

How Network Constraints Can Affect Video Calls: The Impact on 4 Video Conferencing Applications

The increasing reliance on remote communication tools has made the performance of audio and video conferencing applications critical. Namely, it's essential to understand how video conferencing applications work in a dynamic environment. For example, a person might start a video call in the office, continue the call while driving to pick up their children from school, and finalize the meeting in a local cafe. Stable and good application behavior at different network constraints is a must.

There are several types of network constraints that should be taken into consideration when talking about dynamic networks that can affect video calls and impact user experience:

- Limited bandwidth
- Packet loss
- High RTT delay
- Jitter
- Disconnections

To gain a deeper understanding of how leading video conferencing applications respond to dynamic networks and perform at different network limitation constraints, we conducted an in-depth analysis of 4 popular video conferencing applications—Google Meet, Slack, Jitsi, and Cisco Webex.

During this research, our aim was to create 17 different network constraint scenarios, identify which network limitation has the highest impact on app performance, and which impacts audio or video data more. Test scenarios and technical information are available in the appendix.

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Executive Summary

With an increased reliance on communication tools, the performance of audio and video conferencing applications under varying network conditions is critical to user experience. This whitepaper presents the findings of a comprehensive performance test conducted on 4 popular audio and video apps—Google Meet, Slack, Jitsi, and Cisco WebEx—evaluating their behavior under 17 different network constraint scenarios, including changes in bandwidth, jitter, delay, RTT, and packet loss and how these constraints affect app performance.

We found that the most challenging network constraint combinations led to disconnections in at least one of the tested applications, while other test scenarios either failed to handle the call altogether or performed at a barely acceptable level:

- Variable Bandwidth
- Variable Bandwidth with Constant Jitter
- Variable Bandwidth with Constant Packet Loss
- Variable Bandwidth with Constant RTT
- Variable Packet loss with Constant Delay
- Variable Jitter with Constant Packet Loss
- Variable Bandwidth, Delay and Jitter with Constant Packet Loss
- Variable Delay and Jitter with Constant Packet Loss

During our evaluation, we assessed which network constraints had the highest impact on different quality metrics.

Video image quality

- Variable Jitter with Constant Bandwidth
- Variable Bandwidth, Delay and Jitter with Constant Packet Loss
- Variable Delay and Jitter with Constant Packet Loss

Video fluidity

- Variable Jitter with Constant Packet Loss
- Variable Packet Loss with Constant Delay
- Variable Delay with Constant Jitter
- Variable Bandwidth, Delay and Jitter with Constant Packet loss

Audio quality

- Variable Bandwidth with Constant Packet Loss
- Variable Packet Loss with Constant Bandwidth
- Variable Delay with Constant Packet Loss

Audio delay

- Variable Bandwidth with Constant Jitter
- Variable Bandwidth, Delay and Jitter with Constant Packet Loss
- Variable Bandwidth

The least impact on audio and video quality was seen in the Variable Queue Size scenario.

Before diving into a deeper analysis, it's important to first establish a baseline for comparison. Let's review the audio and video metrics and examine how the tests performed under optimal conditions—specifically, in an unconstrained network environment. This baseline will help us better understand the impact of the network scenarios with higher constraints that we'll analyze next.

Methodology

Test Scenarios

Each test is 300 seconds long and consists of 60 seconds long limitation periods. In the middle of the test, from 120 to 180 seconds, the limitation is higher, and then decreases to the previous level. This gives us an opportunity to check the app behavior, whether it recovers, and how it performs. Two user group calls were tested on OS version Windows 11 Pro 22H2 (OS Build 22621.819). Tests were done between November–December 2022.

Our approach was to test each application at baseline to see the app performance on a non-limited network. Our aim was to create different limitations constraints, check which network limitation has the highest impact on app performance and which impacts more audio or video data. Read more about how we test audio and video conferencing applications [here](#).

The following scenarios were tested:

1. Baseline (uncapped)
2. Variable Bandwidth
3. Variable Bandwidth with Constant Packet Loss
4. Variable Bandwidth with Constant Jitter
5. Variable Bandwidth with Constant RTT
6. Variable Packet loss with Constant Bandwidth
7. Variable Packet loss with Constant Jitter
8. Variable Packet loss with Constant Delay
9. Variable Delay with Constant Bandwidth
10. Variable Delay with Constant Packet Loss
11. Variable Delay with Constant Jitter
12. Variable Jitter with Constant Bandwidth
13. Variable Jitter with Constant Packet Loss
14. Variable Jitter with Constant Delay
15. Variable Queue Size
16. Variable Bandwidth, Delay and Jitter with Constant Packet Loss
17. Variable Delay and Jitter with Constant Packet Loss
18. Variable Delay and Jitter

Application versions:

- Google Meet (Chrome 108)
- Slack 4.29.149
- Jitsi (Chrome 108)
- Cisco Webex 42.11.0.24187

Metrics

- **POLQA:** A full reference audio quality measurement standard that contains a model to predict speech quality by analyzing digital speech signals.
- **Audio delay:** A part of the POLQA algorithm. Each sample sent during the call is compared to the one received, generating the average audio delay value for every sample. This metric describes the difference in time when the receiver audio sample is received after it was sent. The delay is measured in ms (milliseconds). The value is returned along with POLQA after each sample is processed.
- **Video Delay:** Used to show the image delay from the moment the image (part of the video) is sent and the moment it is received. The algorithm uses color markers to generate differences in frames which is how the delay is measured. Video delay is measured in ms (milliseconds) or s (seconds) depending on the value. It is gathered from the delay video. The color markers are used to measure it. Sometimes FPS QR codes are also used to create more results. Read more about video latency analysis in our [blog article](#).
- **Frames per second (FPS) or frame rate:** This metric is gathered from the Receiver video. The script gives a value for each second. The algorithm splits the whole video into individual frames. The values are calculated from the QR marker on the video we are using. Each frame has its own QR value.
- **Video Multimethod Assessment Fusion (VMAF):** A full-reference video quality metric, developed by Netflix, that predicts subjective quality by combining multiple elementary quality metrics. It combines human vision modeling with machine learning. VMAF values are based on how long each stream was played and during which time period of the session. To reach a single VMAF summary number per session, we must determine an appropriate level of aggregation and build upon these aggregates with metrics that reflect different aspects of perceptual quality. VMAF scores go from 0 to 100: 0–20 (bad), 21–50 (poor), 51–70 (fair), 71–90 (good), 91–100 (excellent).

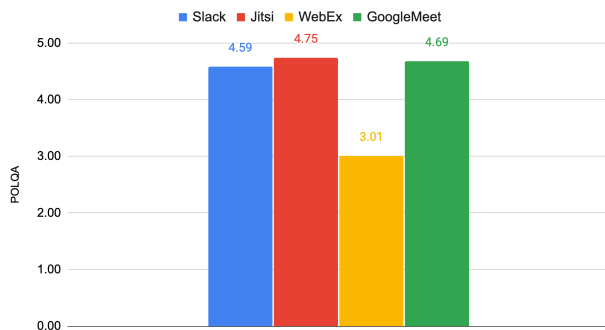
Metrics Score Legend

POLQA		Audio/Video delay	
>4.5	Excellent	100-250	Excellent
3.5-4.5	Good	250-400	Good
3-3.5	Fair	400-600	Fair
2-3	Poor	600-800	Poor
<2	Bad	>800	Bad

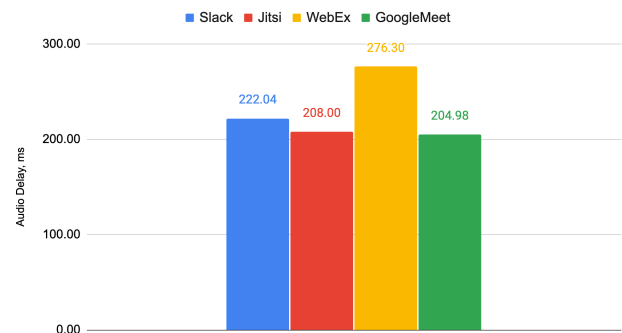
VMAF		FPS	
91-100	Excellent	20-30	Excellent
71-90	Good	12-20	Good
51-70	Fair	8-12	Fair
21-50	Poor	4-7	Poor
0-20	Bad	0-3	Bad

Baseline Data

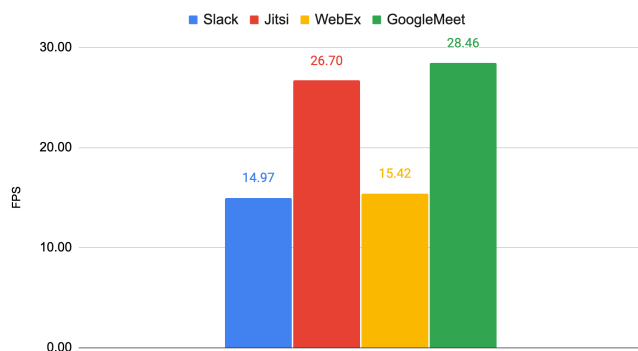
[Baseline] POLQA comparison



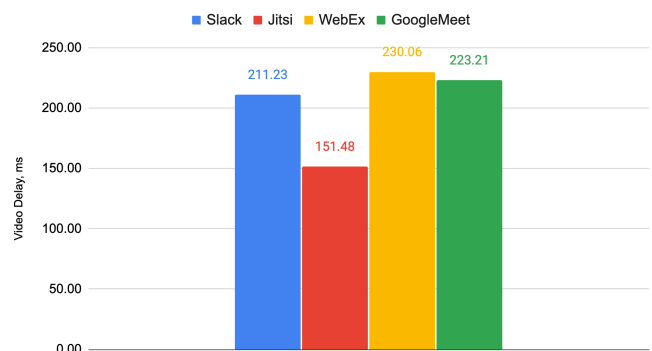
[Baseline] Audio Delay comparison



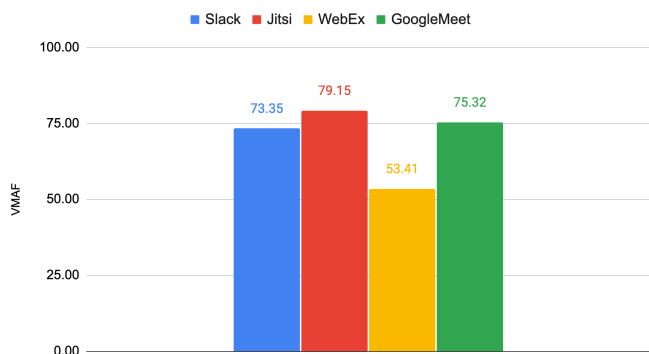
[Baseline] FPS comparison



[Baseline] Video Delay comparison



[Baseline] VMAF comparison



First, we tested selected video conferencing applications on a non-limited network to see how they perform on 2-user calls at baseline with default settings.

Most applications performed similarly, delivering excellent audio quality under non-limited network constraints. Google Meet, Slack and Jitsi had an *Excellent* audio delay below 225 ms, while Cisco Webex had an audio delay below 300 ms which is still considered to be *Good*.

We found Slack prioritizes video image quality over fluidity, having good video image quality with an average FPS 14.97. In comparison, Google Meet and Jitsi have excellent video fluidity and even higher video image quality than Slack on baseline, while Cisco Webex has fair video image quality with an average FPS 15.42.

Let's spend more time analyzing how these 4 applications handled our selected network constraints.

Note: We would like to note that this research was done in November & December 2022 and we have noticed audio quality improvements on Cisco Webex applications in newer app versions.

Findings

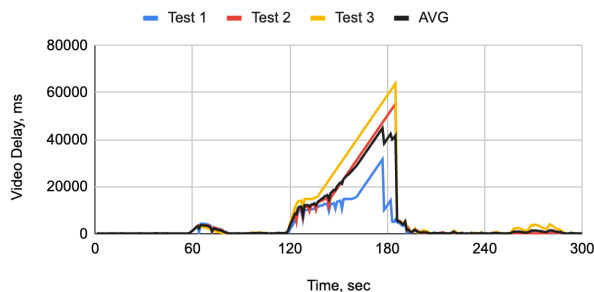
Before we analyze each variable network constraint scenario group individually, let's first identify the most and least challenging scenarios within the testing scope and determine which scenarios have the greatest impact on the metrics.

Most and Least Challenging Scenarios for the Testing Scope

In the **Variable Bandwidth**, **Variable Bandwidth with Constant Jitter**, and **Variable Bandwidth with Constant Packet Loss** scenarios, 2 of the 4 tested applications cannot handle or have disconnections during the test. Slack and Cisco Webex experience disconnections from the call during the **Variable Bandwidth** scenario and the **Variable Bandwidth with Constant Jitter** scenario. Cisco Webex disconnects from the call and Slack cannot handle the call during the **Variable Bandwidth with Constant Jitter** scenario. Below we share an example of video performance. Specifically, Cisco Webex experiencing disconnection from the call during the **Variable Bandwidth** scenario and Slack not being able to handle the call during the **Variable Bandwidth with Constant Packet Loss** scenario by having a video delay of up to 16 seconds.

