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Mapping Diffserv to IEEE 802.11

Abstract

As Internet traffic is increasingly sourced from and destined to wireless endpoints, it is crucial that Quality of Service (QoS) be aligned between wired and wireless networks; however, this is not always the case by default. This document specifies a set of mappings from Differentiated Services Code Point (DSCP) to IEEE 802.11 User Priority (UP) to reconcile the marking recommendations offered by the IETF and the IEEE so as to maintain consistent QoS treatment between wired and IEEE 802.11 wireless networks.

Status of This Memo

This is an Internet Standards Track document.

This document is a product of the Internet Engineering Task Force (IETF). It represents the consensus of the IETF community. It has received public review and has been approved for publication by the Internet Engineering Steering Group (IESG). Further information on Internet Standards is available in Section 2 of RFC 7841.

Information about the current status of this document, any errata, and how to provide feedback on it may be obtained at https://www.rfc-editor.org/info/rfc8325.

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1. Introduction

The wireless medium defined by IEEE 802.11 [IEEE.802.11-2016] has become the preferred medium for endpoints connecting to business and private networks. However, it presents several design challenges for ensuring end-to-end QoS. Some of these challenges relate to the nature of the IEEE 802.11 Radio Frequency (RF) medium itself, being a half-duplex and shared medium, while other challenges relate to the fact that the IEEE 802.11 standard is not administered by the same standards body as IP networking standards. While the IEEE has developed tools to enable QoS over wireless networks, little guidance exists on how to maintain consistent QoS treatment between wired IP networks and wireless IEEE 802.11 networks. The purpose of this document is to provide such guidance.

1.1. Related Work

Several RFCs outline Diffserv QoS recommendations over IP networks, including:

RFC 2474 Specifies the Diffserv Codepoint Field. This RFC also details Class Selectors, as well as the Default Forwarding (DF) PHB for best effort traffic. The Default Forwarding PHB is referred to as the Default PHB in RFC 2474.

RFC 2475 Defines a Diffserv architecture.

RFC 3246 Specifies the Expedited Forwarding (EF) Per-Hop Behavior (PHB).

RFC 2597 Specifies the Assured Forwarding (AF) PHB.

RFC 3662 Specifies a Lower-Effort Per-Domain Behavior (PDB).

RFC 4594 Presents configuration guidelines for Diffserv service classes.

RFC 5127 Presents the aggregation of Diffserv service classes.

RFC 5865 Specifies a DSCP for capacity-admitted traffic.

Note: [RFC4594] is intended to be viewed as a framework for supporting Diffserv in any network, including wireless networks; thus, it describes different types of traffic expected in IP networks and provides guidance as to what DSCP marking(s) should be associated with each traffic type. As such, this document draws heavily on [RFC4594], as well as [RFC5127], and [RFC8100].

In turn, the relevant standard for wireless QoS is IEEE 802.11, which is being progressively updated; at the time of writing, the current version of which is [IEEE.802.11-2016].

1.2. Interaction with RFC 7561

There is also a recommendation from the Global System for Mobile Communications Association (GSMA) on DSCP-to-UP Mapping for IP Packet eXchange (IPX), specifically their Guidelines for IPX Provider networks [GSMA-IPX_Guidelines]. These GSMA Guidelines were developed without reference to existing IETF specifications for various services, referenced in Section 1.1. In turn, [RFC7561] was written based on these GSMA Guidelines, as explicitly called out in [RFC7561], Section 4.2. Thus, [RFC7561] conflicts with the overall Diffserv traffic-conditioning service plan, both in the services specified and the codepoints specified for them. As such, these two plans cannot be normalized. Rather, as discussed in [RFC2474], Section 2, the two domains (IEEE 802.11 and GSMA) are different Differentiated Services Domains separated by a Differentiated Services Boundary. At that boundary, codepoints from one domain are translated to codepoints for the other, and maybe to Default (zero) if there is no corresponding service to translate to.

1.3. Applicability Statement

This document is applicable to the use of Differentiated Services that interconnect with IEEE 802.11 wireless LANs (referred to as Wi-Fi, throughout this document, for simplicity). These guidelines are applicable whether the wireless access points (APs) are deployed in an autonomous manner, managed by (centralized or distributed) WLAN controllers, or some hybrid deployment option. This is because, in all these cases, the wireless AP is the bridge between wired and wireless media.

This document applies to IP networks using Wi-Fi infrastructure at the link layer. Such networks typically include wired LANs with wireless APs at their edges; however, such networks can also include Wi-Fi backhaul, wireless mesh solutions, or any other type of AP-to-AP wireless network that extends the wired-network infrastructure.

1.4. Document Organization

This document is organized as follows:

Section 1 introduces the wired-to-wireless QoS challenge, references related work, outlines the organization of the document, and specifies both the requirements language and the terminology used in this document.

Section 2 begins the discussion with a comparison of IETF Diffserv QoS and Wi-Fi QoS standards and highlights discrepancies between these that require reconciliation.

Section 3 presents the marking and mapping capabilities that wireless APs and wireless endpoint devices are recommended to support.

Section 4 presents DSCP-to-UP mapping recommendations for each of the [RFC4594] service classes, which are primarily applicable in the downstream (wired-to-wireless) direction.

Section 5, in turn, considers upstream (wireless-to-wired) QoS options, their respective merits and recommendations.

Section 6 (in the form of an Appendix) presents a brief overview of how QoS is achieved over IEEE 802.11 wireless networks, given the shared, half-duplex nature of the wireless medium.

Section 7 contains IANA considerations.

Section 8 presents security considerations relative to DSCP-to-UP mapping, UP-to-DSCP mapping, and re-marking.

1.5. Requirements Language

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "NOT RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in BCP 14 [RFC2119] [RFC8174] when, and only when, they appear in all capitals, as shown here.

1.6. Terminology Used in This Document

Key terminology used in this document includes:

AC: Access Category. A label for the common set of enhanced distributed channel access (EDCA) parameters that are used by a QoS station (STA) to contend for the channel in order to transmit medium access control (MAC) service data units (MSDUs) with certain priorities; see [IEEE.802.11-2016], Section 3.2.

AIFS: Arbitration Interframe Space. Interframe space used by QoS stations before transmission of data and other frame types defined by [IEEE.802.11-2016], Section 10.3.2.3.6.

AP: Access Point. An entity that contains one station (STA) and provides access to the distribution services, via the wireless medium (WM) for associated STAs. An AP comprises a STA and a distribution system access function (DSAF); see [IEEE.802.11-2016], Section 3.1.

BSS: Basic Service Set. Informally, a wireless cell; formally, a set of stations that have successfully synchronized using the JOIN service primitives and one STA that has used the START primitive. Alternatively, a set of STAs that have used the START primitive specifying matching mesh profiles where the match of the mesh profiles has been verified via the scanning procedure. Membership in a BSS does not imply that wireless communication with all other members of the BSS is possible. See the definition in [IEEE.802.11-2016], Section 3.1.

Contention Window: See CW.

CSMA/CA: Carrier Sense Multiple Access with Collision Avoidance. A MAC method in which carrier sensing is used, but nodes attempt to avoid collisions by transmitting only when the channel is sensed to be "idle". When these do transmit, nodes transmit their packet data in its entirety.

