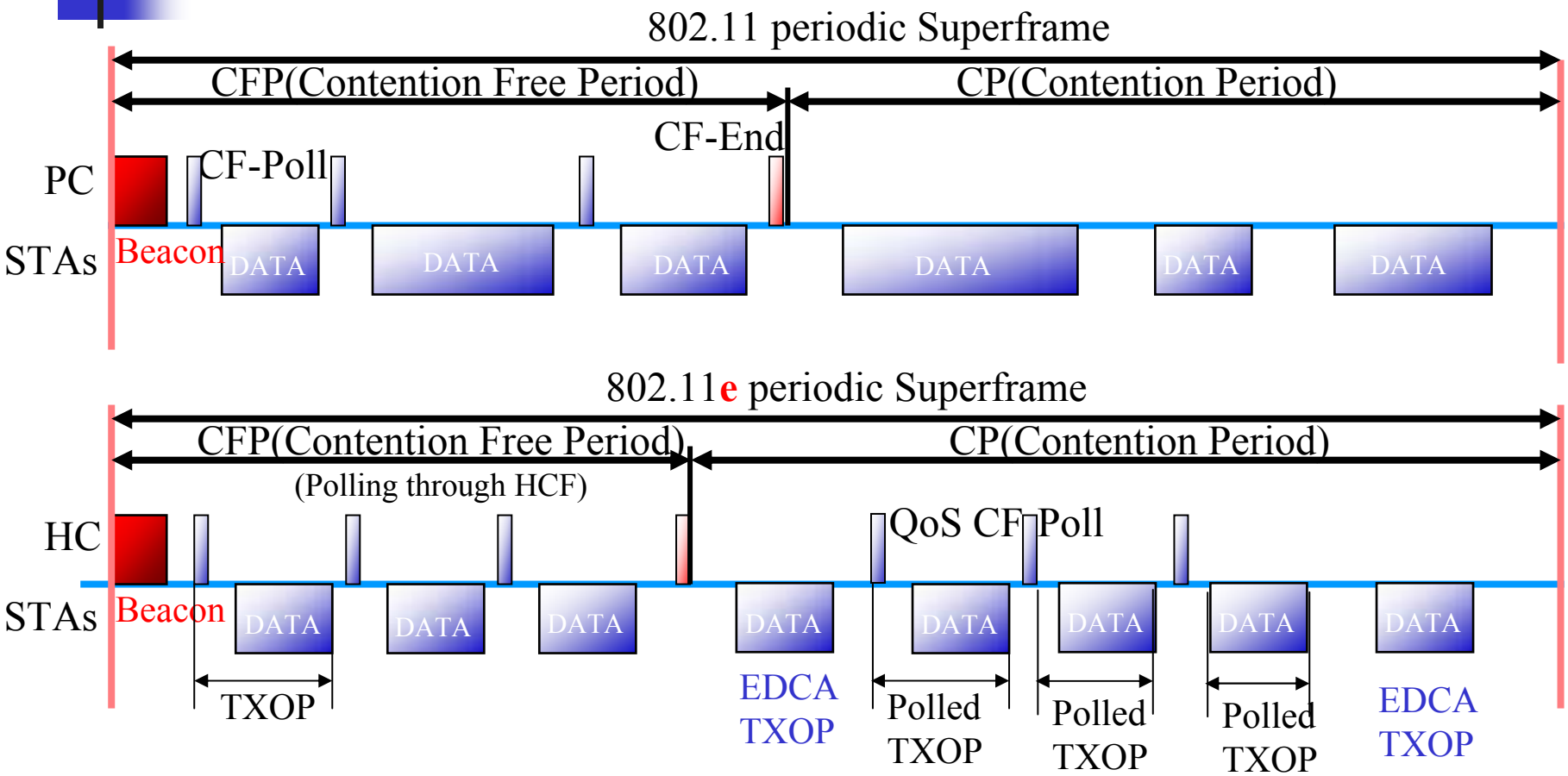


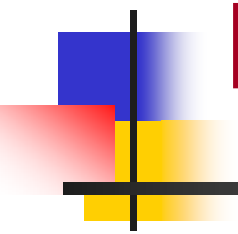
Transmission Opportunity (TXOP) (cont.)

- How is TXOP limit given
  - For EDCA, TXOP limit is given in Beacon Frame (at EDCA Parameter Set Element in frame body)
  - For controlled channel access, TXOP limit is given in "QoS (+)CF-poll" frames (at Qos Control field in MAC header)

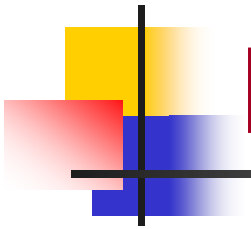
Applicable Frame (sub) Types	Bits 0-3	Bit 4	Bit 5-6	Bit 7	Bits 8-15
QoS (+)CF-Poll frames sent by HC	TID	EOSP	Ack Policy	Reserved	TXOP limit
QoS Data, QoS Null, and QoS Data+CF-Ack frames sent by HC	TID	EOSP	Ack Policy	Reserved	QAP PS Buffer State
QoS data type frames sent by non-AP QSTAs	TID	0	Ack Policy	Reserved	TXOP duration requested
	TID	1	Ack Policy	Reserved	Queue size