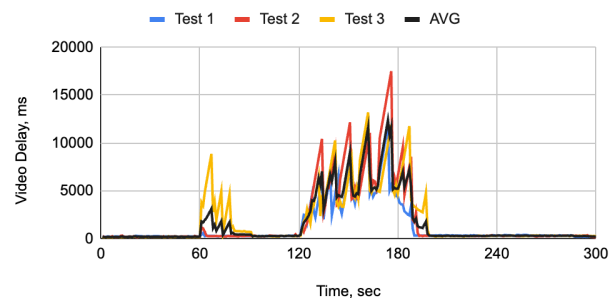
Disconnects during Variable Bandwidth

[WebEx 2U] [Win-Win] [Variable BW] - Video Delay overtime

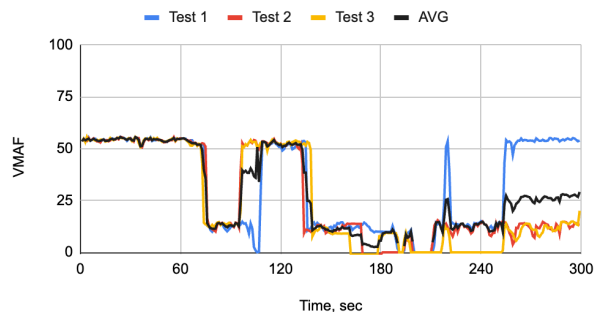


Cannot handle call during Variable Bandwidth with-Constant Packet Loss

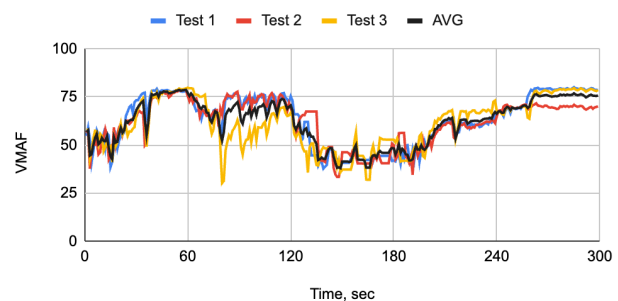
[Slack 2U] [Win-Win] [Variable BW - Constant PL] - Video Delay overtime



[WebEx 2U] [Win-Win] [Variable BW] - VMAF overtime



[Slack 2U] [Win-Win] [Variable BW - Constant PL] - VMAF overtime

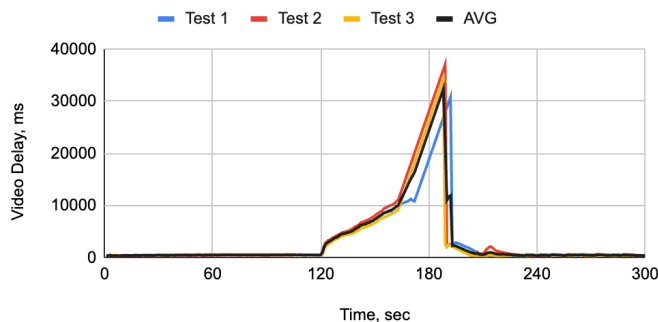


The **Variable Bandwidth** and **Variable Bandwidth with Constant Packet Loss** scenario is also challenging for Google Meet, impacting video fluidity when 500 kbps and 10% packet loss limitation is applied.

One of 4 application from the tested scope experiences disconnections when testing **Variable Bandwidth with Constant RTT** (Slack), **Variable Jitter with Constant Packet Loss** (Cisco Webex), **Variable Packet Loss with Constant Delay** (Slack), **Variable Packet Loss with Constant Bandwidth** (Cisco Webex), **Variable Bandwidth, Delay and Jitter with Constant Packet Loss** (Cisco Webex) and **Variable Delay and Jitter with Constant Packet Loss** (Cisco Webex) scenarios. Here is an example of Slack's video performance during the Variable Bandwidth with Constant RTT scenario and Cisco Webex's video performance during the Variable Packet Loss with Constant Bandwidth scenario:

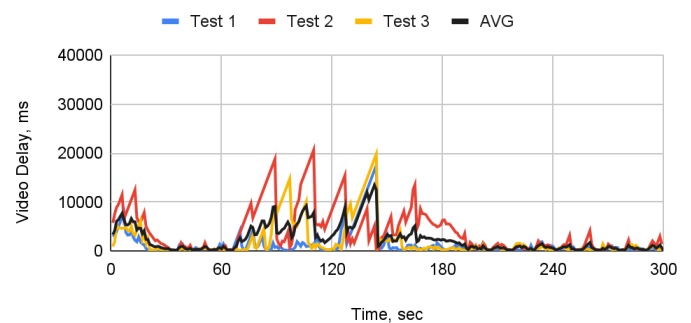
Disconnects during Variable Bandwidth with Constant RTT scenario

[Slack 2U] [Win-Win] [Variable BW - Constant RTT] - Video Delay overtime

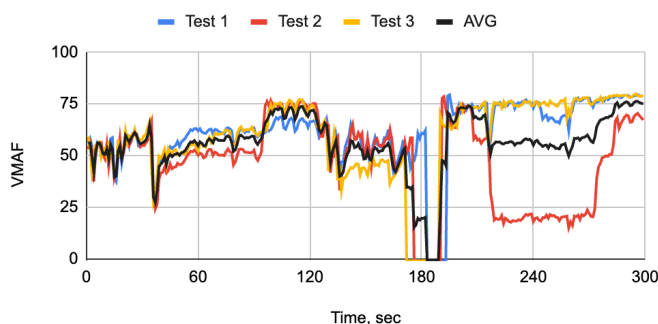


Disconnects during Variable Packet Loss with Constant Bandwidth scenario

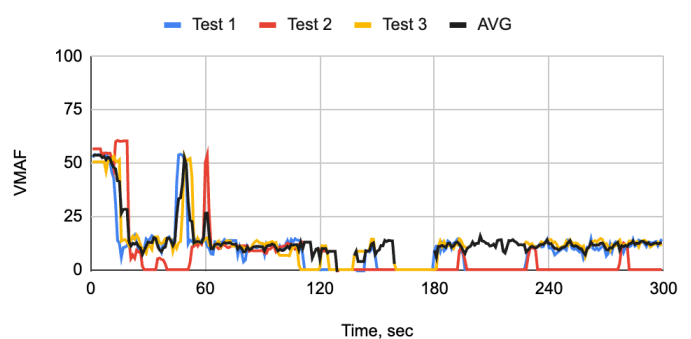
[WebEx 2U] [Win-Win] [Variable PL - Constant BW] - Video Delay overtime



[Slack 2U] [Win-Win] [Variable BW - Constant RTT] - VMAF overtime



[WebEx 2U] [Win-Win] [Variable PL - Constant BW] - VMAF overtime



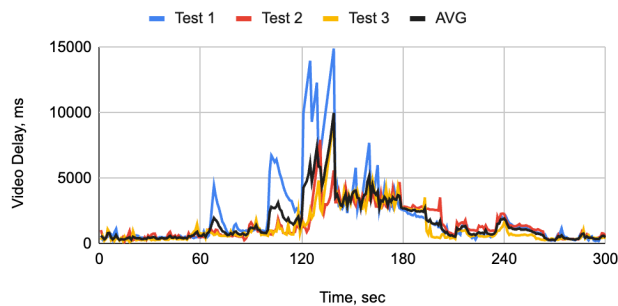
Looking at some less challenging scenarios, Jitsi is not able to handle video calls in the **Variable Packet Loss with Constant Jitter** scenario, while Cisco Webex not able to handle video calls in the Variable Jitter with Constant Bandwidth scenario, experiencing high video delay and poor video quality during the call. For example, Google Meet

drops video image quality and has non stop short freezes during the test when testing **Variable Packet Loss with Constant Jitter** scenario. See an example of Jitsi and Google Meet performance below:

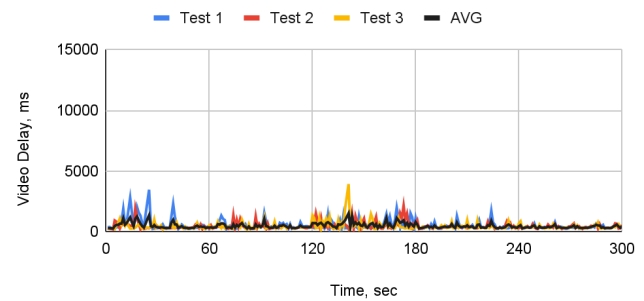
Cannot handle call during Variable Packet Loss with Constant Jitter scenario

Variable Packet Loss with Constant Bandwidth scenario

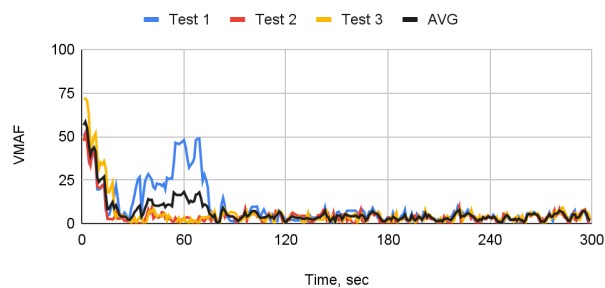
[Jitsi 2U] [Win-Win] [Variable PL - Constant Jitter] - Video Delay overtime



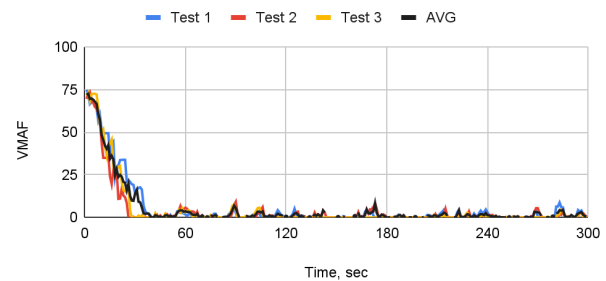
[GoogleMeet 2U] [Win-Win] [Variable PL - Constant Jitter] - Video Delay overtime



[Jitsi 2U] [Win-Win] [Variable PL - Constant Jitter] - VMAF overtime



[GoogleMeet 2U] [Win-Win] [Variable PL - Constant Jitter] - VMAF overtime



When testing the **Variable Delay with Jitter** and **Variable Jitter with Constant Delay** scenarios, we found that although the applications are able to ensure a connection to the call, these scenarios are still challenging.

Scenarios that are less challenging for the tested applications, where the app performance is either Good or Fair are the **Variable Queue Size** scenario, the **Variable Delay with Constant Bandwidth** scenario, and the baseline tests.

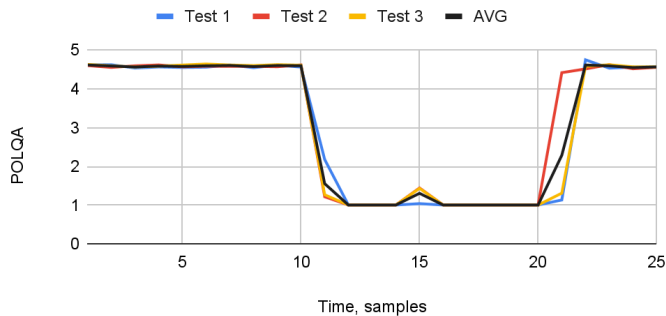
	Best performance	Poorest performance
Audio quality	Variable Queue Size (avg POLQA 4.26) Variable Jitter with Constant Delay; Variable Delay and Jitter (avg POLQA 4.22)	Variable Bandwidth with Constant Packet Loss (avg POLQA 3.45) Variable Packet Loss with Constant Bandwidth (avg POLQA 3.55)
Audio delay	Variable Queue Size (avg delay 231.96 ms) Variable Packet Loss with Constant Jitter (avg delay 487.37 ms)	Variable Bandwidth with Constant Jitter 1997 ms Variable Bandwidth, Delay and Jitter with Constant Packet Loss (avg delay 1651 ms)
Video quality	Variable Queue Size (avg VMAF 69.99) Variable Bandwidth (avg VMAF 56.84)	Variable Jitter with Constant Bandwidth (avg VMAF 16.93) Variable Bandwidth, Delay and Jitter with Constant Packet Loss (avg VMAF 17.64)
FPS	Variable Queue Size (avg FPS 21.35) Variable Bandwidth (avg FPS 18.30)	Variable Jitter with Constant Packet Loss (avg FPS 4.30) Variable Packet Loss with Constant Delay (avg FPS 5.83)
Video delay	Variable Queue Size (avg delay 200.80 ms) Variable Packet Loss with Constant Jitter (avg delay 793.14 ms)	Variable Packet Loss with Constant Delay (avg delay 3156.85 ms) Variable Bandwidth, Delay and Jitter with Constant Packet Loss (avg delay 2989.31 ms)

High Impact on Metrics

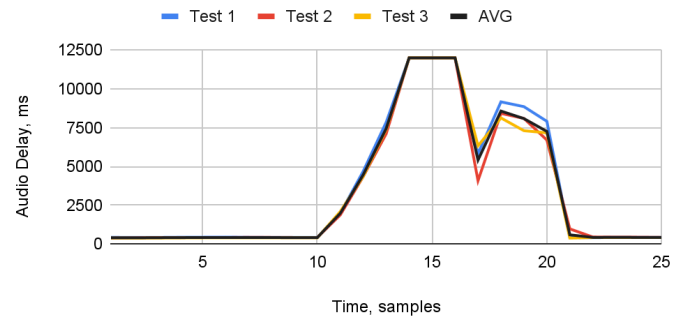
In regards to audio quality, the **Variable Bandwidth with Constant Packet Loss** and the **Variable Packet Loss with Constant Bandwidth** scenarios have a higher impact on POLQA results, while a higher audio delay can be seen in the **Variable Bandwidth with Constant Jitter** and the **Variable Bandwidth, Delay and Jitter with Constant Packet Loss** scenarios.

Example: Slack Audio Performance at Variable Bandwidth with Constant Jitter scenario

[Slack 2U] [Win-Win] [Variable BW - Constant Jitter] - POLQA overtime



[Slack 2U] [Win-Win] [Variable BW - Constant Jitter] - Audio Delay overtime

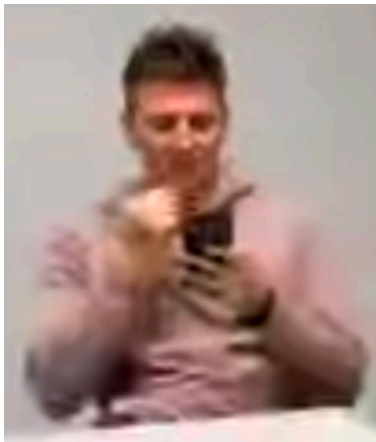


For example, when the network is limited by 200 kbps and 30 ms jitter, audio delay in Slack tests increases up to 12 seconds, which impacts user experience.

