Study of Video Traffic in IPv6 Multicast IEEE 802.11ac Test Bed

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Abstract. The increasing number of multimedia users on networks entails an exponential growth in the demand for bandwidth. End users and applications pose increasing demands on Traffic Engineering, QoS and QoE of video-based products. This paper reports an experimental study of multicast video traffic in an actual laboratory network, in a controlled environment, as a testbed, with IEEE 802.11ac IPv6 wireless clients. Experiments were conducted using a Star Trek movie trailer. Alternatively, for contrast purposes, a video of equal length taken from a video conference on Adobe Connect was used. The videos were coded using H.264, H.265, VP8 and Theora. This study is the sequel to an earlier experimental study conducted on video traffic for wired networks. The main conclusions seek to guide and help simulation analysts, network administrators, designers and planners in determining the best settings to take into account in order to properly manage similar networks, efficiently using available resources without compromising the expected quality and performance levels.

Keywords: Multicast traffic, Codecs, IEEE 802.11ac, IPv6 Networks.

1 Introduction

Video traffic has grown exponentially in the last few years, especially as a result of new mobile device applications. According to Cisco [1], by 2021, smartphone data traffic will surpass PC data traffic, bandwidth speeds will almost double those in 2016, video traffic will account for 82% of total IP traffic, and Internet video and Video on Demand (VoD) will continue to grow. Additionally, IEEE 802.11 (Wi-Fi) networks are currently the most used points of access to networks and services in most of the usual areas, including video traffic.

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However, for video traffic applications, bandwidth availability in Wi-Fi networks as well as the availability of other shared resources need to be taken into account. Wi-Fi networks have improved their service with the adoption of new sets of standards, such as IEEE 802.11n and IEEE 802.11ac. IPv6 multicast traffic in these networks is a convenient way to reduce the impact of a video being streamed simultaneously to a group of users, thus saving network resources by having a single data flow for all receivers. This issue proves very relevant since the traffic of each video flow may be, in proportion, the largest network load when compared to other traffic flows, such as voice traffic, best-effort delivery or background delivery. Furthermore, when analyzing multimedia priority traffic and real-time traffic, video and voice traffic are not alike. The quantification of the load introduced by voice over IP (VoIP) inside the network is deterministic. Quantifying video traffic is a more complex task, one that is specifically dependent on the video in question. Finally, video compression serves as another valuable means to reduce video traffic load. The variety of available codecs makes for differences with one another. They all continue to show increasingly better services and continue to evolve over time. In this scenario, comparing and knowing about codecs in connection with video traffic compression becomes very important, as well as assessing its impact on network load.

This paper describes an experimental study on multicast video traffic as performed on an actual laboratory network used as a testbed. To that end, a new topology of wired and wireless networks was used, featuring IEEE 802.11ac wireless clients, IPv6 protocol, FFmpeg Server and Client software as video server and clients, and WireShark traffic analysis tool. Video traffic was then coded using H.264, H.265, VP8 and Theora, with the goal of assessing, comparing and understanding their impact. The experiments were conducted using a Star Trek film video trailer and, for contrast purposes, a video from a video conference on Adobe Connect, both of the same length and resolution. The experiences correspond to specific cases of pre-recorded, low-demand videos. This study is the continuation of a series of similar experiments conducted on IPv4 wired networks.

The main contributions of this study include: (i) showing, on the basis of detailed direct quantitative data and averages, that the values for the analyzed performance metrics are those expected for the behavior of multicast video traffic, and that they depend on the characteristics of the streamed video and, to a lesser extent, on the video codec that is being used; and (ii) specifying a new testbed comprising eight experimental sub-scenarios (changing the video and codec being tested), as well as a new methodology that uses comparative mechanisms to determine the differences among the sub-scenarios.

The rest of this document is structured as follows: Section 2 analyzes the State of the Art; Section 3, Scenarios and Experimental Resources, describes the topology and tools that were used; Section 4, Results, shows the main results arising from this study; and Section 5, Conclusions, covers the main conclusions and contributions arising from this work.

2 State of the Art

A number of earlier research papers and publications have been taken into account for this study. Unfortunately, experimental studies on these topics often fail to display uniformed, standardized topologies for the scenarios being under study, resulting in discrepancies in the methodology, video(s), or video codecs being used. This situation hinders the comparison and contrast of measurements and conclusions of contemporary studies and/or studies conducted over time by the same or different authors.

This study has especially taken into account the contributions specifically related to the field, such as those resulting from analyzing multicast traffic and video streaming across a variety of networks [2-4], papers on compression techniques and video codecs [5-8], and our own contributions from earlier studies on video traffic in WAN networks [9-10] and Wi-Fi networks [11], which are now enhanced by new results and a fuller, more detailed discussion.

The rest of this section offers a brief description of the main features of the tools and protocols that were used.

2.1 IP Multicast

In general, applications resort to either one of two models of data transmission over IP networks: the unicast model and the multicast one. In the unicast model, a one-to-one association is needed between the source and the receiver in order to send a given flow of data. Therefore, the network needs to be configured in such a way to allow supporting as many flows as receivers potentially interested in receiving the content exist. On the contrary, the multicast model is adaptable to content distribution models such as one-to-many and many-to-many, among other variants. In this case, the network will transport a single flow of data for each source, and the first source is responsible for delivering the flow of data to those receivers who are interested in receiving it. This design offers the possibility to improve in particular scalability and performance.

