Wi-Fi Alliance Technical Committee

Quality of Service (QoS) Task Group

WMM™ (including WMM™ Power Save) Specification

Wi-Fi Alliance

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1 Overview

1.1 Purpose of This Document

This document defines the specification for WMM, an 802.11 quality of service (QoS) implementation based on a subset of the draft 802.11e standard supplement [2]. It is motivated by the need to prevent market fragmentation caused by multiple, non-interoperable pre-standard subsets of the draft 802.11e standard that would otherwise occur. It is intended that WMM can be implemented, subjected to interoperability testing and deployed in the market before the availability of 802.11e. This is facilitated by selecting a subset of the features of 802.11e. In no way should WMM be taken to detract from 802.11e itself, which is viewed as the long term endpoint of WMM. Deployment of WMM will deliver useful QoS functionality for voice over 802.11, streaming media and also provide key lessons which will benefit eventual deployment of 802.11e.

1.2 Terms and Definitions

AC (Access category): A label for the common set of enhanced distributed channel access (EDCA) parameters that are used by a WMM STA to contend for the channel in order to transmit MSDUs with certain priorities. WMM defines 4 ACs.

Admitted AC: Traffic transmitted using an AC based on parameters in a WMM TSPEC element contained in an ADDTS response management action frame

AIFS: Arbitration Inter Frame Spacing

AIFSN: Arbitration Inter Frame Spacing Number

Delivery-enabled AC: An AC for a specific STA, to deliver traffic in that STA specific AC using WMM when an Unscheduled Service Period (USP) is triggered by that STA.

ECWmin: Exponent form of CWmin

ECWmax: Exponent form of CWmax

EDCA: Enhanced Distributed Channel Access

EDCF: Enhanced Distributed Coordination Function

Group traffic: Multicast and broadcast traffic

TID: Traffic Identifier; a 4-bit number that uniquely identifies a TSPEC.

Trigger-enabled AC: An AC for a specific STA to initiate an Unscheduled Service Period (USP), if one is not already in progress, when frames are received from that STA of subtype QoS Data or QoS Null associated with that AC.

Trigger Frame: A QoS Data or QoS Null frame from a WMM STA in Power Save Mode associated with an AC the WMM STA has configured to be a trigger-enabled AC. A QoS Data or QoS Null frame that indicates transition to/from Power Save Mode is not considered to be a Trigger Frame and the AP shall not respond with a QoS Null frame.

TS: Traffic Stream, A traffic stream is a set of MSDUs to be delivered subject to the QoS parameter values provided to the MAC in a particular TSPEC.

TXOP (Transmission Opportunity): An interval of time when a particular WMM STA has the right to initiate transmissions onto the wireless medium (WM).

Un-admitted AC: Traffic transmitted using an AC that did not require admission.

UP: User Priority; is identical to the 3 bit priority subfield carried in the 802.1D Priority field.

Service Period (SP): A service period is a contiguous time during which one or more downlink unicast frames are transmitted to a WMM STA and/or one or more TXOPs are granted to the same WMM STA. Service Periods can be Scheduled or Unscheduled. For a WMM STA, there can be at most one Service Period active at any time.

Unscheduled Service Period (USP): The Service Period that is started when a WMM STA transmits a trigger frame to the WMM AP.

1.3 WMM Features

The features supported by WMM in this phase are as follows:

1. Capability negotiation independent of 802.11e. That is, WMM devices will not advertise 802.11e capability unless they also support those features independently. This is part of a forward compatibility strategy which is described in detail in a subsequent paragraph.
2. Frame formats and over the air protocols will be based on those currently proposed for 802.11e. However, no attempt will be made to track future changes in 802.11e and reflect them back into the WMM specification. Divergence between the two specifications is a necessary side effect of the need to freeze the WMM specification as soon as possible.
3. WMM will use an EDCF mechanism only, and except where explicitly indicated otherwise in this specification other 802.11e features, including HCF polling and associated signaling, Block Acknowledgement, and side traffic, are not part of WMM.
4. Interfaces to the MAC which signal per-packet priority will be consistent with those used for Ethernet, both in terms of the driver API and bridging to other 802 link layers via an 802.1D bridge.
5. The number of exposed queues will be fixed at four. A fixed mapping of priority information carried in the 802.1D Priority field to those four queues will be defined, together with suggested uses for each priority consistent with the suggested uses in 802.1D.

Capability negotiation is designed to permit ultimate forward compatibility with 802.11e, taking into account the fact that the formats used for QoS data frames cannot be assumed to remain consistent. It is important feature that, on receipt of a frame, it is possible to uniquely decode it.

An AP or STA may support both WMM and 802.11e. Only one may be in use for a specific association at any time, but an AP may permit both 802.11e and WMM associations from different STAs at the same time.

A WMM-only AP or STA does not set the “QoS” bit in the capability field of association, beacon and probe management frames. A new WMM Information Element is defined in this specification and is carried in those frames. An AP may support and advertise both 802.11e and WMM in probe responses and beacons, but both association requests and responses must only request or specify one of these capabilities. As a result, a given association is either WMM or 802.11e, but not both, and this defines how data frames with QoS subtypes must be interpreted, should they ultimately be different.

2 WMM Frame Formats

2.1 Data Frame Formats

2.1.1 Fields

Data, Control and Management frames are indicated by a type subfield in the frame control field, as defined for [1]. Data frames include additional WMM-specified subtypes and conditional fields.

The general frame format for data type frames is shown in Figure 1.

2	2	6	6	6	2	6 or 0	2 or 0	n	4
Frame Control	Dur	Address 1	Address 2	Address 3	Seq Control	Address 4	QoS Control	Body	FCS
MAC Header									

Figure 1 WMM QoS Data Frame Format

The Address 4 and QoS control fields are conditionally present in the MAC header, determined by values in the frame control field. The Address 4 field is present if and only if both toDS and fromDS bits are set in the frame control field (see 2.1.2). The QoS control field is present if and only if the frame is of subtype QoS data or QoS null.

2.1.2 Frame Control Field

There are no changes to the definition of the frame control field division into subfields. Subfield allocations are shown in Figure 2 and are identical to [1].

15	14	13	12	11	10	9	8	7 4	3 2	1 0
Order	WEP	More Data	Power Manage-ment	Retry	More Frag	From Ds	To DS	Subtype	Type	Version

Figure 2 Frame Control Field [1]

Additional data subtypes are defined for WMM as shown in Table 1.

Table 1 Additional WMM Data Subtype Codes

Type (MSB-LSB)	Subtype (MSB-LSB)	Subtype Description
10	1000	QoS data
10	1100	QoS null
00	1101	Management Action

2.1.3 Duration Field

The definition of the duration field is unchanged from [1] aside from the addition of the following provision:

When transmitting bursts of multiple MSDUs using continuation TXOPs, the duration field of a data or management frame in that burst may be selected to protect, using the NAV mechanism, either:

a) only the acknowledgement frame, if present, or

b) the acknowledgement frame, if present, plus the following data or management frame and its expected acknowledgement, if present or

c) the entire burst of frames.

2.1.4 Addresses

The definition and interpretation of address fields is unchanged from [1].

2.1.5 Sequence Control Field

The sequence control field contains two subfields, the sequence number and fragment number. Definition and use of the fragment number is unchanged from [1]. A sequence number is maintained separately for each Access Category and non-QoS traffic including management frames and group traffic.

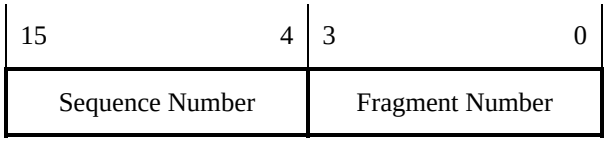


Figure 3 Sequence Control Field

Sequence and fragment numbers shall be selected and inserted on the initial transmission attempt of each data or management frame. Any subsequent retransmissions shall use the same sequence control field as the first transmission attempt.

The sequence number is selected by the transmitter from a modulo-4096 counter, which shall be incremented by 1 for each unique MSDU or MMPDU that is queued to the associated AC for delivery.

In addition to the RA and TA of the frame, the receiver shall use the UP field that is carried in the QoS Control field in order to allow correct differentiation of the sequence number spaces among frames sent using different ACs. The receiver shall use the mappings in Table 14 to identify the sending AC from the received UP field.

2.1.6 QoS Control Field

The QoS control field consists of two octets and is shown in Figure 4.

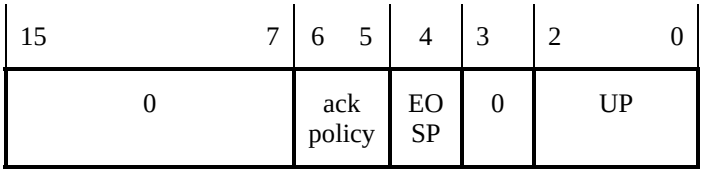


Figure 4 QoS Control Field

The three bit UP field carries the priority bits of the 802.1D Priority and is used to signal the priority for this frame. It also implies the sending AC according to the mappings in Table 14. The UP for each MPDU of a MSDU shall be the same value.

The Ack Policy field specifies the expected acknowledgement response and contains one of the values shown in Table 2. All other bits are reserved and shall be set to zero on transmission and ignored on receipt.

Table 2 Ack Policy Field Values

Ack Policy Value	Meaning
00	Acknowledge
01	Do not Acknowledge

The End of Service Period (EOSP) field is set by the WMM AP to 1 at the end of an Unscheduled Service Period (USP), and is set to 0 otherwise.

2.2 Management Frame Formats

2.2.1 WMM Information Element

The WMM Information Element indicates capability or use of WMM according to context and is shown in Figure 5. The fields contained in the WMM Information Element are listed in Table 3. The WMM Information Element contains a version number, which is 1 for version 1.0 of the WMM specification. The WMM Information Element contains an QoS Info field.

