Wireless Broadband Alliance

E2E QoS Field Trials Report

Maximizing Performance: Unveiling the Real Benefits of Wi-Fi QoS Management

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WBA undertakes programs and activities to address business and technical issues, as well as opportunities, for member companies. WBA work areas include standards development, industry guidelines, trials, certification and advocacy. Its key programs include NextGen Wi-Fi, OpenRoaming, 5G, IoT, Testing & Interoperability and Policy & Regulatory Affairs, with member-led Work Groups dedicated to resolving standards and technical issues to promote end-to-end services and accelerate business opportunities.

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1 Executive Summary

WBA E2E QoS Phase-1 Trials were conducted in three different networks and the corresponding results are summarized here. We used common residential use cases like videoconferencing applications for work-from-home scenario, real-time streaming, and cloud gaming in the trials. The trials used either the Mirrored Stream Classification Service (MSCS) or the Stream Classification Service (SCS) that have been defined within WFA QoS Management R2 specifications [1]. The trials clearly demonstrate that enabling one of these QoS mechanisms for latency-sensitive applications significantly improves the Quality-of-Experience (QoE) of these applications. This report also includes a discussion on the support required in the application layer, an optional middleware layer and in the OS layer to achieve the improved QoE for latency-sensitive applications. Deploying networks supporting these QoS mechanisms require support from OS Vendors and Application Developers (or Middleware developers). Our goal with this report is to demonstrate the benefit of enabling the QoS Mechanisms to motivate corresponding support enabling wider deployment of the QoS Mechanisms.

The rest of the report is organized as follows:

Section-2 is a high-level description of the QoS Mechanisms that have been studied in this report. Section-3, which is the bulk of this report, describes the network setup for the Trials and the corresponding results. Section-4 provides the conclusion.

2 Review of Wi-Fi QoS Management Mechanisms

IEEE 802.11e standard (and the corresponding WFA WMM specification) defines the Access Category (AC) concept which basically enables prioritization between packets belonging to flows with different QoS requirements [2, 3]. In a Wi-Fi device supporting the AC mechanism (i.e., EDCA) each AC is defined as a separate Wi-Fi interface queue with different medium access parameters. Upon the arrival of a packet, based on its User Priority (UP) value, the packet is placed in one of the AC queues. The UP-to-AC mapping defined both in the IEEE 802.11e standard as well as the WFA WMM specification. However, UP is a data link layer field and no standardized mapping with the layer 3 type of traffic field, the DSCP field had been defined in these standards. Moreover, it had been observed that packets over the Internet may have their DSCP values modified by the network resulting in a lower prioritization for the packet, e.g., set to the "default" value (00).

This is mainly due to applications not using DSCP fields as intended. When DSCP is used by applications as intended, it may not be preserved across DSCP trust domains or when transitioning between DSCP trust domains. [13].

Wi-Fi QoS Management R2 specification aims to address these two missing links in providing QoS in Wi-Fi networks [1]. The specifications define two mechanisms to set the UP values of downlink traffic: MSCS (Mirrored Stream Classification Service), and SCS (Stream Classification Service). As for the DSCP-to-UP mapping, it considers the mapping within RFC 8325 as a mandatory feature to connect the DSCP to WMM AC pipeline [4].

2.1 MSCS

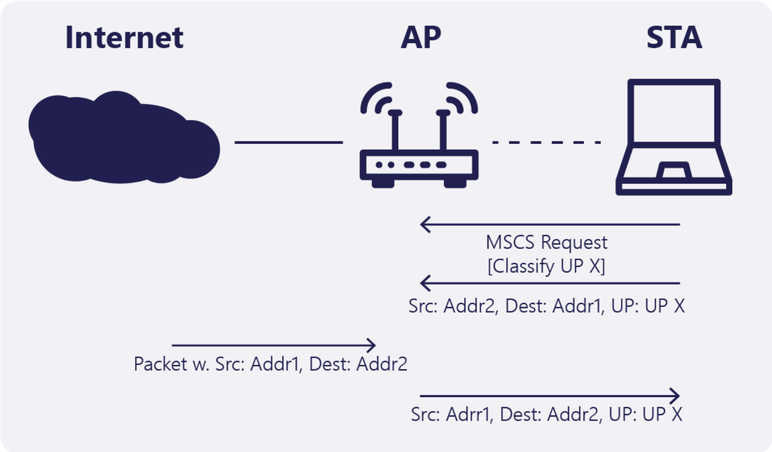

Figure 1: Messaging diagram of MSCS

MSCS has been defined in WFA QoS Management R1 specification and is initiated by STAs. An initiator STA starts a prioritization negotiation by sending an MSCS request to its AP with a UP list and stream timeout. Upon receiving this request, the AP conducts an admission control process. If the request is accepted, the AP starts observing this STA's uplink traffic and for each stream, a five-tuple is constructed based on the UP, source IP and port addresses, destination IP and port addresses. Then, the UP of the five-tuple is checked against the UP values within the MSCS request's UP list. If there is a match, this stream's five-tuple is stored in a structure called the MSCS context. Afterwards, when a downlink stream arrives with a reverse IP and port address pair of any stream within the MSCS context, AP marks packets of this stream with the same UP. So, in essence, for each stream prioritized in the uplink direction, its corresponding downlink stream is also given the same priority.

2.2 SCS

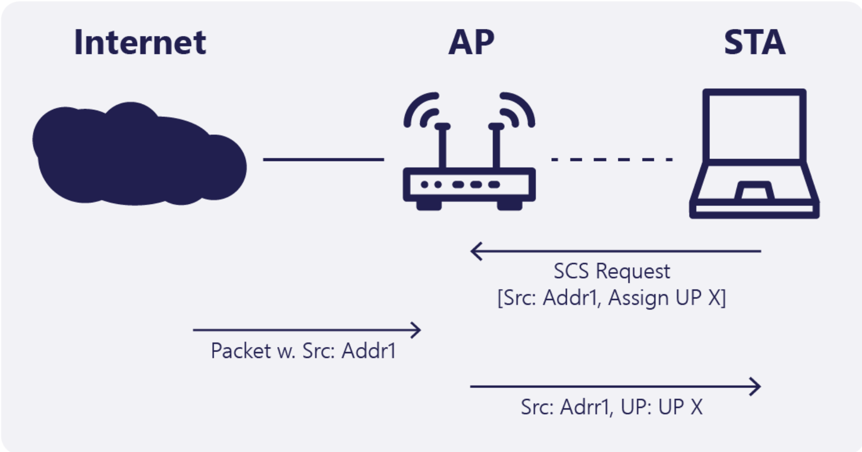

Figure 2: Messaging diagram of SCS

At its core, SCS is like MSCS, targeting the downlink traffic and setting UP values of downlink packets based on the request of a STA. In SCS, the prioritization negotiation starts via an SCS request sent by the STA. Unlike the MSCS request, SCS request states an explicit downlink stream defined by a five-tuple (i.e., source IP and port addresses, destination IP and port addresses, and transport layer protocol) specified in a traffic class definition. In such five-tuple stream definitions, any one of these fields can be omitted (except the destination IP) to define a broader stream. Afterwards, upon reception of any packets matching this five-tuple, the AP shall mark the UP values of these packets as defined by the SCS request. When a stream matches multiple stream definitions, AP should decide based on the granularity of the classification rule (i.e., a five-tuple classification is more granular than a classification with only the destination IP address).