Comparison


802.11 periodic Superframe
CFP(Contention Free Period)
CP(Contention Period)
CF-End
PC
CF-Poll
STAs
Beacon
DATA
DATA
DATA
DATA
DATA
DATA
802.11e periodic Superframe
CFP(Contention Free Period)
CP(Contention Period)
(Polling through HCF)
HC
QoS CF-Poll
STAs
Beacon
DATA
DATA
DATA
DATA
DATA
DATA
DATA
DATA
TXOP
EDCA TXOP
Polled TXOP
Polled TXOP
Polled TXOP
EDCA TXOP



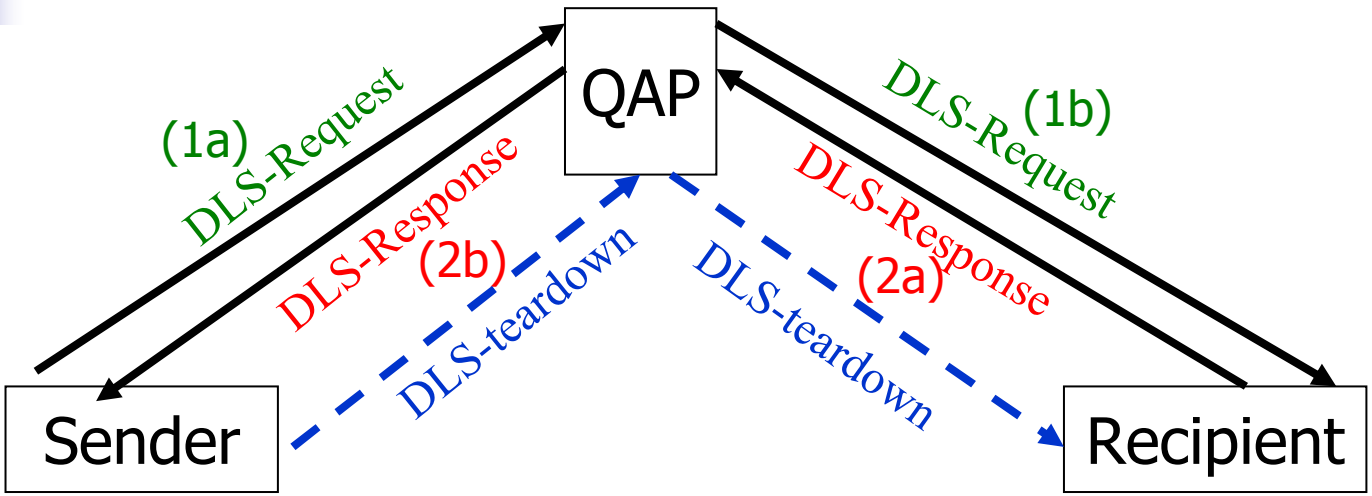
Direct Link Protocol (DLP)



Direct Link Setup (DLS)

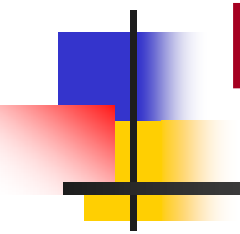
- Direct Link
  - Directly send frames from one QSTA to another in QBSS
- Motivation of DLS
  - Wake up the recipient in PS mode via QAP
  - Exchange information between sender and recipient

The handshake procedure



Notes:

1. DLS Request and DLS Response are both Action management frame
2. The direct link will become inactive if no frames have been exchanged for DLPTimeoutValue duration.
3. Recipient shall not go into power save for DLPTimeoutValue duration.
4. After timeout, the frames are transmitted via AP again.