Routers are responsible for replicating and distributing the multicast content to all the receivers within a multicast group. Routers resort to multicast protocols that create distribution trees in order to transmit multicast content. IPv6 uses PIM-SM, PIM-SSM or other protocols. For this study, in an attempt to keep in line with the research conducted on IPv4, PIM-SM (Protocol Independent Multicast – Sparse Mode) was used.

2.2 Video Codec

Codecs are used to digitally compress or reduce the size of a video in order to improve service delivery as well as transmission or storage efficiency. A large number of algorithms or codecs are available, be they standard or proprietary. Oftentimes, video compression may compromise quality image and other application requirements.

The video codecs that were used in this study are listed and described below:

- H.264/MPEG-4 AVC: A video compression standard promoted jointly by the ITU and the ISO, offering significant advances in terms of compression efficiency, which result in half or lower bit rate when compared to MPEG-2 and MPEG-4 Simple Profile.

- H.265/ MPEG-H Part 2/ High Efficiency Video Coding (HEVC): A video compression format following H.264/MPEG-4 AVC, developed jointly by the ISO/IEC Moving Picture Experts Group (MPEG) and ITU-T Video Coding Experts Group (VCEG), corresponding to ISO/IEC CD 23008-2 High Efficiency Video Coding. This standard may be used to deliver higher quality, low bit-rate video while requiring the same bit rate. It is compatible with ultra-high-definition television and 8192 × 4320 display resolution.
- VP8: A video codec by On2 Technologies, released on September 13, 2008. On May 19, 2010, Google, having acquired On2 Technologies back in 2009, released VP8 as an open-source codec (under a BSD-like license).
- Theora: A free video compression format developed by the Xiph.Org Foundation as part of the Ogg project. It derives from VP3 codec. In 2010, Google began funding part of the Ogg Theora Vorbis project. Theora stands for a general purpose video codec requiring low CPU usage.

2.3 Video Streaming

A broad range of video streaming options are available, each of which may display different sets of behavior. Video traffic may be point-to-point, multicast or broadcast. Additionally, videos may be precoded (stored) or they may be coded in real time (for example, while an interactive videophone communication or video conference ensues). Video channels may be static or dynamic, and require a packet-based or a circuit-based switching system. Additionally, channels may withstand a constant or a variable bit rate speed. They may have also reserved a number of resources in advance or they may simply be offering best-effort capacity.

Clearly, a few basic issues are at play here, since only best-effort delivery is generally offered, which means that there are no guarantees regarding bandwidth, jitter or potential packet losses. Therefore, a key goal in video streaming involves designing a reliable system that delivers high quality video and takes into account Traffic Engineering, QoS (Quality of Service) and QoE (Quality of Experience).

2.4 IEEE 802.11ac Standard

In 1990, the IEEE 802 Committee created the IEEE 802.11 working group, which concerned wireless LAN networks specifically, with a view to developing specifications for medium access control (MAC) and physical layer (PHY) functions. Although IEEE 802.11 was the first standard to become widely known, it was only in 1999 that wide industry adoption was gained, with 802.11a and 802.11b. More recently, in an attempt to meet new and increasing demands, new IEEE projects were created with a view to providing a VHT (Very High Throughput) system. The Task Group TGac has specified IEEE 802.11ac as an extension of IEEE 802.11n.

The IEEE 802.11ac standard works on a 5 GHz band, which shows much less saturation, resulting in a cleaner signal and reduced interference. It also offers greater performance by using up to eight MIMO flows at 160 MHz, improving signal intensity by means of Beamforming technology, and accelerating data transmission by means of 256-QAM modulation.

2.5 Internet Protocol version 6 – IPv6

IPv6 represents the evolution of IPv4. In most devices and operating systems, this protocol is installed as a software update. In early 2011, IPv6 native users represented about 0.2%. In 2014, IPv6 was used by almost 3% of Internet users, representing about 72 million people. As of early 2020, IPv6 has achieved 30% penetration. The number of IPv6 Internet users has been doubling steadily every nine months approximately.

IPv6's main advantage is its extended address mode (represented in 128 bits). Furthermore, it offers several additional features, such as allocating an IP address from the client's end, allocating several addresses to the same device, integrated encryption and IPsec, enhanced performance, faster connection and much reduced latency, among others.

3 Scenarios and Experimental Resources

The main objective of the experiment reported in this paper has been studying Wi-Fi video traffic streaming by assessing on a testbed both the limitations imposed by these networks as well as issues derived from varying the type of video or codec being used, and the use of IPv6 multicast in combination with IEEE 802.11ac.

3.1 Network Topology

The topology that has been put forward includes a general scenario featuring a streaming server, mobile devices, and desktop PCs, IEEE 802.11ac Wi-Fi connectivity, and users connected to the ends of the network. The network comprises a series of routers and switches with different types of links interconnecting them. Figure 1 shows the experiment topology, where solid lines depict Fast Ethernet links with a transmission speed of up to 100 Mbps, while the end users' devices are connected by means of the IEEE 802.11ac standard. For the operation between routers, the unicast OSPFv2 and the multicast PIM-SM routing protocols were set. Cisco 2811 routers and Cisco Linksys LAPAC 1200 APs were used. The software used as the streaming server and the receiving clients are based on FFmpeg [12].

