802.11 QoS Tutorial

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Abstract

The channel access schemes for 802.11 are outlined and the two QoS schemes, introduce in 802.11e, described in more detail.

The major differences between the QoS schemes are discussed

Acronyms

- **AC** 802.11 Access Category
- **CP** Contention Period
- **CFP** Contention Free Period)
- **CSMA/CA** Carrier Sense Multiple Access with Collision Avoidance
- **CW** Contention Window
- **DCF** Distributed Coordination Function
- **EDCA** Enhanced DCF Channel Access
- **HC** Hybrid Controller
- **HCCA** Hybrid Coordination Function Channel Access
- **IFS** Inter-frame Spacing
- **PCF** Point Coordination Function
- **(Q)AP** (QoS) Access Point
- **STA** 802.11 non-AP Station
- **TXOP** Transmit Opportunity
- **WMM** Wi-Fi Multi Media (Wi-Fi Alliance version of EDCA)
- **WMM-SA*** Wi-Fi Multi Media Scheduled Access

***Name for Wi-Fi Alliance version of HCCA**

802.11 Protocols

- **Originally IEEE 802.11 standard defined exchanges using:**
  - DCF (Distributed Coordination Function)
  - PCF (Point Coordination Function)

- **IEEE 802.11e introduced:**
  - ***PRIORITY SCHEME***
    EDCA Enhanced DCF Channel Access
    (WMM* Wi-Fi Multi Media)

  - ***PARAMETIZED QOS SCHEME***
    HCCA Hybrid Coordination Function Channel Access
    (WMM-SA* Wi-Fi Multi Media Scheduled Access)

**Note: Due to pressure to have QoS, Wi-Fi Alliance introduced WMM Specification before 11e was ratified (in 2003 when 802.11e was at Draft 3.0) - WMM (including WMM Power Save) Specification*

WMM-SA Specification was also introduced later but never became a certification

DCF

- **DCF is fundamental access method**
- **IFS – Inter-frame Spacing**
  - SIFS< PIFS < DIFS < EIFS
  - 11n has introduced RIFS which is the smallest Inter-Frame spacing
- **CSMA/CA (Carrier Sense Multiple Access with Collision Avoidance**
  - Look for activity, if free, wait (DIFS) and transmit if still free
  - If medium busy, random back-off a number of Slots (min 15, max 1023)
  - Count down Slots as long as Medium is not busy
  - When count down is zero, if packet fails (e.g. collision), back-off with increased random window, up to a preconfigured upper limit

PCF

- **PCF is a priority that is centrally controlled**
  - PC (Point Coordinator), usually also the AP (Access Point)
- **CP (Contention Period) and CFP (Contention Free Period)**
  - After each Beacon
  - Uses PIFS to keep control (shorter than any DCF)
  - PC keeps list of stations eligible for polling

- **PCF drawbacks:**
  - Fixed to length of time after a Beacon, synchronized to Beacon intervals
    - Not compatible with voice or video streams requiring, say, 10, 20 or 30ms intervals
  - No mechanism to reserve BW or characterize the traffic
  - No back-to-back packets
  - Case of overlapping PCs is not meaningfully addressed
  - *Note: PCF is not used in practice*

EDCA – Priority Scheme

EDCA is effectively DCF with 4 priorities.

User Priority 802.1D	Access Class	Designation
1 & 2	AC0	Background
0 & 3	AC1	Best Effort
4 & 5	AC2	Video
6 & 7	AC3	Voice

Highest Priority

Bursting is possible: AC2 (AC_VI) TXOP limit 3ms

AC3 (AC_VO) TXOP limit 1.5ms

By setting different min and max back-off slots, one stream has an advantage over another. These max & min back-offs are configurable through the management interface, but choosing the optimum values for every scenario is not obvious