The poorest video image quality is noticed in the **Variable Jitter with Constant Bandwidth** and **Variable Bandwidth, Delay and Jitter with Constant Packet Loss** scenarios. These scenarios also have a high impact on FPS, to the point where the video looks like a slideshow at some parts of the test, and the average FPS score is very poor. The highest video delay is also noticed while testing the same **Variable Bandwidth, Delay and Jitter with Constant Packet Loss** scenario and the **Variable Packet Loss with Constant Delay** scenario.

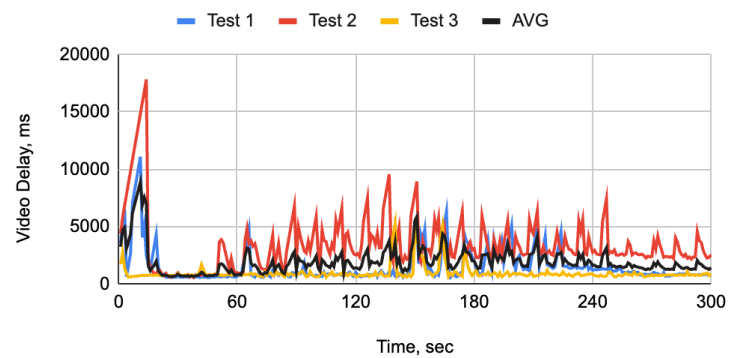
Testing results show that although 1 out of 4 applications (Cisco Webex) has disconnection during the **Variable Bandwidth, Delay, and Jitter with Constant Packet Loss** scenario, this scenario has one of the highest impacts of all collected audio and video quality, and performance metrics.

Example: Poor video image quality during the Variable Jitter with Constant Bandwidth scenario

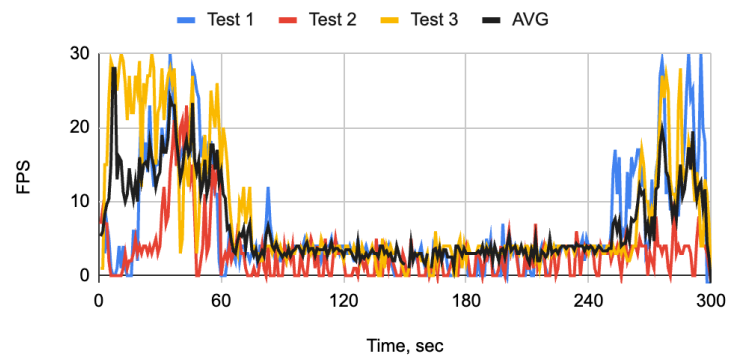


Google Meet
Test 2, 143rd second
VMAF 0.81

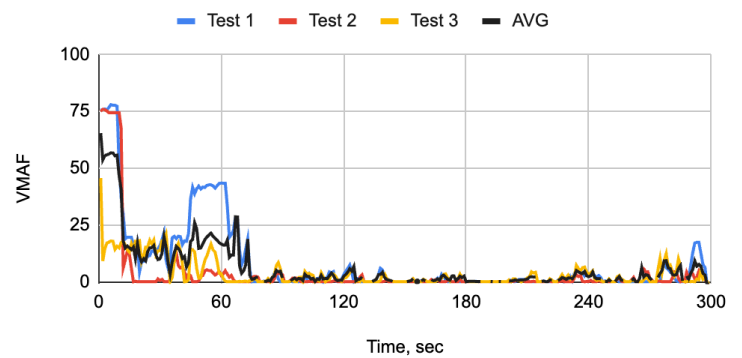
[GoogleMeet 2U] [Win-Win] [Variable Jitter - Constant BW]
- Video Delay overtime



[GoogleMeet 2U] [Win-Win] [Variable Jitter - Constant BW]
- FPS overtime



[GoogleMeet 2U] [Win-Win] [Variable Jitter - Constant BW]
- VMAF overtime



In the example above, we see how Google Meet's video image quality performs in the **Variable Jitter with Constant Bandwidth** scenario at the 143rd second where video image quality drops to poor. This scenario also has a high impact on video fluidity.

Low Impact on Metrics

The **Variable Queue Size** scenario has the lowest impact on audio and video metrics. The second highest average POLQA is noticed during the **Variable Jitter with Constant Delay** and the **Variable Delay and Jitter** scenarios.

The second lowest audio delay is observed in the **Variable Packet Loss with Constant Jitter** scenario. Although it is the second lowest, it is still considered to be a fair audio delay that impacts user experience (above 400 ms). Regarding video metrics, the second-highest video image quality and FPS were noticed during the **Variable Bandwidth** scenario tests.

The **Variable Packet Loss with Constant Jitter** scenario has the second lowest video delay from the tested scope, but the value is still high (793 ms), and has an impact on user experience while the user is in video conferencing calls.

We see that all **Variable Bandwidth** scenarios are the most challenging for tested applications, having a high impact on audio and video quality, and performance, even causing disconnection for some of the applications. The lowest impact on audio and video data is noticed in the **Queue Size** and the **Variable Delay with Constant Bandwidth** scenarios.

Impact Assessment of Network Constraint Scenarios

In this section, we delve deeper into each scenario group to analyze the behavior of the applications under varying conditions.

Variable Bandwidth Test Scenarios

	Variable Bandwidth with Constant RTT	Variable Bandwidth with Constant Jitter	Variable Bandwidth with Constant Packet Loss	Variable Bandwidth
Bandwidth limitation	*5000Kbps → 500Kbps → 200Kbps → 500Kbps → 5000Kbps			
Packet loss limitation	none	none	10%	none
Jitter	none	30ms	none	none
Delay	none	100ms	none	none
RTT	500ms	none	none	none
Queue size	1000			

*Each limitation period is 60 seconds long.

From our testing scope, the **Variable Bandwidth** scenario, and the **Variable Bandwidth** scenario together with other settings like **Constant RTT**, **Jitter**, and **Packet Loss**, are the most challenging for audio and video during 2-user video conferencing calls.

Slack and Cisco Webex had disconnections, and Google Meet performance was poor during the **Variable Bandwidth** and the **Variable Bandwidth with Constant Jitter** scenarios.

Slack could not handle the call, while Cisco Webex disconnected from the call during the **Variable Bandwidth with Constant Packet Loss** scenario. Google Meet performance was also poor during these scenarios.

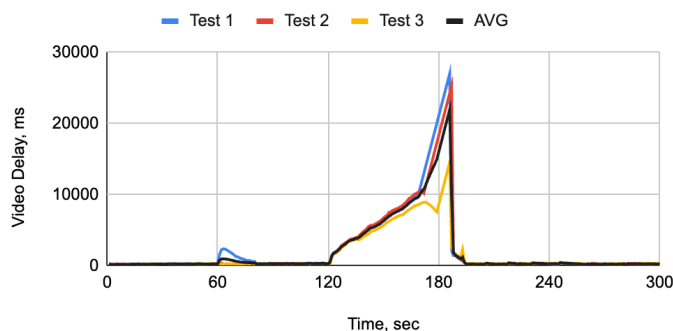
When looking at the **Variable Bandwidth** scenario metrics , we saw the following average values for the tested scope:

Audio quality is affected by network constraints. Though the average POLQA score is still considered to be *Good* (3.87), the average audio delay is high (1427 ms). The **Variable Bandwidth** scenario had the second highest average FPS score (18.30), but video fluency is still impacted, causing a high average video delay (2204 ms). Overall, this scenario's tests have an average *Fair* video image quality (VMAF 56.84).

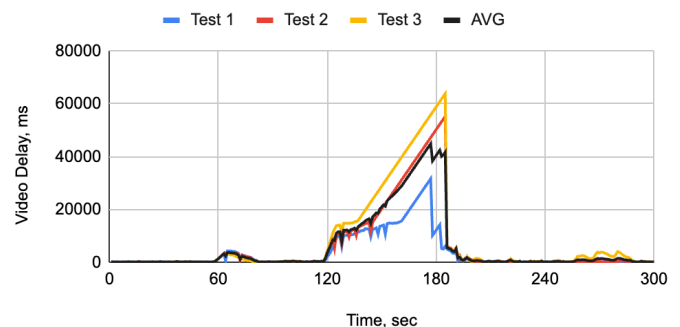
In terms of disconnections, 2 of 3 Slack tests and 3 of 3 Cisco Webex tests experienced disconnection from the video call when testing the **Variable Bandwidth** scenario. See examples below.

Slack and Cisco Webex disconnect from the call during the Variable Bandwidth scenario

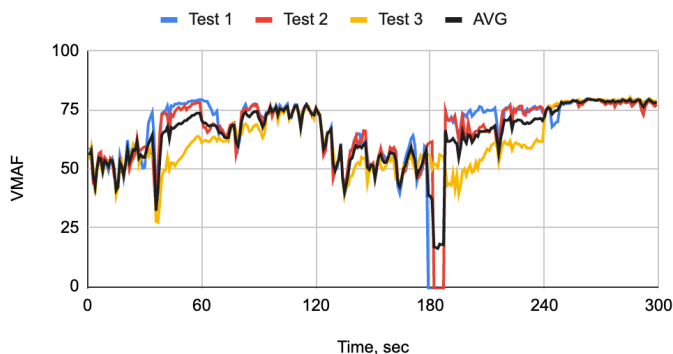
[Slack 2U] [Win-Win] [Variable BW] - Video Delay overtime



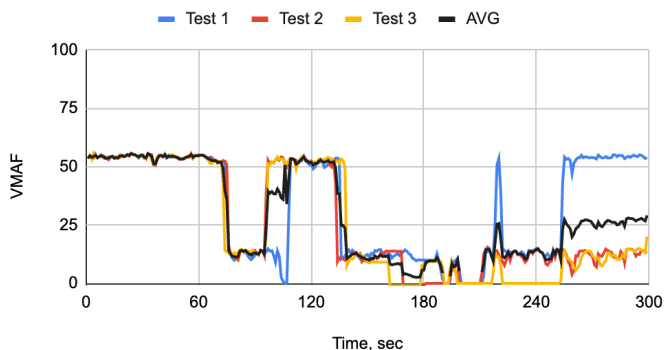
[WebEx 2U] [Win-Win] [Variable BW] - Video Delay overtime



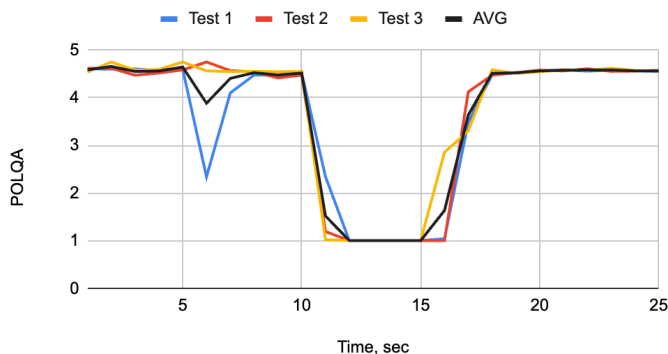
[Slack 2U] [Win-Win] [Variable BW] - VMAF overtime



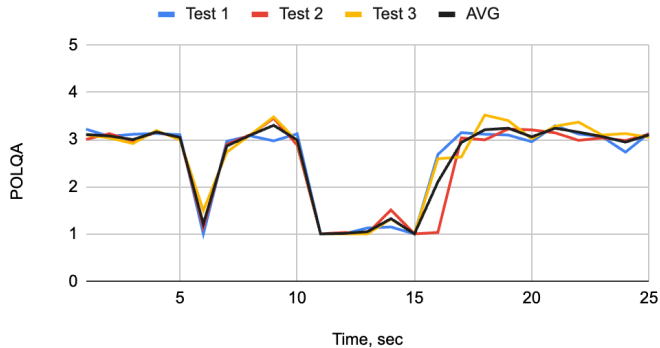
[WebEx 2U] [Win-Win] [Variable BW] - VMAF overtime



[Slack 2U] [Win-Win] [Variable BW] - POLQA overtime



[WebEx 2U] [Win-Win] [Variable BW] - POLQA overtime

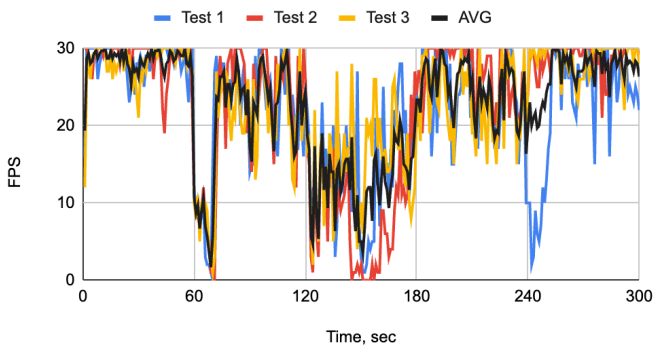


15 seconds after the 500 kbps limitation is applied, the video image quality of Cisco Webex drops to *Poor* and video delay spikes up an average 3.5 seconds. When the network is limited by 200 kbps, all 3 tests experience a disconnect. Only 1 out of 3 tests manage to recover to the previous video image quality at the end of the test.

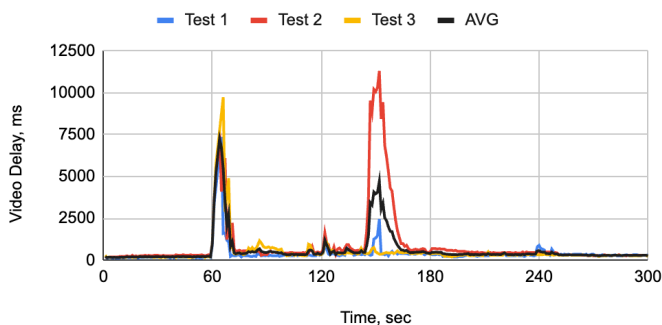
Google Meet tries to keep its FPS close to 30 but has constant FPS drops during limitation changes. Video delay increases up to 10 seconds in 1 out of 3 tests when the first limitation period is applied.