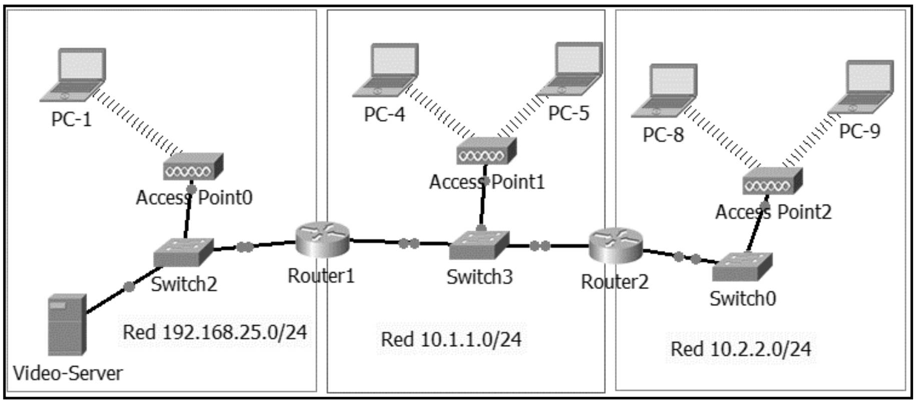

Fig. 1. Network topology.

3.2 Videos

Two on-demand video files were used, which were coded alternatively using the codecs selected for this experiment. One of the videos was a Star Trek movie trailer (Fig. 2-Video 1) [13], while the other one was an extract from a video conference using Adobe Connect (Fig. 3-Video 2)[14], which will be referenced to as Video 2, of the same length and quality as Video 1. Tables 1 and 2 compare the features of each codec for each video.

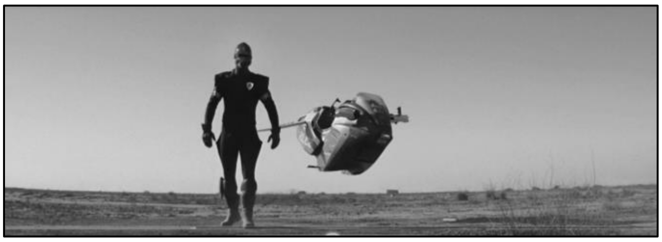

Fig. 2. Screenshot of the Star Trek movie trailer – Video 1.

Fig. 3. Screenshot of VC on Adobe Connect – Video 2.

Table 1. Video 1 Properties – Star Trek movie trailer.

Video 1	H.264	H.265	Theora	VP8
Format	MPEG-4	MPEG-4	Ogg	WebM v2
File size	79.9 MiB	72.3 MiB	83.3 MiB	78.6 MiB
Length	2 min 11 s	2 min 11 s	2 min 11 s	2 min 11 s
Bit rate mode	Variable	Variable	Variable	Variable
Bit rate	5,109 kb/s	4,620 kb/s	5,329 kb/s	5,028 kb/s
Video				
Format	AVC	HEVC	Theora	VP8
Bit rate	5,011 kb/s	4,514 kb/s	5,010 kb/s	4,721 kb/s
Width [in pixels]	1,280 pixels	1,280 pixels	1,280 pixels	1,280 pixels
Height [in pixels]	528 pixels	528 pixels	528 pixels	528 pixels
Aspect ratio	2.4:1	2.4:1	2.4:1	2.4:1
Frame rate mode	constant	constant	constant	constant
Frame rate [in fps]	23.976 fps	23.976 fps	23.976 fps	23.976 fps
*Bits/(pixel*frame)*	0.309	0.279	0.309	0.291
Audio				
Format	AAC LC	AAC LC	Vorbis	Vorbis
Bit rate mode	Variable	constant	Variable	Variable
Bit rate	98.7 kb/s	99.7 kb/s	98.7 kb/s	98.7 kb/s
Maximum bit rate	167 kb/s	167 kb/s	167 kb/s	167 kb/s
Channel	2 channels	2 channels	2 channels	2 channels
Sampling rate	44.1 kHz	44.1 kHz	44.1 kHz	44.1 kHz
Track size	1.54 MiB (2%)	1.56 MiB (2%)	1.54 MiB (2%)	1.54 MiB (2%)

3.3 Methods and Procedures

Based on the previous topology, the tasks in this experiment comprised the steps and considerations listed below:

a) Video 1 files were coded in the streaming server using the 4 formats;
b) Prior to being measured, all equipment items in the topology were synchronized by means of an NTP local server.
c) Video 1 was streamed to the network in multicast format, from the server, and using a specific codec.
d) Step c) was repeated until Video 1 was assessed using all codecs.
e) The same process was followed for Video 2.

In each of the 8 experiments that were conducted (which involved 4 codecs per video), measurements were made by capturing traffic on the server as well as on each of the end devices connected through Wi-Fi. Traffic capture was achieved by means of Wireshark sniffer software [15]. Using this software, a capture file was created at each point of measurement (the streaming server and the end devices) for each of the 8 tests. Each capture file contained the data on individual video traffic frames. These files contained data for each of the frames captured during the test, including the exact date and time of frame capture, origin and destination MAC and IP addresses, transport and/or application layer protocol, frame size, etc.