EDCA Channel Access

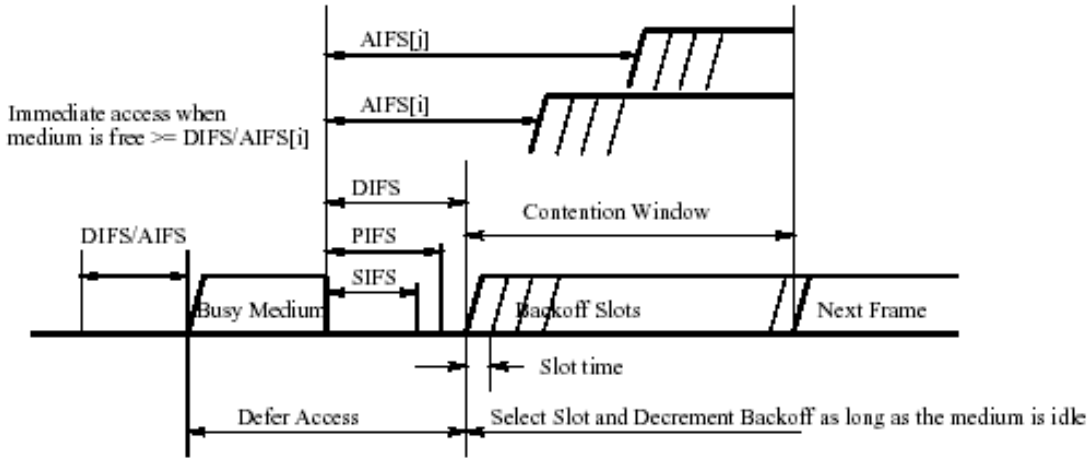


Fig. 1. IFS relationships and EDCA channel access

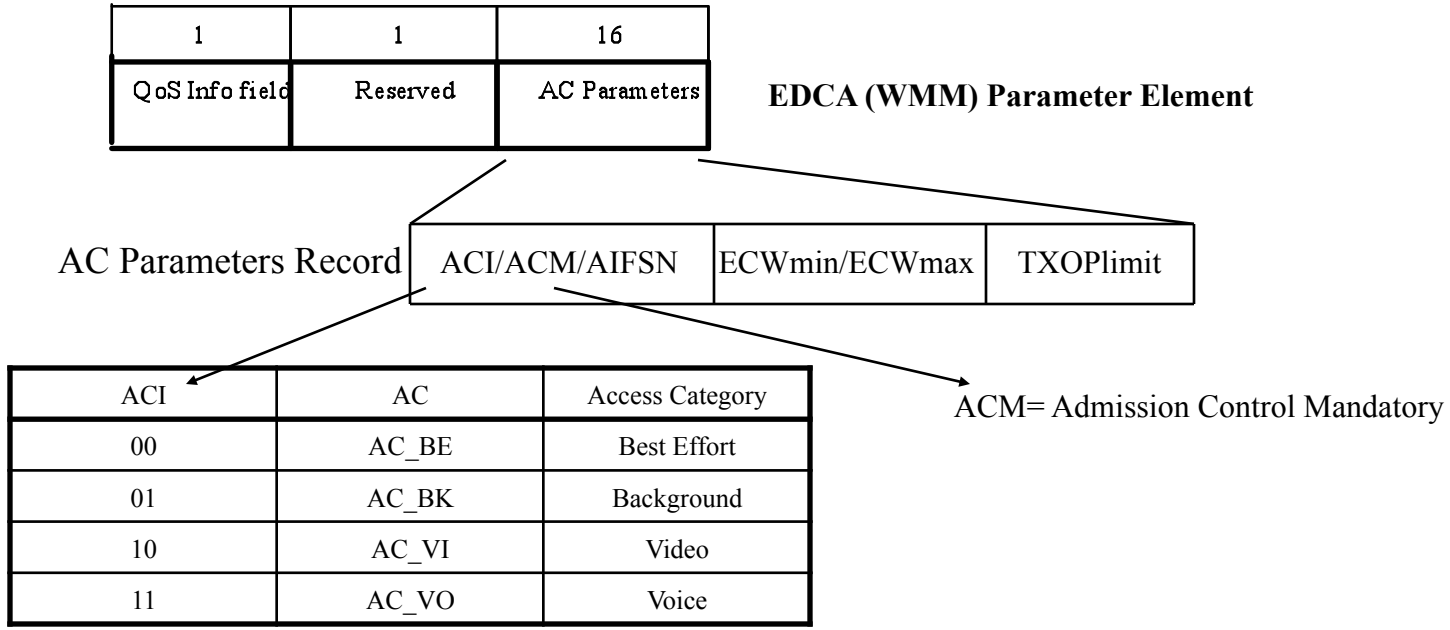
Default Parameter Set

	CWmin		CWmax		AIFSN
	OFDM	CCK	OFDM	CCK	
AC_BK	15	31	1023		7
AC_BE	15	31	1023		3
AC_VI	7	15	15	31	2 or 1 (AP)
AC_VO	3	7	7	15	2 or 1 (AP)