Octets:1	1	3	1	1	1	1
Element ID	Length	OUI	OUI Type	OUI Subtype	Version	QoS Info field

Figure 5 WMM Information Element

Table 3 WMM Information Element Field Values

Field	Value
Element ID	221
Length	7
OUI	00:50:f2 (hex)
OUI Type	2
OUI Subtype	0
Version	1
QoS Info field	See Figure 6 and Figure 7

The QoS Info field is shown in Figure 6. The QoS Info field contains the Parameter Set Count, which is initially arbitrary and is incremented each time any of the AC parameters changes.

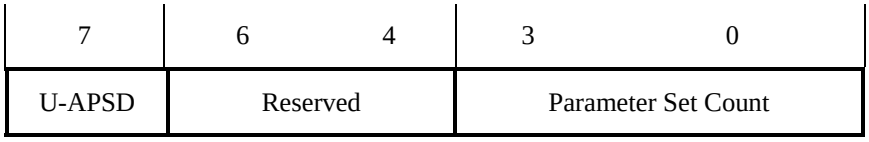


Figure 6 QoS Info field when sent from WMM AP

The reserved bits are set to 0 upon transmission and should be ignored upon reception. When set to 1, the U-APSD bit indicates the WMM AP is currently supporting unscheduled automatic power save delivery as described in §3.6.

The format of the QoS Info field, when sent by the WMM STA, is defined in Figure 7.

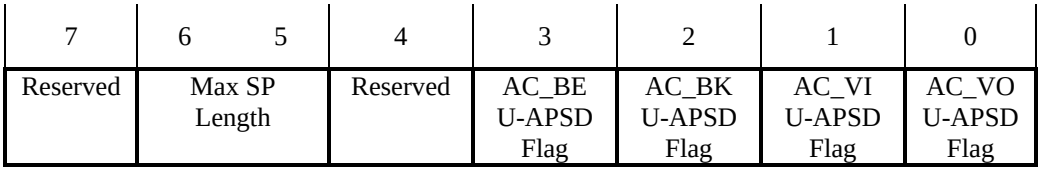


Figure 7 QoS Info field when sent from WMM STA

Each of the ACs U-APSD Flag subfield is one bit in length and set to 1 in (re) association request frames to indicate that the corresponding AC (AC_BE, AC_BK, AC_VI, or AC_VO) is both trigger-enabled and delivery-enabled. It is set to 0 in (re) association request frames to indicate that the corresponding AC is neither trigger-enabled nor delivery-enabled. MMPDUs are considered part of AC_VO for the purposes of U-APSD delivery. A TSPEC as described in sections 2.2.11 and 3.6 may be used to make a particular AC exclusively either trigger-enabled or delivery-enabled. These subfields are always set to 0 when the U-APSD subfield in the Qos Info Field of a WMM Information Element is set to 0.

Max SP Length subfield is 2 bits in length and indicates the maximum number of total buffered MSDUs and MMPDUs the WMM AP may deliver to a WMM STA during any Service Period triggered by the WMM STA. This subfield is reserved when the U-APSD subfield in the QoS Info Field of a WMM Information Element is set to 0. This subfield is also reserved when all four U-APSD flags are set to 0. If the U-APSD subfield in the QoS Info Field of a WMM Information Element sent by a WMM AP is set to 1 and at least one of the four AC U-APSD flags is set to 1, the settings of the values in the Max SP Length subfield are defined in the following Table 4

Table 4 Max SP Length Usage

Bit 5	Bit 6	Usage
0	0	WMM AP may deliver all buffered frames (MSDUs and MMPDUs)
1	0	WMM AP may deliver a maximum of 2 buffered frames (MSDUs and MMPDUs) per USP
0	1	WMM AP may deliver a maximum of 4 buffered frames (MSDUs and MMPDUs) per USP
1	1	WMM AP may deliver a maximum of 6 buffered frames (MSDUs and MMPDUs) per USP
		Note: The maximum number of buffered frames does not include QoS-NULL frames.

2.2.2 WMM Parameter Element

The WMM Parameter Element contains a set of parameters (EDCA parameters) for the EDCF channel access protocol and is shown in Figure 8. The fields contained in the WMM Parameter Element are listed in Table 5. The WMM Parameter Element contains a QoS Info field. The format of the QoS Info field is shown in Figure 6 and Figure 7. The QoS Info field contains the Parameter Set Count, which is initially arbitrary and is incremented each time any of the AC parameters changes. The reserved bits are set to 0 upon transmission and shall be ignored upon reception.

Octets: 1	1	3	1	1	1	1	1	16
ElementID	Length	OUI	OUI Type	OUI Subtype	Version	QoS Info field	Reserved	AC Parameters

Figure 8 WMM Parameter Element

Table 5 WMM Parameter Element Field Values

Field	Value
Element ID	221
Length	24
OUI	00:50:f2 (hex)
OUI Type	2
OUI Subtype	1
Version	1
QoS Info field	See Figure 6 and Figure 7
Reserved	0
AC Parameters Best_Effort	AC Parameters Record AC_BE
AC Parameters Background	AC Parameters Record AC_BK
AC Parameters Video	AC Parameters Record AC_VI
AC Parameters Voice	AC Parameters Record AC_VO

Each access category (AC) parameter record has the format shown in Figure 9. The formats of the ACI/AIFSN and ECWmin/ECWmax fields are shown in Figure 10 and Figure 11, respectively.

Octets: 1	1	2
ACI/AIFSN	ECWmin/ ECWmax	TXOP Limit

Figure 9 AC Parameters Record Format

7	6 5	4	3 0
Reserved	ACI	ACM	AIFSN

Figure 10 ACI/AIFSN Field

The value of TXOP limit is specified as an unsigned integer, with the least significant octet transmitted first, in units of 32μs. A TXOP limit value of 0 indicates that a single MPDU, in addition to a possible RTS/CTS exchange or CTS to itself, may be transmitted at any rate for each TXOP. The value of the ACI references the AC to which all parameters in this record correspond. The mapping between AC index (ACI) and AC is defined in Table 6. The AIFSN value indicates the number of time slots inside the Arbitration Interframe space to be used. The minimum value for AIFSN shall be 2.

Table 6 ACI to AC coding

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

The ACM (Admission Control Mandatory) flag indicates that Admission Control is required for the AC. If bit ACM is set to 0, the AC may be used without Admission Control. If bit ACM is set to 1, admission control must be performed prior to transmission with the parameters of the corresponding AC Parameter Record.

7 4	3 0
ECW_{max}	ECW_{min}

Figure 11 ECWmin/ECWmax field

The fields ECWmin and ECWmax encode the values of CWmin and CWmax respectively in an exponent form. The values ECWmin and ECWmax are defined such that:

$$CW_{\min} = 2^{ECW_{\min}} - 1$$

$$CW_{\max} = 2^{ECW_{\max}} - 1$$

Hence the minimum encoded value of CWmin is 0, and the maximum value is 32767.

2.2.3 Beacon Frame

Every beacon frame transmitted by a WMM-enabled AP shall contain, in addition to those elements specified in [1], either a WMM Information Element or a WMM Parameter Element.

2.2.4 Probe Request Frame

Probe request frames transmitted by a WMM-enabled STA are unchanged from [1].

2.2.5 Probe Response Frame

A probe response frame transmitted by a WMM-enabled AP shall contain a WMM Parameter Element. A probe response frame transmitted by a WMM-enabled STA shall contain a WMM Parameter Element if the corresponding probe request was transmitted by a member of the same (I)BSS as the transmitter of the probe response, otherwise, the probe response frame transmitted by a WMM-enabled STA shall not contain a WMM Parameter Element.

2.2.6 Association Request Frame

A WMM association request frame contains a WMM Information Element in addition to the information elements specified in [1].

2.2.7 Association Response Frame

An association response frame shall contain a WMM Parameter Element in addition to the information specified elements in [1] if the corresponding association request contained a WMM Information element and shall not contain a WMM Parameter Element if the corresponding association request did NOT contain a WMM Information element.

2.2.8 Re-Association Request Frame

A re-association request frame contains a WMM Information Element in addition to the information elements specified in [1].

2.2.9 Re-Association Response Frame

A re-association response frame shall contain a WMM Parameter Element in addition to the information specified elements in [1] if the corresponding re-association request contained a WMM Information element and shall not contain a WMM Parameter Element if the corresponding re-association request did NOT contain a WMM Information element.

2.2.10 Management Action Frame

The management action frame has a format as shown in Figure 12, with fields as described in Table 7.

24/30	1	1	1	1		4
MAC Header	Category Code	Action Code	Dialog Token	Status Code	Elements	FCS

Figure 12 Management Action Frame Format

Table 7 Management Action Frame Fields

Field	Value
MAC Header	See [1]
Category code	17
Action code	See below
Dialog token	See below
Status Code	See below
Elements	One or more information elements
FCS	See [1]

The action code field contains the values shown in Table 8.

Table 8 Management Action Frame Action Codes

Value	Action code
0	ADDTS request
1	ADDTS response
2	DELTS
3-255	Reserved

The ADDTS request, ADDTS response, and DELTS management action frames are used for Admission Control and Power Management and shall at minimum contain a WMM TSPEC element.

The Dialog Token field shall be set by the STA to a non-zero value in the ADDTS request frame and shall be copied into the corresponding ADDTS response management action frame. The Dialog Token shall be set to 0 in the DELTS management action frame.

The status code field is only filled in for the ADDTS response, and contains the values shown in Table 9. For other action codes, this field should be set to zero and ignored on receive.