Table 2. Properties of Video 2 – Adobe Connect video conference

Video 2	H.264	H.265	Theora	VP8
Format	MPEG-4	MPEG-4	Ogg	WebM v2
File size	6.02 MiB	6.10 MiB	8.84 MiB	11.5 MiB
Length	2 min 11 s	2 min 11 s	2 min 11 s	2 min 11 s
Bit rate mode	Variable	Variable	Variable	Variable
Bit rate	385 kb/s	390 kb/s	565 kb/s	733 kb/s
Video				
Format	AVC	HEVC	Theora	VP8
Bit rate	256 kb/s	256 kb/s	407 kb/s	568 kb/s
Width [in pixels]	1,280 pixels	1,280 pixels	1,280 pixels	1,280 pixels
Height [in pixels]	720 pixels	720 pixels	720 pixels	720 pixels
Aspect ratio	16:9	16:9	16:9	16:9
Frame rate mode	constant	constant	constant	constant
Frame rate [in fps]	30.000 fps	30.000 fps	30.000 fps	30.000 fps
*Bits/(pixel*frame)*	0.009	0.009	0.015	0.021
Audio				
Format	AAC LC	AAC LC	Vorbis	Vorbis
Bit rate mode	Variable	Variable	Variable	Variable
Bit rate	126 kb/s	126 kb/s	127 kb/s	127 kb/s
Maximum bit rate	257 kb/s	127 kb/s	257 kb/s	257 kb/s
Channel	2 channels	2 channels	2 channels	2 channels
Sampling rate	44.1 kHz	44.1 kHz	44.1 kHz	44.1 kHz
Track size	43.066 fps	43.066 fps	1.99 MiB	1.99 MiB (17%)

3.4 Metrics

The experiments resulted in a series of metrics for server and for clients. The data for each metric were determined individually for each device, after which, measurement averages were computed.

The metrics obtained were as follows:

- Total running time of video [Tt],
- Total number of packets (or frames) [NP],
- Total numbers of bytes [NB],
- Packet average size [PAS],
- Interframe space or Time between frames or packets [IFS], and
- Effective data transfer rate [BR]: Defined as NB divided by Tt.

Additionally, other metrics and measurements were recorded, such as:

- Streaming timing delay [Td],
- Timing delay difference (or jitter) [DD],
- Amount of errors obtained [Eo], and
- Statistical distribution.

4 Results

Table 3 briefly summarizes the average metrics of the most relevant metrics as defined above. Since the work involved a controlled laboratory topology, no streaming errors or significant frame losses occurred. Additionally, the load of control traffic for protocols OSPFv2 and PIM-SM was non-significant. The values at individual measurement points proved very similar.

High levels of dependency were observed between the characteristics of the video type that was streamed and the codec that was used. In bit rate, the video conference represents a traffic load volume around 90% lower than a movie of similar resolution, which will consequently exhibit fewer frames, greater average interframe space, or a smaller number of bytes in similar proportion.

Additionally, it is worth highlighting in Table 4 that the average across all codecs amounted to 99,793 frames to be streamed for Video 1. For Video 2, on its part, it took 8,220 frames to stream the video conference, which had the same length as Video 1. This means Video 2 required almost 82% fewer frames. Since both videos have the same length, it should be expected that the interframe space in Video 1 would be substantially lower. Indeed, the average codec interframe time for Video 1 was 1.24 ms, while for Video 2 it was 15.31 ms, i.e. about 12.34 times more.

Table 3. Average metrics per codec for each video.

Codec	Number of frames NP	Average inter-frame space IFS [s]	Number of bytes NB [Mbytes]	Packet average size PAS [bytes]	Bit Rate BR [Mbits/s]
Video 1 – *Star Trek* Movie Trailer					
H264	111,203	0.00097	82.80746	806.62	5.04901
H265	87,852	0.00147	70.85176	806.02	4.34782
Theora	82,292	0.00145	60.37944	802.72	3.69813
VP8	117,826	0.00109	82.28519	802.38	5.01721
Video 2 – Adobe Connect Video Conference					
H264	8,067	0.01582	6.90888	856.44	0.42142
H265	7,943	0.01618	6.91067	870.03	0.42150
Theora	6,782	0.01652	9.78550	1442.86	0.59661
VP8	10,090	0.01274	12.76103	1264.72	0.77831

Table 4. Average metrics for each video.

Average between codecs	Number of frames NP	Average inter-frame space IFS [s]	Number of bytes NB [Mbytes]	Packet average size PAS [bytes]	Bit Rate BR [Mbits/s]
Video 1 – *Star Trek* Movie Trailer					
Video 1	99,793	0.00124	74.08096	804.43	4.52804
Video 2 – Adobe Connect Video Conference					
Video 2	8,220	0.01531	9.09152	1104.01	0.55446
Difference	82.37%	12.34 times +	88.91%	25.44%	88.91%

4.1 H.264 Codec Behavior

Fig. 4 and 5 respectively show the distribution of frame sizes and interframe spaces for Video 1. Fig. 4 shows high frame concentration, of around 54,000 frames for each case, for a length below 100 bytes and above 1,500 bytes (almost the total of frames). In Fig. 5, on its part, it should be pointed out that almost 97% of the frames have an interframe space under 1 ms.