Slot Time = 9µs

SIFS Time = 16µs, .11a
= 10µs, .11g

EDCA (WMM) Parameter Element

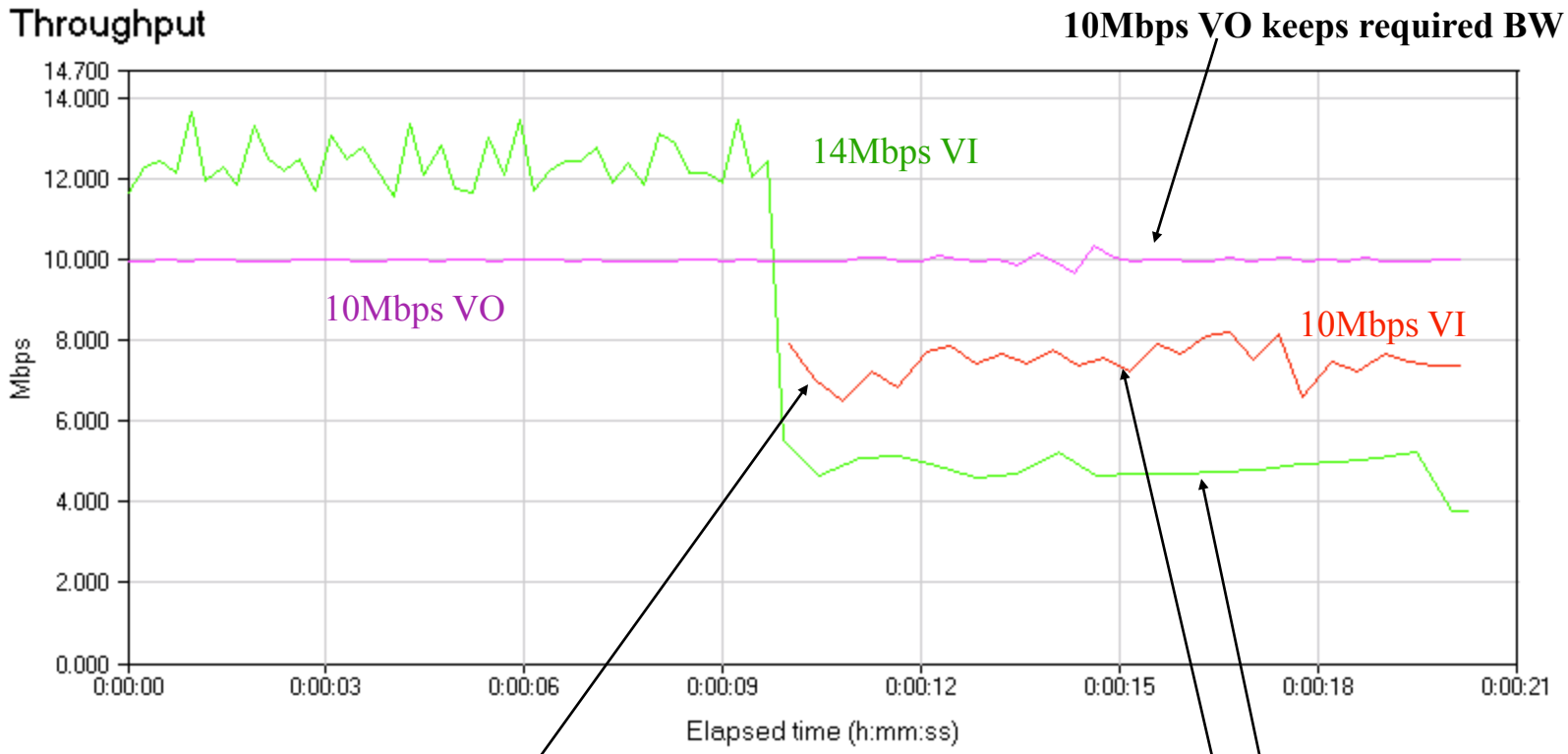


ACI	AC	Access Category
00	AC_BE	Best Effort
01	AC_BK	Background
10	AC_VI	Video
11	AC_VO	Voice

AP sets the EDCA (WMM) parameters for each AC and indicates if Admission Control is required

Advantage is that this allows 'tuning' of the parameters for any specific network/application
Disadvantage is that if OBSS situation, sharing may not be predictable