CSMA/CD: Carrier Sense Multiple Access with Collision Detection. A MAC method (used most notably in early Ethernet technology) for local area networking. It uses a carrier-sensing scheme in which a transmitting station detects collisions by sensing transmissions from other stations while transmitting a frame. When this collision condition is detected, the station stops transmitting that frame, transmits a jam signal, and then waits for a random time interval before trying to resend the frame.

CW: Contention Window. Limits a CWMin and CWMax, from which a random backoff is computed.

CWMax: Contention Window Maximum. The maximum value (in units of Slot Time) that a CW can take.

CWMin: Contention Window Minimum. The minimum value that a CW can take.

DCF: Distributed Coordinated Function. A class of coordination function where the same coordination function logic is active in every station (STA) in the BSS whenever the network is in operation.

DIFS: Distributed (Coordination Function) Interframe Space. A unit of time during which the medium has to be detected as idle before a station should attempt to send frames, as per [IEEE.802.11-2016], Section 10.3.2.3.5.

DSCP: Differentiated Service Code Point [RFC2474] and [RFC2475]. The DSCP is carried in the first 6 bits of the IPv4 Type of Service (TOS) field and the IPv6 Traffic Class field (the remaining 2 bits are used for IP Explicit Congestion Notification (ECN) [RFC3168]).

EIFS: Extended Interframe Space. A unit of time that a station has to defer before transmitting a frame if the previous frame contained an error, as per [IEEE.802.11-2016], Section 10.3.2.3.7.

HCF: Hybrid Coordination Function. A coordination function that combines and enhances aspects of the contention-based and contention-free access methods to provide QoS stations (STAs) with prioritized and parameterized QoS access to the WM, while continuing to support non-QoS STAs for best-effort transfer; see [IEEE.802.11-2016], Section 3.1.

IFS: Interframe Space. Period of silence between transmissions over IEEE 802.11 networks. [IEEE.802.11-2016] describes several types of Interframe Spaces.

Random Backoff Timer: A pseudorandom integer period of time (in units of Slot Time) over the interval (0,CW), where CWmin is less than or equal to CW, which in turn is less than or equal to CWMax. Stations desiring to initiate transfer of data frames and/or management frames using the DCF shall invoke the carrier sense mechanism to determine the busy-or-idle state of the medium. If the medium is busy, the STA shall defer until the medium is determined to be idle without interruption for a period of time

equal to DIFS when the last frame detected on the medium was received correctly or after the medium is determined to be idle without interruption for a period of time equal to EIFS when the last frame detected on the medium was not received correctly. After this DIFS or EIFS medium idle time, the STA shall then generate a random backoff period for an additional deferral time before transmitting. See [IEEE.802.11-2016], Section 10.3.3.

RF: Radio Frequency.

SIFS: Short Interframe Space. An IFS used before transmission of specific frames as defined in [IEEE.802.11-2016], Section 10.3.2.3.3.

Slot Time: A unit of time used to count time intervals in IEEE 802.11 networks; it is defined in [IEEE.802.11-2016], Section 10.3.2.13.

Trust: From a QoS-perspective, "trust" refers to the accepting of the QoS markings of a packet by a network device. Trust is typically extended at Layer 3 (by accepting the DSCP), but may also be extended at lower layers, such as at Layer 2 by accepting UP markings. For example, if an AP is configured to trust DSCP markings and it receives a packet marked EF, then it would treat the packet with the Expedite Forwarding PHB and propagate the EF marking value (DSCP 46) as it transmits the packet. Alternatively, if a network device is configured to operate in an untrusted manner, then it would re-mark packets as these entered the device, typically to DF (or to a different marking value at the network administrator’s preference). Note: The terms "trusted" and "untrusted" are used extensively in [RFC4594].

UP: User Priority. A value associated with an MSDU that indicates how the MSDU is to be handled. The UP is assigned to an MSDU in the layers above the MAC; see [IEEE.802.11-2016], Section 3.1. The UP defines a level of priority for the associated frame, on a scale of 0 to 7.

Wi-Fi: An interoperability certification defined by the Wi-Fi Alliance. However, this term is commonly used, including in the present document, to be the equivalent of IEEE 802.11.

Wireless: In the context of this document, "wireless" refers to the media defined in IEEE 802.11 [IEEE.802.11-2016], and not 3G/4G LTE or any other radio telecommunications specification.

2. Service Comparison and Default Interoperation of Diffserv and IEEE 802.11

(Section 6 provides a brief overview of IEEE 802.11 QoS.)

The following comparisons between IEEE 802.11 and Diffserv services should be noted:

- [IEEE.802.11-2016] does not support an EF PHB service [RFC3246], as it is not possible to assure that a given access category will be serviced with strict priority over another (due to the random element within the contention process)

- [IEEE.802.11-2016] does not support an AF PHB service [RFC2597], again because it is not possible to assure that a given access category will be serviced with a minimum amount of assured bandwidth (due to the non-deterministic nature of the contention process)

- [IEEE.802.11-2016] loosely supports a Default PHB ([RFC2474]) via the Best Effort Access Category (AC_BE)

- [IEEE.802.11-2016] loosely supports a Lower Effort PDB service ([RFC3662]) via the Background Access Category (AC_BK)

As such, these high-level considerations should be kept in mind when mapping from Diffserv to [IEEE.802.11-2016] (and vice versa); however, APs may or may not always be positioned at Diffserv domain boundaries, as will be discussed next.

2.1. Diffserv Domain Boundaries

It is important to recognize that the wired-to-wireless edge may or may not function as an edge of a Diffserv domain or a domain boundary.

In most commonly deployed WLAN models, the wireless AP represents not only the edge of the Diffserv domain, but also the edge of the network infrastructure itself. As such, only client endpoint devices (and no network infrastructure devices) are downstream from the access points in these deployment models. Note: security considerations and recommendations for hardening such Wi-Fi-at-the-edge deployment models are detailed in Section 8; these recommendations include mapping network control protocols (which are not used downstream from the AP in this deployment model) to UP 0.

Alternatively, in other deployment models, such as Wi-Fi backhaul, wireless mesh infrastructures, wireless AP-to-AP deployments, or in cases where a Wi-Fi link connects to a device providing service via another technology (e.g., Wi-Fi to Bluetooth or Zigbee router), the wireless AP extends the network infrastructure and thus, typically, the Diffserv domain. In such deployments, both client devices and infrastructure devices may be expected downstream from the APs, and, as such, network control protocols are RECOMMENDED to be mapped to UP 7 in this deployment model, as is discussed in Section 4.1.1.

Thus, as can be seen from these two examples, the QoS treatment of packets at the AP will depend on the position of the AP in the network infrastructure and on the WLAN deployment model.

However, regardless of whether or not the AP is at the Diffserv boundary, marking-specific incompatibilities exist from Diffserv to 802.11 (and vice versa) that must be reconciled, as will be discussed next.

2.2. EDCF Queuing

[IEEE.802.11-2016] displays a reference implementation queuing model in Figure 10-24, which depicts four transmit queues, one per access category.

However, in practical implementations, it is common for WLAN network equipment vendors to implement dedicated transmit queues on a per-UP (versus a per-AC) basis, which are then dequeued into their associated AC in a preferred (or even in a strict priority manner). For example, it is common for vendors to dequeue UP 5 ahead of UP 4 to the hardware performing the EDCA function (EDCAF) for the Video Access Category (AC_VI).