Google Meet performance in the call during the Variable Bandwidth scenario

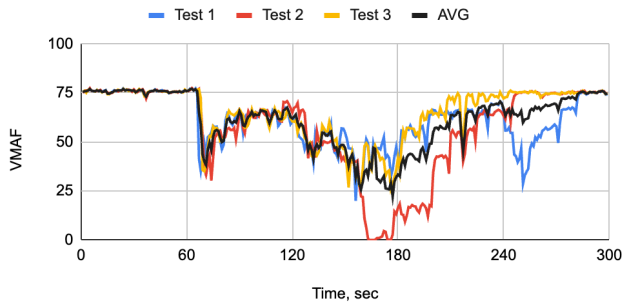
[GoogleMeet 2U] [Win-Win] [Variable BW] - FPS overtime



[GoogleMeet 2U] [Win-Win] [Variable BW] - Video Delay overtime



[GoogleMeet 2U] [Win-Win] [Variable BW] - VMAF overtime



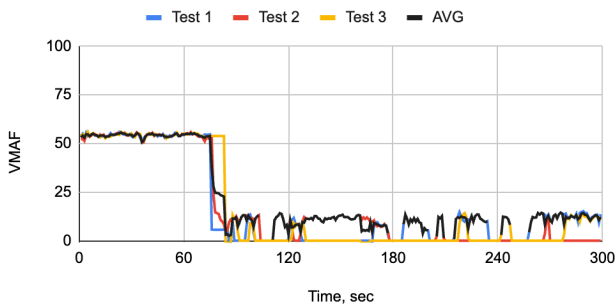
Although video delay spikes up high and video image quality drops right after the first limitation is applied, Google Meet manages to recover video fluidity in ~10 seconds. Google Meet recovers its image quality to previous level at the end of the test.

Slack and Cisco Webex disconnected from the call during the **Variable Bandwidth with Constant Jitter** scenario testing. The Jitsi app has perfect audio quality with an average delay of 400 ms, however, video image quality is *poor* (average VMAF of 30.46) and video image quality is very degraded.

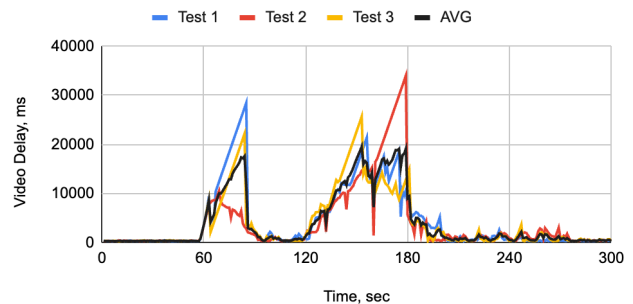
Google Meet has dual behaviour. Specifically, some parts of the tests have good audio performance and good video delay, while other parts of the tests have low POLQA, and high audio and video delay. VMAF is low for all tests. The app struggles to maintain quality.

Slack, Cisco Webex and Google Meet video performance during Variable Bandwidth with Constant Jitter scenario

[WebEx 2U] [Win-Win] [Variable BW - Constant Jitter] - VMAF overtime



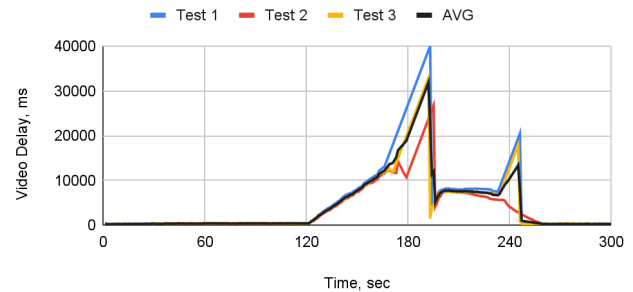
[WebEx 2U] [Win-Win] [Variable BW - Constant Jitter] - Video Delay overtime



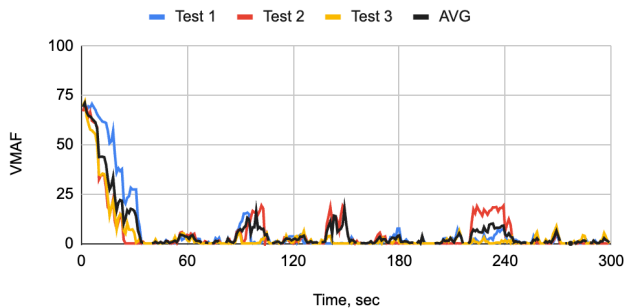
[Slack 2U] [Win-Win] [Variable BW - Constant Jitter] - VMAF overtime



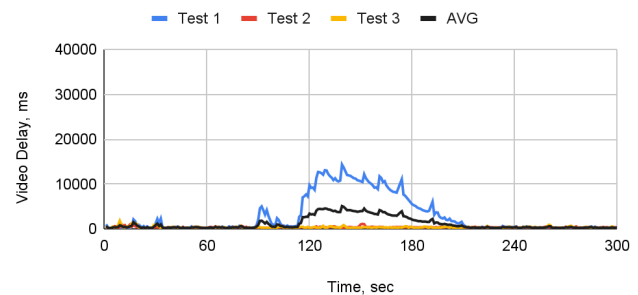
[Slack 2U] [Win-Win] [Variable BW - Constant Jitter] - Video Delay overtime



[GoogleMeet 2U] [Win-Win] [Variable BW - Constant Jitter] - VMAF overtime



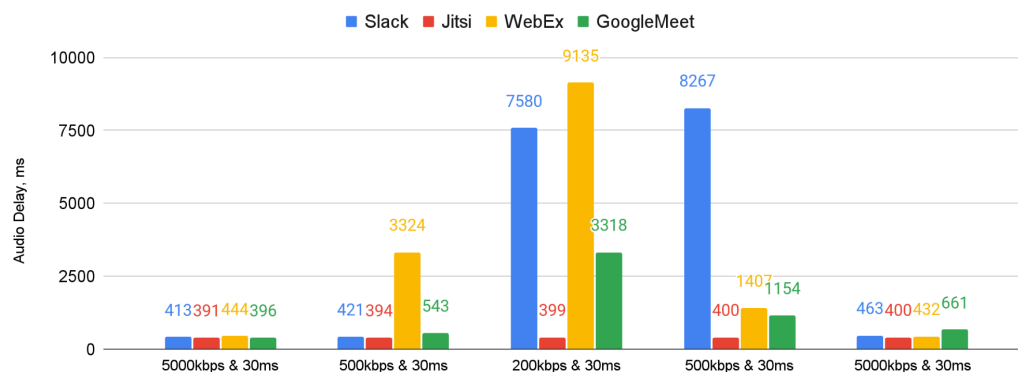
[GoogleMeet 2U] [Win-Win] [Variable BW - Constant Jitter] - Video Delay overtime



When looking at the **Variable Bandwidth with Constant Jitter** scenario metrics, we noted the following average values for the tested scope:

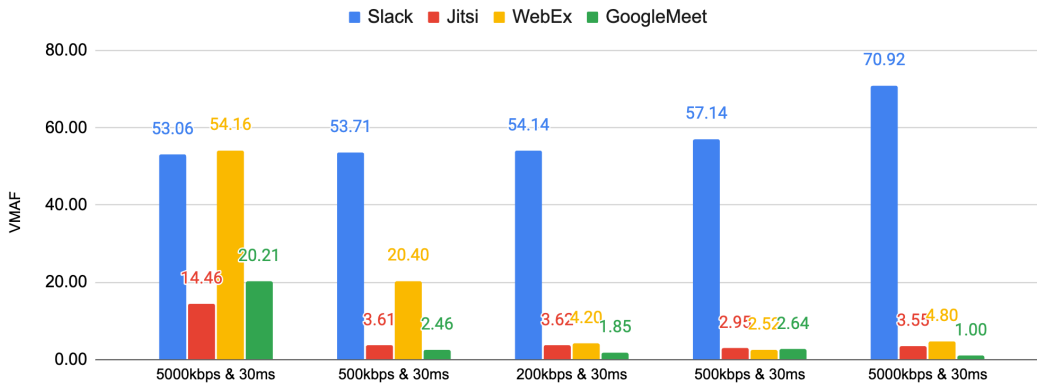
This scenario has the poorest audio delay (1997 ms on average) from the tested scope.

[Variable BW - Constant Jitter] Audio Delay comparison

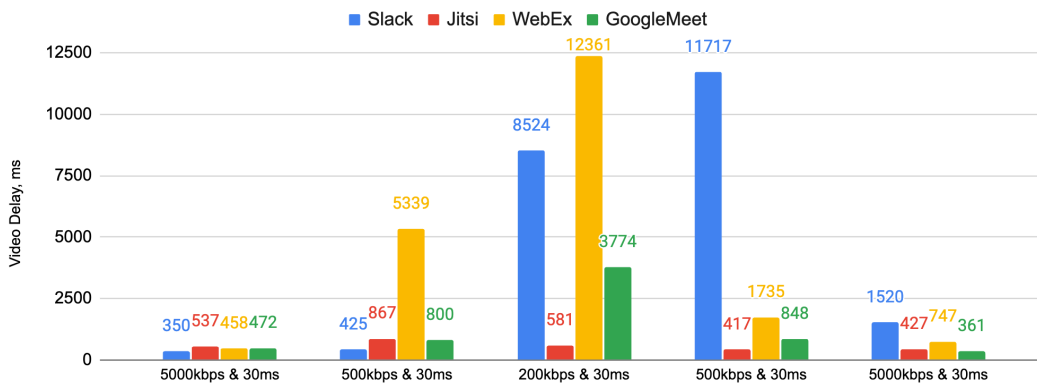


Audio quality is affected by network constraints, the average POLQA score is 3.63. The average video quality during the **Variable Bandwidth with Constant Jitter** scenario is *poor* with an average VMAF value of 21.57. Fluidity is also impacted with an average FPS of 11.45 and an average video delay value of 2613 ms.

[Variable BW - Constant Jitter] VMAF comparison



[Variable BW - Constant Jitter] Video Delay comparison



Results show that Slack is not able to handle the call, while Google Meet's performance is *poor* and Cisco Webex had a disconnection during the **Variable Bandwidth with Constant Packet Loss** test scenario. This is considered to be one of the most challenging scenarios where the available network is low, and an additional 10% packet loss causes either a disconnection or a high delay and quality drops.

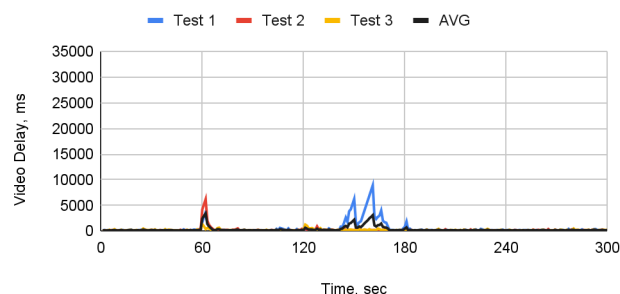
Slack cannot handle this limitation, resulting in high delay, while Cisco Webex disconnects from the call, and Google Meet's performance is *poor*, showing high video delay when limitation changes, Jitsi performance is acceptable under these limitation constraints.

In 1 out of 3 Jitsi tests, the delay spikes up, but the other 2 tests manage to keep it at a decent level. At the same time, video image quality drops to *poor* in the middle of the test, but the app restores video image quality to previous level by the end of the test. Video fluidity is also impacted by unstable FPS and several freezes.

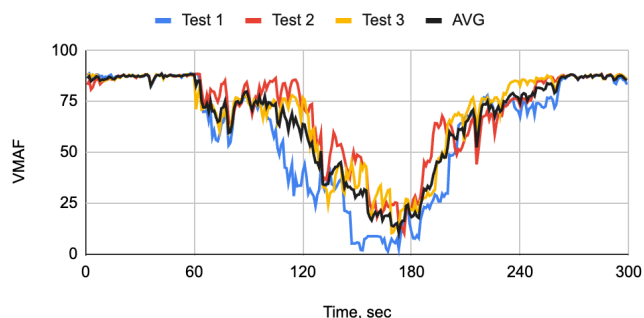
For example, although Google Meet audio delay is affected, FPS is unstable and has several deep drops to 1/2 FPS, and video image quality drops when limitation increases, the app recovers and maintains fair video fluency and audio performance during this challenging scenario.