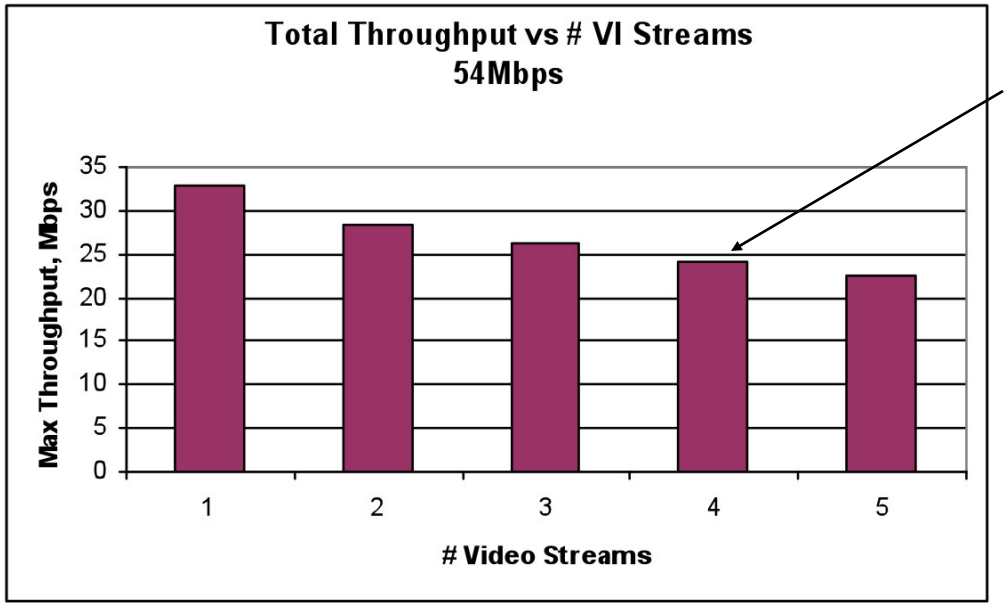
EDCA/WMM Test Example



EDCA Video
Total Throughput drops with # streams

As number of video streams increases, the contention also increases.
In order to keep latency low the total throughput of the Channel is decreased.

Maximum throughput on channel as number of video streams increases.



Four 6Mbps streams is simulated maximum for a 54Mbps channel
In practice it will be lower than this

EDCA

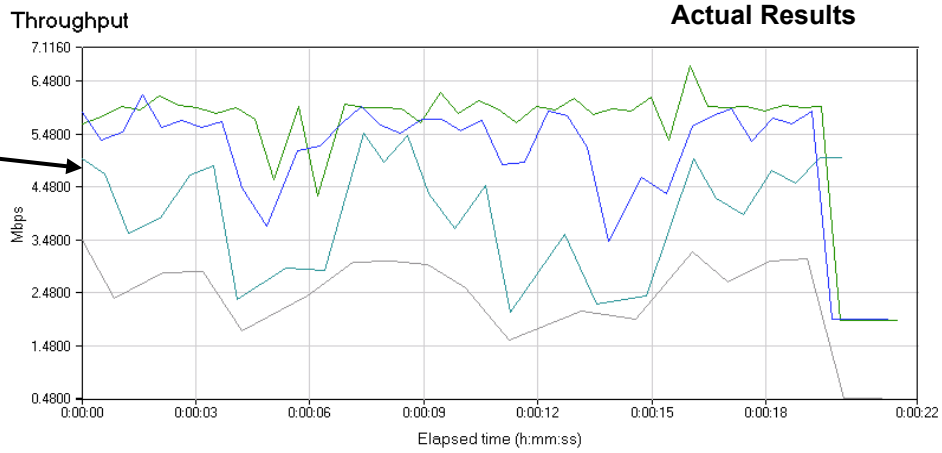
- **Advantages of EDCA**
  - Voice and Video streams have priority over data
  - Works well if network is lightly loaded, such as a Voice based network
  - No stream set-up instructions required
  - Still based on "Fairness", lower priority can still get through
  - EDCA Power Save is big advantage over legacy power save; (not described here)

  BUT
  - Streams of the same Priority compete; not able to guarantee access, BW, Latency, or Jitter
  - Variations in QoS performance do occur in practice due to product hardware and software variations,
  - Also EDCA relies on every individual STA and the AP to control the priorities and access to the medium