This explicit nature makes SCS easier to implement than MSCS and makes it applicable to uplink/downlink traffic couples with different IP and port addresses. With SCS, UPs for uplink and downlink can also be different depending on the application whereas in MSCS, UP will be the same (i.e., symmetric), for UL and DL traffic. Like MSCS, SCS also has an admission control process. The AP can reject any request that can degrade the network performance. This can be more applicable to very broad stream classifications (i.e., streams where only the destination address is defined).

3 Key Use Case Testing Results

Three WBA members - Airties, Intel, and Zebra - conducted several tests to present the performance improvement of the two Wi-Fi QoS mechanisms: MSCS and SCS. These tests are grouped in terms of their use-cases: Audio/Video/Data conferencing, Cloud gaming, and Live streaming.

3.1 Audio/Video/Data Conferencing

3.1.1 Intel – Microsoft Teams (MSCS tests)

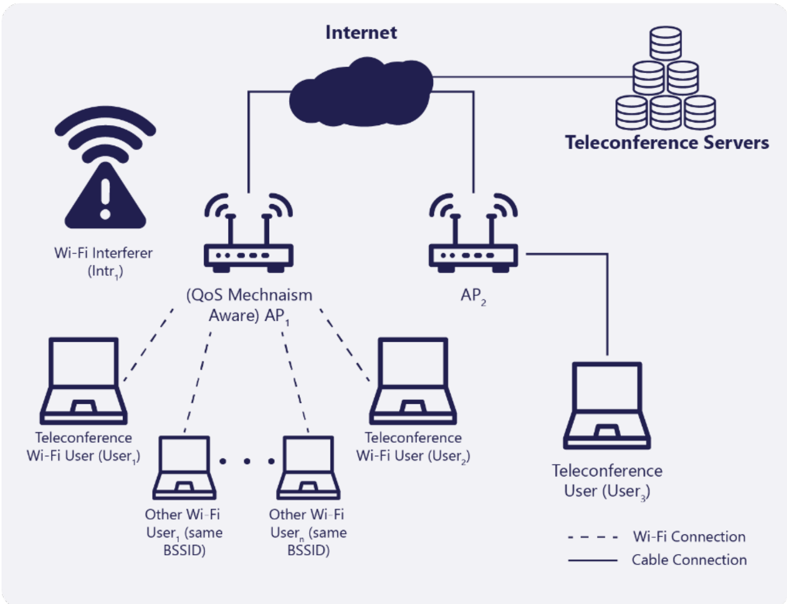

Figure 3 Trial Setup for Microsoft Teams

Figure-3 describes the setup used for this Trial. A Teams meeting is setup with three users ($User_1$, $User_2$ and $User_3$). $User_1$ has MSCS setup with the QoS Mechanism Aware AP (AP_1). AP_1 is operating in the 5GHz band over a 20 MHz Channel 48. $User_2$ is not QoS-aware (has no support for MSCS and does not use DSCP tags in the payload corresponding to the Teams application). Both User1 and $User_2$ are associated with AP_1 (Test BSS). $User_3$ is associated with AP_2 (not QoS Mechanism Aware) and is used primarily to compare the video streams from $User_1$ and $User_2$ (using a side-by-side display of the video streams). Associated with AP_1 are a set of IxChariot Users (IxChariot $User_1$ through IxChariot $User_4$). All the STAs associated with AP_1 are placed to have an RSSI of -45 dBm for AP_1. The Other Wi-Fi User STAs generate Best-Effort IxChariot traffic to saturate the Wi-Fi Channel. There is also an interferer BSS operating in the same band/channel as the Test BSS. Key Performance Indices are obtained using the Call Health feature of Microsoft Teams application.

The Wi-Fi STA labeled User1 is also executing ICPS which is a middleware between the Microsoft Teams application and the Wi-Fi stack. The responsibility of ICPS to set up MSCS with AP1 for the Teams Application and to tag the payload (RTP packets) corresponding to the Teams Application with corresponding DSCP tags

Note that the Call Health screen snapshots are periodically sampled, and an offline tool does screen scraping to extract the performance indices to derive statistics.

Table 1 KPI with and without MSCS for Microsoft Teams

Microsoft Teams – Call Health Metrics	QoS Management Client MSCS enabled, ICPS* active	Regular Client No MSCS enabled, No ICPS
Round Trip Time, Average	107 ms	362 ms
Round Trip Time, Min	86 ms	136 ms
Round Trip Time, Max	144 ms	1191 ms
Frame Rate, Average	27.2	20.9
Frame Rate, Min	21.6	11.8
Frame Rate, Max	29.9	26.2

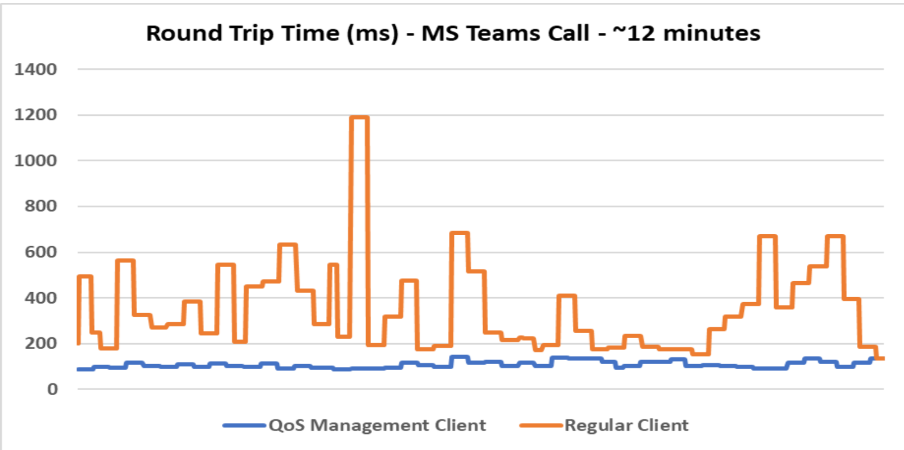

Figure 4: Instantaneous KPI values for the duration of the Trial (300 seconds)

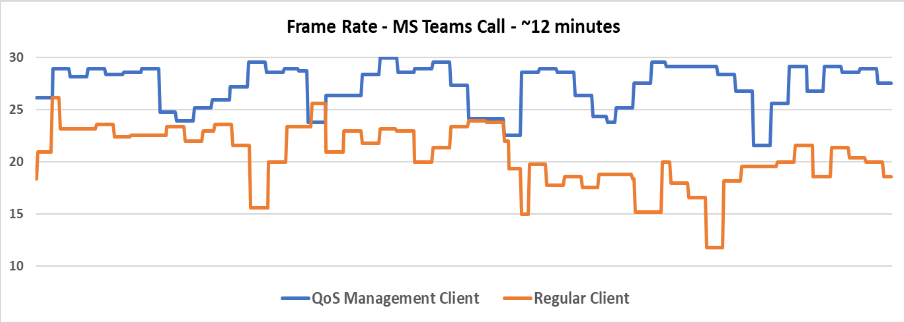

Figure 5: Frame Rate change with and without MSCS enabled

3.1.2 Zebra – Zoom Screen Share (SCS Tests)

In this trial, Zoom was utilized to evaluate the video conferencing use case. The initial test focused on the screen-sharing function, while the subsequent test evaluated video capabilities.