Fig. 6 and 7 respectively show the distribution of frame sizes and interframe spaces. Fig. 6 shows greater frame distribution depending on the size; where 24% correspond to frames above 1,500 bytes, 26% to frames around 1,150 bytes, and about 25% to frames below 150 bytes. In Fig. 7, 50% of the frames display an interframe space under 3 ms, 26% around 30 ms, 9.5% around 39 ms, and the remainder is distributed within the work range.

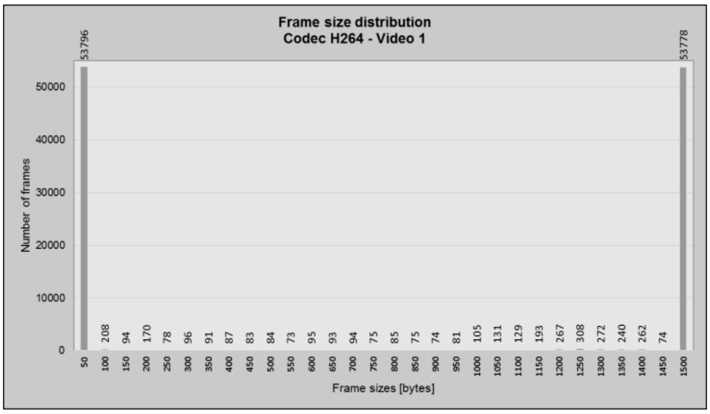

Fig. 4. Frame size distribution of Video 1 using H264.

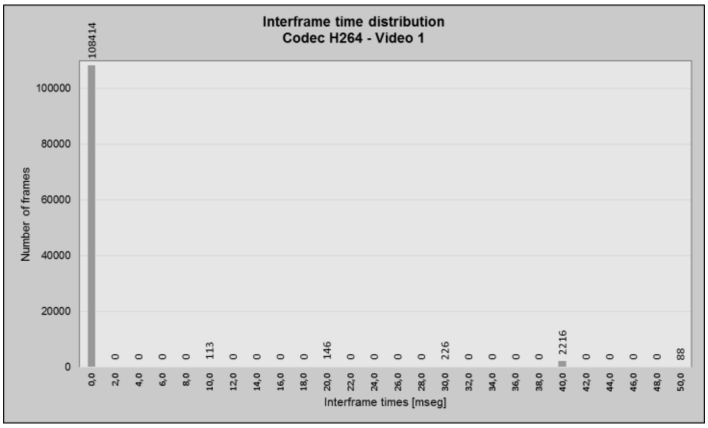

Fig. 5. Interframe space distribution of Video 1 using H264.

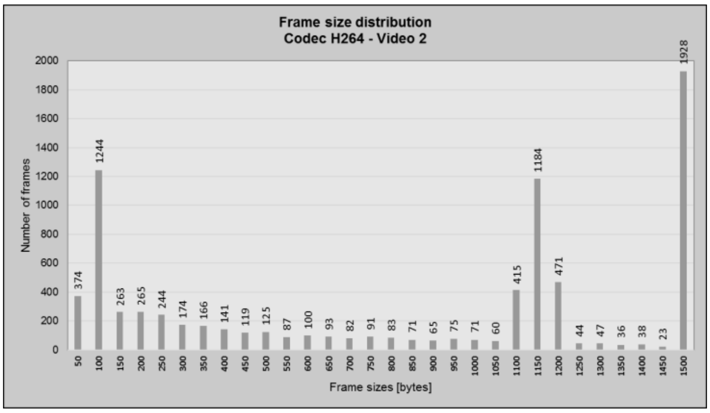

Fig. 6. Frame size distribution of Video 2 using H264.

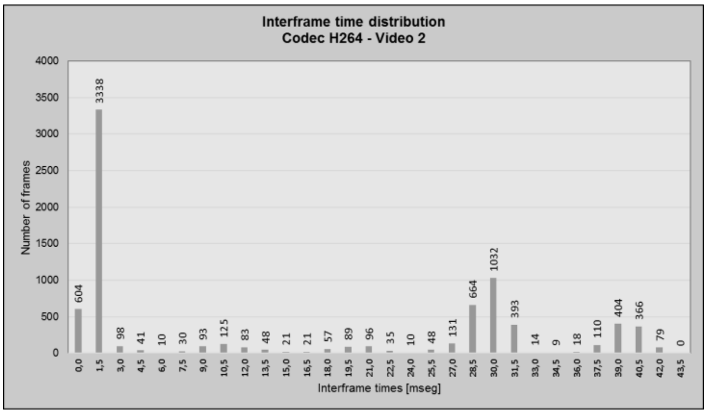

Fig. 7. Interframe space distribution of Video 2 using H264.

4.2 H.265 Codec Behavior

Fig. 8 and 9 respectively show the distribution of frame sizes and interframe spaces for Video 1. Fig. 8, as in the case of H.264, shows high frame concentration, of about 42,000 frames for each case, for a length below 100 bytes and above 1,500 bytes. In Fig. 9, on its part, it should be highlighted that almost 94% of the frames have an interframe space under 2 ms.