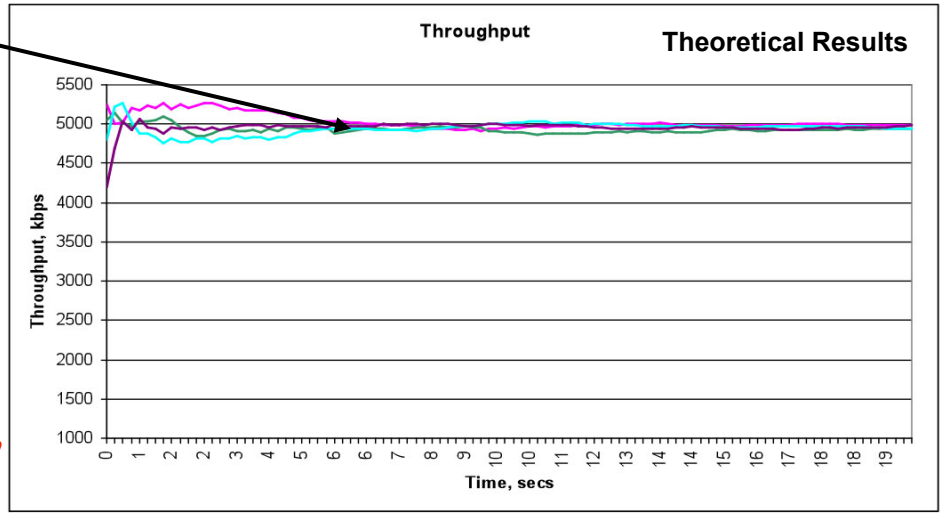
Admission Control is used to overcome some of these disadvantages

EDCA – Over subscribed

- **Four 6Mbps streams, EDCA AC_VI at 36Mbps**
- *Oversubscribed*
- *Small variations in STAs result in throughputs that are not equal*



- **Theoretical results show about 5Mbps for each STA (total ~20Mbps)**
- ***Still over-subscribed***



PROBLEMS IF CHANNEL IS OVER SUBSCRIBED SOLUTION - ADMISSION CONTROL!!

[1] STAs A and B were not set for bursting.

Admission Control

- **EDCA/WMM has no guarantees for QoS, but Admission Control can be used to improve situation:**
- **Limit admission to an Access Category (VO and VI)**
  - Limits the latency of QoS streams
  - Prevents too many streams such that bandwidth cannot handle them

- **Generally suffers from OBSS problem in that APs may allocate independent of each other**
  - Centrally Managed Enterprise Networks can manage OBSS
  - "Home" Networks do have this problem
  - 802.11aa intends to solve this problem

Admission Control

- **AP advertises ACM bit in Beacon to indicate if admission control is mandatory for any Access Category**
- **To use AC that has ACM bit set, STA sends ADDTS Request Action Frame to AP that includes a TSPEC**
  Required parameters for Admission Control:
  - *Nominal MSDU size*
  - *Mean Data Rate*
  - *Min PHY Rate*
  - *Surplus Bandwidth Allowance (SBA)*
- **AP runs the admission control algorithm and communicates back to the station the admission decision using ADDTS Response Action frame**
  - Medium Time (>0 if TSPEC Admitted)
- **STA checks "Used Time" over a preset period (WMM specifies 1sec)**
  - If Used Time > Medium Time, STA must cease using that AC's EDCA parameters (may use an AC that does not have ACM bit set)

TSPEC Element

TSPEC Body format

Octets: 3	2	2	4	4	4	4	4	4
TS Info	Nominal MSDU	Maximum MSDU Size	Minimum Service Interval	Maximum Service Interval	Inactivity Interval	Suspension Interval	Service StartTime	Minimum Data Rate

4	4	4	4	4	2	2
Mean Data Rate	Peak Data Rate	Maximum Burst Size	Delay Bound	Minimum PHY Rate	Surplus Bandwidth Allowance	Medium Time

RED indicates required parameters used in Admission Control TSPEC

Value returned by AP if Admission Accepted (Admission Control)

TS Info Field TSPEC Element

23 17	16	15 14	13 11	10	9	8	7	6 5	4 1	0
Reserved	Reserved (Schedule)	Reserved (TSInfo Ack Policy)	User Priority	PSB	Aggregation	0	1	Direction	TID	Reserved

801.D User Priority

1=APSD

Access Policy EDCA, HCCA

Up
Down
Bi

0-7 WMM
8-15 HCCA

Note: Often TID 0-7 = UP

Admission Control

- **Improvement on EDCA/WMM in attempt to contain the higher priority streams and offer protection to streams already in progress**
- **TSPEC requires inputting of the basic parameters of the QoS stream**
  - STA sends the TSPEC
- **Suffers from OBSS problem in that APs will allocate independent of each other**
  - This is being solved as part of 802.11aa
- **As streams still contend, bandwidth efficiency is not optimum**