Jitsi, Slack and Cisco Webex video performance during the Variable Bandwidth with Constant Packet Loss scenario

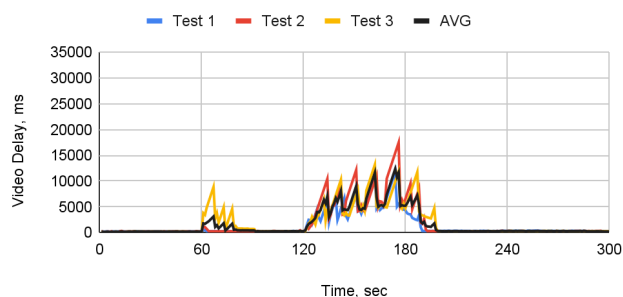
[Jitsi 2U] [Win-Win] [Variable BW - Constant PL] - Video Delay overtime



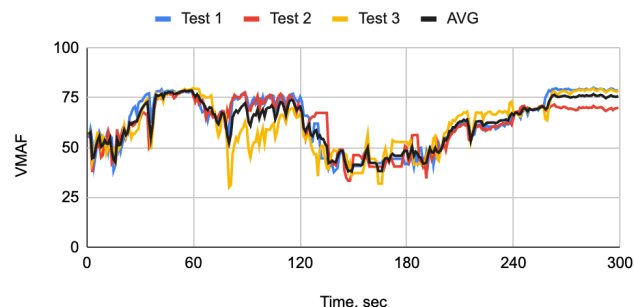
[Jitsi 2U] [Win-Win] [Variable BW - Constant PL] - VMAF overtime



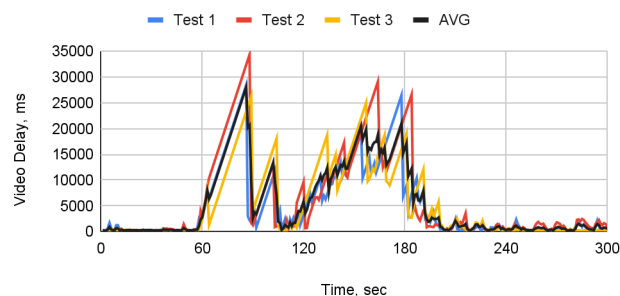
[Slack 2U] [Win-Win] [Variable BW - Constant PL] - Video Delay overtime



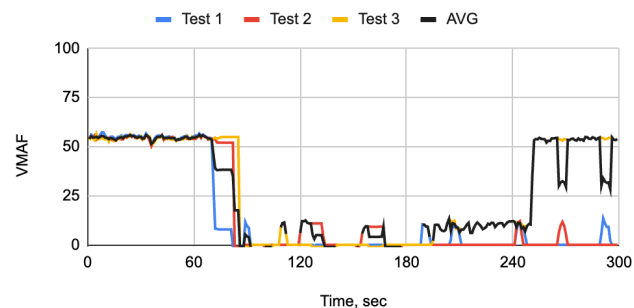
[Slack 2U] [Win-Win] [Variable BW - Constant PL] - VMAF overtime



[WebEx 2U] [Win-Win] [Variable BW - Constant PL] - Video Delay overtime



[WebEx 2U] [Win-Win] [Variable BW - Constant PL] - VMAF overtime



As noticed in the overtime graphs, apps struggle during the **Variable Bandwidth with Constant Packet Loss** scenario. Video fluency is affected, causing high video delay, audio delay is high, and video image quality is degraded—all of which impact the user experience.

In this scenario, the average FPS value is 14.71, while the average video delay is very high at 2056 ms. Video image quality is degraded with an average VMAF score of 56.06. Audio quality is also affected. The average POLQA value is 3.45 and the audio delay is high at 1163 ms.

When analyzing the **Variable Bandwidth with Constant RTT** scenario tests, we noticed that it is less challenging than the previously described scenarios. Slack has a disconnection from the call, while Google Meet, Jitsi, and Cisco Webex have acceptable performance.

In this scenario, audio quality is *good*, with an average POLQA value of 3.99, however, the audio delay is 1301 ms. Video performance is also affected with an average FPS of 18.22, a video delay of 1375ms, and an average video quality VMAF score of 48.51.

The analysis of video and audio performance metrics across various **Variable Bandwidth** scenarios reveals differences in the quality.

The **Variable Bandwidth with Constant Jitter** scenario consistently exhibited the most detrimental impact on video performance, with the lowest average FPS (11.45) and VMAF (21.57), indicating poor image quality and fluidity. Additionally, this scenario also resulted in the highest audio delay (1997 ms), further degrading the overall user experience.

The **Variable Bandwidth** scenario without additional impairments showed the best performance, with the highest average FPS (18.30) and VMAF (56.84), indicating higher video quality. However, audio performance varied across scenarios, with the **Variable Bandwidth with Constant Packet Loss** scenario producing the lowest audio quality (POLQA 3.45). However, the lowest audio delay (1163 ms), and the **Variable Bandwidth with Constant RTT** scenario offer better audio quality (POLQA 3.99).

Overall, the results highlight that while **Variable Bandwidth** alone can maintain acceptable video and audio quality, the introduction of constant jitter or packet loss significantly degrades both video and audio performance, with jitter being particularly challenging to both video quality and audio delay.

Variable Packet Loss Test Scenarios

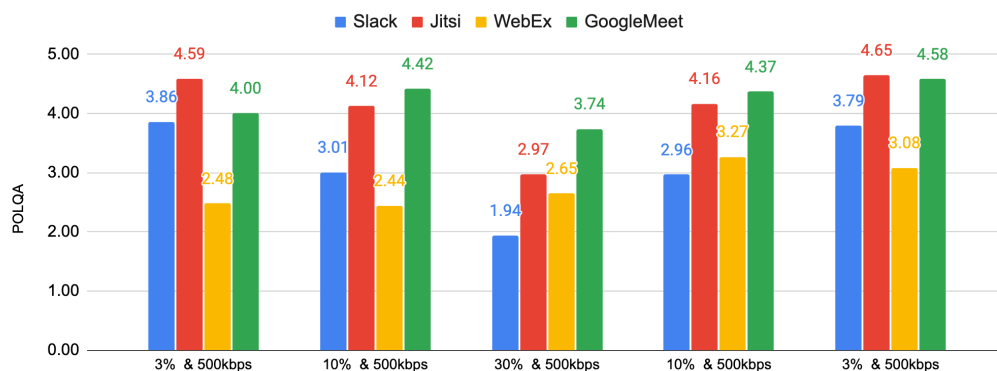
	Variable Packet Loss with Constant Jitter	Variable Packet Loss with Constant Delay	Variable Packet Loss with Constant Bandwidth
Bandwidth limitation	non-limited	non-limited	500 kbps
Packet loss limitation	*3% → 10% → 30% → 10% → 3%		
Jitter	none	30 ms	none
Delay	none	100 ms	none
RTT	500ms	none	none
Queue size	1000		

*Each limitation period is 60 seconds long.

Overall, testing the **Variable Packet Loss** scenarios is less challenging compared to the **Variable Bandwidth** scenarios. Slack disconnects from the call and Jitsi and Google Meet performance is poor when testing **Variable Packet Loss with Constant Delay** scenario. Cisco Webex disconnects during the **Variable Packet Loss with Constant Bandwidth** scenario and Jitsi is not able to handle the call in the **Variable Packet Loss with Constant Jitter** scenario. Other applications performance is being considered acceptable under network constraints.

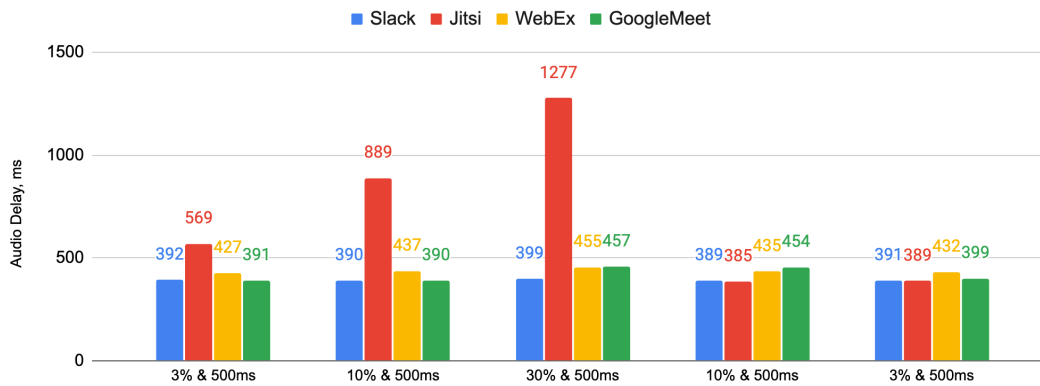
The **Variable Packet Loss** scenario tests have relatively low audio compared to the **Variable Bandwidth** scenarios. The average POLQA is 3.55 during the **Variable Packet Loss with Constant Bandwidth** scenario, 3.6 during the **Variable Packet Loss with Constant Delay** scenario, and 3.62 during the **Variable Packet Loss with Constant Jitter** scenario.

[Variable PL - Constant BW] POLQA comparison



The **Variable Packet Loss with Constant Bandwidth** scenario has the second poorest audio quality (POLQA 3.55) after the **Variable Bandwidth, Delay and Jitter with Constant Packet Loss** (average POLQA 3.63) from the tested scope.

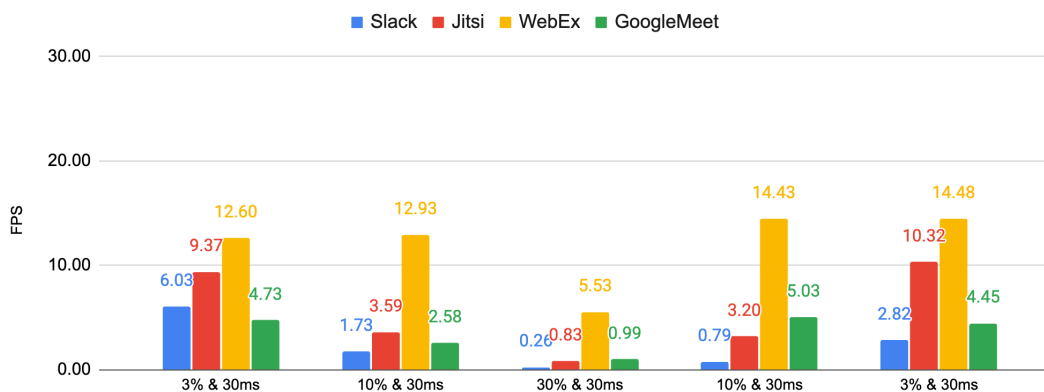
[Variable PL - Constant Jitter] Audio Delay comparison



The **Variable Packet Loss with Constant Jitter** scenario has the second lowest audio delay (488ms) after **Variable Queue Size** (232 ms) from all the tested scenarios.

The FPS is low with an average FPS of 5.83 during the **Variable Packet Loss with Constant Delay** scenario and it is second poorest FPS after the **Variable Jitter with Constant Packet Loss** scenario (average FPS 4.30) from the tested scope. The average FPS in the **Variable Packet Loss with Constant Jitter** scenario is 10.54, while the average FPS is 14.05 in the **Variable Packet Loss with Constant Bandwidth** scenario.

[Variable PL - Constant Delay] FPS comparison



The highest video image quality among these scenarios is observed in the **Variable Packet Loss with Constant Delay** scenario, with a VMAF score of 55.57. In contrast, video quality is notably poorer in the **Variable Packet Loss with Constant Jitter** (VMAF 28.75) and **Variable Packet Loss with Constant Bandwidth** (VMAF 41.32) scenarios.

When comparing the tested **Variable Packet Loss** scenarios, it becomes evident that the **Variable Packet Loss with Constant Delay** and **Variable Packet Loss with Constant Bandwidth** scenarios present more challenges in terms of video delay compared to the **Variable Packet Loss with Constant Jitter** scenario. Notably, the **Variable Packet Loss with Constant Jitter** scenario records the second-lowest video delay (793 ms), following the **Variable Queue Size** scenario (201 ms), across all tested scenarios.

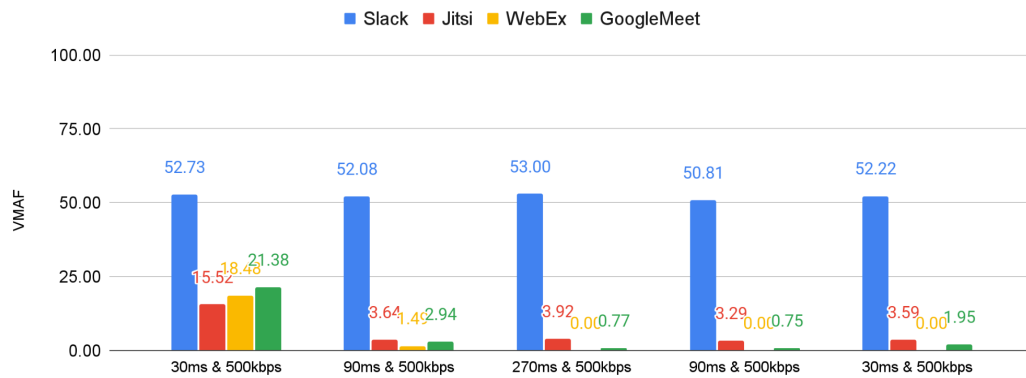
Variable Jitter Test Scenarios

	Variable Jitter with Constant Delay	Variable Jitter with Constant Packet Loss	Variable Jitter with Constant Bandwidth
Bandwidth limitation	non-limited	non-limited	500Kbps
Packet loss limitation	none	10%	none
Jitter	*30ms → 90ms → 270ms → 90ms → 30ms		
Delay	500kbps	500kbps	500kbps
RTT	none	none	none
Queue size	1000		

*Each limitation period is 60 seconds long.

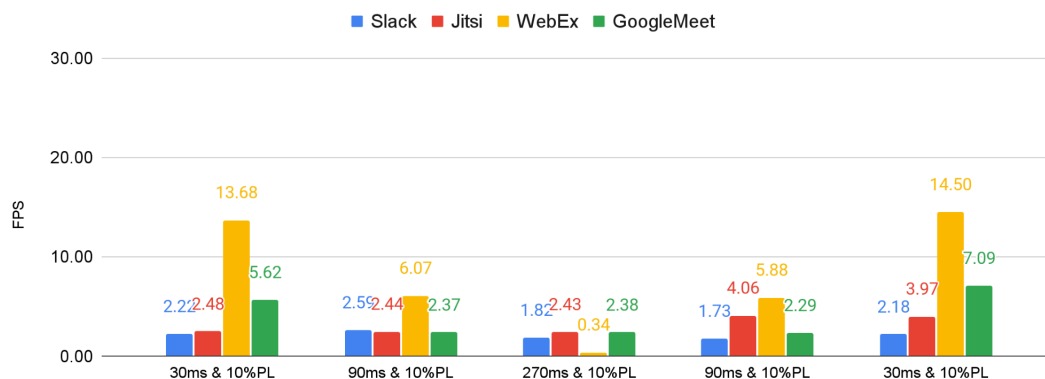
Overall, **Variable Jitter** scenarios have an impact on app performance, causing disconnection from the call as well. Cisco Webex disconnects from the call during the **Variable Jitter with Constant Packet Loss** scenario and cannot handle the call in the **Variable Jitter with Constant Bandwidth** scenario tests. The app's performance is considered to be acceptable during the **Variable Jitter with Constant Delay** scenario and is less challenging than the **Variable Jitter with Constant Packet Loss** and **Variable Jitter with Constant Bandwidth** scenarios.