Table 9 ADDTS Response Status Codes

Value	Operation
0	Admission accepted
1	Invalid parameters
2	Reserved
3	Refused
4-255	Reserved

2.2.11 WMM TSPEC Element

The format of the WMM TSPEC element is shown in Figure 13. The fields contained in the WMM TSPEC element are listed in Table 10. (Note: The fields are a snapshot of the TSPEC element in IEEE Std 802.11e/D6 plus an appended Medium Time field.) Fields marked with a hyphen are optional, and shall be set to zero if not used. The value of zero for any field is a special reserved value, meaning "no information provided". The WMM TSPEC body format is shown in Figure 14.

Octets: 1	1	3	1	1	1	55
ID	Length	OUI	OUI Type	OUI Subtype	Version	WMM TSPEC body

Figure 13 WMM TSPEC Element

Octets: 3	2	2	4	4	4	4	4	4
TS Info	Nominal MSDU Size	Maximum MSDU Size	Minimum Service Interval	Maximum Service Interval	Inactivity Interval	Suspension Interval	Service Start Time	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

Figure 14 WMM TSPEC Body format

A WMM TSPEC request shall be transmitted by a STA to an AP in order to request admission for an AC that requires admission control. The STA may transmit unadmitted traffic for those ACs for which the AP does not mandate admission control. A STA may need to transmit a WMM TSPEC request for an AC that does not mandate admission control, e.g for the establishment of the triggered power save mode of operation.

Table 10 WMM TSPEC Element Field Values

Field	Value
Element ID	221
Length	6 + 55 = 61
OUI	00:50:f2 (hex)
OUI Type	2
OUI Subtype	2
Version	1
TS Info	See below
Nominal MSDU Size	See below
Maximum MSDU Size	-
Minimum Service Interval	-
Maximum Service Interval	-
Inactivity Interval	-
Suspension Interval	-
Service Start Time	-
Minimum Data Rate	-
Mean Data Rate	See below
Peak Data Rate	-
Maximum Burst Size	
Delay Bound	-
Minimum PHY Rate	See below
Surplus Bandwidth Allowance	See below
Medium Time	See below

The TS Info field contains the subfields shown in Figure 15. The TID field, combined with the RA and the TA of the frame containing the TSPEC element, uniquely identifies the TS for which a request is being made. The UP field contains the 802.1D priority information, and is the same value used in QoS data frames associated with this TS. The direction field contains values shown in Table 11.

23 17	16	15 14	13 11	10	9	8	7	6 5	4 1	0
Reserved	Reserved	Reserved	UP	PSB	Reserved	0	1	Direction	TID	Reserved

Figure 15 TS Info Field in WMM TSPEC Element

Table 11 Direction Field Values

Direction Value	Meaning
00	Uplink
01	Downlink
10	Reserved
11	Bi-directional

The uplink and downlink characteristics are symmetric for a bidirectional reservation. The value of a TSPEC field for a bidirectional reservation represents the resources for one direction.

The Power Save Behavior (PSB) field is coded according to Table 12.

Table 12 Power Save Behavior Field Values

PSB Value	Meaning
0	Legacy
1	U-APSD

The PSB bit determines the power save method of delivery of buffered traffic used when the station is operating in PS-mode, as described in section 3.6.

The Nominal MSDU Size field is 2 octets long and contains an unsigned integer that specifies the nominal size, in octets, of MSDUs belonging to the traffic under this traffic specification and is defined in Figure 16. If the Fixed subfield is set to 1, then the size of the MSDU is fixed and is indicated by the Size Subfield. If the Fixed subfield is set to 0, then the size of the MSDU might not be fixed and the Size indicates the nominal MSDU size.

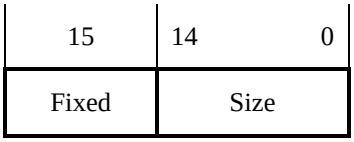


Figure 16 Nominal MSDU Size Field

The Mean Data Rate field is 4 octets long and contains an unsigned integer that specifies the average data rate, in units of bits per second, for transport of MSDUs belonging to this traffic within the bounds under this traffic specification. The Mean Data Rate does not include the MAC and PHY overheads incurred in transferring the MSDUs.

The Minimum PHY Rate field is 4 octets long and contains an unsigned integer that specifies the minimum PHY rate, in units of bits per second that is required for transport of the MSDUs belonging to the traffic in this TSPEC.

The Surplus Bandwidth Allowance Factor field is 2 octets long and specifies the excess allocation of time (and bandwidth) over and above the stated rates required to transport an MSDU belonging to the traffic in this TSPEC. This field is represented as an unsigned binary number with an implicit binary point after the leftmost 3 bits. This field is included to account for retransmissions. As such, the value of this field must be greater than unity.

Medium Time is a 16-bit unsigned integer that describes the amount of time admitted to access the medium, in units of 32 microsecond periods per second.

3 WMM Protocol Specification

3.1 Association and Capability Negotiation

3.1.1 Procedure at an AP

An AP that supports WMM shall include either a WMM Information Element or a WMM Parameter Element in every beacon. In response to a probe request, a WMM-enabled AP shall include a WMM Parameter Element in its probe response.

On receipt of an association request and subsequent transmission of a corresponding association response: the AP shall include a WMM Parameter Element in the association response if the corresponding association request contained a WMM Information element and shall treat the association as WMM association. The same applies to re-association request / re-association response.

If the destination address of a data frame to be transmitted on the wireless medium corresponds to a STA with a WMM association, the AP shall use WMM QoS data subtype frame formats when transmitting the frame to it. If the destination address corresponds to a STA associated as a non-WMM STA, the AP shall not use QoS subtype data frames.

3.1.2 Procedure at a STA in an Infrastructure Network

A WMM-enabled STA shall determine the WMM capability of an AP with which it wishes to associate before transmitting an association request to it. It may do this either passively, by receiving a beacon frame, or actively, by transmitting a probe request to it.

From the most recently received probe response or beacon from a specific AP, the STA shall determine whether the AP supports WMM.

A STA shall include a WMM Information Element in an association request if it has determined that the recipient AP supports WMM and shall treat the association as a WMM association if the association response contained a WMM Parameter element. A STA shall not include a WMM Information Element in an association request if it has determined that the recipient AP does not support WMM and shall treat the association as legacy (i.e. non-WMM) association if the association response did not contain a WMM Parameter element. The same applies to re-association request / re-association response.

3.1.3 Procedure at a STA in an IBSS

WMM may be used in an IBSS, but since there is no negotiation of capability via association in this case, any STA wishing to use QoS data frame subtypes when transmitting to each STA must first infer the capability at that STA by other means.

A WMM-capable STA operating in an IBSS shall maintain an inferred WMM capability state for each destination address in the IBSS that it is aware of. It may set WMM capability state to “supported” for a given destination address on receipt of a beacon frame from that STA containing a WMM element, or on receipt of a probe response frame from that STA containing a WMM Information Element. The WMM capability state for each other STA shall be set to “not supported” until receipt of such a beacon or probe response.

WMM STAs operating in an IBSS shall respond to probe request frames from other STAs in the same IBSS by transmitting a probe response frame to that STA, containing a WMM Information Element. WMM STA operating in an IBSS shall respond to unicast directed probe request frames (provided that they are the target of the unicast) even if they were not the last STA in the IBSS to have transmitted a beacon.

3.2 Setting of WMM Parameters

3.2.1 Default WMM parameters

Table 13 Default WMM Parameters

AC	CW_{min}	CW_{max}	AIFSN	TXOP Limit (802.11b)	TXOP Limit (802.11a/g)
AC_BK	aCW_{min}	aCW_{max}	7	0	0
AC_BE	aCW_{min}	aCW_{max}	3	0	0
AC_VI	$(aCW_{min} + 1)/2 - 1$	aCW_{min}	2	6.016ms	3.008ms
AC_VO	$(aCW_{min}+1)/4 - 1$	$(aCW_{min}+1)/2 - 1$	2	3.264ms	1.504ms

3.2.2 WMM Parameters in an Infrastructure Network

A WMM-enabled AP may arbitrarily determine values for the parameters CW_{min}, CW_{max}, AIFS and TXOP limit for each of the four access categories. An AP may change the values of these parameters at any beacon time.

An AP shall include a WMM Parameter Element containing its currently determined values for all WMM parameters in all beacons, beginning within two or more DTIM periods when WMM parameters have changed. The AC parameter set count that is contained in the WMM Parameter Element and WMM Information Element is incremented following the change of one or multiple WMM parameters. An AP shall include a WMM Parameter element in probe response frames and in association response frames.

The STA is required to monitor the change of WMM parameters conveyed in the WMM Parameter Element in beacons and shall update its values accordingly. Prior to association (and used only for transmitting probe, authentication and association request frames) it shall set these parameters to the default values shown in Table 13.

A STA shall subsequently update the values of these parameters from any successfully received probe response frame, association response frame, which are addressed to the STA or beacon frame transmitted by the AP with which the STA is associated. It is the responsibility of the STA to use the current WMM parameters for accessing the wireless medium.

The AP may use a different set of parameters than it advertises. A recommended set of default parameters for the AP is listed in the annex. The value of AIFSN shall be greater than or equal to 1 for APs.

3.2.3 WMM Parameters in an IBSS

A STA which is a member of an IBSS shall set the values of all WMM parameters to the defaults listed in Table 13. In an IBSS, the WMM Parameter element is not included in the beacon.

3.3 Assignment of Frames to Queues

3.3.1 Mappings for Unicast Frames

The MAC data service at a STA or AP provides for connectionless, asynchronous transport of MSDUs. Each MSDU transfer request includes an 802.1D Priority field equal to that value. The priority bits of the 802.1D field are mapped to Access Category (AC) according to Table 14 and are listed in increasing

priority order. The UP field is carried in the QoS control field of an MPDU. The UP field references the AC the MPDU is transmitted at using the mapping defined in Table 14. At the receiver, the UP field carried in the MPDU shall be used to re-create the 802.1D priority information of the MSDU.