HCCA (WMM-SA)
Parametized QoS

HCCA is extension of PCF, uses Contention Free Periods (CFP)

- **Hybrid Coordinator (HC) can initiate HCCA, CFP:**
  - Provides CF-Poll to station to provide TXOP
  - Specifies start time and maximum duration (hence other stations do not attempt to access the medium)
  - Station (STA) transmits within SIFS and then using PIFS periods between packets
  - If no transmission after a PIFS, HC takes over and issues new TXOP or end of CFP.
  - CFPs can be synchronized to the individual source traffic intervals instead of the Beacon intervals

STAs send information on their TC and TSPEC, this allows HC to allocate the TXOPs and calculate QoS requirements (jitter, latency, bandwidth, etc.)

HCCA is optional and has not been implemented to any significant level

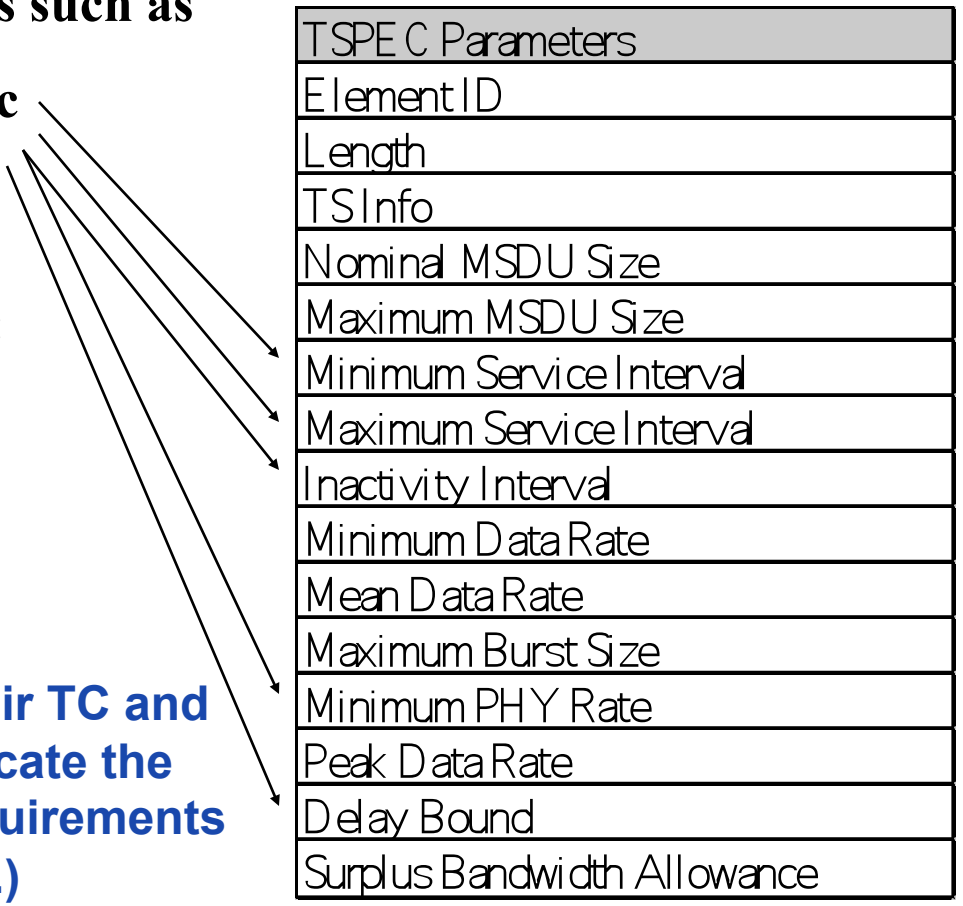
TSPECs for HCCA (WMM-SA)

The basic QoS requirements such as jitter, latency, bandwidth etc are defined by the TSPEC

'Standard' TSPECs exist for:

- **Voice**
- **Multi-Media (Video)**
- **Audio**

STAs send information on their TC and TSPEC, this allows HC to allocate the TXOPs and calculate QoS requirements (jitter, latency, bandwidth, etc.)