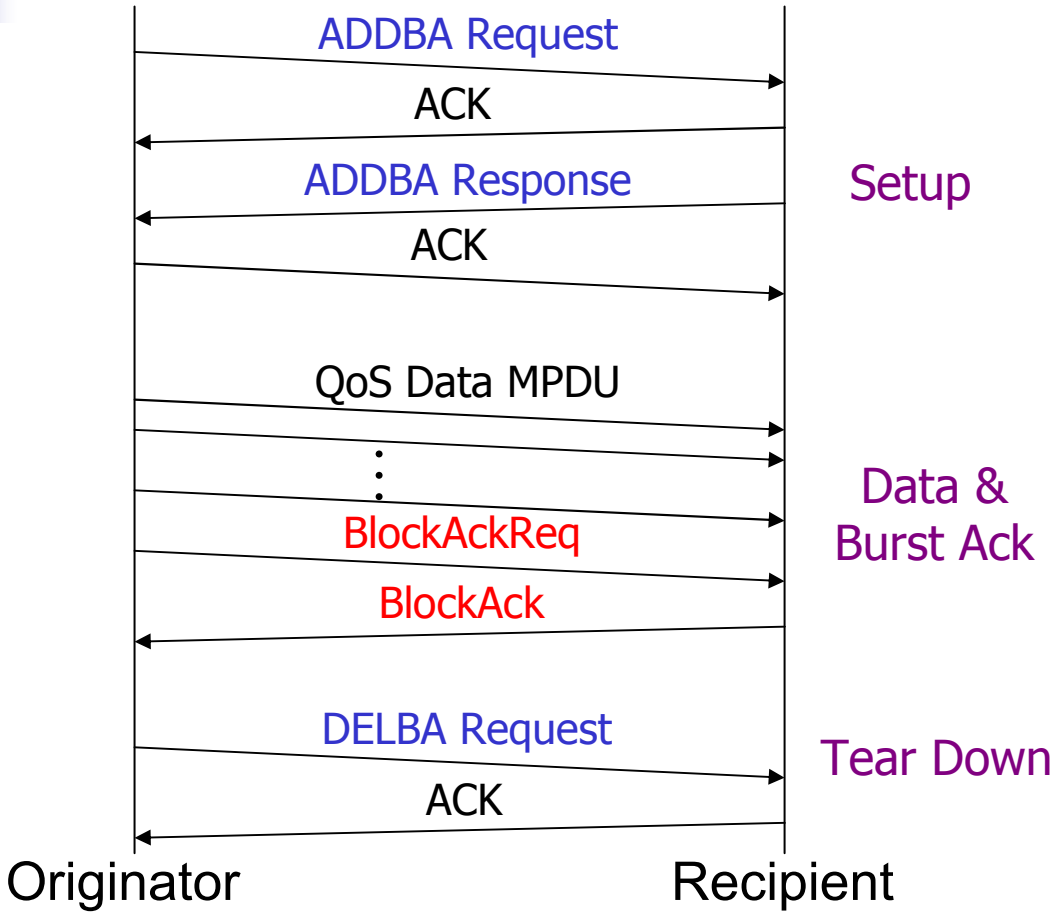


Block Acknowledgement

Brief of Block Ack

- (Optional function in implementation)
- Improve channel efficiency
  - By aggregating several acks into one frame
- Two types
  - Immediate Block Ack
    - Suitable for High-bandwidth, low latency traffic
  - Delayed Block Ack
    - Suitable for applications tolerating moderate latency