Figure 6 describes the setup used for this trial. Five STAs are associated with the QoS Mechanism Aware AP (AP_1) where the RSSI level of $User_4$, $User_5$, and $User_6$ are set as -45 dBm; the RSSI level of $User_1$ and $User_2$ are set as -65 dBm. The Wi-Fi network is a 5 GHz network with 80 MHz channel bandwidth.

A Zoom session has started where $User_3$ is the presenter and $User_1$ and $User_2$ are also participating in the call. The three other Wi-Fi STAs generate iperf traffic to saturate the Wi-Fi channel. Each of them opens 10 TCP flows each with 20 Mbps rate towards another STA (i.e., $User_3$ to $User_4$; $User_4$ to $User_5$; and $User_5$ to $User_6$). KPIs are obtained using the application status feature of Zoom application. Among all the STAs, only $User_1$ has SCS setup with AP_1 to request downlink flows to be sent over either AC_VI or AC_VO (test parameter) queues while $User_1$ STA does not do uplink tagging (i.e., uplink packets are put to the AC_BE queue).

The test lasted for a duration of two minutes, during which Twitch statistics were recorded from the outset. After 30 seconds, background traffic using iperf Best Effort (BE) was introduced by $User_4$, $User_5$, and $User_6$ devices, as depicted in the figure. This introduction of background traffic led to airtime saturation, with interference levels reaching approximately 90%.

All STAs connected to AP1 are Zebra's Wi-Fi 6E devices: $User_1$ and $User_2$ use Zebra's ET65 tablets whereas $User_4$, $User_5$, and $User_6$ are Zebra's TC58 and TC53 mobile computers [5, 6, 7].

In the screen-sharing scenario, Zoom operates at a fixed resolution, maintaining consistency regardless of network conditions. Mirroring the setup depicted in the figure above, $User_1$ had Screen Capture Service enabled, whereas $User_2$ did not. $User_3$, using a laptop, acted as the meeting presenter. During the first test, screen sharing was activated for $User_3$, with $User_1$ and $User_2$ joining the same meeting. KPIs were extracted from Zoom's call statistics.

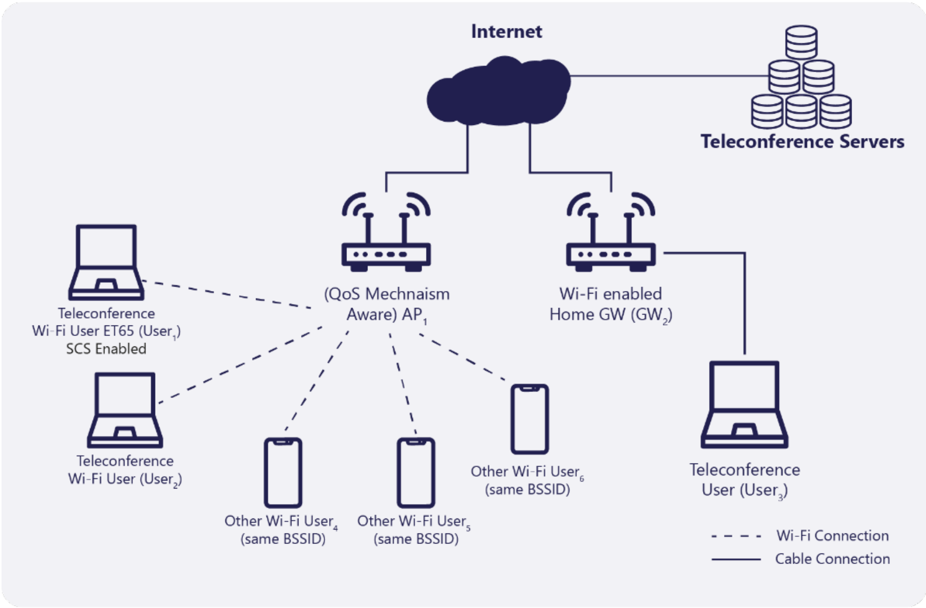

Figure 6: Trial Topology for Zebras Video Conference tests

Figure 7: Zebra STAs used In Zebra trials, ET65, TC58, and TC53

3.1.2.1 Latency

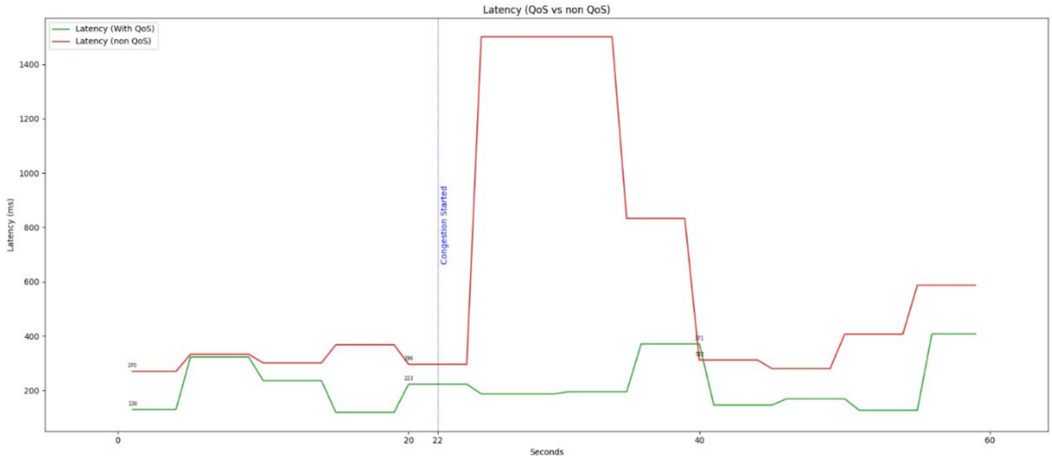

Figure 8: Latency Variation through the Trial with and without SCS enabled

3.1.2.2 Frames Per Second

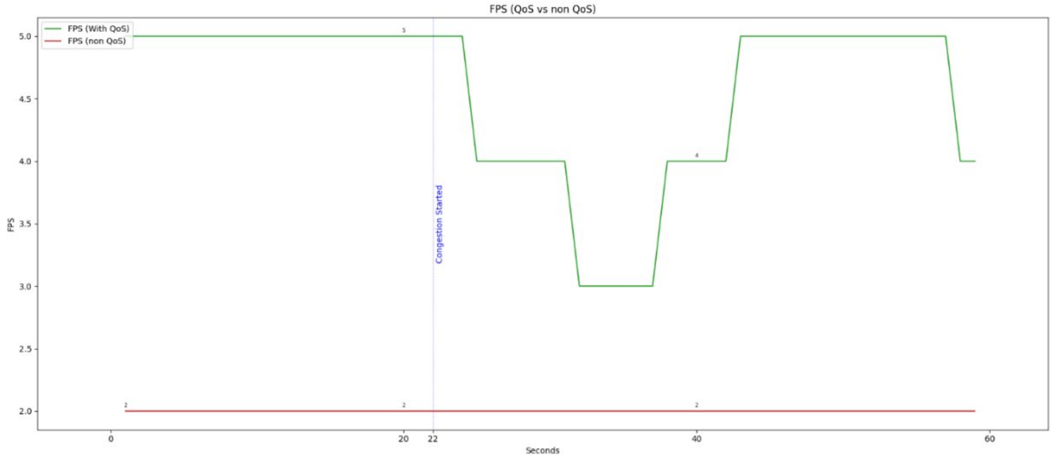

Figure 9: Frames per second variation through the Trial with and without SCS enabled

3.1.3 Zebra – Zoom Video Conference (SCS Tests)

In the second test, video functionality was activated for $User_3$ in place of screen sharing. The tests were executed using the same topology and methodology as the previous video conference scenario.