[Variable Jitter - Constant BW] VMAF comparison



Video quality and performance are significantly impacted by various constraint limitations. The **Variable Jitter with Constant Bandwidth** scenario exhibits the poorest video image quality, with an average VMAF of 16.93, which is not only the lowest among the **Variable Jitter** scenarios but also the lowest across the entire tested scope. Other scenarios also show subpar video quality. The **Variable Jitter with Constant Packet Loss** scenario has an average VMAF of 26.54, while the **Variable Jitter with Constant Delay** scenario has a VMAF of 28.02. Applications like Google Meet, Jitsi and also Cisco Webex (only in the **Variable Jitter with Constant Bandwidth** scenario) drop their image quality in all Variable Jitter scenarios to poor.

[Variable Jitter - Constant PL] FPS comparison



FPS scores are similarly poor, with the **Variable Jitter with Constant Packet Loss** recording the lowest FPS (4.30) among all scenarios tested. The **Variable Jitter with Constant Bandwidth** follows with an FPS of 9.72, and the **Variable Jitter with Constant Delay** scenario with an FPS of 11.25, all while experiencing high video delay.

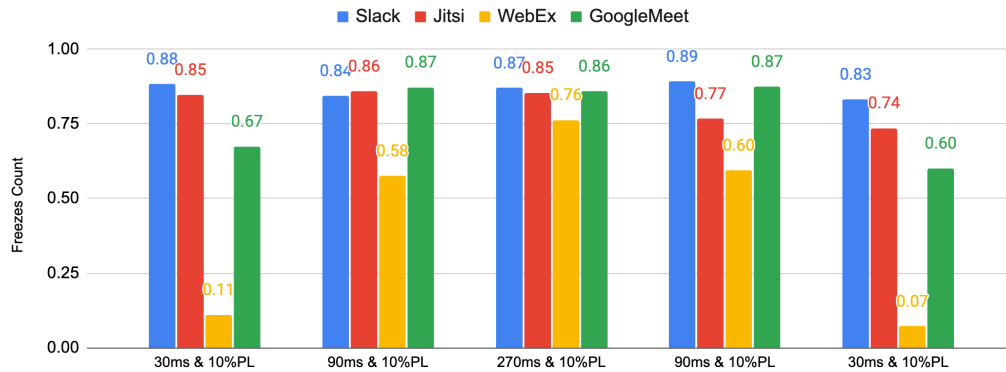
Audio quality is still good, but audio delay is high at all limitation periods of Variable Jitter tests. The **Variable Jitter with Constant Delay** has the second highest POLQA from the tested scope with an average POLQA of 4.22.

Cisco Webex has disconnections during the **Variable Jitter with Constant Packet Loss** scenario. Although other apps' performance is considered to be acceptable, lots of freezes, including long freezes, are noticed in tests.

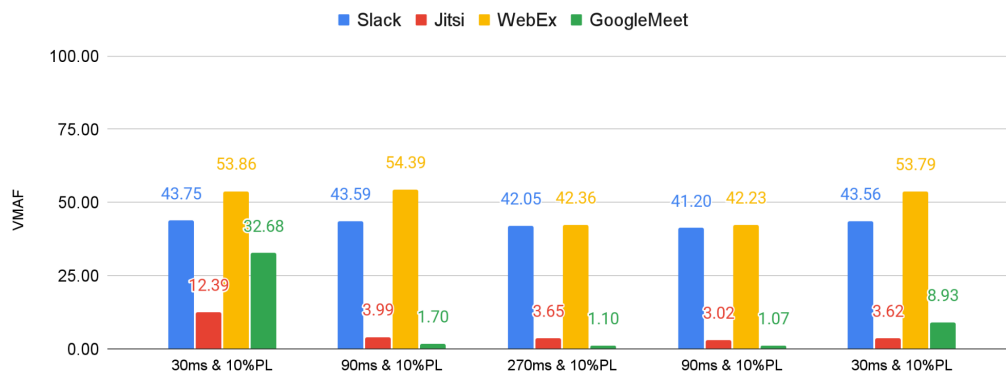
Freezes are noticed at all limitation periods, not only during the heaviest middle part of the test. Also, video image quality for some of the apps, specifically Jitsi and Google Meet, is poor.

Video performance during the Variable Jitter with Constant Packet Loss scenario

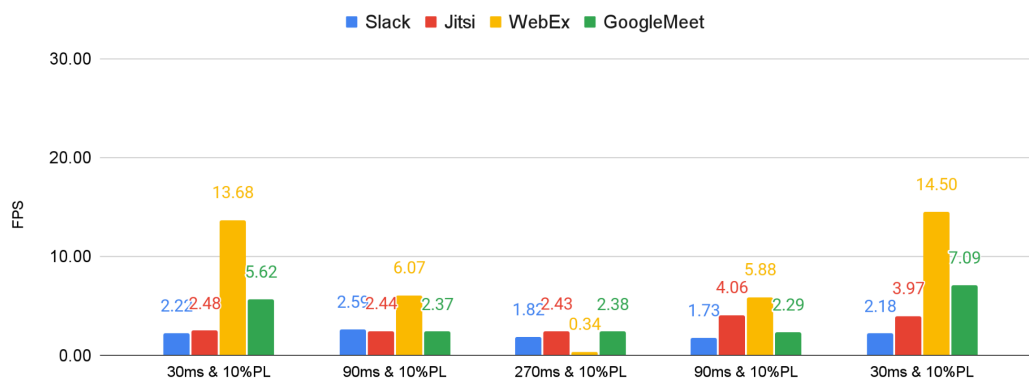
[Variable Jitter - Constant PL] Freezes Count comparison



[Variable Jitter - Constant PL] VMAF comparison

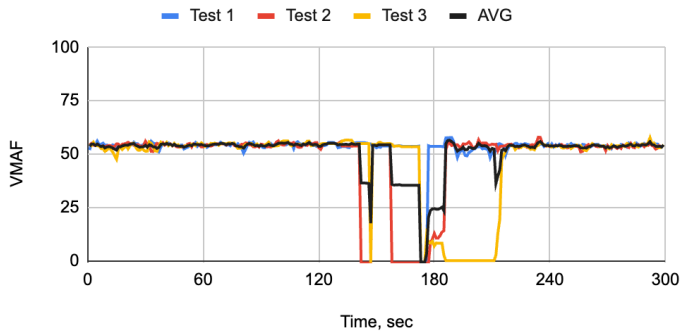


[Variable Jitter - Constant PL] FPS comparison

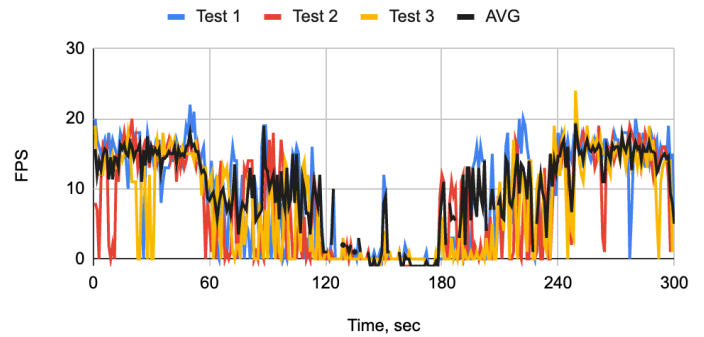


Performance during the Variable Jitter with Constant Packet Loss scenario

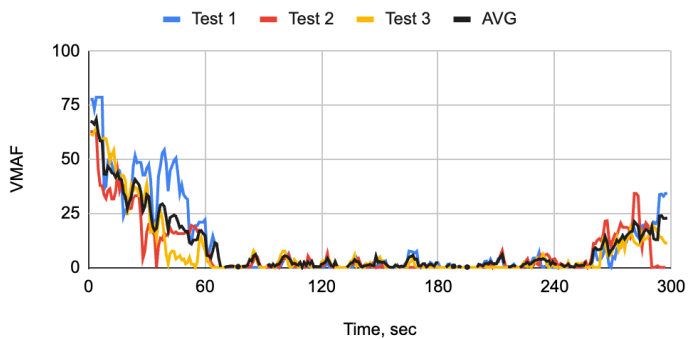
[WebEx 2U] [Win-Win] [Variable Jitter - Constant PL] - VMAF overtime



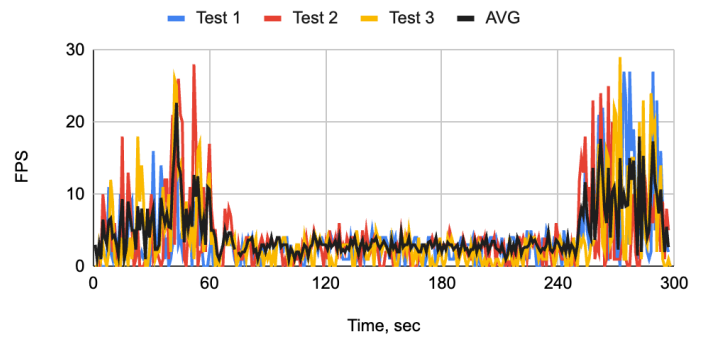
[WebEx 2U] [Win-Win] [Variable Jitter - Constant PL] - FPS overtime



[GoogleMeet 2U] [Win-Win] [Variable Jitter - Constant PL] - VMAF overtime



[GoogleMeet 2U] [Win-Win] [Variable Jitter - Constant PL] - FPS overtime

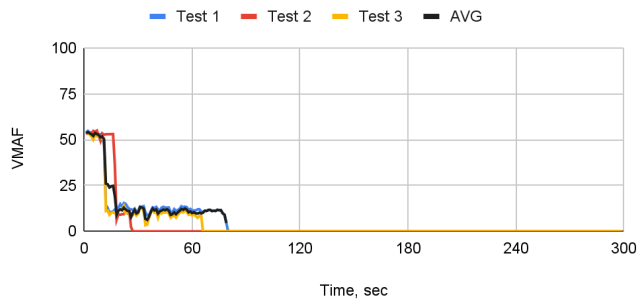


In the example above, we see that although Cisco Webex maintains its video image during the test, video fluidity is unstable and the application disconnects from the video call. Google Meet drops its video image quality at the beginning of tests, has several freezes, and the video looks like a slideshow at some moments, however, it manages to stay in the call. Audio performance is less affected by the network constraints.

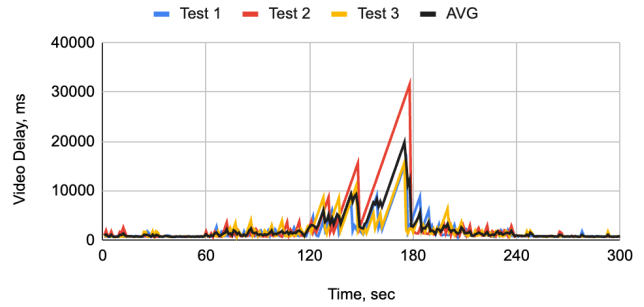
When testing the **Variable Jitter with Constant Bandwidth** scenario, we noticed that although none of the applications experience disconnections, Cisco Webex is not able to handle the call. Not only does the video image quality drop to poor, but it also has long freezes and a high video delay of up to 30 seconds.

Cisco Webex video performance during the Variable Jitter with Constant Bandwidth scenario

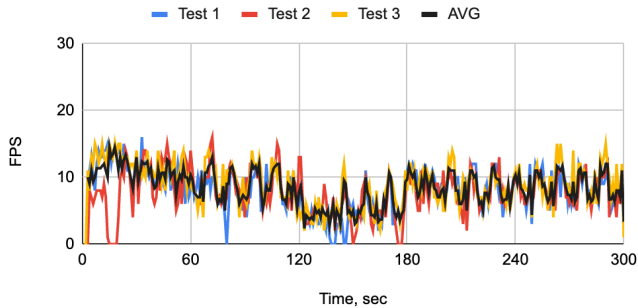
[WebEx 2U] [Win-Win] [Variable Jitter - Constant BW] - VMAF overtime



[WebEx 2U] [Win-Win] [Variable Jitter - Constant BW] - Video Delay overtime



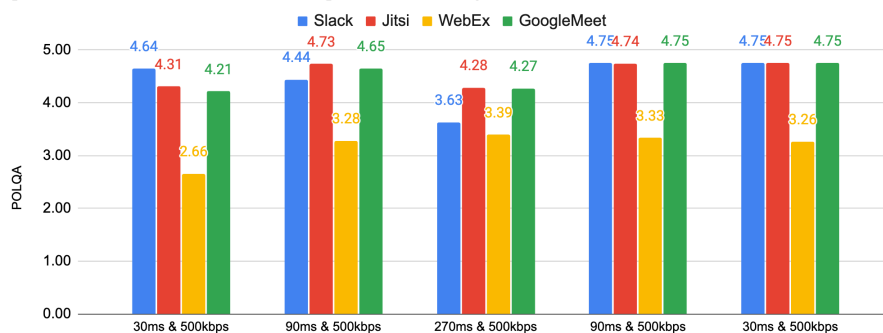
[WebEx 2U] [Win-Win] [Variable Jitter - Constant BW] - FPS overtime



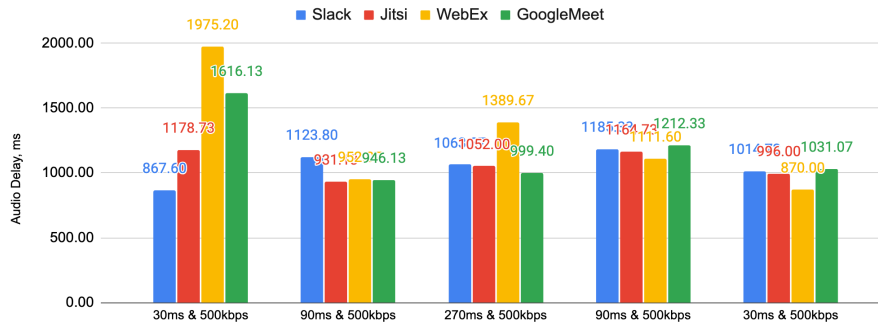
As mentioned before, the **Variable Jitter with Constant Bandwidth** scenario tests have poor video image quality, with an average VMAF value of 16.93, a low average FPS score of 9.72, and a high video delay that is 1926 ms on average, which has a high impact on user experience during the video call. Although the average audio quality is good (POLQA 4.18), audio delay is high at all limitation periods, and the average is 1134 ms, which impacts user experience.