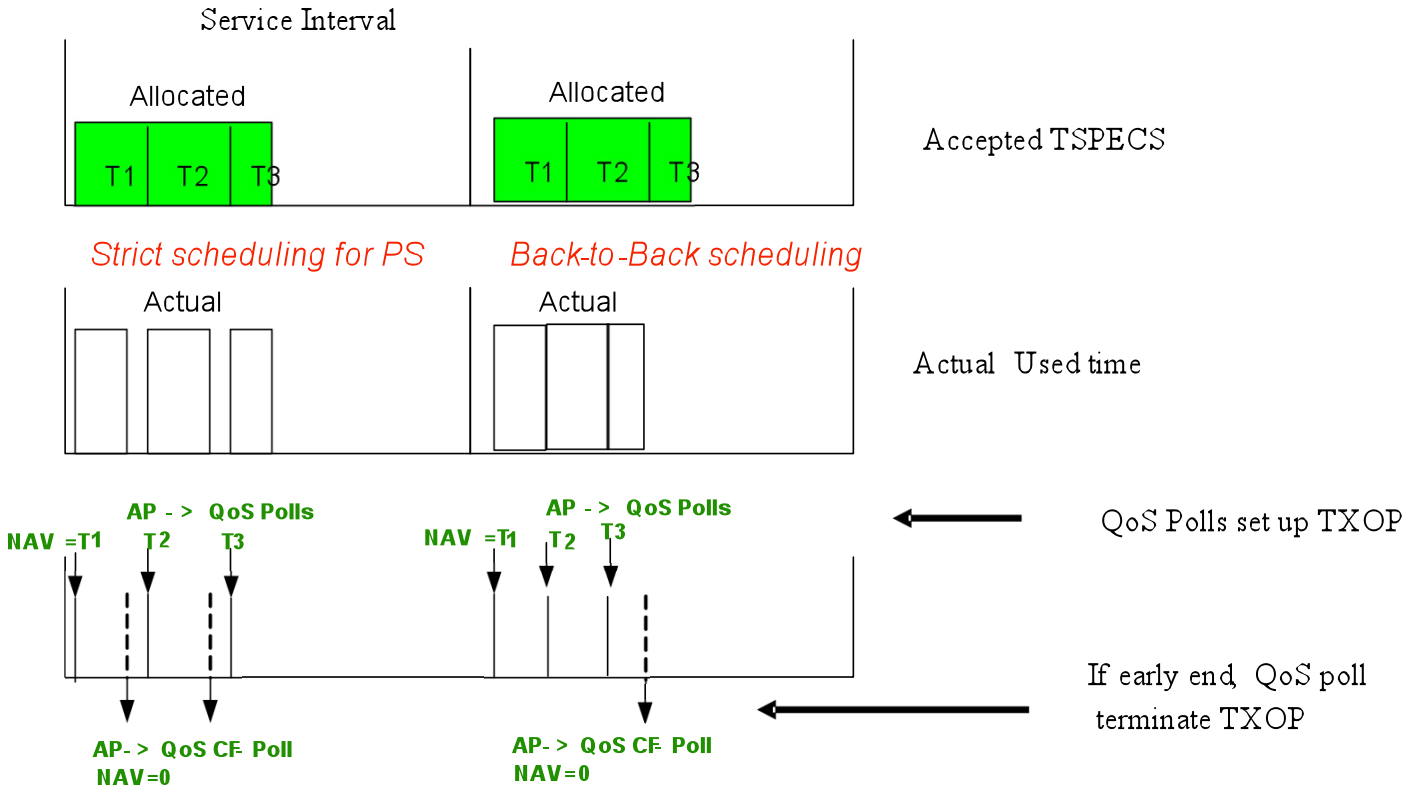


Scheduling

- **The scheduling is complex and can be more complex if Scheduled Power Save is required**
- **The Scheduling Policy for Admission Control and HCCA can become very complex if Controller wants to use high level allocation policies**

- **QAP indicates the Schedule in ADDTS accepted Response:**
  - Service Start time (anticipated)
  - Service Interval
  - Specification Interval (verify schedule conformance)