Table 14 802.1D Priority to AC mappings

Priority	802.1D Priority (= UP)	802.1D Designation	Access Category	WMM Designation
lowest ↓ highest	1	BK	AC_BK	Background
	2	-		
	0	BE	AC_BE	Best Effort
	3	EE		
	4	CL	AC_VI	Video
	5	VI		
	6	VO	AC_VO	Voice
	7	NC		

Transmit frames are then placed in queues according to AC. The AP and STA may implement more queues for internal prioritization. Data frames with no priority information are treated as best effort.

Management frames have no QoS Control field, but should be transmitted with parameters of AC_VO

PS-Poll frames should be mapped to AC_BE.

3.3.2 Mappings for Received Unicast Frames at an AP

Unicast frames received by an AP may be:

a) Non-QoS subtypes, in which case the AP shall assign an 802.1D priority of 0 (best effort) to them. See section 2.1

b) QoS subtypes, in which case the AP shall use the UP subfield of the QoS control field as the priority information.

In the event that the received frame has a destination address within the BSS, the AP shall determine the transmit queue according to the procedure described in section 3.3.1.

3.3.3 Mappings for Group Addressed and Buffered Frames at an AP

The AP forwards all group addressed frames (Multicast/Broadcast) using non-QoS data frame subtypes, if not all the recipients are WMM capable STAs. The AP may forward Power Save frames that are buffered with QoS Data frame subtype only to WMM capable STAs. Otherwise, the frames must be sent using non-QoS data frame subtypes. The AP is not required to implement multiple AC queues for transmission of group addressed and buffered Power Save frames, and may use a single dedicated queue for this purpose. If the AP uses a single queue for pending group addressed frames, then the AP should maintain the queue in priority order if possible.

3.4 Channel Access Protocol

3.4.1 Reference Implementation

The channel access protocol is derived from the DCF procedures described in [1]. This document specifies only differences between the WMM channel access protocol and the reference.

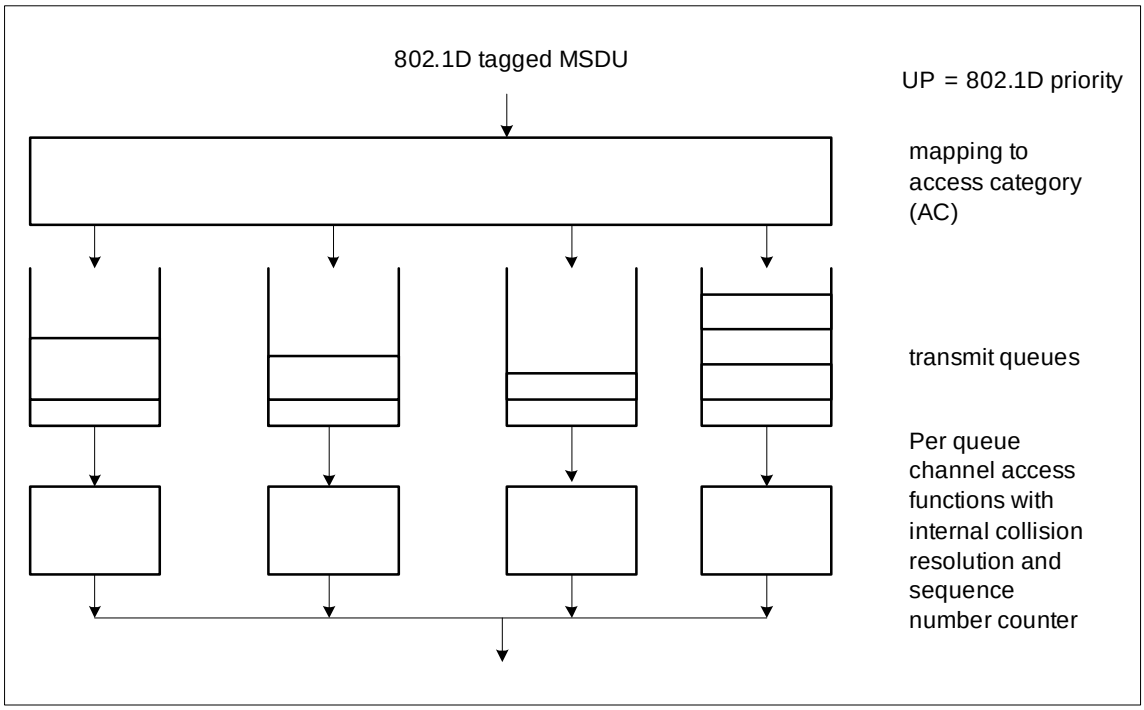


Figure 17 Reference Implementation Model

A model of the reference implementation is shown in Figure 17 and illustrates the mapping of the priority bits of the 802.1D Priority information that is contained in the MSDU to UP, access category (AC), the four transmit queues, and four independent channel access functions, one for each queue. The mapping of AC to priority is described in section 3.3. Each AC is associated with its own sequence number counter as described in 2.1.5.

3.4.2 Transmit Opportunities & TXOP Limits

There are two modes of TXOP defined, EDCA TXOP and continuation TXOP.

An EDCA TXOP occurs when the EDCA rules permit access to the medium.

A continuation TXOP occurs when a channel access function retains the right to access the medium following the completion of a frame exchange sequence, such as on receipt of an Ack frame.

The TXOP limit duration values for each AC are advertised by the QAP in the WMM Parameter Element in Beacons, Probe response, and Association response frames. A TXOP limit value of 0 indicates that a single MSDU or MMPDU in addition to a possible RTS/CTS or CTS to itself may be transmitted at any PHY rate for each TXOP.

STAs shall ensure that the duration of TXOPs obtained using the EDCA rules do not exceed the TXOP limit. The duration of a TXOP is the time the TXOP holder maintains uninterrupted control of the medium, and it includes the time required to transmit frames sent as an immediate response to TXOP holder transmissions.

An STA shall fragment an MSDU so that the transmission of the first MPDU of the TXOP does not cause the TXOP limit to be exceeded at the PHY rate selected for the initial transmission attempt of that MPDU. The TXOP limit may be exceeded, when using a lower PHY rate than selected for the initial transmission attempt of the first MPDU, for a retransmission of an MPDU, or for the initial transmission of an MPDU if any previous MPDU in the current MSDU has been retransmitted. When the TXOP limit is exceeded due to the retransmission of a MPDU at a reduced PHY rate, the STA shall not transmit more than one MPDU in the TXOP.

3.4.3 Obtaining an EDCA TXOP

Each channel access timer shall maintain a backoff function timer, which has a value measured in backoff slots.

The duration AIFS[AC] is a duration derived from the value AIFSN[AC] by the relation

$$AIFS[AC] = AIFSN[AC] \times aSlotTime + aSIFSTime$$

An EDCA TXOP is granted to a channel access function when the channel access function determines that it shall initiate the transmission of a frame exchange sequence. Transmission initiation shall be determined according to the following rules:

On specific slot boundaries, each channel access function shall make a determination to perform one and only one of the following functions:

a) Initiate the transmission of a frame exchange sequence for that access function

b) Decrement the backoff timer for that access function

c) Invoke the backoff procedure due to an internal collision

d) Do nothing for that access function.

The specific slot boundaries at which exactly one of these operations shall be performed are defined as follows, for each channel access function:

a) Following AIFSN[AC] * aSlotTime – aRxTxTurnaraoundTime of medium idle indication after SIFS (not necessarily idle time) after the last busy medium on the antenna, if the last busy medium indication was the result of a frame reception with a correct FCS ; or

b) Following EIFS – DIFS + AIFSN[AC] * aSlotTime of medium idle indication after the last indicated busy medium as determined by the carrier sense mechanism if the last busy medium indication was the result of a frame reception with an FCS error or PHY-RXEND.indication (RXERROR), where the value of RXERROR is not NoError.

c) When any other channel access function at this QSTA transmitted a frame requiring acknowledgement, the earlier of:

    a. the end of the ACK-Timeout interval timed from the PHY_TXEND.confirm, followed by AIFSN[AC] * aSlotTime – aTxRxTurnaraoundTime of IDLE Time

    b. at the end of the first AIFSN[AC] * aSlotTime – aTxRxTurnaraoundTime of IDLE medium after the PHY-RXEND.indication when a PHY-RXSTART.indication occurs as specified in subclause 9.2.8 of [1],

d) following AIFSN[AC] * aSlotTime– aTxRxTurnaraoundTime of medium idle indication after SIFS (not necessarily idle time) after the last indicated busy medium on the antenna that was the result of a transmission of a frame for any channel access function and which did not require an acknowledgement; or

e) following AIFSN[AC] * aSlotTimeof medium idle time indication after the last indicated idle medium as indicated by the carrier sense mechanism that is not covered by a) through d).

f) following aSlotTime of medium idle indication which occurs immediately after a decrement of the backoff counter for that channel access function.

At each of the above-described specific slot boundaries, each channel access function shall initiate a transmission sequence, if:

a) there is a frame available for transmission at that channel access function, and

b) the backoff timer for that channel access function has a value of zero, and

c) initiation of a transmission sequence is not allowed to commence at this time for a channel access function of higher UP.

At each of the above-described specific slot boundaries, each channel access function shall decrement the backoff timer by one, if:

a) The backoff timer for that channel access function has a value which is greater than zero.

At each of the above-described specific slot boundaries, each channel access function shall invoke the backoff procedure due to an internal collision, if:

a) There is a frame available for transmission at that channel access function, and

b) the backoff timer for that channel access function has a value of zero, and

c) initiation of a transmission sequence is allowed to commence at this time for a channel access function of higher UP.

At each of the above-described specific slot boundaries, each channel access function shall do nothing, if none of the above actions is taken.