Some of the recommendations made in Section 4 make reference to this common implementation model of queuing per UP.

2.3. Default DSCP-to-UP Mappings and Conflicts

While no explicit guidance is offered in mapping (6-Bit) Layer 3 DSCP values to (3-Bit) Layer 2 markings (such as IEEE 802.1D, 802.1p or 802.11e), a common practice in the networking industry is to map these by what we will refer to as "default DSCP-to-UP mapping" (for lack of a better term), wherein the three Most Significant Bits (MSBs) of the DSCP are used as the corresponding L2 markings.

Note: There are mappings provided in [IEEE.802.11-2016], Annex V Tables V-1 and V2, but it bears mentioning that these mappings are provided as examples (as opposed to explicit recommendations). Furthermore, some of these mappings do not align with the intent and recommendations expressed in [RFC4594], as will be discussed in this and the following section (Section 2.4).

However, when this default DSCP-to-UP mapping method is applied to packets marked per recommendations in [RFC4594] and destined to 802.11 WLAN clients, it will yield a number of inconsistent QoS mappings, specifically:

- Voice (EF-101110) will be mapped to UP 5 (101), and treated in the Video Access Category (AC_VI) rather than the Voice Access Category (AC_VO), for which it is intended

- Multimedia Streaming (AF3-011xx0) will be mapped to UP 3 (011) and treated in the Best Effort Access Category (AC_BE) rather than the Video Access Category (AC_VI), for which it is intended

- Broadcast Video (CS3-011000) will be mapped to UP 3 (011) and treated in the Best Effort Access Category (AC_BE) rather than the Video Access Category (AC_VI), for which it is intended

- OAM traffic (CS2-010000) will be mapped to UP 2 (010) and treated in the Background Access Category (AC_BK), which is not the intent expressed in [RFC4594] for this service class

It should also be noted that while [IEEE.802.11-2016] defines an intended use for each access category through the AC naming convention (for example, UP 6 and UP 7 belong to AC_VO, the Voice Access Category), [IEEE.802.11-2016] does not:

- define how upper-layer markings (such as DSCP) should map to UPs (and, hence, to ACs)

- define how UPs should translate to other mediums' Layer 2 QoS markings

- strictly restrict each access category to applications reflected in the AC name

2.4. Default UP-to-DSCP Mappings and Conflicts

In the opposite direction of flow (the upstream direction, that is, from wireless-to-wired), many APs use what we will refer to as "default UP-to-DSCP mapping" (for lack of a better term), wherein DSCP values are derived from UP values by multiplying the UP values

by 8 (i.e., shifting the three UP bits to the left and adding three additional zeros to generate a DSCP value). This derived DSCP value is then used for QoS treatment between the wireless AP and the nearest classification and marking policy enforcement point (which may be the centralized wireless LAN controller, relatively deep within the network). Alternatively, in the case where there is no other classification and marking policy enforcement point, then this derived DSCP value will be used on the remainder of the Internet path.

It goes without saying that when six bits of marking granularity are derived from three, then information is lost in translation. Servicing differentiation cannot be made for 12 classes of traffic (as recommended in [RFC4594]), but for only eight (with one of these classes being reserved for future use (i.e., UP 7, which maps to DSCP CS7).

Such default upstream mapping can also yield several inconsistencies with [RFC4594], including:

- Mapping UP 6 (which would include Voice or Telephony traffic, see [RFC4594]) to CS6, which [RFC4594] recommends for Network Control

- Mapping UP 4 (which would include Multimedia Conferencing and/or Real-Time Interactive traffic, see [RFC4594]) to CS4, thus losing the ability to differentiate between these two distinct service classes, as recommended in [RFC4594], Sections 4.3 and 4.4

- Mapping UP 3 (which would include Multimedia Streaming and/or Broadcast Video traffic, see [RFC4594]) to CS3, thus losing the ability to differentiate between these two distinct service classes, as recommended in [RFC4594], Sections 4.5 and 4.6

- Mapping UP 2 (which would include Low-Latency Data and/or OAM traffic, see [RFC4594]) to CS2, thus losing the ability to differentiate between these two distinct service classes, as recommended in [RFC4594], Sections 4.7 and 3.3, and possibly overwhelming the queues provisioned for OAM (which is typically lower in capacity (being Network Control Traffic), as compared to Low-Latency Data queues (being user traffic))

- Mapping UP 1 (which would include High-Throughput Data and/or Low-Priority Data traffic, see [RFC4594]) to CS1, thus losing the ability to differentiate between these two distinct service classes, as recommended in [RFC4594], Sections 4.8 and 4.10, and causing legitimate business-relevant High-Throughput Data to receive a [RFC3662] Lower-Effort PDB, for which it is not intended

The following sections address these limitations and concerns in order to reconcile [RFC4594] and [IEEE.802.11-2016]. First downstream (wired-to-wireless) DSCP-to-UP mappings will be aligned and then upstream (wireless-to-wired) models will be addressed.

3. Recommendations for Capabilities of Wireless Device Marking and Mapping

This document assumes and RECOMMENDS that all wireless APs (as the interconnects between wired-and-wireless networks) support the ability to:

- mark DSCP, per Diffserv standards
- mark UP, per the [IEEE.802.11-2016] standard
- support fully configurable mappings between DSCP and UP
- process DSCP markings set by wireless endpoint devices

This document further assumes and RECOMMENDS that all wireless endpoint devices support the ability to:

- mark DSCP, per Diffserv standards
- mark UP, per the [IEEE.802.11-2016] standard
- support fully configurable mappings between DSCP (set by applications in software) and UP (set by the operating system and/or wireless network interface hardware drivers)

Having made the assumptions and recommendations above, it bears mentioning that, while the mappings presented in this document are RECOMMENDED to replace the current common default practices (as discussed in Sections 2.3 and 2.4), these mapping recommendations are not expected to fit every last deployment model; as such, they MAY be overridden by network administrators, as needed.

4. Recommendations for DSCP-to-UP Mapping

The following section specifies downstream (wired-to-wireless) mappings between [RFC4594], "Configuration Guidelines for Diffserv Service Classes" and [IEEE.802.11-2016]. As such, this section draws heavily from [RFC4594], including service class definitions and recommendations.

This section assumes [IEEE.802.11-2016] wireless APs and/or WLAN controllers that support customizable, non-default DSCP-to-UP mapping schemes.

This section also assumes that [IEEE.802.11-2016] APs and endpoint devices differentiate UP markings with corresponding queuing and dequeuing treatments, as described in Section 2.2.

4.1. Network Control Traffic

Network Control Traffic is defined as packet flows that are essential for stable operation of the administered network [RFC4594], Section 3. Network Control Traffic is different from user application control (signaling) that may be generated by some applications or services. Network Control Traffic MAY be split into two service classes:

- Network Control, and
- Operations, Administration, and Maintenance (OAM)

4.1.1. Network Control Protocols

The Network Control service class is used for transmitting packets between network devices (e.g., routers) that require control (routing) information to be exchanged between nodes within the administrative domain, as well as across a peering point between different administrative domains.

[RFC4594], Section 3.2, recommends that Network Control Traffic be marked CS6 DSCP. Additionally, as stated in [RFC4594], Section 3.1: "CS7 DSCP value SHOULD be reserved for future use, potentially for future routing or control protocols."