QoS Polling Example

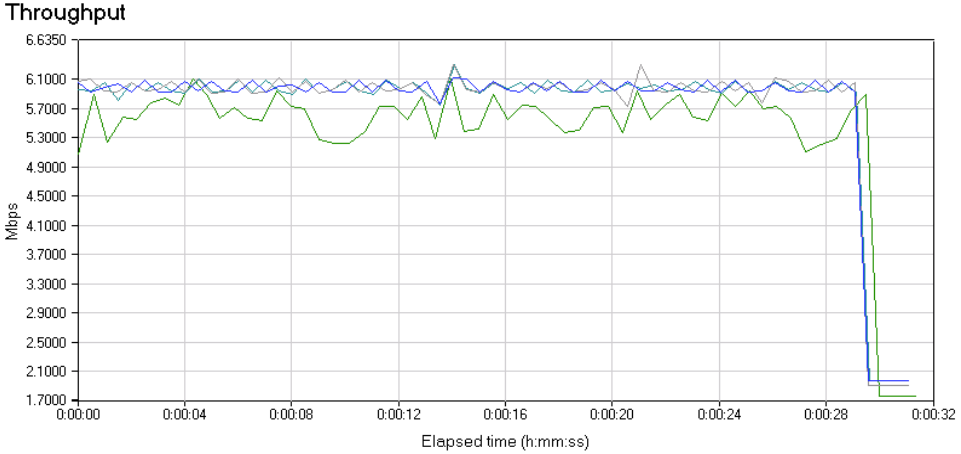


If power save not an issue, the QAP simply starts the next TXOP as soon as the previous finishes. Better bandwidth utilization but less efficient Scheduled Power Save.

HCCA Efficiency - Measurement

As HCCA uses contention free periods to send the streams, hence the bandwidth efficiency is good when the channel is highly loaded.

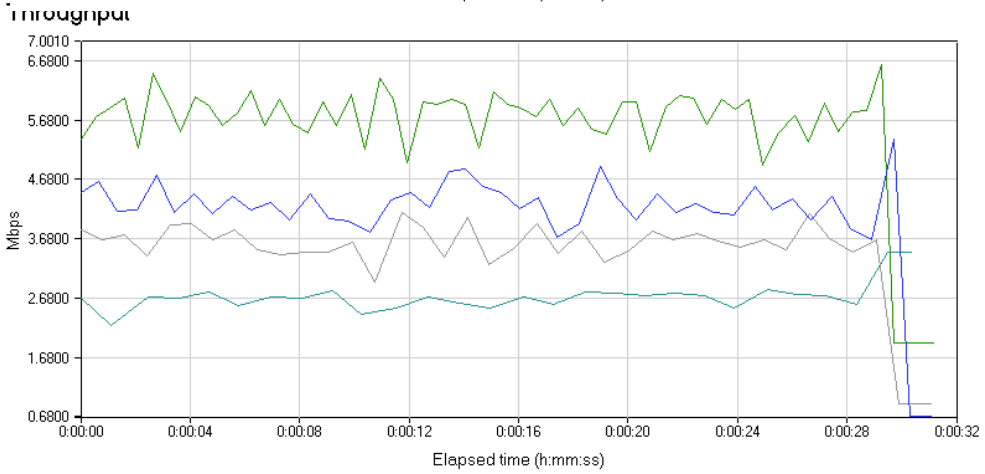
Examples below show that the practical difference (single channel, no OBSS) between HCCA and EDCA



WMM-SA

Four 6Mbps up-streams at 36Mbps 3 using WMM-SA

- **~24Mbps** throughput



WMM

Four 6Mbps up-streams on 4 different WMM certified devices. WMM AC_VI. STAs connected at 36Mbps

- **~16.5Mbps** throughput

HCCA

- **Efficient use of Bandwidth**
  - Contention free periods used
  - Returns channel out of CF as soon as packets sent for that TXOP are over
- **"Guarantees" latency**
  - Important in high bandwidth streaming applications
  - Regularly grants TXOPs as required by the TSPEC
- **"Guarantees" Bandwidth**
  - For quality video stream, for example, data rate must be assured
  - Very efficient use of available bandwidth, e.g. # of simultaneous voice calls is much higher than WMM allows (due to limited back-off slots)
- **Changes OBSS problems**
  - All STAs and APs that hear the QoS Poll will obey the TXOP
  - OBSS networks are more fragile due to scheduling at same time
  - ACKs from QSTAs should include Duration Field with outstanding TXOP time – extends range of CFP to other networks

BUT

- **Requires a relatively complex Scheduler and added complexity**

QoS Requirements

- **802.11 QoS can be considered as:**
  - EDCA Admission Control
  - HCCA
- **Both schemes require TSPECs**
- **TSPECs require knowledge of certain parameters of the desired QoS stream, at least:**
  - Nominal MSDU size
  - Mean Data Rate

  For HCCA
  - Maximum Service Interval