Fig. 10 and 11 respectively show the distribution of frame sizes and interframe spaces. Fig. 10, as in the case of H.264, shows greater frame distribution depending on the size; where 27% correspond to frames above 1,500 bytes, 25% to frames around 1,150 bytes, and about 33% to frames below 200 bytes. In Fig. 11, 32 % of the frames display an interframe space under 2.5 ms, 31% around 19 ms, 13% around 29 ms, and the remainder is distributed within the work range.

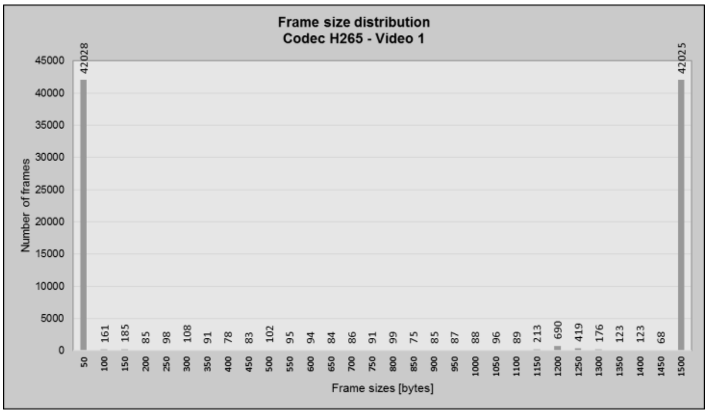

Fig. 8. Frame size distribution of Video 1 using H265.

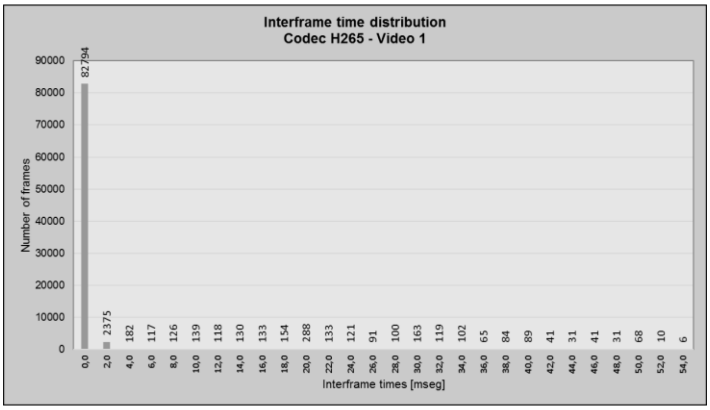

Fig. 9. Interframe space distribution of Video 1 using H265.

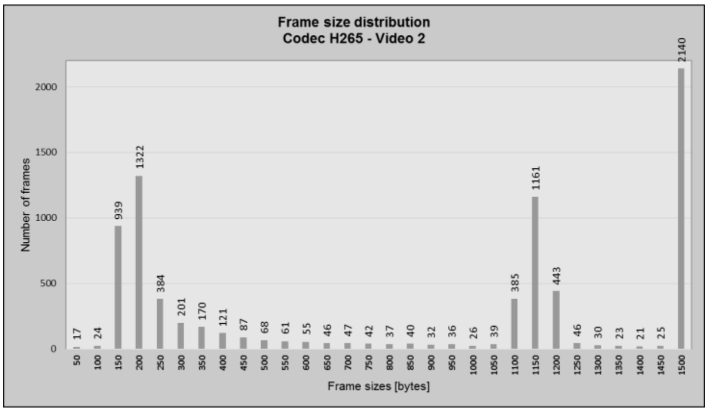

Fig. 10. Frame size distribution of Video 2 using H265.

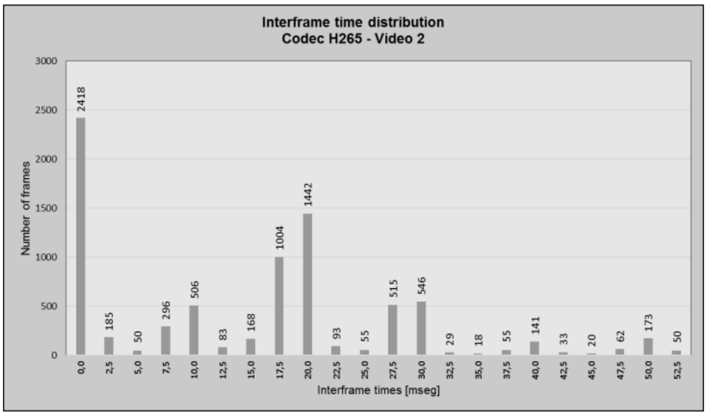

Fig. 11. Interframe space distribution of Video 2 using H265.

4.3 Theora Codec Behavior

Fig. 12 and 13 respectively show the distribution of frame sizes and interframe spaces for Video 1. In Fig. 12, almost the total amount of frames is distributed into two groups, of around 42,300 frames each, for a length below 100 bytes and above 1,500 bytes. In Fig. 13, on its part, it should be pointed out that almost 97% of the frames have an interframe space under 2 ms.

Fig. 14 and 15 respectively show the distribution of frame sizes and interframe spaces for Video 2. Fig. 14 shows 74% of the frames are above 1,500 bytes, while 13% are around 130 bytes. In Fig. 15, 93% of the frames have an interframe space under 3 ms.