3.1.3.1 Zoom Video - Latency

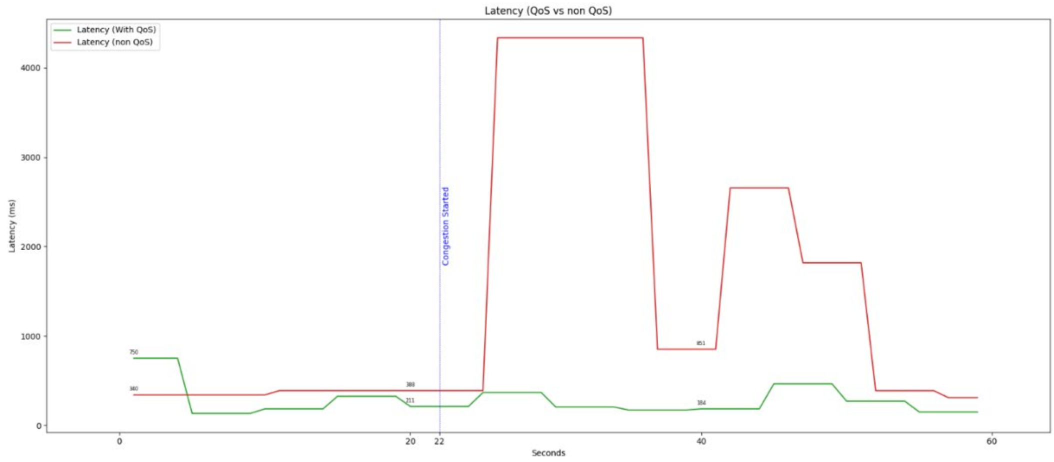

Figure 10: Latency Variation through the Trial with and without SCS enabled

3.1.3.2 Zoom Video - Jitter

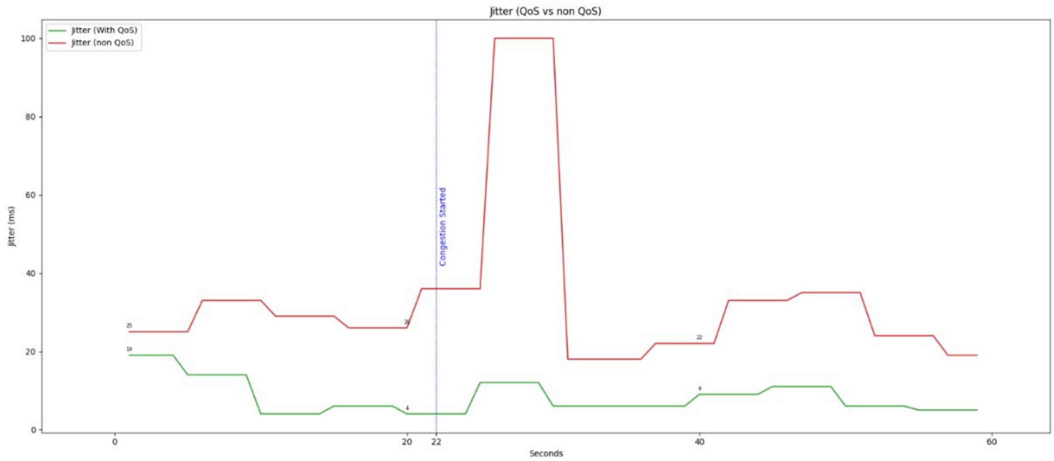

Figure 11: Jitter variation through the Trial with and without SCS enabled

3.1.3.3 Zoom Video – FPS

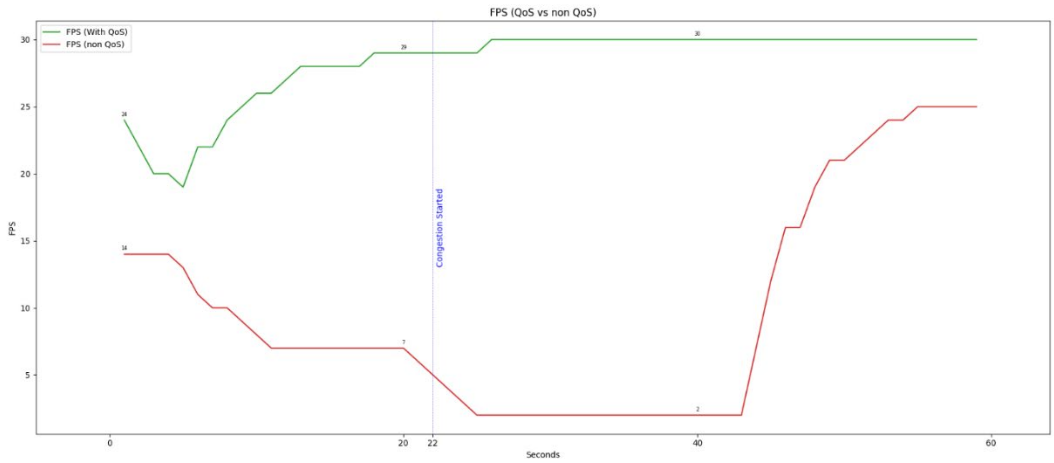

Figure 12: Frames per second variation through the Trial with and without SCS enabled

3.2 Cloud Gaming

3.2.1 Airties – Geforcenow Cloud Gaming – (SCS Tests)

In this Trial, SCS is used as the QoS mechanism to improve the QoE of Nvidia Cloud Gaming application, Geforcenow with the game Cyberpunk 2077.