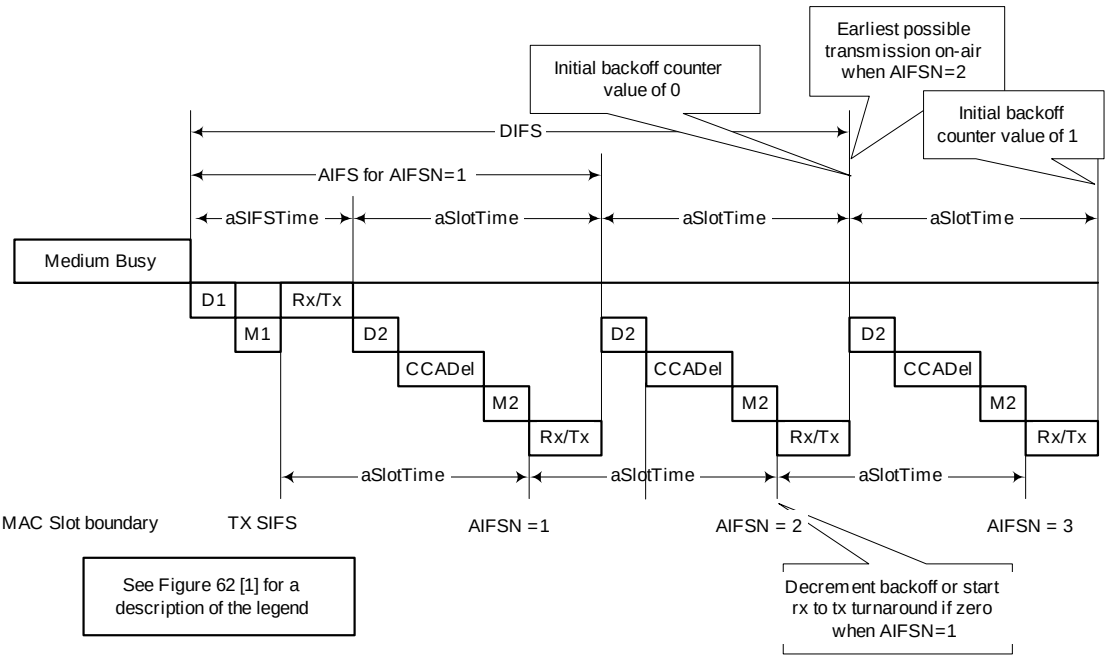


Figure 18 EDCA Mechanism Timing

An example showing the relationship between AIFS, AIFSN, DIFS and slot times immediately following a medium busy condition (and assuming that medium busy condition was not caused by a frame in error) is shown in Figure 18. In this case, with AIFSN=2, the channel access function may decrement the backoff counter for the first time at

2 * aSlotTime

following the end of the medium busy condition. Note: The end of the medium busy condition happens at the end of M1 in Figure 18. If, in this example, the backoff counter contained a value of 1 at the time the medium became idle, transmission would start as a result of an EDCA TXOP on-air at a time

$$aSIFSTime + 3 \times aSlotTime$$

following the end of the medium busy condition.

3.4.4 Obtaining a Continuation of TXOP

A continuation of TXOP is granted to a channel access function at a SIFS period following the successful completion of a frame exchange if there is a frame available for transmission that fits in any remaining EDCA TXOP duration. If a STA has in its transmit queue an additional frame of the same access category as the one just transmitted, and the duration of transmission of that frame plus any expected acknowledgement for that frame is less than the remaining medium occupancy timer value, then the STA may commence transmission of that frame at SIFS after the completion of the immediately preceeding frame exchange sequence.

A frame exchange may be either a multicast frame transmitted by an AP or a frame transmitted with “no acknowledgement” policy, for which there is no expected acknowledgement, or a unicast frame followed by a correctly received acknowledgement frame transmitted by either a STA or an AP.

Note that, as for an EDCA TXOP, a continuation TXOP is granted to a channel access function, not to a STA or AP, such that a continuation TXOP is only permitted for the transmission of a frame of the same access category as the access category of the frame that was granted the EDCA TXOP.

3.4.5 Backoff Procedure

Each channel access function shall maintain a state variable CW[AC], which shall be initialized to the value of the parameter CWmin[AC] (see section 3.2).

If a frame is successfully transmitted for a specific channel access function, indicated by either the successful reception of a CTS in response to an RTS, or the successful reception of an Ack in response to a unicast MPDU, or by transmitting a multicast frame or a frame with “no acknowledgement” policy, CW[AC] shall be reset to CWmin[AC].

The backoff procedure shall be invoked for a channel access function when either:

a) A frame with that AC is requested to be transmitted and the medium is busy as indicated by either physical or virtual carrier sense, and the backoff timer has a value of zero for that AC.

b) The final transmission by the TXOP holder initiated during the TXOP for that AC was successful

c) The transmission of a frame of that AC fails, indicated by a failure to receive a CTS in response to an RTS, or a failure to receive an Ack that was expected in response to a unicast MPDU or MMPDU.

d) The transmission attempt collides internally with another channel access function of an AC that has higher priority, that is, two or more channel access functions in the same STA or AP are granted a TXOP at the same time.

If the backoff procedure is invoked because of reason a) above the value of CW[AC] shall be left unchanged. If the backoff procedure is invoked because of reason b) above, the value of CW[AC] shall be reset to CWmin[AC].

If the backoff procedure is invoked because of a failure event (either reason c) or d) above) the value of CW[AC] shall be updated as follows before invoking the backoff procedure:

a) if the short or long retry count for the STA has reached aShortRetryLimit or aLongRetryLimit[AC] respectively, CW[AC] will be reset to CWmin[AC].

b) Otherwise,

1) if CW[AC] is less than CWmax[AC], CW[AC] shall be set to the value (CW[AC]+1)*2-1

2) if CW[AC] is equal to CWmax[AC], CW[AC] shall remain unchanged for the remainder of any retries

Following the update of the value of CW[AC], the backoff timer is set to an integer value chosen randomly with a uniform distribution taking values in the range (0,CW[AC]) inclusive.

3.4.6 Retransmit Procedures

If a STA or AP, in an infrastructure BSS or an IBSS, transmits frames to a destination using QoS data types, it may following a failed transmission of a frame attempt to transmit another frame with a different access category to the same or any other destination. The STA has to contend for the medium when transmitting another frame with a different access category to the same or any other destination using the rules defined in [1].

If a STA or an AP does not use QoS data types when transmitting frames to a particular receiver address, once an initial attempt, excluding internal collisions, has been made to transmit a frame, it shall not transmit other data frames to that receiver address until the first frame is either successfully transmitted or discarded. It may, however, transmit other frames to different receiver addresses.

3.5 ADDTS and DELTS Procedures

A STA uses an ADDTS request frame to setup a Traffic Stream (TS) between it and an AP. DELTS may be used by the STA or AP to discontinue and delete the use of a TS.

A TS serves two purposes within WMM:

- For the modification of AC parameters used for APSD. (§3.6)
- For the STA to gain admission to use an AC within a BSS. (§3.5.1)

A TS is identified uniquely by its TID value within the context of the RA and TA. The TID is contained within the TS Info Field in the WMM TSPEC Element of ADDTS and DELTS frames (Figure 15). Within a WMM STA in an infrastructure BSS, the RA and TA are constant.

TSs may be unidirectional, STA to AP or AP to STA, or bi-directional (Table 11).

In WMM, TSs are identified with TIDs values 0 through 7. Any TID may map onto any UP and thus onto any AC, however for each AC used between an RA and TA, only the following combinations are valid:

- No TS,
- One unidirectional TS,

or

- One Bi-directional TS.

An AP may reject invalid combinations.

There shall be only one outstanding active TS from a WMM STA for any given AC. When there is an existing TS admitted with the AP for a given AC, then an ADDTS request frame initiates the replacement of the existing TS with a new TS. Reception of an ADDTS Response Frame with the Status Code equal to 0 for a given STA and AC overwrites any previous ADDTS Response frame for a given STA and AC. Hence a WMM AP supports only one admitted TS per AC per WMM STA.

TSs may only be setup after successful association. All TSs between a STA and AP are discontinued and deleted upon disassociation. Re-association has no effect on TSs.

3.5.1 Admission Control Procedures

WMM STA may support admission control procedures. APs shall support admission control procedures, at least to the minimal extent of advertising that admission is not mandatory on its ACs.

The AP uses the ACM (admission control mandatory) flags advertised in the WMM Parameter element to indicate whether admission control is required for each of the ACs, as a matter of policy. While the CWmin, CWmax, AIFS, TXOP limit parameters may be adjusted over time by the AP, the ACM bit shall be static for the duration of the lifetime of the BSS. A WMM TSPEC request shall be transmitted by a STA to an AP in order to request admission of a TS in any direction (uplink, downlink, or bidirectional) using the AC parameters of those ACs that require admission control.

A WMM STA may choose to aggregate data flows locally by combining the parameters of multiple flows into a single TSPEC, thereby allowing more than one data flow to exist per TS. The STA may transmit unadmitted traffic using AC parameters of those ACs which the AP does not require admission control.

Each channel access function shall maintain two variables. The first of these is the admitted time, and the second is the used time. The admitted time and used time shall be set at association time to zero.

The channel access function shall update the value of used time:

a) at one second intervals

used_time = max((used_time - admitted_time), 0)

b) after each frame exchange

used_time = used_time + FrameExchangeTime .

The FrameExchangeTime equals the time required to transmit the frame plus one ACK frame plus one SIFS interval. If the used time reaches or exceeds the admitted time value, the corresponding channel access function shall no longer transmit using the EDCA parameters for that AC as specified in the QoS parameter set element.

If an explicit admission is torn down, the admitted time and the used time for the AC shall both be set to zero.

A Setup request (ADDTS) for a TS (TID) that has an established explicit admission shall be regarded as a request for a change to the existing admitted TS.

If a request for a change to an admitted TS is refused, the previously accepted admission for the same TS remains valid.