By default (as described in Section 2.4), packets marked DSCP CS7 will be mapped to UP 7 and serviced within the Voice Access Category (AC_VO). This represents the RECOMMENDED mapping for CS7, that is, packets marked to CS7 DSCP are RECOMMENDED to be mapped to UP 7.

However, by default (as described in Section 2.4), packets marked DSCP CS6 will be mapped to UP 6 and serviced within the Voice Access Category (AC_VO); such mapping and servicing is a contradiction to the intent expressed in [RFC4594], Section 3.2. As such, it is RECOMMENDED to map Network Control Traffic marked CS6 to UP 7 (per [IEEE.802.11-2016], Section 10.2.4.2, Table 10-1), thereby admitting it to the Voice Access Category (AC_VO), albeit with a marking distinguishing it from (data-plane) voice traffic.

It should be noted that encapsulated routing protocols for encapsulated or overlay networks (e.g., VPN, Network Virtualization Overlays, etc.) are not Network Control Traffic for any physical network at the AP; hence, they SHOULD NOT be marked with CS6 in the first place.

Additionally, and as previously noted, the Security Considerations section (Section 8) contains additional recommendations for hardening Wi-Fi-at-the-edge deployment models, where, for example, network control protocols are not expected to be sent nor received between APs and client endpoint devices that are downstream.

4.1.2. Operations, Administration, and Maintenance (OAM)

The OAM (Operations, Administration, and Maintenance) service class is recommended for OAM&P (Operations, Administration, and Maintenance and Provisioning). The OAM service class can include network management protocols, such as SNMP, Secure Shell (SSH), TFTP, Syslog, etc., as well as network services, such as NTP, DNS, DHCP, etc. [RFC4594], Section 3.3, recommends that OAM traffic be marked CS2 DSCP.

By default (as described in Section 2.3), packets marked DSCP CS2 will be mapped to UP 2 and serviced with the Background Access Category (AC_BK). Such servicing is a contradiction to the intent expressed in [RFC4594], Section 3.3. As such, it is RECOMMENDED that a non-default mapping be applied to OAM traffic, such that CS2 DSCP is mapped to UP 0, thereby admitting it to the Best Effort Access Category (AC_BE).

4.2. User Traffic

User traffic is defined as packet flows between different users or subscribers. It is the traffic that is sent to or from end-terminals and that supports a very wide variety of applications and services [RFC4594], Section 4.

Network administrators can categorize their applications according to the type of behavior that they require and MAY choose to support all or a subset of the defined service classes.

4.2.1. Telephony

The Telephony service class is recommended for applications that require real-time, very low delay, very low jitter, and very low packet loss for relatively constant-rate traffic sources (inelastic traffic sources). This service class SHOULD be used for IP telephony service. The fundamental service offered to traffic in the Telephony

service class is minimum jitter, delay, and packet loss service up to a specified upper bound. [RFC4594], Section 4.1, recommends that Telephony traffic be marked EF DSCP.

Traffic marked to DSCP EF will map by default (as described in Section 2.3) to UP 5 and, thus, to the Video Access Category (AC_VI) rather than to the Voice Access Category (AC_VO), for which it is intended. Therefore, a non-default DSCP-to-UP mapping is RECOMMENDED, such that EF DSCP is mapped to UP 6, thereby admitting it into the Voice Access Category (AC_VO).

Similarly, the VOICE-ADMIT DSCP (44 decimal / 101100 binary) described in [RFC5865] is RECOMMENDED to be mapped to UP 6, thereby admitting it also into the Voice Access Category (AC_VO).

4.2.2. Signaling

The Signaling service class is recommended for delay-sensitive client-server (e.g., traditional telephony) and peer-to-peer application signaling. Telephony signaling includes signaling between 1) IP phone and soft-switch, 2) soft-client and soft-switch, and 3) media gateway and soft-switch as well as peer-to-peer using various protocols. This service class is intended to be used for control of sessions and applications. [RFC4594], Section 4.2, recommends that Signaling traffic be marked CS5 DSCP.

While Signaling is recommended to receive a superior level of service relative to the default class (i.e., AC_BE), it does not require the highest level of service (i.e., AC_VO). This leaves only the Video Access Category (AC_VI), which it will map to by default (as described in Section 2.3). Therefore, it is RECOMMENDED to map Signaling traffic marked CS5 DSCP to UP 5, thereby admitting it to the Video Access Category (AC_VI).

Note: Signaling traffic is not control-plane traffic from the perspective of the network (but rather is data-plane traffic); as such, it does not merit provisioning in the Network Control service class (marked CS6 and mapped to UP 6). However, Signaling traffic is control-plane traffic from the perspective of the voice/video telephony overlay-infrastructure. As such, Signaling should be treated with preferential servicing versus other data-plane flows. This may be achieved in common WLAN deployments by mapping Signaling traffic marked CS5 to UP 5. On APs supporting per-UP EDCAF queuing logic (as described in Section 2.2), this will result in preferential treatment for Signaling traffic versus other video flows in the same access category (AC_VI), which are marked to UP 4, as well as preferred treatment over flows in the Best Effort (AC_BE) and Background (AC_BK) Access Categories.

4.2.3. Multimedia Conferencing

The Multimedia Conferencing service class is recommended for applications that require real-time service for rate-adaptive traffic. [RFC4594], Section 4.3, recommends Multimedia Conferencing traffic be marked AF4x (that is, AF41, AF42, and AF43, according to the rules defined in [RFC2475]).

The primary media type typically carried within the Multimedia Conferencing service class is video; as such, it is RECOMMENDED to map this class into the Video Access Category (AC_VI), which it does by default (as described in Section 2.3). Specifically, it is RECOMMENDED to map AF41, AF42, and AF43 to UP 4, thereby admitting Multimedia Conferencing into the Video Access Category (AC_VI).

4.2.4. Real-Time Interactive

The Real-Time Interactive service class is recommended for applications that require low loss and jitter and very low delay for variable-rate inelastic traffic sources. Such applications may include inelastic video-conferencing applications, but may also include gaming applications (as pointed out in [RFC4594], Sections 2.1 through 2.3 and Section 4.4). [RFC4594], Section 4.4, recommends Real-Time Interactive traffic be marked CS4 DSCP.

The primary media type typically carried within the Real-Time Interactive service class is video; as such, it is RECOMMENDED to map this class into the Video Access Category (AC_VI), which it does by default (as described in Section 2.3). Specifically, it is RECOMMENDED to map CS4 to UP 4, thereby admitting Real-Time Interactive traffic into the Video Access Category (AC_VI).

4.2.5. Multimedia Streaming

The Multimedia Streaming service class is recommended for applications that require near-real-time packet forwarding of variable-rate elastic traffic sources. Typically, these flows are unidirectional. [RFC4594], Section 4.5, recommends Multimedia Streaming traffic be marked AF3x (that is, AF31, AF32, and AF33, according to the rules defined in [RFC2475]).

The primary media type typically carried within the Multimedia Streaming service class is video; as such, it is RECOMMENDED to map this class into the Video Access Category (AC_VI), which it will by default (as described in Section 2.3). Specifically, it is RECOMMENDED to map AF31, AF32, and AF33 to UP 4, thereby admitting Multimedia Streaming into the Video Access Category (AC_VI).