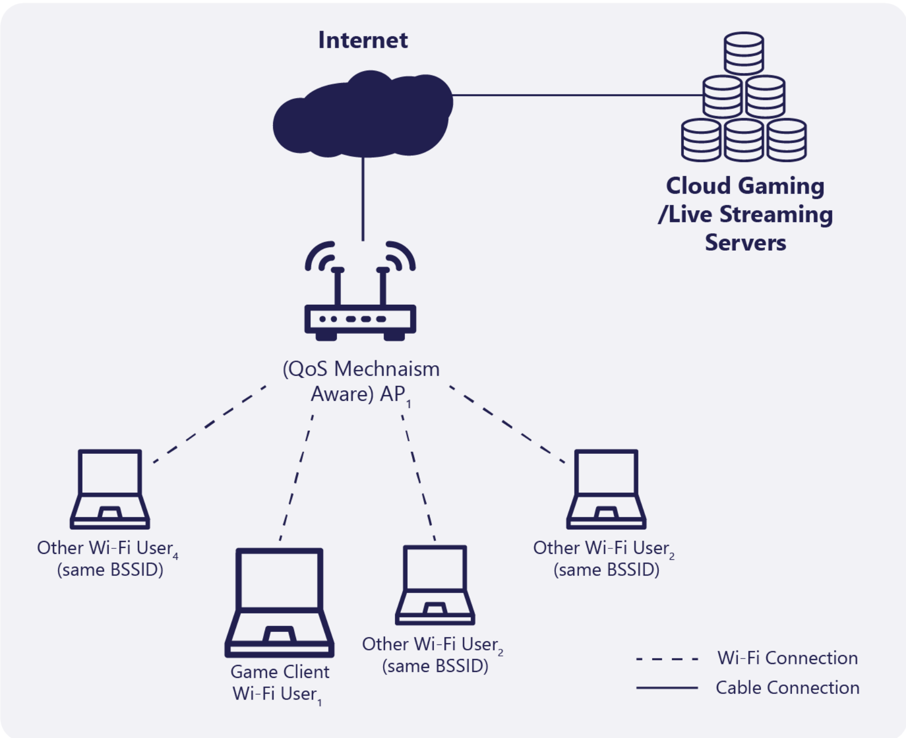

Figure 13: Trial Topology for Airties's Geforcenow tests

Figure 13 describes the setup used for this trial. Four STAs are associated with the QoS Mechanism Aware AP (AP_1) where the RSSI level of $User_2$, $User_3$, and $User_4$ are set as -45 dBm; the RSSI level of $User_1$ is a test parameter (close: -45 dBm, mid: -60 dBm). The Wi-Fi network is a 5 GHz network with 80 MHz channel bandwidth.

A Cyberpunk 2077 game session has started over Geforcenow from $User_1$. The three other Wi-Fi STAs generate iperf traffic to saturate the Wi-Fi channel. Each of them opens 10 TCP and 1 UDP flows each with 9 Mbps rate towards another STA (i.e., $User_2$ to $User_3$; $User_3$ to $User_4$; and $User_4$ to $User_2$). KPIs are obtained using the application status feature of Geforcenow application. Among all the STAs, only $user_1$ has SCS setup with AP_1 to request downlink flows to be sent over either AC_VI or AC_VO (test parameter) queues while $User_1$ STA also puts uplink packets with to the same AC queue.

As seen in Figure 14, enabling SCS for either AC_VI or AC_VO reduces the E2E latency of the cloud gaming session considerably in both close (i.e., -45 dBm) and mid (i.e., -60 dBm) scenarios while the improvement is more profound in "close" scenario from a P99 value of 180 to 35 ms.

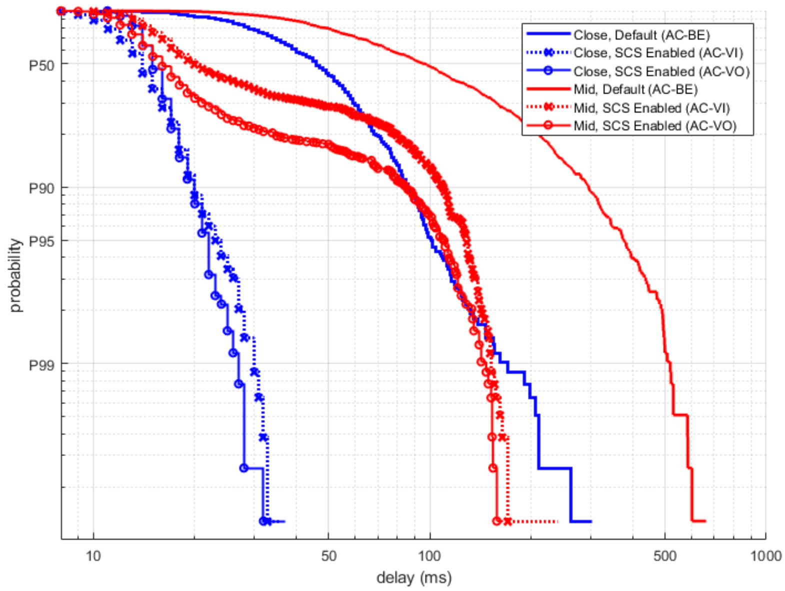

Figure 14: Airties's Cloud gaming tests, Application E2E latency Close: $User_1$ at -45 dBm, Mid: $User_1$ at -60 dBm to AP_1

Figure 15 shows the total time spent in different resolutions for different prioritization levels. In both close and mid scenario, enabling SCS either for AC_VI or AC_VO also keeps the resolution from being reduced to 540p or 720p. Therefore, we can observe that using SCS to set cloud gaming packets to pass through AC_VI or AC_VO queues improves the E2E latency as well as prevent any deterioration in the resolution.

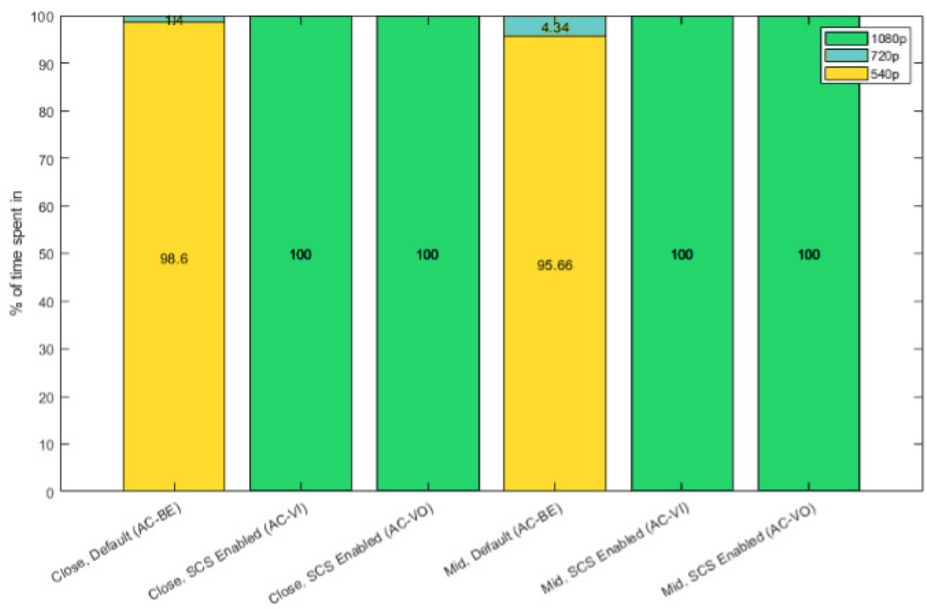

Figure 15: Airties's cloud gaming tests, Time spent in each resolution; Close: $User_1$ at -45 dBm, Mid: $User_1$ at -60 dBm to AP_1

3.2.2 Intel – Geforcenow Cloud Gaming (Rocket League):

The setup for this Use Case is the same as the one described in Section 3.1.1 The number of Other Wi-Fi Users is set to 2 in this case. There is only $User_1$ in this case, and the test is executed with $User_1$ without MSCS enabled and the corresponding KPIs collected. The test is then re-executed with $User_1$ with MSCS enabled the corresponding KPIs collected. KPI collection is based on periodic sampling (every second) of the application-specific KPI screen and performing offline screen scraping to collect the data for statistics.