Admitted time for each channel access function is the sum of the Medium time values for all admitted TS that map into that AC. A WMM STA may choose to police admitted time and used time on a per-TS basis, with the rules for not transmitting when admitted time is exceeded applying per TS as well.

It should be noted that acceptance by an AP of a STA association request that specifies U-APSD flags does not constitute admission to the corresponding ACs. Uplink traffic from a STA must still be admitted using the ADDTS request mechanism in order to transmit in an AC for which the ACM bit is set to 1.

3.5.2 Procedures at the AP

The AP shall respond to requests for admission conveyed in the WMM TSPEC request elements for those AC with set ACM flag. If the ACM flag is set to 0 for an AC, the AP is not required to respond to a TSPEC request. On receipt of a WMM TSPEC request element conveyed in any management action frame except a probe request from an associated STA, the AP shall make a determination as to whether to

a) accept the request

b) deny the request

The AP may use any algorithm in making such a determination. If the AP decides to accept the request, the AP shall also derive the Medium Time from the information conveyed in the WMM TSPEC request element. The AP may use any algorithm in deriving the Medium Time, but normally it will use the procedure described in the Annex. Having made such a determination, the AP shall transmit a WMM TSPEC element to the requesting STA contained in a ADDTS response management action frame. If the AP is accepting the request, the Medium Time field shall be specified.

The AP may choose at any time to tear down an explicit admission by sending a management action frame with the action code set to DELTS.

By observing the used time and the admitted time variables for admitted traffic destined to an STA, the AP may drop MPDUs that are in excess of the admitted traffic using an unspecified algorithm.

3.5.3 Procedure at STAs

At any point, following association, the STA may decide, to explicitly request admission of traffic to be transmitted or/and received on a specific AC. The STA shall use the mappings in Table 14 to identify the sending AC from the UP field

In order to make such a request, the STA shall transmit a WMM TSPEC element contained in a ADDTS request management action frame with the following fields specified (i.e. non-zero): Nominal MSDU Size, Mean Data Rate, Minimum PHY Rate, and Surplus Bandwidth Allowance. The Medium Time field is not used in the request frame and shall be set to zero.

The STA or AP may choose to tear down the explicit request at any time. In order for the STA to tear down an explicit admission, the STA shall transmit a DELTS management action frame containing the WMM TSPEC element to the AP.

If the STA receives a management action frame with the action code set to DELTS it shall disable the use of the specified AC.

If an explicit admission is torn down, the STA shall disable the use of the AC.

By observing the used time and the admitted time variables for admitted traffic for an AC, the STA shall drop MPDUs that are in excess of the admitted traffic using an unspecified algorithm

If, for example, a STA has made and had accepted an explicit admission for an AC, and the channel conditions subsequently worsen, possibly including a change in PHY layer data rate, such that it requires more time to send the same data, the STA shall drop excess traffic and may make a request for more admitted time to the AP.

3.6 WMM Power Save (PS) Procedures

3.6.0 U-APSD General Operation

3.6.0.1 The procedures defined in this section apply to unicast QoS-Data and QoS-Null frames that are to be delivered to a WMM STA when the STA is in PS-mode. U-APSD shall only be used to deliver unicast frames to a WMM STA. Broadcast/multicast frame delivery shall follow the frame delivery rules defined for broadcast/multicast frames (See 11.2.1.4 in [1]).

3.6.0.2 The WMM power-save procedures are based on the legacy procedures defined in [1], but an option for unscheduled automatic power-save delivery (U-APSD) is added. WMM APs capable of supporting U-APSD ("U-APSD-capable WMM AP") shall signal this capability through the use of the U-APSD subfield (b7) in the QoS Info Field in Beacon, Probe Response and (Re)Association Response management frames.

3.6.0.3 In order to configure a WMM AP to deliver frames, the WMM STA designates one or more of its ACs to be delivery-enabled ACs and one or more of its AC to be trigger-enabled ACs. A WMM STA may configure a WMM AP to use U-APSD using two methods.

3.6.0.4 First, a WMM STA may set individual U-APSD Flag bits (b3~b0) in the QoS Info field of the WMM Information element carried in (re) association request frames (see §2.2.1). When a U-APSD Flag bit is set to 1, it indicates that the corresponding AC is both a delivery-enabled AC and trigger-enabled AC. When a U-APSD Flag bit is set to 0, it indicates that the corresponding AC is neither a deliver-enabled AC nor a trigger-enabled AC. When all four U-APSD Flag subfields are set to 1 in the most recent (re) association request frames, all the ACs associated with the WMM STA are trigger-enabled ACs and delivery-enabled ACs upon successful (re) association. When all four U-APSD Flag subfields are set to 0 in (re) association request frames, the ACs associated with the WMM STA are neither trigger-enabled ACs nor delivery-enabled ACs upon successful (re) association.

3.6.0.5 Alternatively, a WMM STA may request one or more AC as a trigger-enabled AC and one or more AC as delivery-enabled ACs by sending an ADDTS request per AC to the WMM AP with the PSB subfield (b10) in the TS Info field in the TSPEC element. In an ADDTS Response, a WMM AP must preserve the setting of the PSB subfield from the ADDTS Request. Requests to designate an AC as a delivery-enabled AC or trigger-enabled AC are admitted when the Status Code is equal to 0 in an ADDTS response. A WMM STA may request an AC to be a trigger-enabled AC with a TSPEC with the PSB subfield set to 1 in the uplink direction. A WMM STA may request an AC to be a delivery-enabled AC with a TSPEC with the PSB subfield set to 1 in the downlink direction. A bi-directional TSPEC with the PSB subfield set to 1, makes an AC both a trigger-enabled AC and delivery-enabled AC. A bi-directional TSPEC with the PSB subfield set to 0, makes that AC neither a trigger-enabled AC nor a delivery-enabled AC.

3.6.0.6 APSD settings in an admitted TSPEC (i.e., Status Code equal to 0 in an ADDTS response) take precedence over the static U-APSD settings carried in the WMM Information element in the most recent (re) association request. In other words, an admitted TSPEC overwrites any previous U-APSD setting of an AC. An acknowledged DELTS for an AC reverts that AC to the static U-APSD settings carried in the WMM Information element in the most recent (re) association request.

3.6.0.7 WMM STAs use the Power Management field (b12) in the frame control field (§2.1.2) of a frame to indicate whether it is in active or power-save mode. As U-APSD is a mechanism for the delivery of downlink frames to powersaving stations, the uplink frames sent by a WMM STA using U-APSD shall have the Power Management bit in the frame control field set to 1 for

buffering to take place at the WMM AP. WMM STAs may use U-APSD to have some or all frames of delivery-enabled ACs delivered during Unscheduled Service Periods (USPs). A WMM STA chooses legacy versus U-APSD behavior on a per-AC basis.

3.6.0.8 If, for a particular WMM STA, an AC is not a delivery-enabled AC, then all downlink frames destined to that WMM STA that map to that AC are buffered and delivered using the procedures described in [1]. The buffer used to hold these frames will be referred to as the legacy PS buffer. The WMM AP uses the TIM and the More Data bit (b13) carried in Frame Control Field to indicate the status of the legacy PS buffer as specified in [1].

3.6.0.9 Transmission of a Trigger Frame is not implicitly allowed by admission of a downlink TS. If the Trigger Frame maps to an AC that has ACM=1, then the WMM STA must establish a suitable uplink TS before sending Trigger Frames.

3.6.0.10 The WMM STA must remain awake as long as an USP is still in progress.

3.6.1 U-APSD AP Operation

3.6.1.1 WMM APs shall maintain a Power Management status for each currently associated STA that indicates in which Power Management mode the STA is currently operating. U-APSD-capable WMM APs shall maintain the per-AC U-APSD status for each currently associated WMM STA.

3.6.1.2 If a WMM STA is in power-save mode, as indicated by a 1 in the power management field (b12) in the frame control field (§2.1.2), an AP shall temporarily buffer the MSDUs or MMPDUs destined to the STA. If a WMM STA is in Active mode, as indicated by a 0 in the power management field (b12) in the frame control field (§2.1.2), MSDUs or MMPDUs destined to that STA shall not be buffered for power management reasons by the WMM AP.

3.6.1.3 MSDUs or MMPDUs in delivery-enabled ACs (as described in §3.6) destined for a particular WMM STA using APSD shall be temporarily buffered in the U-APSD-capable WMM AP. The algorithm to manage this buffering is beyond the scope of this standard, with the exception that since the AP is WMM-enabled, it shall preserve the order of arrival of frames on a per TID, per STA basis.

3.6.1.4 At every beacon interval, the U-APSD-capable WMM AP shall assemble the Partial Virtual Bitmap containing the buffer status of non delivery-enabled ACs (if there exists at least one non delivery-enabled AC) per destination for WMM STAs in PS mode, and shall send this out in the TIM field of the beacon. In case all ACs are delivery-enabled ACs, the U-APSD-capable WMM AP shall assemble the Partial Virtual Bitmap containing the buffer status for all ACs per destination for WMM STAs. .

3.6.1.5 If the WMM STA has set up to use USPs by configuring trigger-enabled ACs, the WMM AP shall buffer frames belonging to delivery-enabled ACs until it has received a Trigger Frame associated with a trigger-enabled AC from the WMM STA, which indicates the start of an USP. A Trigger Frame received by the WMM AP from a WMM STA that already has an USP underway shall not trigger the start of a new USP. The WMM AP transmits frames destined for the WMM STA and associated with delivery-enabled ACs during an USP.