Procedure of Block Ack



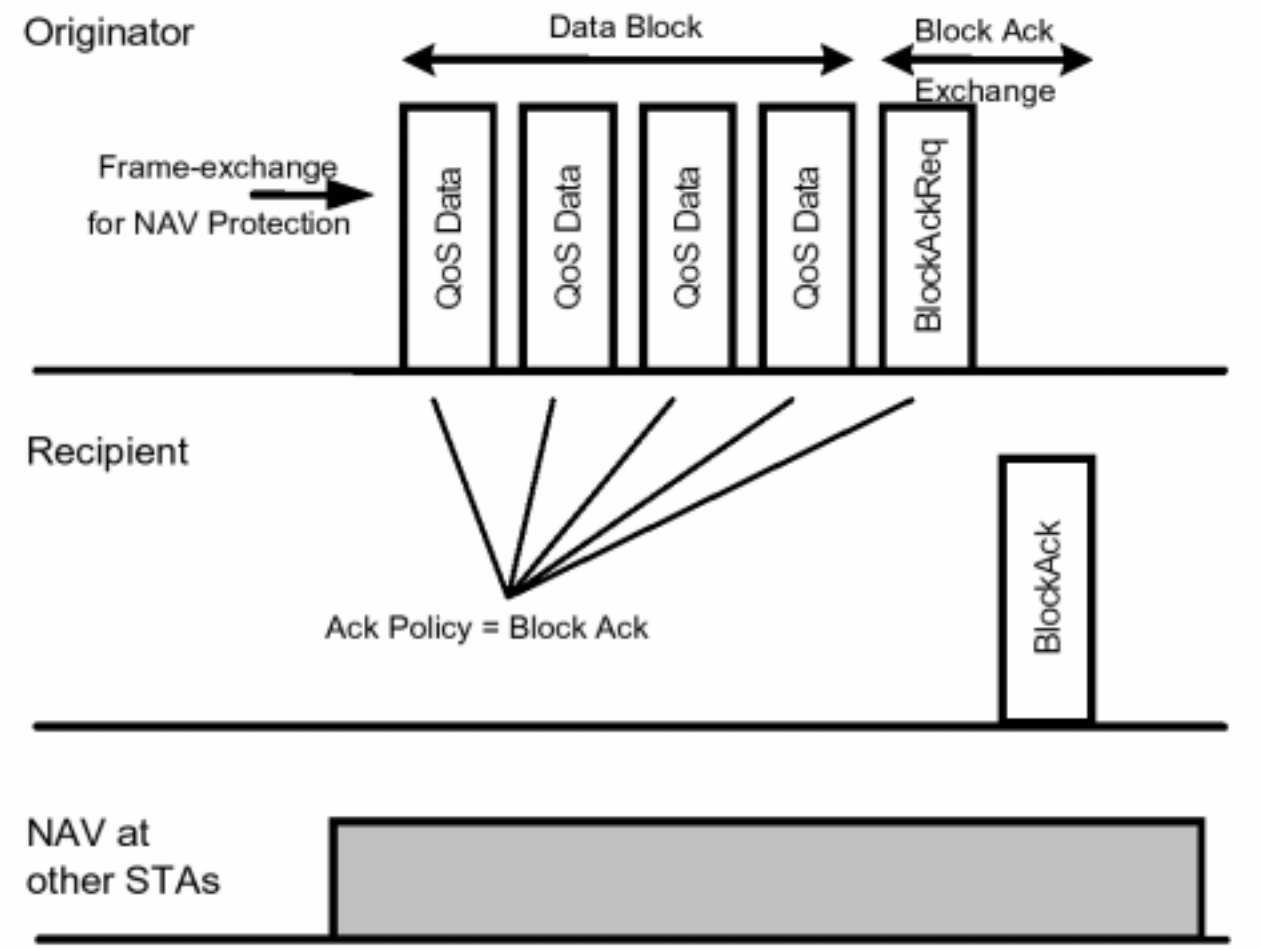
XXX: Action frame

XXX: Control Frame

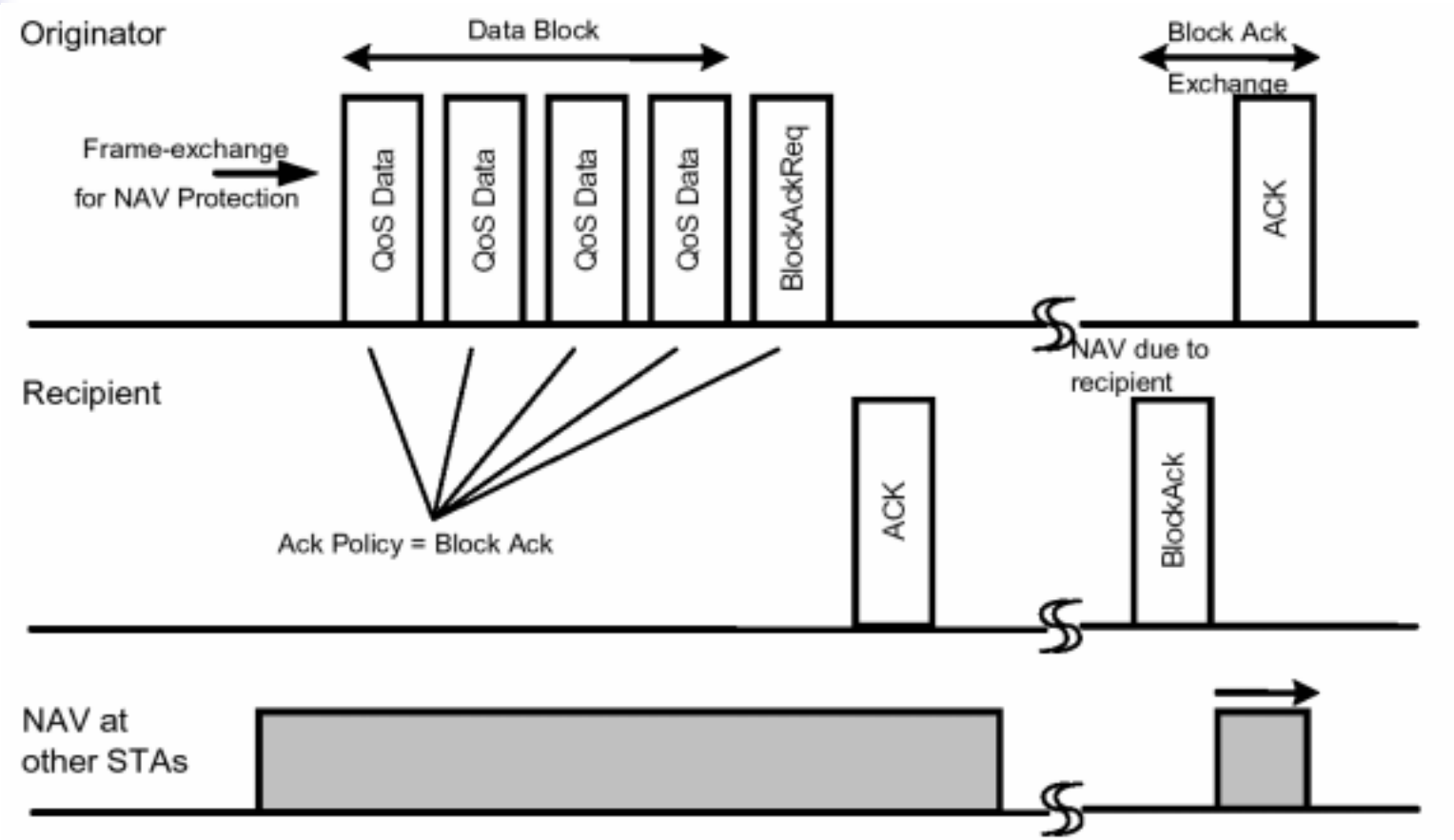
Setup Burst Ack Parameters

- Action Frames (Management frames)
  - *ADDBA Request*, with parameters
    - TID
    - Block Ack Policy (Immediate or delayed)
    - Transmit Buffer Size
    - Timeout Value
  - *ADDBA Response*, with parameters
    - Status Code
    - Burst Ack Policy (1 for Immediate, 0 for Delayed)
    - TID
    - Re-ordering Burst Size (number of buffers)
    - Timeout value
  - DELBA
    - Initiator
    - TID

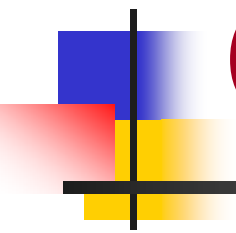
Immediate Block Ack



Delayed Block Ack



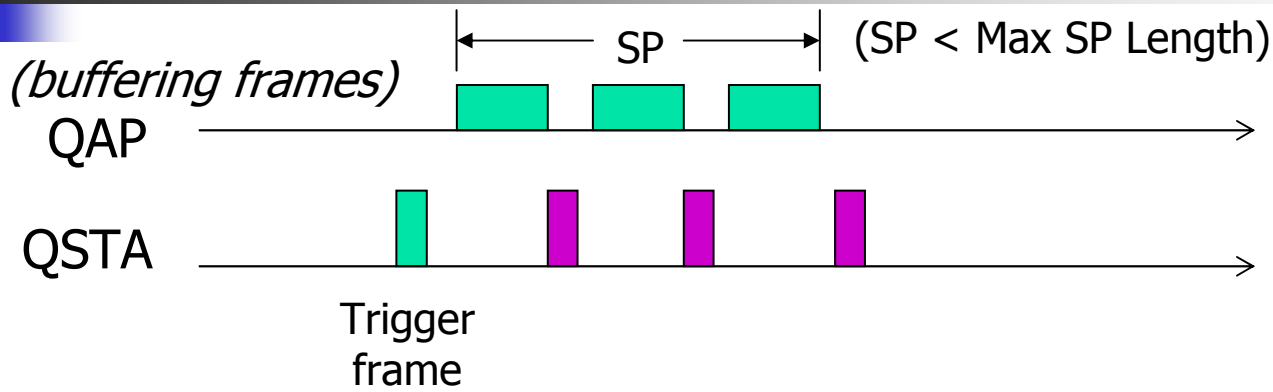
Automatic Power-Save Delivery (APSD)