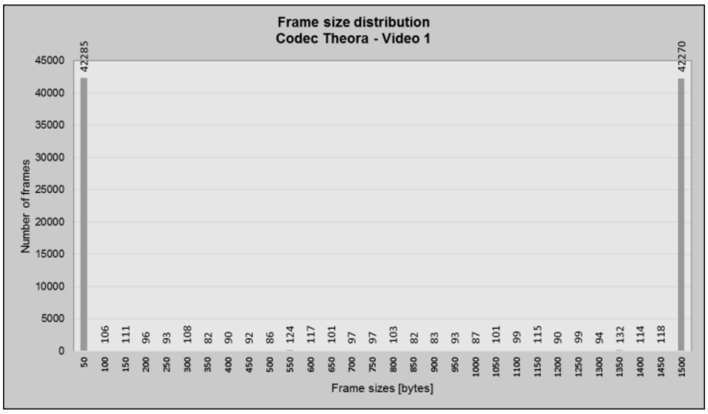

Fig. 12. Frame size distribution of Video 1 using Theora.

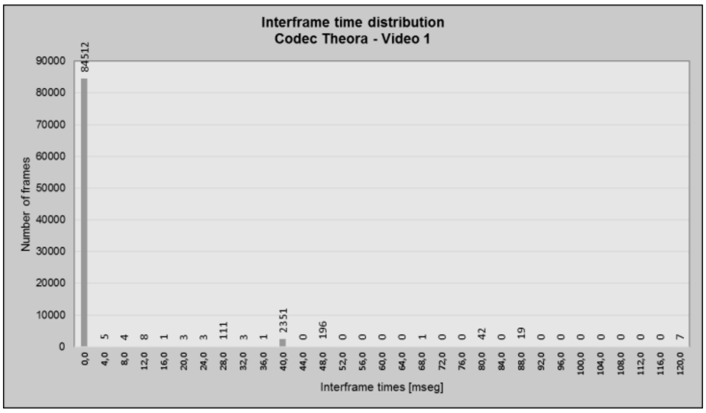

Fig. 13. Frame size distribution of Video 1 using Theora.

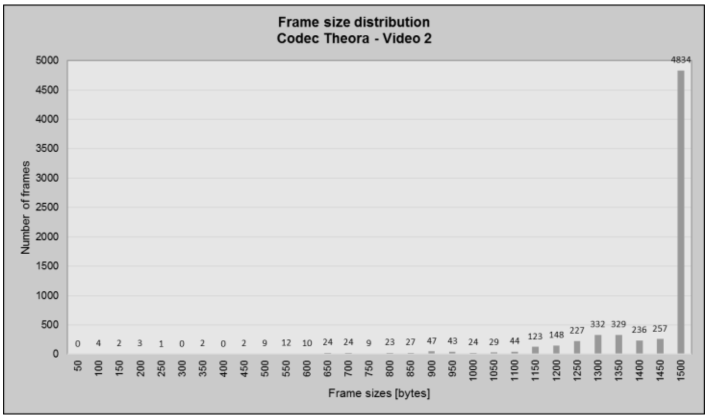

Fig. 14. Frame size distribution of Video 2 using Theora.

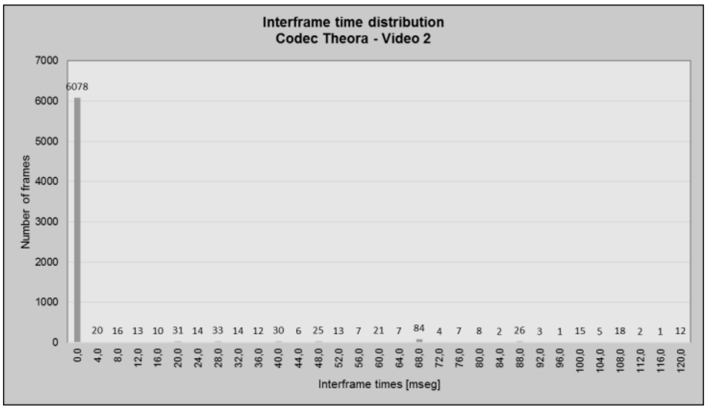

Fig. 15. Frame size distribution of Video 2 using Theora.

4.4 VP8 Codec Behavior

Fig. 16 and 17 respectively show the distribution of frame sizes and interframe spaces for Video 1. In Fig. 16, virtually all the frames (97.4%) are distributed into two size groups, of around 57,390 frames each, for lengths below 100 bytes and above 1,500 bytes. In Fig. 17, on its part, it should be pointed out that almost 97.3% of the frames have an interframe space under 0.3 ms.

Fig. 18 and 19 respectively show the distribution of frame sizes and interframe spaces for Video 2. Fig. 18 shows a group represented by 45% of the frames above 1,500 bytes, and another one, represented by 40% of the frames, evenly distributed between 1,000 and 1,450 bytes. Finally, in Fig. 19, 50% of the frames have an interframe space below 3 ms, 19% have one around 19 ms, and the rest are distributed mostly between 9 and 29 ms.