4.2.6. Broadcast Video

The Broadcast Video service class is recommended for applications that require near-real-time packet forwarding with very low packet loss of constant rate and variable-rate inelastic traffic sources. Typically these flows are unidirectional. [RFC4594] Section 4.6 recommends Broadcast Video traffic be marked CS3 DSCP.

As directly implied by the name, the primary media type typically carried within the Broadcast Video service class is video; as such, it is RECOMMENDED to map this class into the Video Access Category (AC_VI); however, by default (as described in Section 2.3), this service class will map to UP 3 and, thus, the Best Effort Access Category (AC_BE). Therefore, a non-default mapping is RECOMMENDED, such that CS4 maps to UP 4, thereby admitting Broadcast Video into the Video Access Category (AC_VI).

4.2.7. Low-Latency Data

The Low-Latency Data service class is recommended for elastic and time-sensitive data applications, often of a transactional nature, where a user is waiting for a response via the network in order to continue with a task at hand. As such, these flows are considered foreground traffic, with delays or drops to such traffic directly impacting user productivity. [RFC4594], Section 4.7, recommends Low-Latency Data be marked AF2x (that is, AF21, AF22, and AF23, according to the rules defined in [RFC2475]).

By default (as described in Section 2.3), Low-Latency Data will map to UP 2 and, thus, to the Background Access Category (AC_BK), which is contrary to the intent expressed in [RFC4594].

Mapping Low-Latency Data to UP 3 may allow targeted traffic to receive a superior level of service via per-UP transmit queues servicing the EDCAF hardware for the Best Effort Access Category (AC_BE), as described in Section 2.2. Therefore it is RECOMMENDED to map Low-Latency Data traffic marked AF2x DSCP to UP 3, thereby admitting it to the Best Effort Access Category (AC_BE).

4.2.8. High-Throughput Data

The High-Throughput Data service class is recommended for elastic applications that require timely packet forwarding of variable-rate traffic sources and, more specifically, is configured to provide efficient, yet constrained (when necessary) throughput for TCP longer-lived flows. These flows are typically not user interactive. According to [RFC4594], Section 4.8, it can be assumed that this class will consume any available bandwidth and that packets

traversing congested links may experience higher queuing delays or packet loss. It is also assumed that this traffic is elastic and responds dynamically to packet loss. [RFC4594], Section 4.8, recommends High-Throughput Data be marked AF1x (that is, AF11, AF12, and AF13, according to the rules defined in [RFC2475]).

By default (as described in Section 2.3), High-Throughput Data will map to UP 1 and, thus, to the Background Access Category (AC_BK), which is contrary to the intent expressed in [RFC4594].

Unfortunately, there really is no corresponding fit for the High-Throughput Data service class within the constrained 4 Access Category [IEEE.802.11-2016] model. If the High-Throughput Data service class is assigned to the Best Effort Access Category (AC_BE), then it would contend with Low-Latency Data (while [RFC4594] recommends a distinction in servicing between these service classes) as well as with the default service class; alternatively, if it is assigned to the Background Access Category (AC_BK), then it would receive a less-then-best-effort service and contend with Low-Priority Data (as discussed in Section 4.2.10).

As such, since there is no directly corresponding fit for the High-Throughout Data service class within the [IEEE.802.11-2016] model, it is generally RECOMMENDED to map High-Throughput Data to UP 0, thereby admitting it to the Best Effort Access Category (AC_BE).

4.2.9. Standard

The Standard service class is recommended for traffic that has not been classified into one of the other supported forwarding service classes in the Diffserv network domain. This service class provides the Internet's "best-effort" forwarding behavior. [RFC4594], Section 4.9, states that the "Standard service class MUST use the Default Forwarding (DF) PHB".

The Standard service class loosely corresponds to the [IEEE.802.11-2016] Best Effort Access Category (AC_BE); therefore, it is RECOMMENDED to map Standard service class traffic marked DF DSCP to UP 0, thereby admitting it to the Best Effort Access Category (AC_BE). This happens to correspond to the default mapping (as described in Section 2.3).

4.2.10. Low-Priority Data

The Low-Priority Data service class serves applications that the user is willing to accept without service assurances. This service class is specified in [RFC3662] and [LE-PHB].

[RFC3662] and [RFC4594] both recommend Low-Priority Data be marked CS1 DSCP.

Note: This marking recommendation may change in the future, as [LE-PHB] defines a Lower Effort (LE) PHB for Low-Priority Data traffic and recommends an additional DSCP for this traffic.

The Low-Priority Data service class loosely corresponds to the [IEEE.802.11-2016] Background Access Category (AC_BK); therefore, it is RECOMMENDED to map Low-Priority Data traffic marked CS1 DSCP to UP 1, thereby admitting it to the Background Access Category (AC_BK). This happens to correspond to the default mapping (as described in Section 2.3).

4.3. Summary of Recommendations for DSCP-to-UP Mapping

Figure 1 summarizes the [RFC4594] DSCP marking recommendations mapped to [IEEE.802.11-2016] UP and Access Categories applied in the downstream direction (i.e., from wired-to-wireless networks).

IETF Diffserv Service Class	PHB	Reference RFC	IEEE 802.11 User Priority	IEEE 802.11 Access Category
Network Control (reserved for future use)	CS7	RFC 2474	7 OR 0	AC_VO (Voice) OR AC_BE (Best Effort) See Security Considerations-Sec.8
Network Control	CS6	RFC 2474	7 OR 0	AC_VO (Voice) OR AC_BE (Best Effort) See Security Considerations
Telephony	EF	RFC 3246	6	AC_VO (Voice)
VOICE-ADMIT	VA	RFC 5865	6	AC_VO (Voice)
Signaling	CS5	RFC 2474	5	AC_VI (Video)

Multimedia Conferencing	AF41 AF42 AF43	RFC 2597	4	AC_VI (Video)
Real-Time Interactive	CS4	RFC 2474	4	AC_VI (Video)
Multimedia Streaming	AF31 AF32 AF33	RFC 2597	4	AC_VI (Video)
Broadcast Video	CS3	RFC 2474	4	AC_VI (Video)
Low-Latency Data	AF21 AF22 AF23	RFC 2597	3	AC_BE (Best Effort)
OAM	CS2	RFC 2474	0	AC_BE (Best Effort)
High-Throughput Data	AF11 AF12 AF13	RFC 2597	0	AC_BE (Best Effort)
Standard	DF	RFC 2474	0	AC_BE (Best Effort)
Low-Priority Data	CS1	RFC 3662	1	AC_BK (Background)

Note: All unused codepoints are RECOMMENDED to be mapped to UP 0
(See Security Considerations below)

Figure 1: Summary of Mapping Recommendations from Downstream DSCP to IEEE 802.11 UP and AC

5. Recommendations for Upstream Mapping and Marking

In the upstream direction (i.e., wireless-to-wired), there are three types of mapping that may be implemented:

- DSCP-to-UP mapping within the wireless client operating system, and
- UP-to-DSCP mapping at the wireless AP, or
- DSCP-Passthrough at the wireless AP (effectively a 1:1 DSCP-to-DSCP mapping)

As an alternative to the latter two options, the network administrator MAY choose to use the wireless-to-wired edge as a Diffserv boundary and explicitly set (or reset) DSCP markings according to administrative policy, thus making the wireless edge a Diffserv policy enforcement point; this approach is RECOMMENDED whenever the APs support the required classification and marking capabilities.