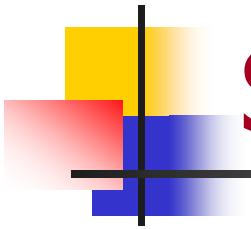
Brief of APSD

- Enhancing PS-mode in QBSS
- QAP deliver downlink frames, which belong to some specified AC, to power-saving stations automatically
- Two type of delivery mechanism
  - Unscheduled APSD (U-APSD)
  - Scheduled APSD (S-APSD)

Unscheduled APSD (U-APSD)



- Steps:
  - Power-saving QSTA wakes up and send a “trigger” data frame belonging to “trigger-enabled” AC to QAP
  - After receiving “trigger” frame, a service period (SP) is started
  - QAP send frames belonging to “delivery-enabled” AC to QSTA
  - The limit of SP is Max SP Length given by the QSTA at association
  - (Frames not in “delivery-enabled” AC are delivered via original PS-poll mechanism)



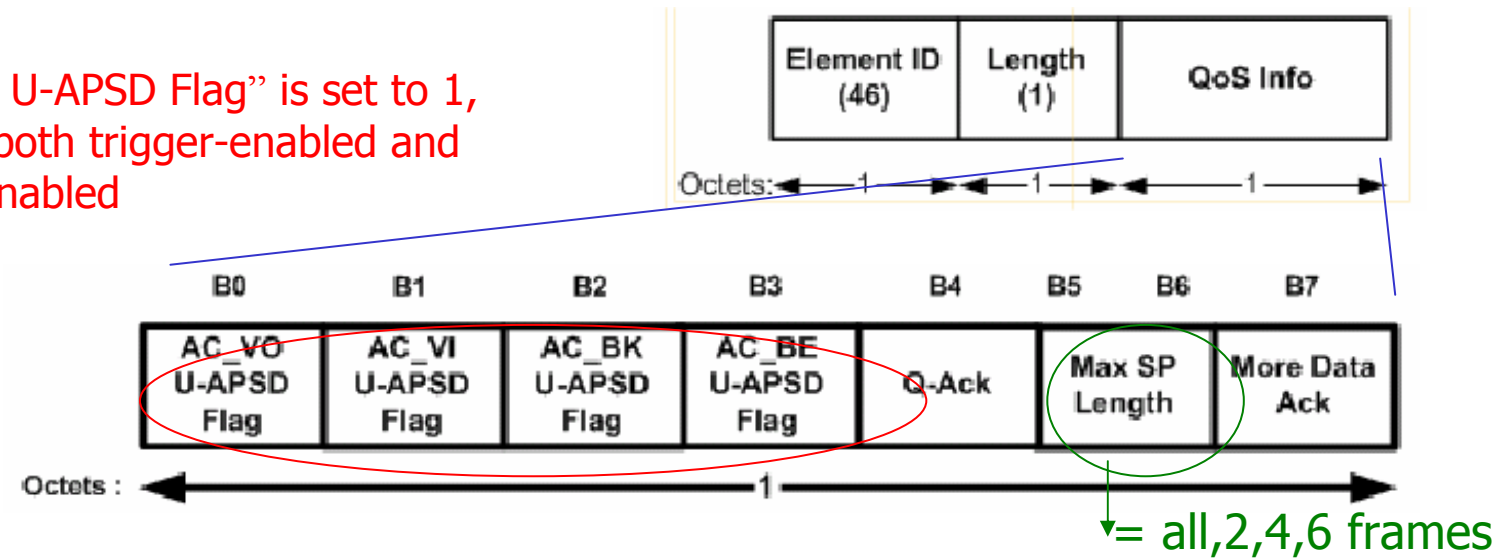
Scheduled APSD (S-APSD)

- QSTA negotiate a APSD Schedule with QAP via ADDTS
- QAP start transmitting the frames of the specified TS at Service Start Time and the following periods
- QSTA must wake up at Service Start Time and the following periods to receive frames

Specifying Trigger-Enabled / Delivery-Enabled AC

- QSTA Specifying
- By Association
  - Association Frame contains "QoS Capability" element

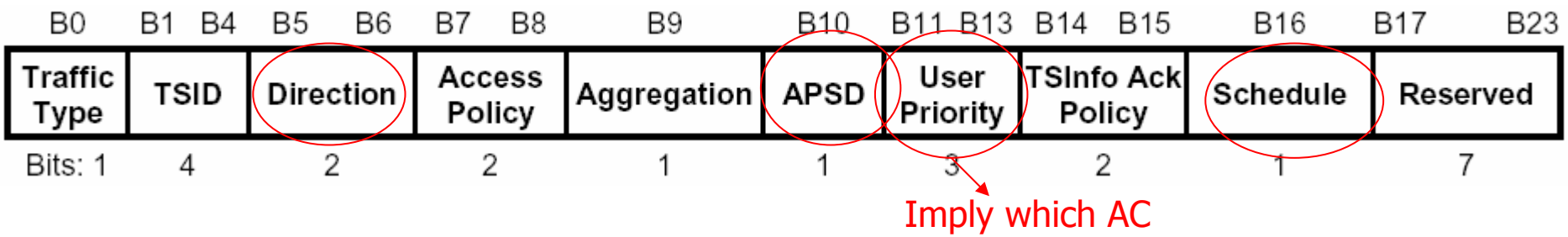
If "AC_XX U-APSD Flag" is set to 1, AC_XX is both trigger-enabled and delivery-enabled



Specifying Trigger-Enabled / Delivery-Enabled AC (cont.)