Table 2 Trial Results with MSCS and Without MSCS (Rocket League)

Rocket League Game Health Metrics	QoS Management Client MSCS enabled, ICPS*active	Regular Client No MSCS enabled, No ICPS
Instantaneous Latency**Average	115 ms	177 ms
Latency, Min (Average)	38 ms	41 ms
Latency, Max (Average)	203 ms	947 ms

Latency as defined in the application documentation: the time, in milliseconds, that it takes for information to get from client to server and back to the client, also displayed as your Ping on the scoreboard. *High (above 100) or inconsistent values may be caused by local connection or routing issues*

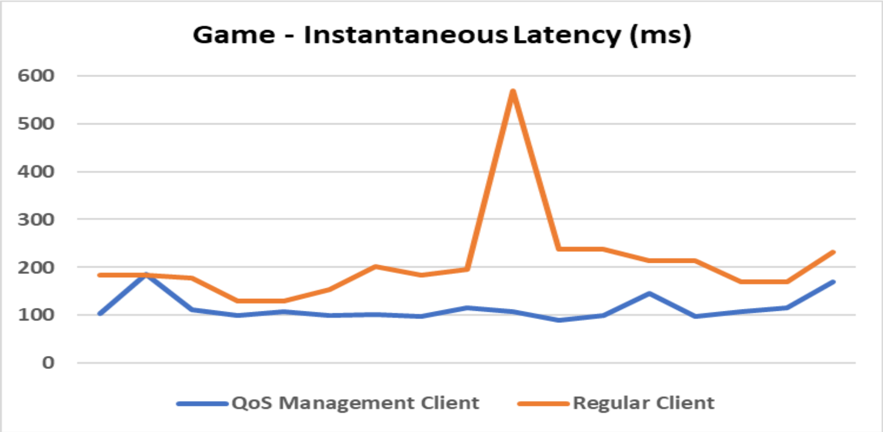

Figure 16: Trial Results with MSCS and Without MSCS (Rocket League)

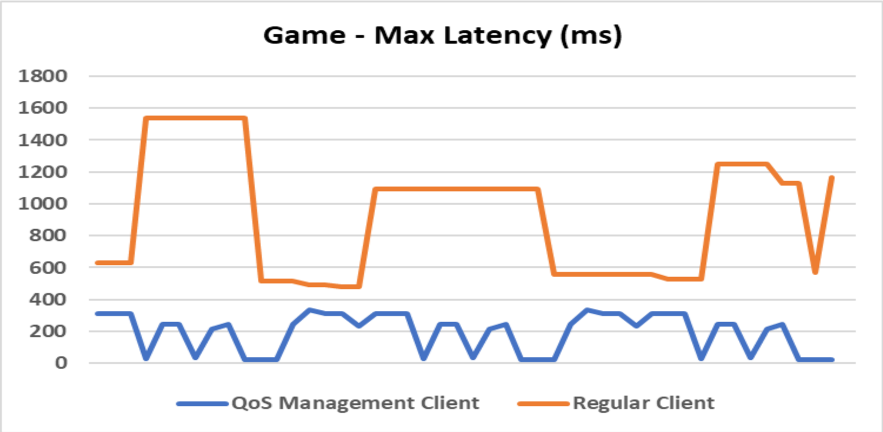

Figure 17: Trial Results with MSCS and Without MSCS (Rocket League)

3.3 Live Streaming

3.3.1 Airties – Twitch (SCS Tests)

In this Trial, SCS is used as the QoS mechanism to improve the QoE of Twitch live streaming application where a stream of a popular streamer has been selected.

The setup for this Use Case is the same as the one described in Section 3.2.1. KPIs are obtained using Twitch's video details feature.

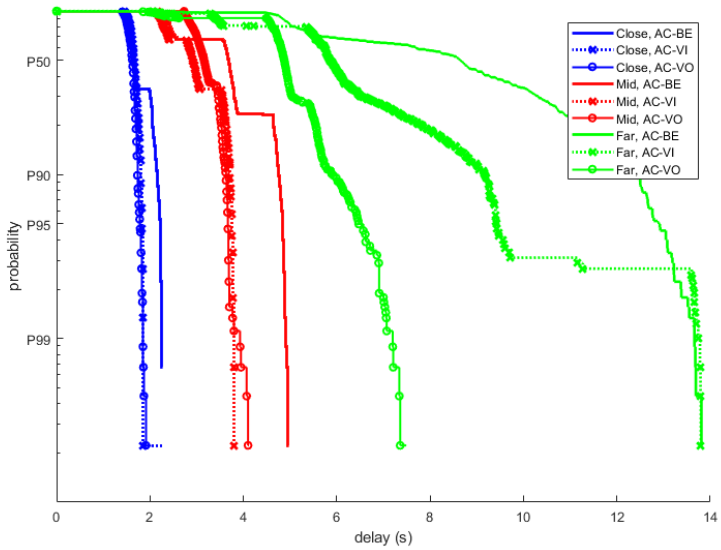

Figure 18: Twitch Application, latency-to-streamer for different prioritization levels; Close: $User_1$ at -45 dBm, Mid: refers to $User_1$ at -60 dBm, Far: $User_1$ at -75 dBm to AP_1

As seen in Figure 18, enabling SCS for either AC_VI or AC_VO reduces the E2E latency of the live streaming flow considerably in all three scenarios: close (i.e., -45 dBm), mid (i.e., -60 dBm), and far (i.e., -75 dBm). The improvement is more observable in "mid" scenario and especially in the "far" scenario.

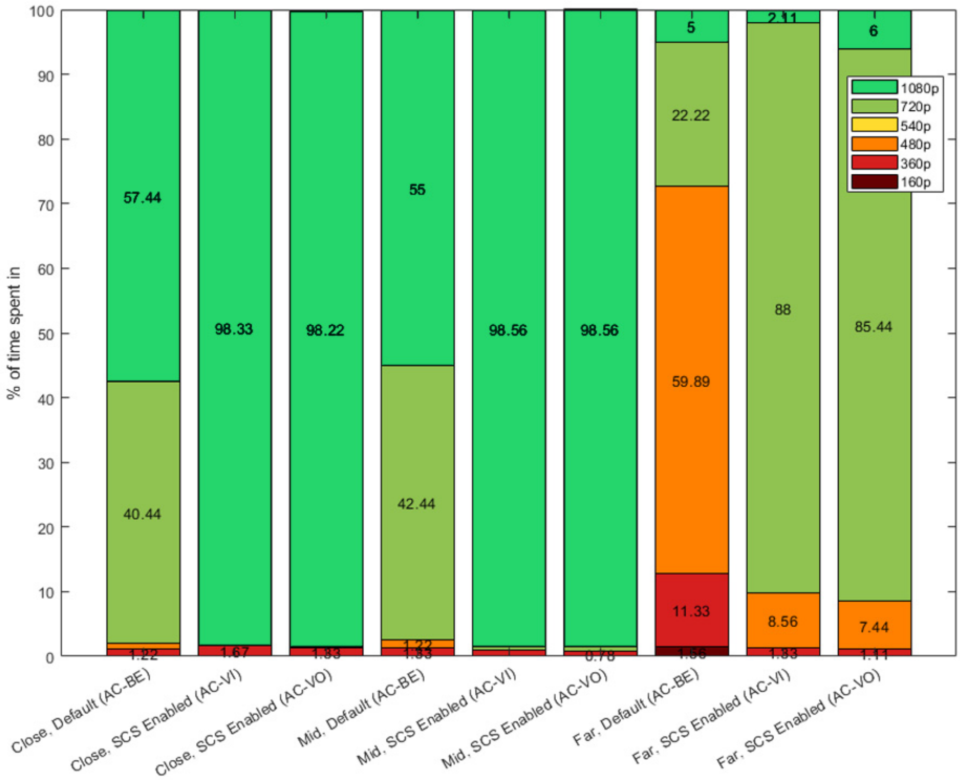

Figure 19: Twitch Application, Time spent in each resolution for different prioritization levels; Close: $User_1$ at -45 dBm, Mid: refers to $User_1$ at -60 dBm, Far: $User_1$ at -75 dBm to AP_1

Figure 19 shows the total time spent in different resolutions for different prioritization levels. Here both the "close" and "mid" scenarios only yield some improvement from 720p to the application's native 1080p. On the other hand, in the "far" scenario, enabling SCS considerably mitigates a sharp drop in resolution from 720p to 480p. Therefore, we can observe that using SCS to set live streaming packets to pass through AC_VI or AC_VO queues improves the E2E latency as well as reduces deterioration in the resolution.