Audio performance during the Variable Jitter with Constant Bandwidth scenario

[Variable Jitter - Constant BW] POLQA comparison



[Variable Jitter - Constant BW] Audio Delay comparison



Variable Delay Test Scenarios

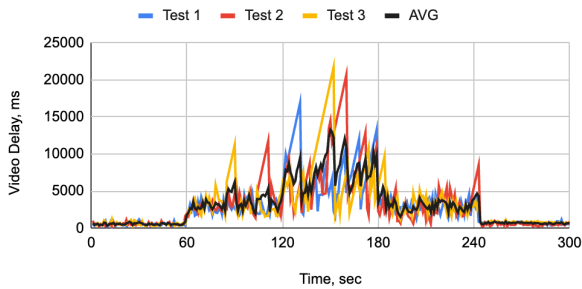
	Variable Delay with Constant Packet Loss	Variable Delay with Constant Jitter	Variable Delay with Constant Bandwidth
Bandwidth limitation	non-limited	non-limited	500Kbps
Packet loss limitation	10%	none	none
Jitter	none	30ms	none
Delay	*100ms → 500ms → 1500ms → 500ms → 100ms		
RTT	none	none	none
Queue size	1000		

*Each limitation period is 60 seconds long.

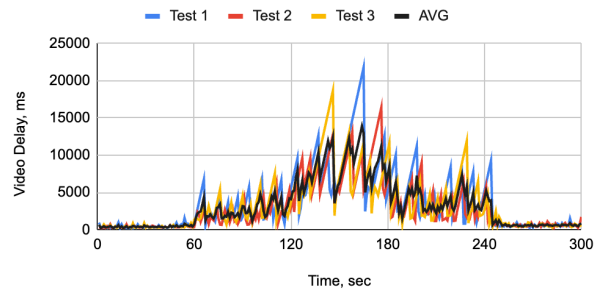
Overall, when looking at the impact of network constraints on an application's ability to stay in the call, the Variable Delay scenarios are less challenging for applications than the **Variable Bandwidth**, **Variable Packet Loss** or **Variable Jitter** scenarios. At the same time, however, Google Meet, Slack and Jitsi cannot handle the call, experiencing high video delays during the **Variable Delay with Constant Packet Loss** scenario. Slack is also not able to handle the **Variable Delay with Constant Jitter** scenario, having a high video delay that spikes up to 15 seconds in the middle of the test.

Video delay during the Variable Delay with Constant Packet Loss scenario

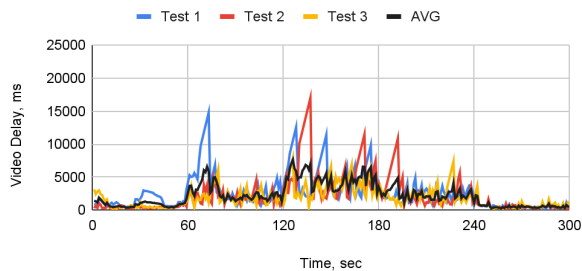
[GoogleMeet 2U] [Win-Win] [Variable Delay - Constant PL] - Video Delay overtime



[Slack 2U] [Win-Win] [Variable Delay - Constant PL] - Video Delay overtime



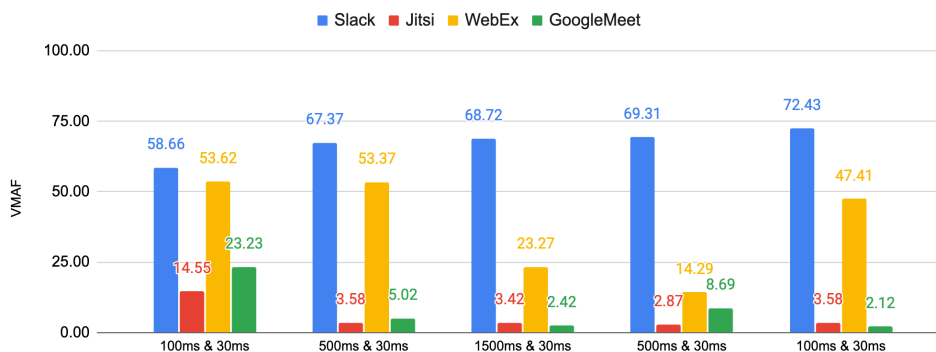
[Jitsi 2U] [Win-Win] [Variable Delay - Constant PL] - Video Delay overtime



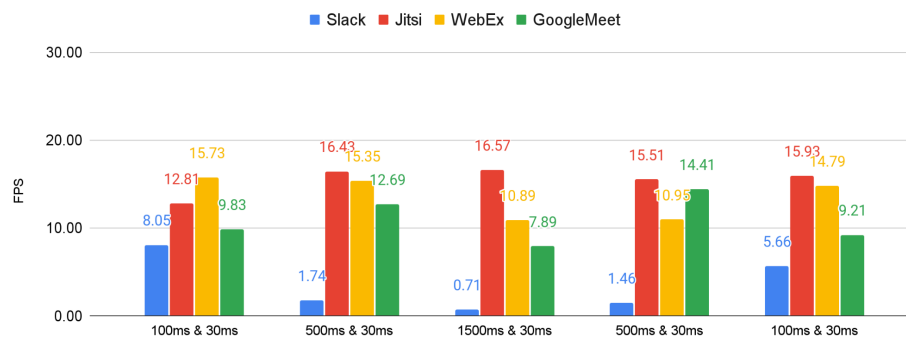
Apps exhibit lower video quality in the **Variable Delay with Constant Jitter** scenario (an average VMAF of 29.9). When it comes to video fluidity, the **Variable Delay with Constant Packet Loss** scenario has a more significant impact, with an average FPS of 6.48, compared to 10.83 FPS during the **Variable Delay with Constant Jitter** and 17.45 FPS during the **Variable Delay with Constant Bandwidth**.

Audio performance during the Variable Delay with Constant Packet Loss and the Variable Delay with Constant Bandwidth scenarios

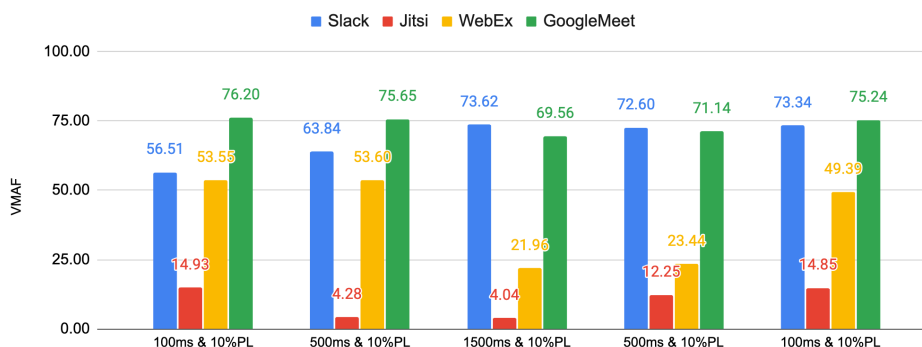
[Variable Delay - Constant Jitter] VMAF comparison



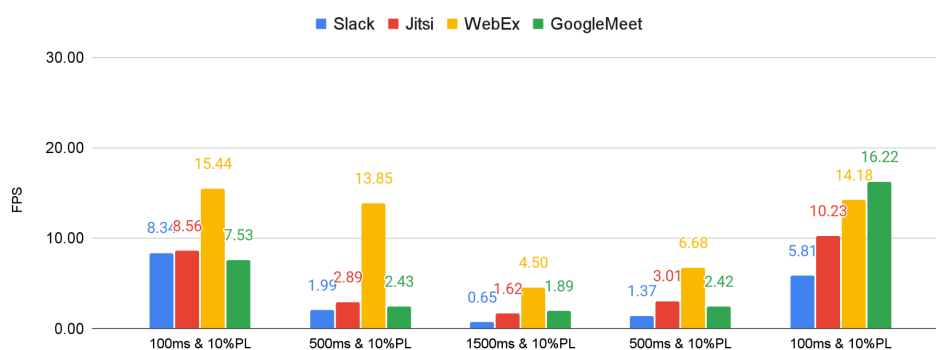
[Variable Delay - Constant Jitter] FPS comparison



[Variable Delay - Constant PL] VMAF comparison



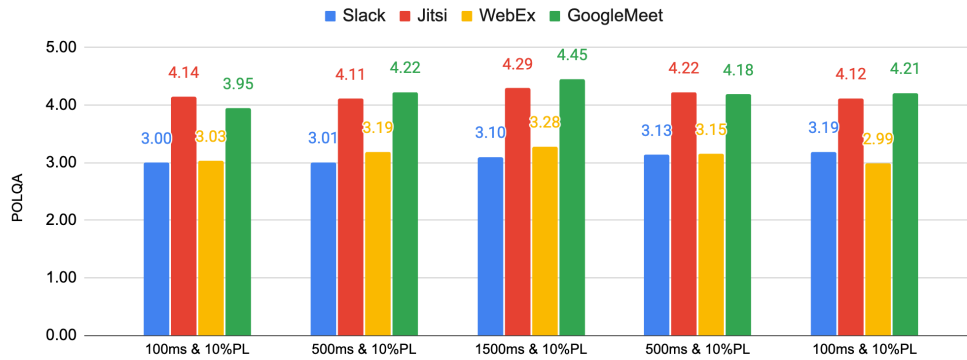
[Variable Delay - Constant PL] FPS comparison



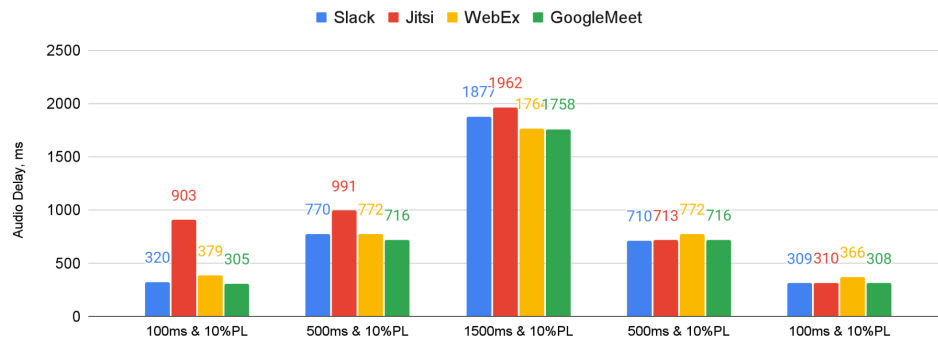
Regarding audio quality, the **Variable Delay with Constant Packet Loss** scenario results in a lower average POLQA score of 3.65, while the **Variable Delay with Constant Bandwidth** scenario shows a higher average POLQA score of 4.17. However, the **Variable Delay with Constant Bandwidth** scenario also has the highest audio delay (an average of 1078 ms), whereas the **Variable Delay with Constant Packet Loss** scenario experiences the lowest audio delay (an average of 836 ms).

Audio performance during the Variable Delay with Constant Packet Loss and the Variable Delay with Constant Bandwidth scenarios

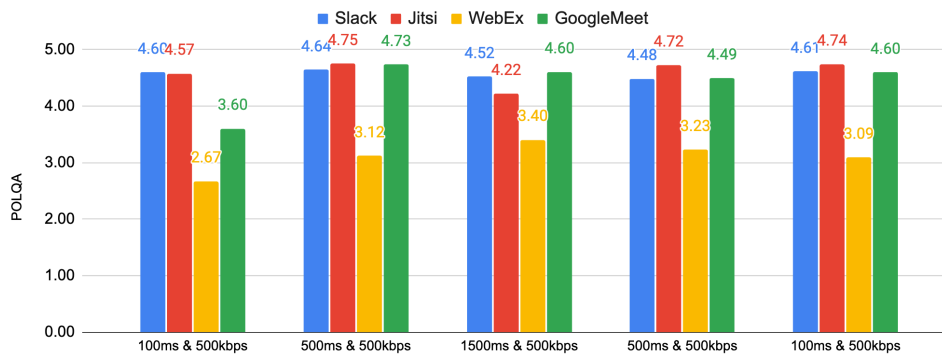
[Variable Delay - Constant PL] POLQA comparison



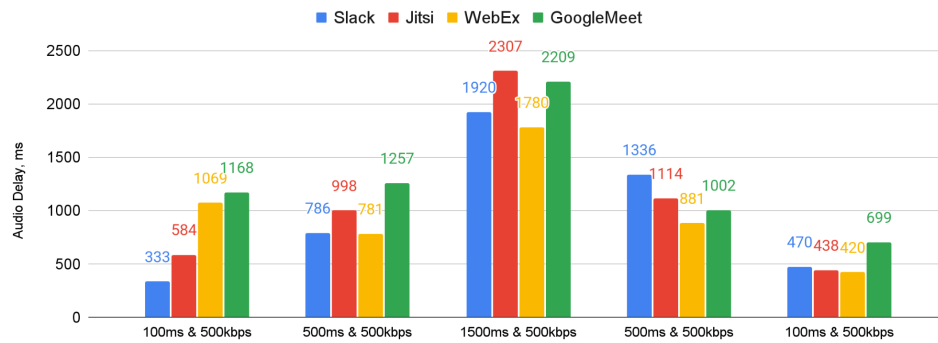
[Variable Delay - Constant PL] Audio Delay comparison



[Variable Delay - Constant BW] POLQA comparison



[Variable Delay - Constant BW] Audio Delay comparison



Multiple Variable Constraints Test Scenarios

	Variable Bandwidth, Delay and Jitter with Constant Packet Loss	Variable Delay and Jitter with Constant Packet Loss	Variable Delay and Jitter
Bandwidth limitation	*5000Kbps → 500Kbps → 200Kbps → 500Kbps → 5000Kbps	non-limited	non-limited
Packet loss limitation	3%		none
Jitter	*30ms → 90ms → 270ms → 90ms → 30ms		*0ms → 30ms → 90ms → 270ms → 90ms → 30ms → 0ms
Delay	*100ms → 500ms → 1500ms → 500ms → 100ms		*0ms → 100ms → 500ms → 1500ms → 500ms → 100ms → 0ms
RTT	none	none	none
Queue size	1000		

*Each limitation period is 60 seconds long.