- By ADDTS (TSPEC)

TS Info:

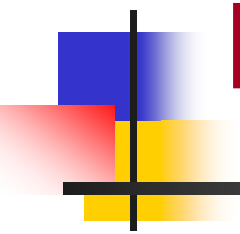


APSD = 1, Schedule = 0, Direction = uplink ➔ the implied AC is "trigger-enable"

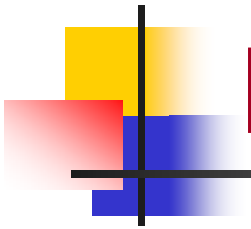
APSD = 1, Schedule = 0, Direction = downlink ➔ the implied AC is "delivery-enable"

Implementation-Dependent Issues

- HC scheduling
  - Mixture of downlink and polled TXOP scheduling
- QSTA scheduling
  - During a polled TXOP, schedule frame transmissions
- Admission control by HC
  - To decide whether to admit a TS or not

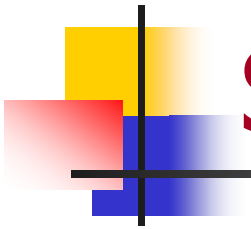


Performance Evaluation



Brief

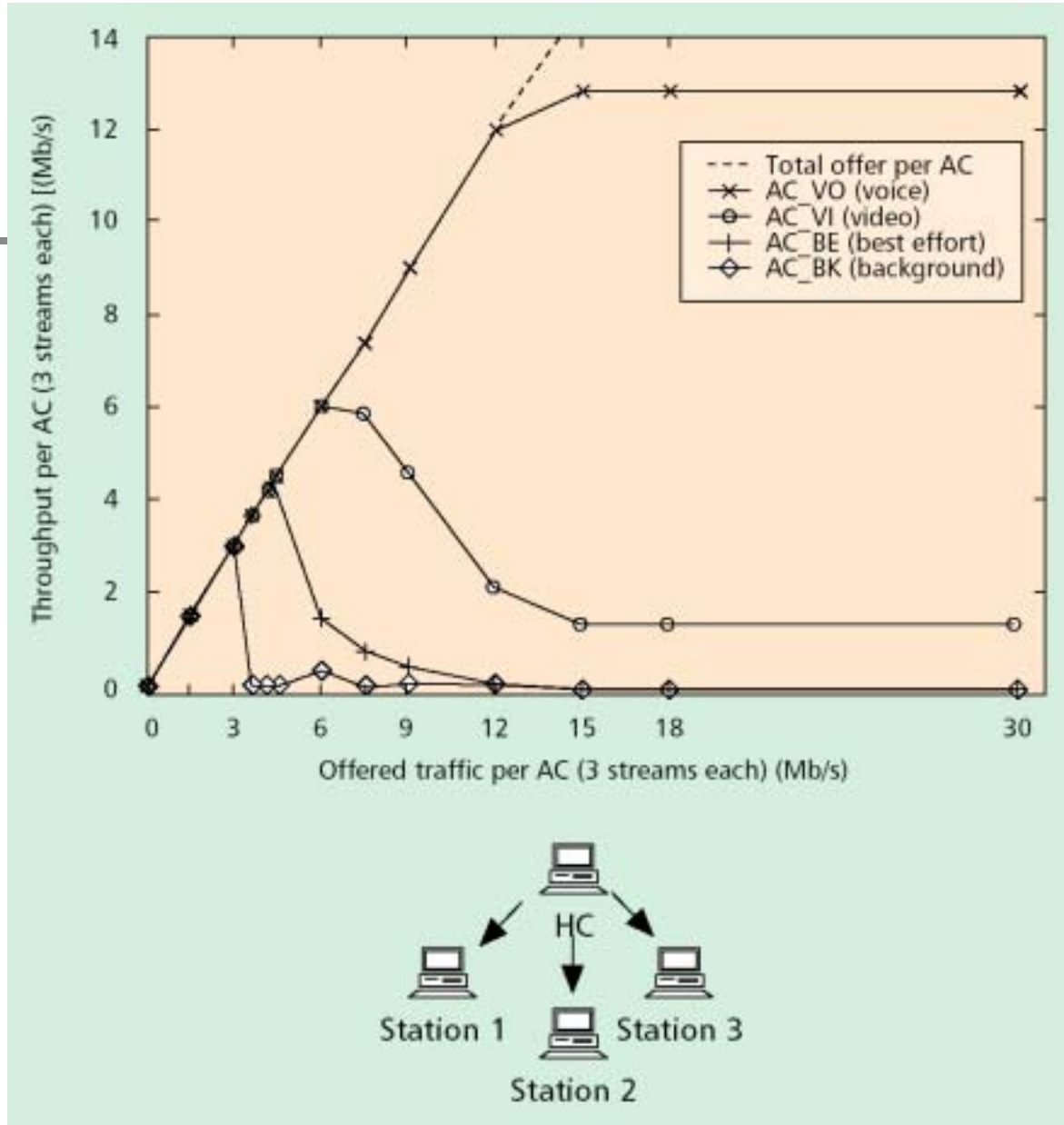
- Source:
  - *Stefan Mangold, et al.*, “Analysis of IEEE 802.11e for QoS support in wireless LANs
  - ,” *IEEE Wireless Communications, Dec. 2003.*
- Evaluations (802.11e w/ 802.11a PHY)
  - Achievable EDCA throughput
  - QoS Guarantees with Prioritized Access of HC