3.3.2 Zebra – Twitch (SCS Tests)

In this Trial, SCS is used as the QoS mechanism to improve the QoE of Twitch live streaming application where a stream of a popular streamer has been selected.

The setup for this Use Case is the same as the one described in Section 3.1.2 KPIs are obtained using Twitch's video details feature. Both devices were connected to a QoS enabled AP and were streaming the same Twitch content. The SCS session was manually established between $User_1$ and the AP_1. No uplink tagging was applied to the uplink data flow.

3.3.2.1 Resolution

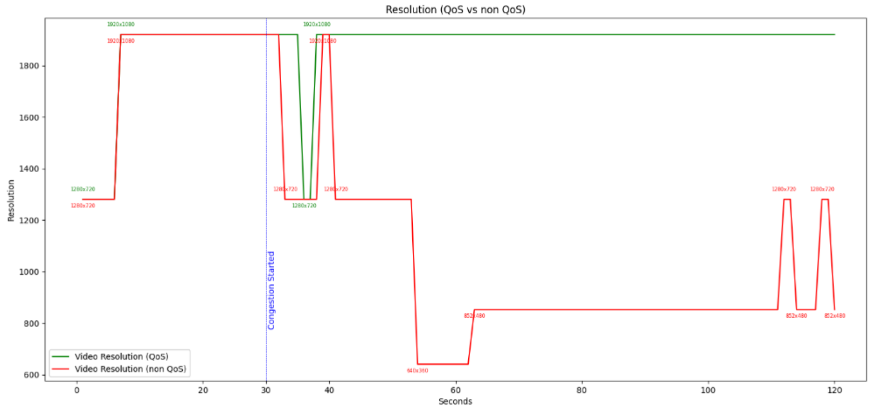

Figure 20: Frame Resolution variation through the Trial with and without SCS enabled

3.3.2.2 Latency to Broadcaster

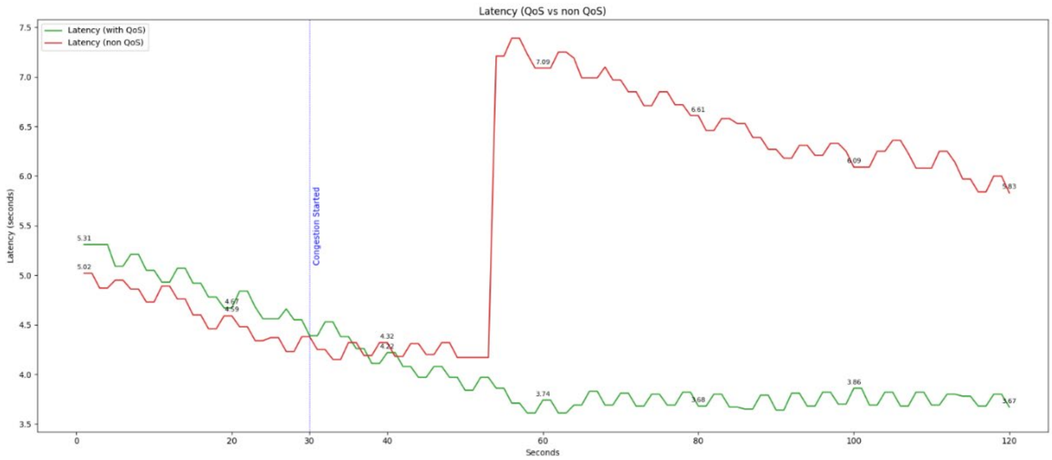

Figure 21: 'Latency to Broadcaster' variation through the Trial with and without SCS enabled

Live streaming applications measure "latency to broadcaster" in seconds, indicating the delay from video capture to display. They use a chunk-based system for video transmission, adding inherent latency based on chunk size. Real-time services, like videoconferencing, send frames individually to minimize delay. Buffers in live streaming help manage jitter but add latency, which can be adjusted based on network conditions.