In our audio and video application testing experience, we have observed that, most of the time, applications struggle more during changing network limitation scenarios than during constant network limitations. The first challenge is to maintain good quality when limitation increases in the middle of the test, and then observe what happens when it decreases. The application has the option to recover and maintain good performance.

Therefore, it is interesting to see how applications will perform in our new scenario that is a combination of multiple variable network settings, like Bandwidth, Delay and Jitter, as well as an added constant, but low, packet loss to it.

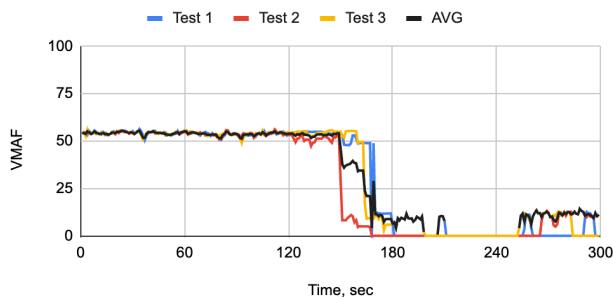
Testing results show that application performance is acceptable without any application disconnecting from the video call during the **Variable Delay and Jitter** scenario. This test scenario is 420 seconds long, as our aim was to cover a wider set of limitations by adding 0 ms Delay and 0 ms Jitter limitations at the beginning and end of tests. Audio quality is good (average POLQA 4.22), with high audio delay (average 870 ms). Regarding video quality metrics, a high difference in video image quality is observed in the tested scope. Some apps like Discord, Slack, and Zoom are able to maintain *Good* or *Fair* video quality, others have *Poor* or even *Very Poor* image quality when limitation increases. The average video image quality is *Poor* (VMAF 44.98)

The FPS is considered to be *Good* (average value 13), except in the middle of the test when the Delay is 270 ms and Jitter is 1500 ms, and here the average FPS is 4.49. The average video delay is *High* at 1224 ms.

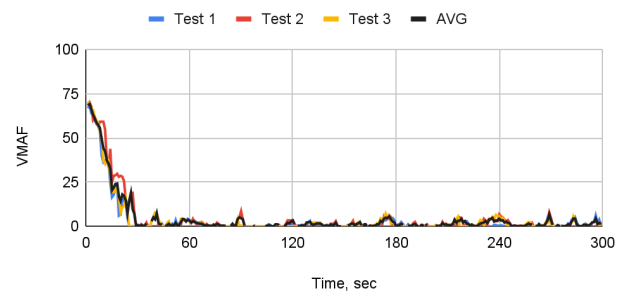
Cisco Webex experiences disconnection, while other applications have a high video delay and low FPS, however, it is able to stay in the call during the **Variable Delay and Jitter with Constant Packet Loss** scenario. Audio quality is *Good* with an average POLQA value of 4.03, however, audio delay is *High* at 1070 ms. The average FPS is *Fair* (average value 7.42), including a *Very Low* FPS (value of 1.86 that looks like a slideshow) in the middle of tests when limitation is higher. The average video delay is 2169 ms, while the video image quality is *Poor* (average value 21.37).

Video performance during the Variable Delay and Jitter with Constant Packet Loss scenario

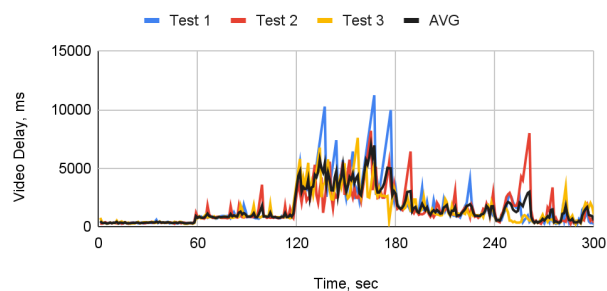
[WebEx 2U] [Win-Win] [Variable Delay and Jitter + low PL] - VMAF overtime



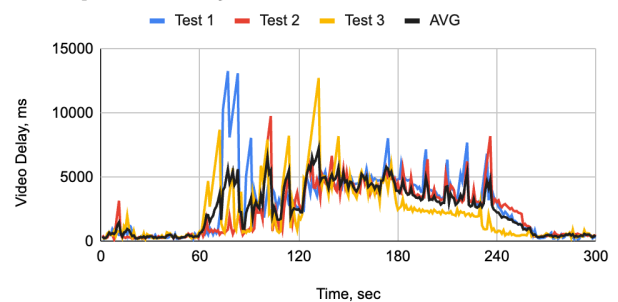
[GoogleMeet 2U] [Win-Win] [Variable Delay and Jitter + low PL] - VMAF overtime



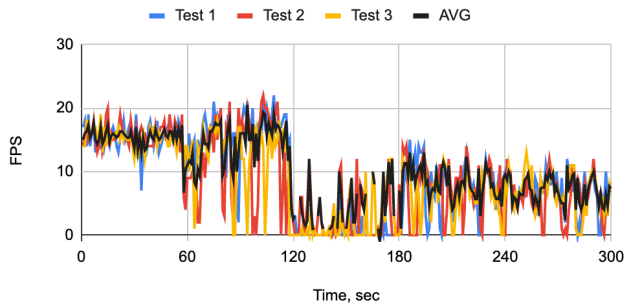
[WebEx 2U] [Win-Win] [Variable Delay and Jitter + low PL] - Video Delay overtime



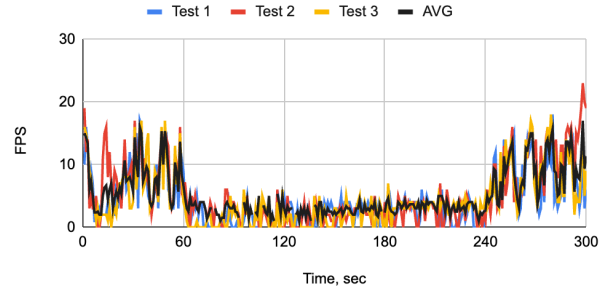
[GoogleMeet 2U] [Win-Win] [Variable Delay and Jitter + low PL] - Video Delay overtime



[WebEx 2U] [Win-Win] [Variable Delay and Jitter + low PL] - FPS overtime



[GoogleMeet 2U] [Win-Win] [Variable Delay - Constant PL] - FPS overtime

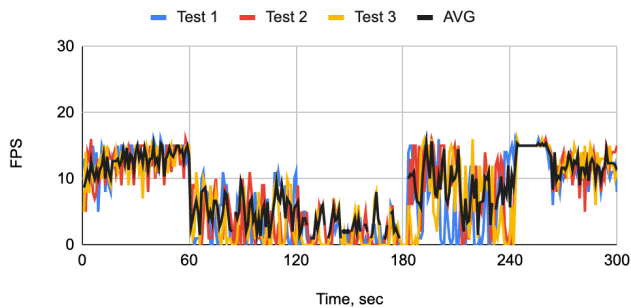


Cisco Webex has a disconnection during the video call, while other applications are struggling with long freezes and high video delays during the **Variable Bandwidth, Delay, Jitter with Constant Packet Loss** scenario.

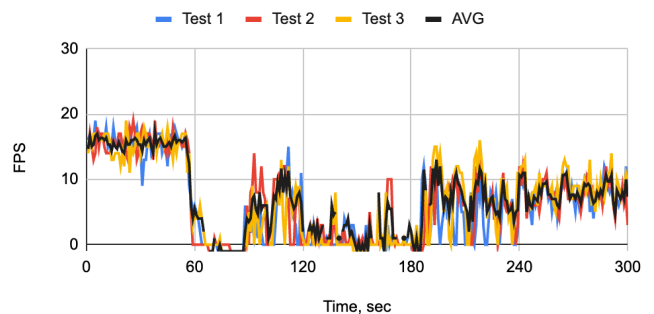
Overall, audio quality is still considered to be *Good* (average POLQA 3.87). Audio delay (on average 1651 ms) is two times higher than during the **Variable Delay and Jitter with Constant Packet Loss** scenario (on average 890 ms), which has a high impact on user experience.

Average FPS is 7.05 during the Variable Bandwidth, Delay, Jitter with Constant Packet Loss scenario

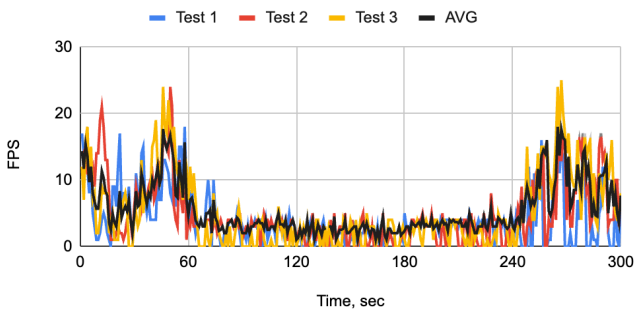
[Slack 2U] [Win-Win] [Variable BW, Delay and Jitter + low PL] - FPS overtime



[WebEx 2U] [Win-Win] [Variable BW, Delay and Jitter + low PL] - FPS overtime



[GoogleMeet 2U] [Win-Win] [Variable BW, Delay and Jitter + low PL] - FPS overtime



Video fluency is *Poor* (average value 7.05 FPS), video delay is *High* (average value 2989 ms), and video fluency is similar to that of a slideshow in the middle of the test when limitation is higher. Video image quality is *Poor* as well with an average VMAF value of 17.64.

Variable Queue Size Scenario

We used variable Queue Size (limitation periods: 1000 → 100 → 10 → 100 → 1000), while other settings, like Bandwidth, Packet Loss, Jitter, Delay and RTT were not limited. This scenario has less impact on audio and video data, and all applications handle this scenario well. The average audio quality in this test scenario is *Good* and close to *Excellent*. Audio delay is low and considered to be *Excellent*. Video fluency is *Excellent*, with an average FPS value of 21.35, and a low average video delay value of 200.80. Video quality is *Good*, with an average VMAF value of 69.99.

Key Takeaways

In our research, we tested 4 popular video conferencing apps: Google Meet, Slack, Jitsi and Cisco Webex, under 18 different network limitations constraints. All of them (excluding baseline) have at least one variable network setting, either Bandwidth, Delay, Jitter, or Packet Loss.

We noticed that applications handle some of the selected scenarios well, like the **Variable Queue Size** scenario, but most of the selected scenarios have a high impact on audio and video data, and are even causing disconnections from the call.

The scenarios with the poorest video quality were the **Variable Jitter with Constant Bandwidth** scenario and the **Variable Bandwidth, Delay, and Jitter with Constant Packet Loss**. These scenarios significantly impacted the FPS, at times reducing the video to a near slideshow with an overall low average FPS. Additionally, the highest video delays were observed in the **Variable Bandwidth, Delay, and Jitter with Constant Packet Loss** scenario and the **Variable Packet Loss with Constant Delay** scenario.

For audio quality, the most considerable drops in POLQA scores occurred in the **Variable Bandwidth with Constant Packet Loss** scenario and the **Variable Packet Loss with Constant Bandwidth** scenarios. The greatest audio delays were seen in the **Variable Bandwidth with Constant Jitter** and **Variable Bandwidth, Delay, and Jitter with Constant Packet Loss** scenarios.

Want to read up on our other research projects? Check out our blog on the [Netembox Limiter](#), our in-house controllable network limiter device, which we use to test the performance of devices under various network conditions. If you're interested in how our Audio and Video department can assist in your testing needs, [send us a message](#).

Appendix

Variable Bandwidth Test Scenarios

	Variable Bandwidth with Constant RTT	Variable Bandwidth with Constant Jitter	Variable Bandwidth with Constant Packet Loss	Variable Bandwidth
Bandwidth limitation	*5000Kbps → 500Kbps → 200Kbps → 500Kbps → 5000Kbps			
Packet loss limitation	none	none	10%	none
Jitter	none	30ms	none	none
Delay	none	100ms	none	none
RTT	500ms	none	none	none
Queue size	1000			

*Each limitation period is 60 seconds long.

Variable Packet Loss Test Scenarios

	Variable Packet Loss with Constant Jitter	Variable Packet Loss with Constant Delay	Variable Packet Loss with Constant Bandwidth
Bandwidth limitation	non-limited	non-limited	500 kbps
Packet loss limitation	*3% → 10% → 30% → 10% → 3%		
Jitter	none	30 ms	none
Delay	none	100 ms	none
RTT	500ms	none	none
Queue size	1000		

*Each limitation period is 60 seconds long.

Variable Jitter Test Scenarios

	Variable Jitter with Constant Delay	Variable Jitter with Constant Packet Loss	Variable Jitter with Constant Bandwidth
Bandwidth limitation	non-limited	non-limited	500Kbps
Packet loss limitation	none	10%	none
Jitter	*30ms → 90ms → 270ms → 90ms → 30ms		
Delay	500kbps	500kbps	500kbps
RTT	none	none	none
Queue size	1000		

*Each limitation period is 60 seconds long.