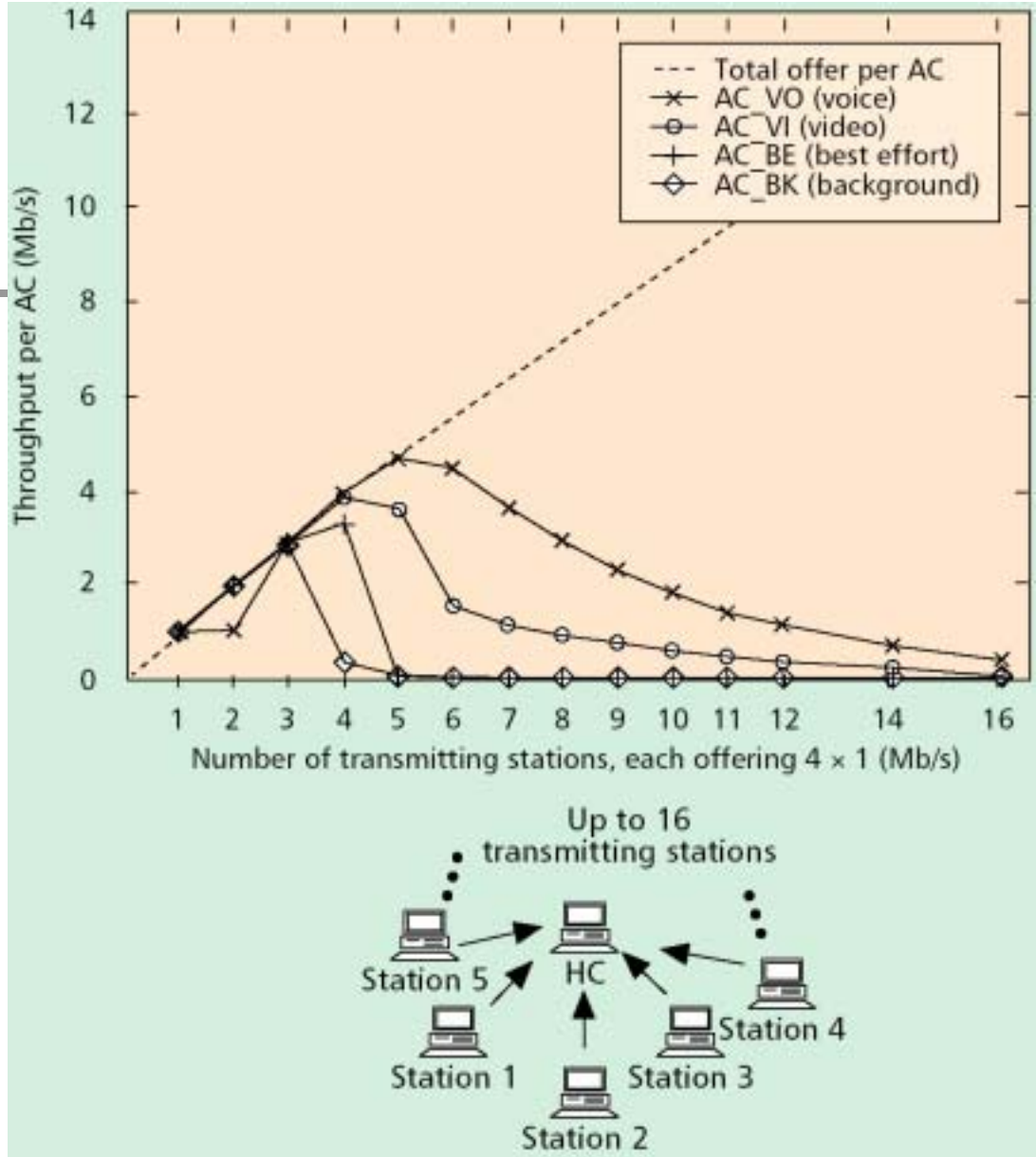
Scenario 1

- Assumption
  - IEEE 802.11e MAC + IEEE 802.11a PHY
  - Control frames are sent at 6 Mbps
  - Data frames are sent at 24 Mbps
  - Each stream 250 kbps
  - 1 station (HC) transmits to 3 stations one stream per AC
  - Default EDCA parameters are used

Result 1


Throughput per AC (3 streams each) [(Mb/s)
Offered traffic per AC (3 streams each) (Mb/s)
0
2
4
6
8
10
12
14
0
3
6
9
12
15
18
30
Total offer per AC
AC_VO (voice)
AC_VI (video)
AC_BE (best effort)
AC_BK (background)
HC
Station 1
Station 3
Station 2

Result 2


Total offer per AC
AC_VO (voice)
AC_VI (video)
AC_BE (best effort)
AC_BK (background)
Throughput per AC (Mb/s)
0
2
4
6
8
10
12
14
1
2
3
4
5
6
7
8
9
10
11
12
14
16
Number of transmitting stations, each offering 4 × 1 (Mb/s)
Up to 16
transmitting stations
Station 5
HC
Station 4
Station 1
Station 3
Station 2