Each of these options will now be considered.

5.1. Upstream DSCP-to-UP Mapping within the Wireless Client Operating System

Some operating systems on wireless client devices utilize a similar default DSCP-to-UP mapping scheme as that described in Section 2.3. As such, this can lead to the same conflicts as described in that section, but in the upstream direction.

Therefore, to improve on these default mappings, and to achieve parity and consistency with downstream QoS, it is RECOMMENDED that wireless client operating systems instead utilize the same DSCP-to-UP mapping recommendations presented in Section 4. Note that it is explicitly stated that packets requesting a marking of CS6 or CS7 DSCP SHOULD be mapped to UP 0 (and not to UP 7). Furthermore, in such cases, the wireless client operating system SHOULD re-mark such packets to DSCP 0. This is because CS6 and CS7 DSCP, as well as UP 7 markings, are intended for network control protocols, and these SHOULD NOT be sourced from wireless client endpoint devices. This recommendation is detailed in the Security Considerations section (Section 8).

5.2. Upstream UP-to-DSCP Mapping at the Wireless AP

UP-to-DSCP mapping generates a DSCP value for the IP packet (either an unencapsulated IP packet or an IP packet encapsulated within a tunneling protocol such as Control and Provisioning of Wireless Access Points (CAPWAP) -- and destined towards a wireless LAN controller for decapsulation and forwarding) from the Layer 2 [IEEE.802.11-2016] UP marking. This is typically done in the manner described in Section 2.4.

It should be noted that any explicit re-marking policy to be performed on such a packet generally takes place at the nearest classification and marking policy enforcement point, which may be:

- At the wireless AP, and/or

- At the wired network switch port, and/or
- At the wireless LAN controller

Note: Multiple classification and marking policy enforcement points may exist, as some devices have the capability to re-mark at only Layer 2 or Layer 3, while other devices can re-mark at either/both layers.

As such, UP-to-DSCP mapping allows for wireless L2 markings to affect the QoS treatment of a packet over the wired IP network (that is, until the packet reaches the nearest classification and marking policy enforcement point).

It should be further noted that nowhere in the [IEEE.802.11-2016] specification is there an intent expressed for UP markings to be used to influence QoS treatment over wired IP networks. Furthermore, [RFC2474], [RFC2475], and [RFC8100] all allow for the host to set DSCP markings for end-to-end QoS treatment over IP networks. Therefore, wireless APs MUST NOT leverage Layer 2 [IEEE.802.11-2016] UP markings as set by wireless hosts and subsequently perform a UP-to-DSCP mapping in the upstream direction. But rather, if wireless host markings are to be leveraged (as per business requirements, technical constraints, and administrative policies), then it is RECOMMENDED to pass through the Layer 3 DSCP markings set by these wireless hosts instead, as is discussed in the next section.

5.3. Upstream DSCP-Passthrough at the Wireless AP

It is generally NOT RECOMMENDED to pass through DSCP markings from unauthenticated and unauthorized devices, as these are typically considered untrusted sources.

When business requirements and/or technical constraints and/or administrative policies require QoS markings to be passed through at the wireless edge, then it is RECOMMENDED to pass through Layer 3 DSCP markings (over Layer 2 [IEEE.802.11-2016] UP markings) in the upstream direction, with the exception of CS6 and CS7 (as will be discussed further), for the following reasons:

- [RFC2474], [RFC2475], and [RFC8100] all allow for hosts to set DSCP markings to achieve an end-to-end differentiated service
- [IEEE.802.11-2016] does not specify that UP markings are to be used to affect QoS treatment over wired IP networks

- Most present wireless device operating systems generate UP values by the same method as described in Section 2.3 (i.e., by using the 3 MSBs of the encapsulated 6-bit DSCP); then, at the AP, these 3-bit markings are converted back into DSCP values, typically in the default manner described in Section 2.4; as such, information is lost in the translation from a 6-bit marking to a 3-bit marking (which is then subsequently translated back to a 6-bit marking); passing through the original (encapsulated) DSCP marking prevents such loss of information

- A practical implementation benefit is also realized by passing through the DSCP set by wireless client devices, as enabling applications to mark DSCP is much more prevalent and accessible to programmers of applications running on wireless device platforms, vis-a-vis trying to explicitly set UP values, which requires special hooks into the wireless device operating system and/or hardware device drivers, many of which do not support such functionality

CS6 and CS7 are exceptions to this passthrough recommendation because wireless hosts SHOULD NOT use them (see Section 5.1) and traffic with those two markings poses a threat to operation of the wired network (see Section 8.2). CS6 and CS7 SHOULD NOT be passed through to the wired network in the upstream direction unless the AP has been specifically configured to do that by a network administrator or operator.

5.4. Upstream DSCP Marking at the Wireless AP

An alternative option to mapping is for the administrator to treat the wireless edge as the edge of the Diffserv domain and explicitly set (or reset) DSCP markings in the upstream direction according to administrative policy. This option is RECOMMENDED over mapping, as this typically is the most secure solution because the network administrator directly enforces the Diffserv policy across the IP network (versus an application developer and/or the developer of the operating system of the wireless endpoint device, who may be functioning completely independently of the network administrator).

6. Overview of IEEE 802.11 QoS

QoS is enabled on wireless networks by means of the Hybrid Coordination Function (HCF). To give better context to the enhancements in HCF that enable QoS, it may be helpful to begin with a review of the original Distributed Coordination Function (DCF).

6.1. Distributed Coordination Function (DCF)

As has been noted, the Wi-Fi medium is a shared medium, with each station -- including the wireless AP -- contending for the medium on equal terms. As such, it shares the same challenge as any other shared medium in requiring a mechanism to prevent (or avoid) collisions, which can occur when two (or more) stations attempt simultaneous transmission.

The IEEE Ethernet Working Group solved this challenge by implementing a Carrier Sense Multiple Access/Collision Detection (CSMA/CD) mechanism that could detect collisions over the shared physical cable (as collisions could be detected as reflected energy pulses over the physical wire). Once a collision was detected, then a predefined set of rules was invoked that required stations to back off and wait random periods of time before reattempting transmission. While CSMA/CD improved the usage of Ethernet as a shared medium, it should be noted the ultimate solution to solving Ethernet collisions was the advance of switching technologies, which treated each Ethernet cable as a dedicated collision domain.

However, unlike Ethernet (which uses physical cables), collisions cannot be directly detected over the wireless medium, as RF energy is radiated over the air and colliding bursts are not necessarily reflected back to the transmitting stations. Therefore, a different mechanism is required for this medium.

As such, the IEEE modified the CSMA/CD mechanism to adapt it to wireless networks to provide Carrier Sense Multiple Access/Collision Avoidance (CSMA/CA). The original CSMA/CA mechanism used in IEEE 802.11 was the Distributed Coordination Function. DCF is a timer-based system that leverages three key sets of timers, the slot time, interframe spaces and CWs.