3.6.1.6 For a WMM STA using U-APSD, the WMM AP transmits one frame destined for the WMM STA from any AC that is not a delivery-enabled AC in response to a PS-Poll from the WMM STA. In case all ACs associated with the WMM STA are delivery-enabled ACs, then no ACs have been selected for legacy power-save, and the AP shall immediately send either an ACK frame, a Null function Data frame with the More Data bit set to zero, or a Null function QoS

Data frame with the More Data bit and the EOSP bit set to zero in response to the receipt of a PS-Poll frame. If the AP sends an ACK frame in immediate response to the PS-Poll frame, it also shall later send a Null Function Data frame with the More Data bit set to zero or a Null function QoS Data frame with the More Data bit set to zero and the EOSP bit set to zero. In MSDUs sent in response to PS-Poll from a WMM STA using U-APSD, the More Data bit (b13) field shall be set to indicate the presence of further buffered MSDUs or MMPDUs that do not belong to delivery-enabled ACs.

3.6.1.7 At each USP for a WMM STA, the WMM AP shall attempt to transmit at least one MSDU or MMPDU, but no more than the value encoded in the Max SP Length field in the QoS Info Field of a WMM Information Element from delivery-enabled ACs, that are destined for the WMM STA. Each buffered frame shall be delivered using the access parameters of its AC. The More Data bit (b13) of the directed MSDU or MMPDU associated with delivery-enabled ACs and destined for that WMM STA indicates that more frames are buffered for the delivery-enabled ACs. The More Data bit set in MSDUs or MMPDUs associated with non delivery-enabled ACs and destined for that STA indicates that more frames are buffered for the non delivery-enabled ACs. For all frames except for the final frame of the SP, the EOSP subfield of the QoS Control field of the QoS data frame shall be set to 0 to indicate the continuation of the SP. MMPDUs also indicate the continuation of an SP because they do not contain an EOSP subfield. If the WMM AP has no buffered MSDU or MMPDU to transmit or needs to otherwise terminate a USP, the WMM AP may generate an extra QoS Null frame, with the EOSP set to 1. When the WMM AP has transmitted a directed frame to the WMM STA with the EOSP subfield set to 1 during the SP except for retransmissions of that frame, the WMM AP shall not transmit any more frames using this mechanism until the next SP. The WMM AP shall set EOSP subfield to 1 to indicate the end of SP in APSD.

3.6.1.8 If the WMM AP does not receive an Ack to a directed MSDU sent with the EOSP subfield set to 1, it shall retransmit that frame at least once within the same USP - subject to applicable retry or lifetime limit. The maximum number of retransmissions within the same USP is the lesser of the Max Retry Limit and the MIB attribute dot11QAPMissingAckRetryLimit. If an Ack to the retransmission of this last frame in the same USP is not received, it may wait until the next USP to further retransmit that frame subject to its applicable retry or lifetime limit.

3.6.1.9 A WMM AP shall have an aging function to delete pending traffic when it is buffered for an excessive time period. The WMM AP may base the aging function on the listen interval specified by the WMM STA in the most recent (re)association request. The AP may discard buffered frames during power save mode transitions between APSD and legacy power save or vice versa.

3.6.1.10 The AP shall deliver all frames from the legacy PS buffer using the power management procedures described in [1].

3.6.2 U-APSD STA Operation

3.6.2.1 WMM STAs in PS-mode shall operate as follows to receive buffered frames from the WMM AP.

3.6.2.2 WMM STAs shall use the power management procedures defined in [1] to retrieve frames held in the legacy PS buffer.

3.6.2.3 In case one or more ACs are not delivery-enabled ACs, the WMM STA may retrieve MSDUs and MMPDUs belonging to those ACs by sending PS-Polls to the WMM AP. In case all ACs

are delivery enabled ACs, WMM STA should only use trigger frames to retrieve MSDUs and MMPDUs belonging to those ACs, and it should not send PS-Poll frames.

3.6.2.4 To initiate an USP to retrieve MSDUs and MMPDUs from delivery-enabled ACs, a WMM STA shall wake up and transmit a Trigger Frame to the WMM AP. . Frames of delivery-enabled ACs are delivered during a USP that begins after the WMM AP acknowledges the trigger frame transmitted by the WMM STA. The WMM STA shall remain awake until it receives a QoS Data or Null frame addressed to it, with the EOSP subfield in QoS Control field set to 1.

3.6.2.5 A WMM STA may send additional PS-Polls if the More Data subfield is set to 1 in downlink unicast MSDU or MMPDUs that do not belong to any deliver-enabled ACs. WMM STA may send additional trigger frames if the More Data subfield is set to 1 in downlink unicast MSDUs or MMPDUs that belong to delivery-enabled ACs.

3.6.2.6 The WMM STA is recommended to go into active mode to receive buffered frames before transitioning between APSD and legacy power save modes because the WMM AP may discard buffered frames during power save mode transitions between APSD and legacy power save.

WMM (Informative) Recommended Practices Annex

A.1 QoS Parameter Updates

It is recommended that the mechanism to update QoS parameters by way of the WMM Parameter Element in beacon frames be used infrequently. It is not the intent of the designers of the protocol to specify this as a dynamic adaptation mechanism, but rather as a means of auto-configuring policy at different locations.

However, in the event that the number of associated STAs changes or some other event occurs that significantly alters the conditions, it is expected that the AP may change the policy settings. There is no expectation of rapid update by the STAs, which may take of the order of seconds or tens of seconds if necessary to update their parameter settings.

To assure that all STAs use the proper QoS parameters following modification of AC parameters, the WMM Parameter Element should be present for multiple beacon intervals as specified in 3.2.2.

A.2 Use of Admission Control and Downgrading

It is recommended not to require Admission Control for the access categories AC_BE (Best Effort) and AC_BK (Background). The Admission Control Mandatory Bit (ACM) for these categories should be cleared to "0". The AC parameters chosen by the AP should account for unadmitted traffic in these access categories.

In the case the QBSS requires admission control, i.e. ACM bit is set for an AC, and the WMM STA has an MSDU to send on that AC, but the TS to which the MSDU belongs has not been admitted, the following options exist:

(1) The MSDU is dropped

(2) The access parameters of the access function corresponding to the AC are adjusted to match the parameters of a lower AC that does not require admission control. As a result, there will be two access functions with identical admission control parameters within the WMM STA competing for medium access. The cumulative throughput of this WMM STA may be higher.

(3) The MSDU is sent using a different UP. The UP is changed to map to a lower AC that does not require admission control. The UP has to be changed prior to calculating the MIC, assignment of the TSC and mixing the keys. Changing of the UP (2) is performed outside the MAC and is out of the scope of this spec.

It is the responsibility of the application invoking the SAP to assure consistency of traffic that is mapped to one AC, i.e. Admitted and non-admitted traffic mapped to one AC shall not be mixed.

A WMM AP should use option (1) or (3)

A.3 Deriving Medium Time

It is recommended that the AP use the following procedure to derive Medium Time in its ADDTS response.

There are two requirements to consider: 1) the traffic requirements of the application, and 2) the expected error performance of the medium. The application requirements are captured by two TSPEC parameters: Nominal MSDU Size and Mean Data Rate. The medium requirements are captured by two TSPEC parameters: Surplus Bandwidth Allowance and Minimum PHY Rate. The following formula describes how Medium Time may be calculated:

Medium Time = Surplus Bandwidth Allowance * pps * medium time per frame exchange where:

pps = ceiling((Mean Data Rate / 8) / Nominal MSDU Size); medium time per frame exchange = duration(Nominal MSDU Size, Minimum PHY Rate) + SIFS + ACK duration; duration() is the PLME-TXTIME primitive defined in the standard that returns the duration of a packet based on its payload size and the PHY data rate employed.

A.4 WMM AP Default Parameter

It is recommended that the AP uses the default EDCA parameter listed in Table 15 and advertises the Table 13 values in WMM Parameter Elements.

Table 15 Default EDCA Parameters for the AP

AC	CW_{min}	CW_{max}	AIFSN	TXOP Limit (802.11b)	TXOP Limit (802.11a/g)
AC_BK	aCW_{min}	aCW_{max}	7	0	0
AC_BE	aCW_{min}	4*(aCWmin+1) - 1	3	0	0
AC_VI	$(aCW_{min} + 1)/2 - 1$	aCW_{min}	1	6.016ms	3.008ms
AC_VO	$(aCW_{min}+1)/4 - 1$	$(aCW_{min}+1)/2 - 1$	1	3.264ms	1.504ms

A.5 Changes to WPA for WMM

A.5.1 Michael MIC Generation

Per the WPA pointer document, the TKIP MIC is computed over the MSDU destination address (DA), MSDU source address (SA), the MSDU priority, 3 zero bytes and the entire unencrypted MSDU data (payload):

6	6	1	3	M	1	1	1	1	1	1	1	1
DA	SA	Priority	0	Data	M0	M1	M2	M3	M4	M5	M6	M7

Figure 19 TKIP MIC Processing Format

Figure 19 is treated as a byte stream using the conventions described in Clause 7.1.1 of IEEE Std. 802.11, 1999 Edition. M0 – M7 are each byte of the Michael MIC.

On transmit, the MSDU priority used to calculate the Michael MIC shall be the numeric value of the UP for each MPDU of the MSDU. On receive, the MSDU priority shall be the numeric value of the UP for each MPDU of the MSDU.

A.5.2 TKIP Replay Counters

Each receiver shall maintain at least 4 unicast replay counters for each MAC address it receives WMM traffic (at least 1 for each AC). (Note: All WPA stations must also maintain 1 replay counter for each MAC address it receives multicast traffic.) The number of unicast replay counters supported by a receiving station is indicated by the Number of Replay Counters sub-field in the RSN Capabilities field of the WPA IE (a value of 2 = 4 replay counters, a value of 3 = 16 replay counters). When a receiver supports 4 replay counters, transmitters shall not 'reorder' MPDUs within an AC that have the same MAC address, but different TID, once the TSC has been assigned (prevents discarding out of order MPDUs at the receiver). Receivers may support 16 unicast replay counters, as indicated by the Number of Replay Counters. In this case, there will be 1 replay counter for each TID and transmitters may 'reorder' MPDUs within an AC that have the same MAC address but different TID, after the TSC has been assigned. Note: It is never allowed to reorder MPDUs within an AC that have the same MAC address and TID.