3.3.2.3 Bitrate

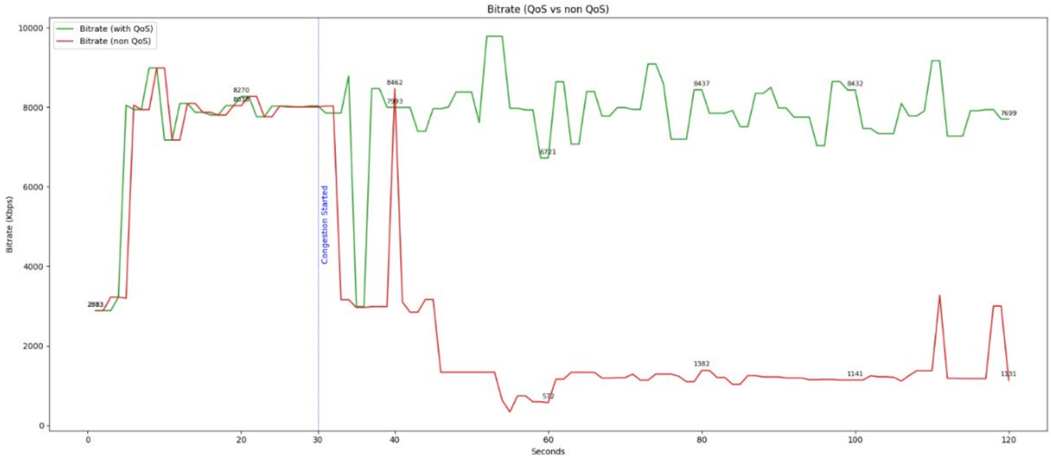

Figure 22: Bit Rate variation through the Trial with and without SCS enabled

3.3.2.4 Frames Per Second (FPS)

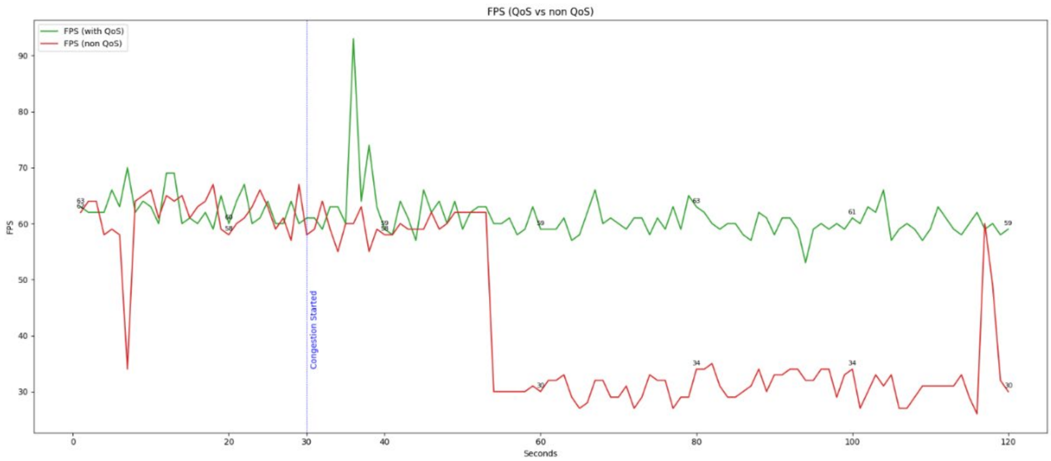

Figure 23: Frame Rate Variation through the Trial with and without SCS enabled

4 Conclusion

In providing E2E QoS/QoE to applications over the Internet, Wi-Fi networks play a critical part since a considerable portion of latency related issues occur at the wireless last mile; the Wi-Fi networks [8]. The EDCA mechanism introduced in WFA's WMM certification program provides a framework to address such issues by prioritizing packets of latency-sensitive flows over latency-insensitive flows. The DSCP field within the networking layer header of each IP packet defines the QoS-criticality of each packet which can be used by the AP for prioritization purposes. However, the DSCP field had been defined to be preserved only within a single network and is often defaulted to standard service class (i.e., Default Forwarding) when transitioning between networks [9]. recent studies show that only 2 - 8.5% of Internet traffic is observed to be carrying correct DSCP values [10].

WFA's QoS Management certification introduces two mechanisms, MSCS and SCS which allow Wi-Fi STAs to negotiate with their APs and set the DSCP fields of incoming downlink packets according to the flow's requirements. Based on the three trials and corresponding results discussed in this document, enabling MSCS or SCS for streams that are latency-sensitive results in significant improvement in the performance of the corresponding application in terms of latency, bit rate, and resolution Therefore we can summarize that the end user QoE of such applications will also increase when these mechanisms are actively used.

As highlighted in the setup for each of the trials, the performance gain is achieved with additional support at each layer – applications are QoS-aware, the OS supports the relevant QoS-mechanisms and exposes the support to the application layer. To enable wide deployment of the QoS Mechanisms that provide the improved performance we need the following:

(a) The OS exposes an API to the Wi-Fi layer to facilitate setup of the pertinent QoS mechanism from the application layer.
   a. Microsoft Windows OS supports MSCS with the WiFiCx v1.2 in Windows 11 24H2 – builds 26100+ [11].
   b. Android OS supports SCS with Android 14 and supports SCS with QoS characteristics with Android 15. Both supports are limited to system applications meaning third party applications cannot manage the usage of the SCS mechanism.
   c. Linux OS support for SCS and MSCS is in wpa supplicant and hostapd v2.10
(b) Either the application or some middleware should be able to use these API to the Wi-Fi layer to set up the desired QoS mechanism (i.e., MSCS or SCS).
(c) The QoS mechanism should be able to differentiate the latency-sensitive payload from the non-latency-sensitive payload (i.e., payload classification) and apply the selected QoS mechanism to the latency-sensitive payload appropriately. This can be achieved via two alternatives (Figure 24):

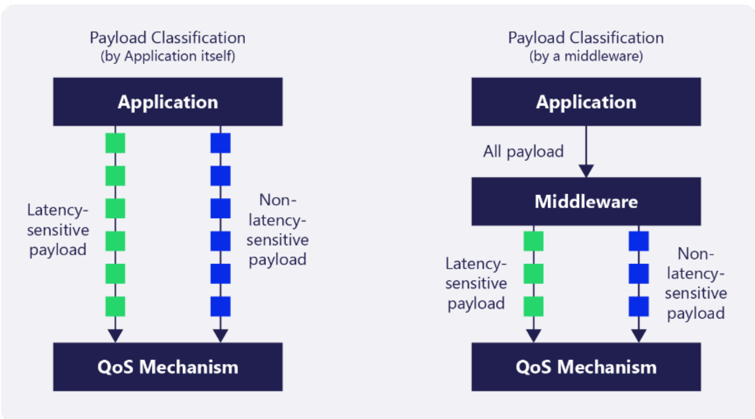

Figure 24: Payload classification alternatives

   a. the Application can classify the latency-sensitive payload with DSCP tags

b. Some middleware between the application layer and the network layer can classify the latency-sensitive payload with DSCP tags. This middleware approach is required to support applications that are not QoS-aware.

(d) Admission Control logic in the AP to throttle the number of streams requiring QoS depending on the operation conditions and is implementation specific.

With this Trial Report, our goal is

(a) to provide a compelling proof-point that there is significant Quality of Experience improvement when QoS Mechanisms are enabled for latency-sensitive applications when there are a few latency-sensitive applications in the network,
(b) to motivate OS vendors, middleware and application developers to enable corresponding support, and
(c) to have Service Providers deploy network elements with corresponding support for their customers.

5 Future Work

Building on the findings from Phase-1 [12], the next phase of trials aims to broaden the scope and deepen understanding of Wi-Fi QoS mechanisms under varied and more demanding conditions. Key areas of future exploration include:

- extending the topology from single AP based BSS to Mesh topology,
- extend the trial to measure the impact of RSSI, channel load, hidden nodes, etc., on QoS for latency-sensitive applications,
- extending the trial to understand the impact of enabling QoS for a latency-sensitive stream on one or more latency-sensitive streams in the network for which QoS is not enabled; and how are latency-insensitive streams impacted
- determine the effectiveness of QoS Mechanisms when the traffic mix in the network is predominantly latency-sensitive
- adding more challenging use cases (e.g., AR/VR applications where uplink traffic and downlink traffic have very different characteristics)
- ESS deployments (stadiums, hotels, etc.) where the Wi-Fi network is managed
- L4S over Wi-Fi Links
- Enabling additional QoS optimizing mechanisms from IEEE802.11 and/or Wi-Fi Alliance QoS Management Technical Specification (e.g. SCS with QoS Characteristics, DSCP Policy, etc.)
- Extend the Trials to include enhanced medium access mechanisms like triggered access with SCS Restricted-Target Wake Time (R-TWT), Multi-Link Operation (MLO)

6 References

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Acronyms and Abbreviations

Acronym / Abbreviation	Definition
WBA	Wireless Broadband Alliance
NGH	Next Generation Wi-Fi
AP	Access Point
TWT	Time Wake Time
ISM	Industrial, Scientific, and Medical
ITU	International Telecommunications Union
OFDM	Orthogonal Frequency Division Multiplexing
Traditional Wi-Fi	Wi-Fi standard in earlier day such as Wi-Fi 4, 5 and 6
BSS	Basic Service Set
PHY	Physical Layer
MAC	Media Access Control
DTIM	Delivery Traffic Indication Map
RAW	Restricted Access Window
LBT	Listen Before Talk
QOS	Quality Of Service
NDP	Null Data Protocol
OTA	Over The Air
OWE	Opportunistic Wireless Encryption
DPP	Device Provisioning Protocol
MCS	Modulation Coding Scheme
LPWAN	Low Power, Wide Area Networks
WFA	Wi-Fi Alliance

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