Scenario 2

- Two scenarios
- Transmission Rate
  - Data Frame: 24 Mbit/s
  - Others: 6 Mbit/s
- Three TCs
  - High: constant arrival (5ms), MSDU 80 bytes, 128 kbps
  - Medium & low: Poisson arrival, MSDU 200 bytes, 160 kbps
- TXOP allows for transmitting one data frame
- Beacon interval: 102.4 ms

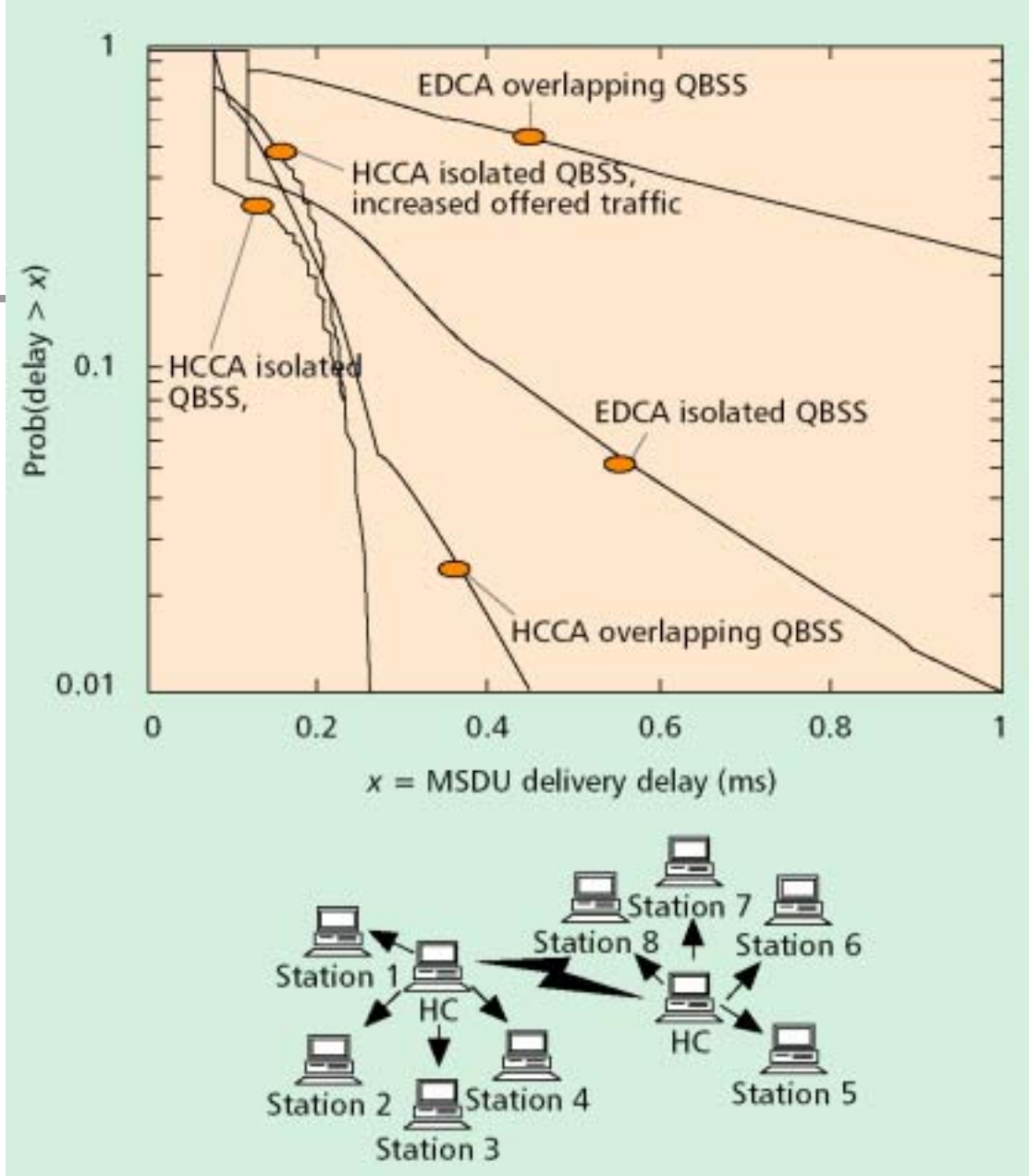
Fig. 7: Scenario with two QBSSs.

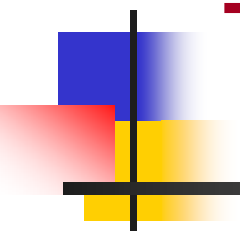
Table 1: Used EDCF parameters for the three TCs.

	High	Medium	Low
AIFS*	*2*	*4*	*7*
CWmin	*7*	*10*	*15*
CWmax	*7*	*31*	*255*
PF	*2*	*2*	*2*

*) When AIFS is represented by a number instead of time, the actual AIFS in time is determined by SIFS (which is *16 us* in 802.11a) + AIFS (in number) * slot_time (which is *9 us* in 802.11a).

Result 3


1
0.1
0.01
Prob(delay > x)
EDCA overlapping QBSS
HCCA isolated QBSS, increased offered traffic
HCCA isolated QBSS,
EDCA isolated QBSS
HCCA overlapping QBSS
0
0.2
0.4
0.6
0.8
1
x = MSDU delivery delay (ms)
Station 1
HC
Station 2
Station 3
Station 4
Station 7
Station 8
Station 6
HC
Station 5



Thank You!

Q & A