A.6 Conveyance of 802.1Q VLAN tags

If an 802.1Q VLAN tag is present within a WMM frame, the frame should have the SNAP encoded tag format as defined in [4] (see section 9.3). The frame format is shown in Figure 20. For comparison a frame without 802.1Q VLAN tag is depicted in Figure 21. The general format of IP Datagrams over IEEE 802 networks and the SNAP header are defined in [3].

24-32	0 or 4	6	2	2	2	n	4
MAC Header	IV	AAAA03000000h	8100 h	VLAN -TAG	Type	Payload and ICV	FCS
MAC Header	WEP	SNAP Header	802.1Q		Ether-type		

Figure 20 Frame Format with 802.1Q VLAN tag

24-32	0 or 4	6	2	n	4
MAC Header	IV	AAAA03000000h	Type	Payload and ICV	FCS
MAC Header	WEP	SNAP Header	Ether-type		

Figure 21 Frame Format without 802.1Q VLAN Tag

WMM STAs shall be able to receive frames with and without VLAN tag as depicted in Figure 20 and Figure 21.

When a VLAN tag is present, the CFI bit in the VLAN tag will be set to 0.

In general, VLAN tags should NOT be present within WMM frames. The UP of the QOS subfield contains the information contained in the priority field of the VLAN tag, such that a priority tagged frame (i.e. a frame with a VLAN tag where VLAN_ID = 0) is not necessary.

In the case of a non-zero VLAN_ID, the use of VLAN tags is generally restricted to trunking links which comprise a larger switching network's backbone, or for the connection of VLAN aware servers. WDS frames would more naturally be employed for trunking purposes, and therefore, VLAN Tags may be deemed necessary within WDS frame types. VLAN tags may appear in non-WDS WMM frames, e.g. when attaching a VLAN aware server to the network wirelessly.

Additionally, VLAN tags may be deemed necessary by some protocols in order to convey priority information across the WMM link where QOS subtypes are not used. In such cases, a priority tagged frame would be employed (i.e. a VLAN tag with VLAN_ID = 0).

Best effort, non-QOS subtype frames should not include VLAN tags where those frames may have a non-WMM STA as the intended receiver. A non-WMM STA might not be capable of interpreting the frame format of Figure 20. WMM STAs shall be able to parse non-QOS subtype frames with a VLAN tag. This ensures that if you are using a mix of legacy and WMM APs a WMM STA works in both situations where tags are present on the network.

A.7 CCMP processing with QC

The CCMP processing protects fields in the MPDU header. This clause describes the additional processing requirements for CCMP when the MPDU contains the QoS Control (QC) field.

A.7.1 AAD Construction with QC

The format of the AAD when the QC field is used is shown in Figure 22. The length of the AAD is 24 octets long when the MPDU includes QC but not A4 and 30 octets long when the MPDU includes both A4 and QC.

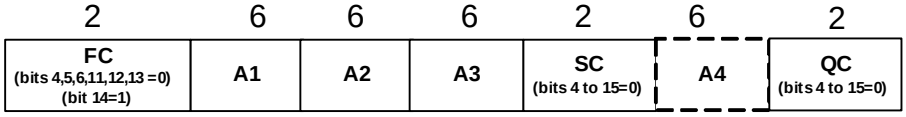


Figure 22—AAD Construction with QC

The calculation of the AAD is as described in the 802.11i specification with the addition that the QC field is now included in the AAD. Only the QC TID is used in the AAD and the remaining QC fields are set to zero for the AAD calculation (bits 4 to 15 are set to zero)

A.7.2 CCM Nonce with Priority Octet

The CCMP Priority must be set to the value of the QC TID field when the QC field is available in the header. The priority is set from bits 0 to 3 of the QC field. The priority bits 4, 5, 6 and 7 are reserved, and they are always set to zero. The Priority Octet is set to the fixed value 0 (0x00) when there is no QC field.

A.8 Differences between Legacy DCF Formulation and WMM

DCF Formulation (IEEE Std 802.11-1999)

A random backoff value is selected in the range 0 to CW inclusive. CW is always of the form 2^n-1. In the case of 802.11a, in which CW_{min} is 15, initial backoff values are therefore in the range [0,15].

In congested conditions, decrement of the backoff counter may be interrupted by a transmission from another STA. The only STAs which will suspend decrement of their backoff counters are those which have not yet counted down to zero. Therefore, when resuming a suspended backoff, the smallest value of backoff counter is 1. As a result, the earliest time that a STA can transmit after the medium is no longer busy depends on whether the STA has selected a new backoff value (minimum value 0) or is resuming a previously suspended backoff (minimum value 1). Figure 23 illustrates the Backoff behavior.

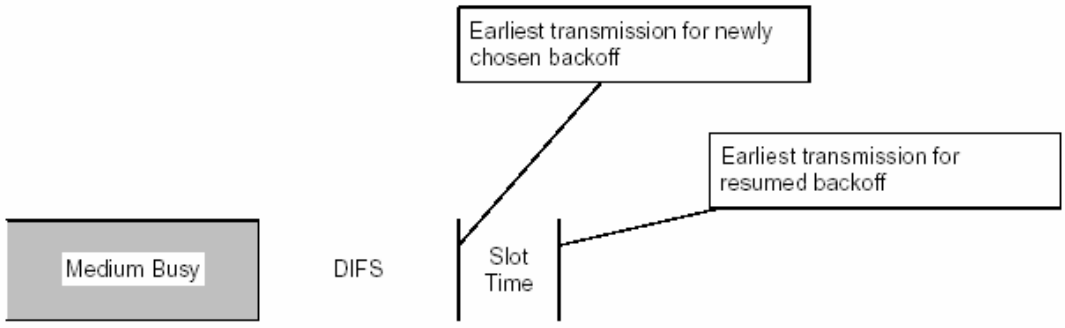
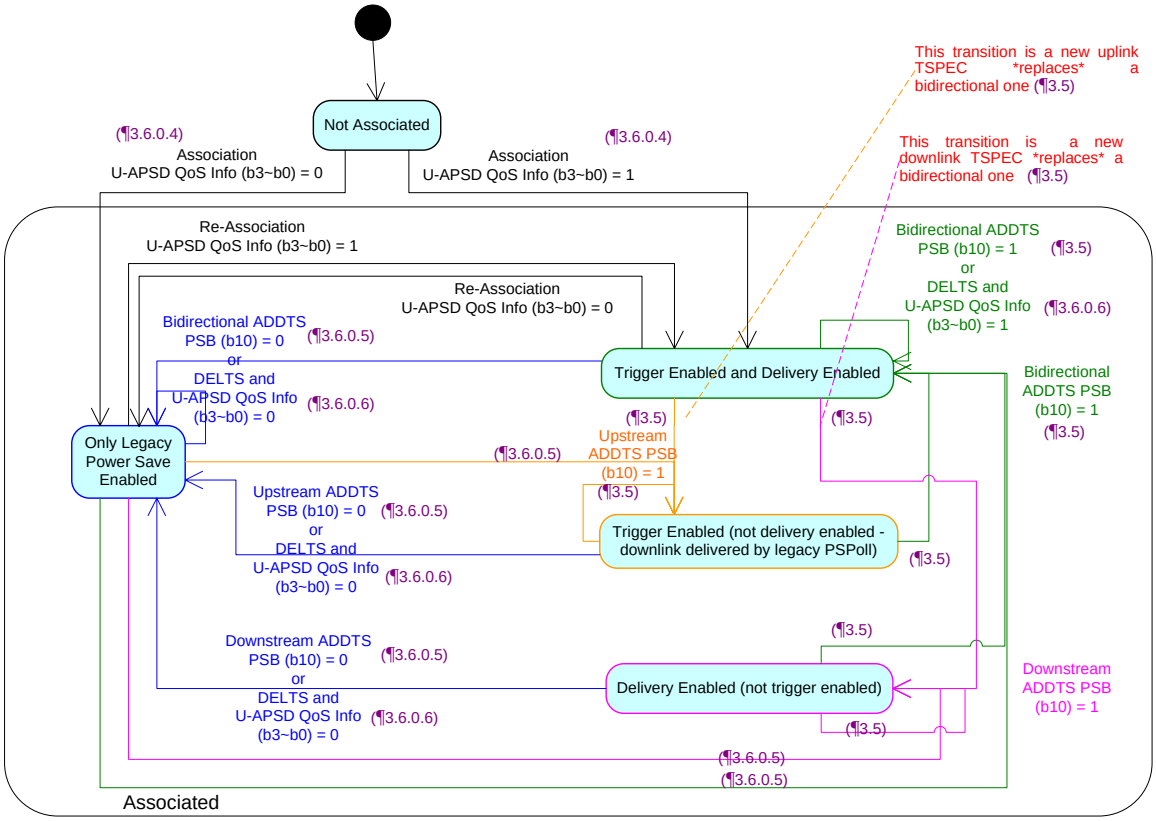


Figure 23 Backoff Behavior

The AP may choose to adjust the backoff parameters for WMM STAs to mitigate differences in the access priority with respect to Best_Effort traffic and legacy STAs.

A.9 Configuration State of AP for one example AC (Informative)



References

[1] ISO/IEC 8802-11:1999(E) ANSI/IEEE Std 802.11, 1999 Reaffirmed 2003 edition

[2] IEEEP802.11e/D6.0 November 2003; Draft amendment to IEEE Std. 802.11, 1999 Edition (Reaff 2003).

[3] IETF RFC1042: A Standard for the Transmission of IP Datagrams over IEEE 802 Networks.

[4] IEEE Std 802.1Q-1998s

[5] IEEEP802.11e/D7.0 January 2004; Draft amendment to IEEE Std. 802.11, 1999 Edition (Reaff 2003).