6.1.1. Slot Time

The slot time is the basic unit of time measure for both DCF and HCF, on which all other timers are based. The slot-time duration varies with the different generations of data rates and performances described by [IEEE.802.11-2016]. For example, [IEEE.802.11-2016] specifies the slot time to be 20 microseconds ([IEEE.802.11-2016], Table 15-5) for legacy implementations (such as IEEE 802.11b, supporting 1, 2, 5.5, and 11 Mbps data rates), while newer implementations (including IEEE 802.11g, 802.11a, 802.11n, and 802.11ac, supporting data rates from 6.5 Mbps to over 2 Gbps per spatial stream) define a shorter slot time of 9 microseconds ([IEEE.802.11-2016], Section 17.4.4, Table 17-21).

6.1.2. Interframe Space (IFS)

The time interval between frames that are transmitted over the air is called the Interframe Space (IFS). Several IFSs are defined in [IEEE.802.11-2016], with the most relevant to DCF being the Short Interframe Space (SIFS), the DCF Interframe Space (DIFS), and the Extended Interframe Space (EIFS).

The SIFS is the amount of time in microseconds required for a wireless interface to process a received RF signal and its associated frame (as specified in [IEEE.802.11-2016]) and to generate a response frame. Like slot times, the SIFS can vary according to the performance implementation of [IEEE.802.11-2016]. The SIFS for IEEE 802.11a, 802.11n, and 802.11ac (in 5 GHz) is 16 microseconds ([IEEE.802.11-2016], Section 17.4.4, Table 17-21).

Additionally, a station must sense the status of the wireless medium before transmitting. If it finds that the medium is continuously idle for the duration of a DIFS, then it is permitted to attempt transmission of a frame (after waiting an additional random backoff period, as will be discussed in the next section). If the channel is found busy during the DIFS interval, the station must defer its transmission until the medium is found to be idle for the duration of a DIFS interval. The DIFS is calculated as:

```
DIFS = SIFS + (2 * Slot time)
```

However, if all stations waited only a fixed amount of time before attempting transmission, then collisions would be frequent. To offset this, each station must wait, not only a fixed amount of time (the DIFS), but also a random amount of time (the random backoff) prior to transmission. The range of the generated random backoff timer is bounded by the CW.

6.1.3. Contention Window (CW)

Contention windows bound the range of the generated random backoff timer that each station must wait (in addition to the DIFS) before attempting transmission. The initial range is set between 0 and the CW minimum value (CWmin), inclusive. The CWmin for DCF (in 5 GHz) is specified as 15 slot times ([IEEE.802.11-2016], Section 17.4.4, Table 17-21).

However, it is possible that two (or more) stations happen to pick the exact same random value within this range. If this happens, then a collision may occur. At this point, the stations effectively begin the process again, waiting a DIFS and generate a new random backoff value. However, a key difference is that for this subsequent

attempt, the CW approximately doubles in size (thus, exponentially increasing the range of the random value). This process repeats as often as necessary if collisions continue to occur, until the maximum CW size (CWmax) is reached. The CWmax for DCF is specified as 1023 slot times ([IEEE.802.11-2016], Section 17.4.4, Table 17-21).

At this point, transmission attempts may still continue (until some other predefined limit is reached), but the CW sizes are fixed at the CWmax value.

Incidentally it may be observed that a significant amount of jitter can be introduced by this contention process for wireless transmission access. For example, the incremental transmission delay of 1023 slot times (CWmax) using 9-microsecond slot times may be as high as 9 ms of jitter per attempt. And, as previously noted, multiple attempts can be made at CWmax.

6.2. Hybrid Coordination Function (HCF)

Therefore, as can be seen from the preceding description of DCF, there is no preferential treatment of one station over another when contending for the shared wireless media; nor is there any preferential treatment of one type of traffic over another during the same contention process. To support the latter requirement, the IEEE enhanced DCF in 2005 to support QoS, specifying HCF in IEEE 802.11, which was integrated into the main IEEE 802.11 standard in 2007.

6.2.1. User Priority (UP)

One of the key changes to the frame format in [IEEE.802.11-2016] is the inclusion of a QoS Control field, with 3 bits dedicated for QoS markings. These bits are referred to the User Priority (UP) bits and these support eight distinct marking values: 0-7, inclusive.

While such markings allow for frame differentiation, these alone do not directly affect over-the-air treatment. Rather, it is the non-configurable and standard-specified mapping of UP markings to the Access Categories (ACs) from [IEEE.802.11-2016] that generate differentiated treatment over wireless media.

6.2.2. Access Category (AC)

Pairs of UP values are mapped to four defined access categories that correspondingly specify different treatments of frames over the air. These access categories (in order of relative priority from the top down) and their corresponding UP mappings are shown in Figure 2 (adapted from [IEEE.802.11-2016], Section 10.2.4.2, Table 10-1).

User Priority	Access Category	Designative (informative)
7	AC_VO	Voice
6	AC_VO	Voice
5	AC_VI	Video
4	AC_VI	Video
3	AC_BE	Best Effort
0	AC_BE	Best Effort
2	AC_BK	Background
1	AC_BK	Background

Figure 2: Mappings between IEEE 802.11 Access Categories and User Priority

The manner in which these four access categories achieve differentiated service over-the-air is primarily by tuning the fixed and random timers that stations have to wait before sending their respective types of traffic, as will be discussed next.

6.2.3. Arbitration Interframe Space (AIFS)

As previously mentioned, each station must wait a fixed amount of time to ensure the medium is idle before attempting transmission. With DCF, the DIFS is constant for all types of traffic. However, with [IEEE.802.11-2016], the fixed amount of time that a station has to wait will depend on the access category and is referred to as an Arbitration Interframe Space (AIFS). AIFSs are defined in slot times and the AIFSs per access category are shown in Figure 3 (adapted from [IEEE.802.11-2016], Section 9.4.2.29, Table 9-137).

Access Category	Designative (informative)	AIFS (slot times)
AC_VO	Voice	2
AC_VI	Video	2
AC_BE	Best Effort	3
AC_BK	Background	7

Figure 3: Arbitration Interframe Spaces by Access Category

6.2.4. Access Category CWs

Not only is the fixed amount of time that a station has to wait skewed according to its [IEEE.802.11-2016] access category, but so are the relative sizes of the CWs that bound the random backoff timers, as shown in Figure 4 (adapted from [IEEE.802.11-2016], Section 9.4.2.29, Table 9-137).

Access Category	Designative (informative)	CWmin (slot times)	CWmax (slot times)
AC_VO	Voice	3	7
AC_VI	Video	7	15
AC_BE	Best Effort	15	1023
AC_BK	Background	15	1023

Figure 4: CW Sizes by Access Category

When the fixed and randomly generated timers are added together on a per-access-category basis, then traffic assigned to the Voice Access Category (i.e., traffic marked to UP 6 or 7) will receive a statistically superior service relative to traffic assigned to the Video Access Category (i.e., traffic marked UP 5 and 4), which, in turn, will receive a statistically superior service relative to traffic assigned to the Best Effort Access Category traffic (i.e., traffic marked UP 3 and 0), which finally will receive a statistically superior service relative to traffic assigned to the Background Access Category traffic (i.e., traffic marked to UP 2 and 1).

6.3. IEEE 802.11u QoS Map Set

IEEE 802.11u [IEEE.802-11u-2011] is an addendum that has now been included within the main standard ([IEEE.802.11-2016]), and which includes, among other enhancements, a mechanism by which wireless APs can communicate DSCP to/from UP mappings that have been configured on the wired IP network. Specifically, a QoS Map Set information element (described in [IEEE.802.11-2016], Section 9.4.2.95, and commonly referred to as the "QoS Map element") is transmitted from an AP to a wireless endpoint device in an association / re-association Response frame (or within a special QoS Map Configure frame).

The purpose of the QoS Map element is to provide the mapping of higher-layer QoS constructs (i.e., DSCP) to User Priorities. One intended effect of receiving such a map is for the wireless endpoint device (that supports this function and is administratively configured to enable it) to perform corresponding DSCP-to-UP mapping within the device (i.e., between applications and the operating system / wireless network interface hardware drivers) to align with what the APs are mapping in the downstream direction, so as to achieve consistent end-to-end QoS in both directions.

The QoS Map element includes two key components:

1) each of the eight UP values (0-7) is associated with a range of DSCP values, and

2) (up to 21) exceptions from these range-based DSCP to/from UP mapping associations may be optionally and explicitly specified.

In line with the recommendations put forward in this document, the following recommendations apply when the QoS Map element is enabled:

1) each of the eight UP values (0-7) are RECOMMENDED to be mapped to DSCP 0 (as a baseline, so as to meet the recommendation made in Section 8.2, and

2) (up to 21) exceptions from this baseline mapping are RECOMMENDED to be made in line with Section 4.3, to correspond to the Diffserv Codepoints that are in use over the IP network.

It is important to note that the QoS Map element is intended to be transmitted from a wireless AP to a non-AP station. As such, the model where this element is used is that of a network where the AP is the edge of the Diffserv domain. Networks where the AP extends the Diffserv domain by connecting other APs and infrastructure devices through the IEEE 802.11 medium are not included in the cases covered by the presence of the QoS Map element, and therefore are not included in the present recommendation.

7. IANA Considerations

This document has no IANA actions.

8. Security Considerations

The recommendations in this document concern widely deployed wired and wireless network functionality, and, for that reason, do not present additional security concerns that do not already exist in these networks. In fact, several of the recommendations made in this document serve to protect wired and wireless networks from potential abuse, as is discussed further in this section.

8.1. Security Recommendations for General QoS

It may be possible for a wired or wireless device (which could be either a host or a network device) to mark packets (or map packet markings) in a manner that interferes with or degrades existing QoS policies. Such marking or mapping may be done intentionally or unintentionally by developers and/or users and/or administrators of such devices.

To illustrate: A gaming application designed to run on a smartphone or tablet may request that all its packets be marked DSCP EF and/or UP 6. However, if the traffic from such an application is forwarded without change over a business network, then this could interfere with QoS policies intended to provide priority services for business voice applications.

To mitigate such scenarios, it is RECOMMENDED to implement general QoS security measures, including:

- Setting a traffic conditioning policy reflective of business objectives and policy, such that traffic from authorized users and/or applications and/or endpoints will be accepted by the network; otherwise, packet markings will be "bleached" (i.e., re-marked to DSCP DF and/or UP 0). Additionally, Section 5.3 made it clear that it is generally NOT RECOMMENDED to pass through DSCP markings from unauthorized and/or unauthenticated devices, as these are typically considered untrusted sources. This is especially relevant for Internet of Things (IoT) deployments, where tens of billions of devices are being connected to IP networks with little or no security capabilities, leaving them vulnerable to be utilized as agents for DDoS attacks. These attacks can be amplified with preferential QoS treatments, should the packet markings of such devices be trusted.

- Policing EF marked packet flows, as detailed in [RFC2474], Section 7, and [RFC3246], Section 3.

In addition to these general QoS security recommendations, WLAN-specific QoS security recommendations can serve to further mitigate attacks and potential network abuse.

8.2. Security Recommendations for WLAN QoS

The wireless LAN presents a unique DoS attack vector, as endpoint devices contend for the shared media on a completely egalitarian basis with the network (as represented by the AP). This means that any wireless client could potentially monopolize the air by sending packets marked to preferred UP values (i.e., UP values 4-7) in the upstream direction. Similarly, airtime could be monopolized if excessive amounts of downstream traffic were marked/mapped to these same preferred UP values. As such, the ability to mark/map to these preferred UP values (of UP 4-7) should be controlled.

If such marking/mapping were not controlled, then, for example, a malicious user could cause WLAN DoS by flooding traffic marked CS7 DSCP downstream. This codepoint would map by default (as described in Section 2.3) to UP 7 and would be assigned to the Voice Access Category (AC_VO). Such a flood could cause Denial-of-Service to not only wireless voice applications, but also to all other traffic classes. Similarly, an uninformed application developer may request all traffic from his/her application be marked CS7 or CS6, thinking this would achieve the best overall servicing of their application traffic, while not realizing that such a marking (if honored by the client operating system) could cause not only WLAN DoS, but also IP

network instability, as the traffic marked CS7 or CS6 finds its way into queues intended for servicing (relatively low-bandwidth) network control protocols, potentially starving legitimate network control protocols in the process.

Therefore, to mitigate such an attack, it is RECOMMENDED that all packets marked to Diffserv Codepoints not authorized or explicitly provisioned for use over the wireless network by the network administrator be mapped to UP 0; this recommendation applies both at the AP (in the downstream direction) and within the operating system of the wireless endpoint device (in the upstream direction).

Such a policy of mapping unused codepoints to UP 0 would also prevent an attack where non-standard codepoints were used to cause WLAN DoS. Consider the case where codepoints are mapped to UP values using a range function (e.g., DSCP values 48-55 all map to UP 6), then an attacker could flood packets marked, for example, to DSCP 49, in either the upstream or downstream direction over the WLAN, causing DoS to all other traffic classes in the process.

In the majority of WLAN deployments, the AP represents not only the edge of the Diffserv domain, but also the edge of the network infrastructure itself; that is, only wireless client endpoint devices are downstream from the AP. In such a deployment model, CS6 and CS7 also fall into the category of codepoints that are not in use over the wireless LAN (since only wireless client endpoint devices are downstream from the AP in this model and these devices do not (legitimately) participate in network control protocol exchanges). As such, it is RECOMMENDED that CS6 and CS7 DSCP be mapped to UP 0 in these Wi-Fi-at-the-edge deployment models. Otherwise, it would be easy for a malicious application developer, or even an inadvertently poorly programmed IoT device, to cause WLAN DoS and even wired IP network instability by flooding traffic marked CS6 DSCP, which would, by default (as described in Section 2.3), be mapped to UP 6, causing all other traffic classes on the WLAN to be starved, as well as hijacking queues on the wired IP network that are intended for the servicing of routing protocols. To this point, it was also recommended in Section 5.1 that packets requesting a marking of CS6 or CS7 DSCP SHOULD be re-marked to DSCP 0 and mapped to UP 0 by the wireless client operating system.

Finally, it should be noted that the recommendations put forward in this document are not intended to address all attack vectors leveraging QoS marking abuse. Mechanisms that may further help mitigate security risks of both wired and wireless networks deploying QoS include strong device- and/or user-authentication, access-control, rate-limiting, control-plane policing, encryption, and other techniques; however, the implementation recommendations for such

mechanisms are beyond the scope of this document to address in detail. Suffice it to say that the security of the devices and networks implementing QoS, including QoS mapping between wired and wireless networks, merits consideration in actual deployments.

9. References

9.1. Normative References

[IEEE.802.11-2016]
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