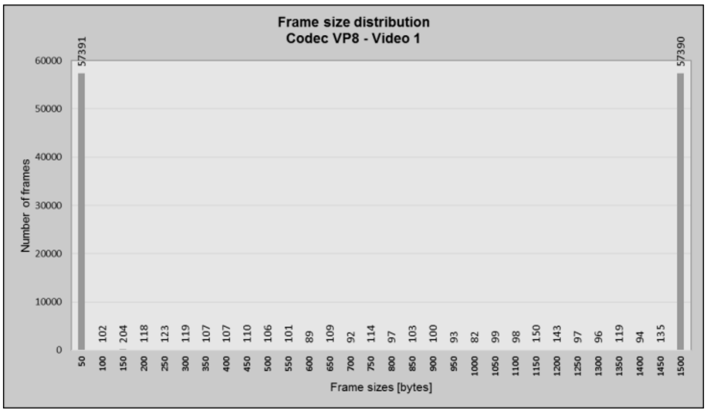

Fig 16. Frame size distribution of Video 1 using VP8.

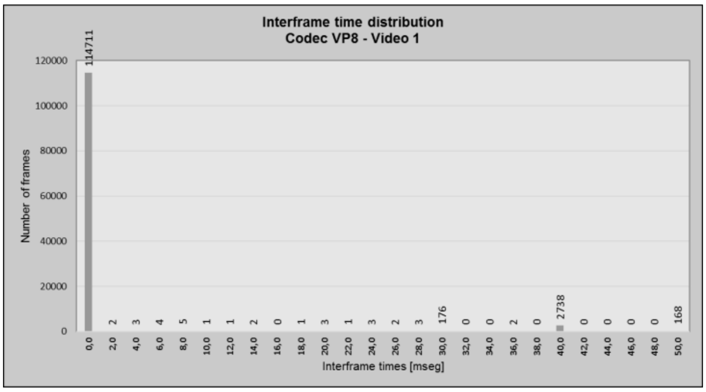

Fig 17. Interframe space distribution of Video 1 using VP8.

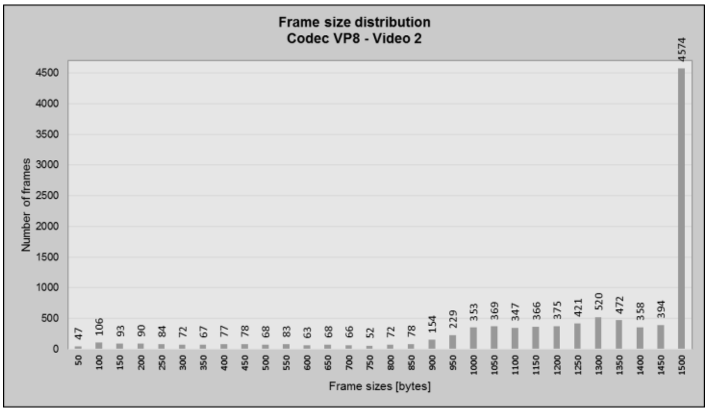

Fig 18. Frame size distribution of Video 2 using VP8.

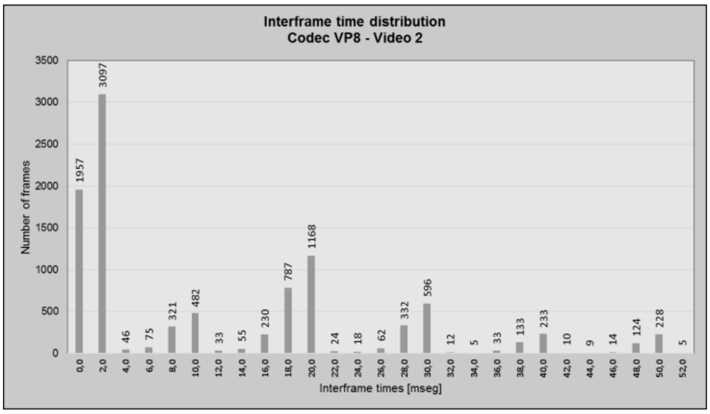

Fig 19. Interframe space distribution of Video 2 using VP8.

5 Conclusions

The primary motivation behind this study was learning about the behavior of video traffic on Wi-Fi networks while using IPv6, and understanding the requirements needed by the network, contrasting two clearly different cases: a movie trailer (Video 1) and a video conference video (Video 2). Using a detailed multicast scenario, a series of tests were conducted, where 8 sub-scenarios were set up. The results include values of direct and average metrics, as well as the distribution as per frame size and interframe space for each of the 4 codecs that were used for Videos 1 and 2.

The videos being compared clearly showed similar characteristics between them in terms of length and resolution, but they were quite different in terms of the dynamics at play.

A quantitative conclusion was made as to the existence of high levels of dependency between the characteristics of the video type being streamed (whether it was a movie or a video conference) and, to a lesser extent, the codec that was used. An additional conclusion is that neither the network topology nor the equipment type exercise significant impact, since their behavior is virtually identical for clients located at different network nodes.

This case study will prove useful to administrators, designers, planners, analysts, and Wi-Fi video traffic simulators for improving the execution of their tests. Although it is not possible to ensure the same type of behavior for all movies and video conferences, for codecs other than those used in this study, or for a standard different from IEEE 802.11, simulation analysts may use the metrics obtained experimentally in this paper as a guide as to the network demands made by video conferences, movies, etc. as well as their characteristics and features. Designers, planners, and network administrators, on their part, with a keener interest in bandwidth data, may use the 4.52 Mbps from the Star Trek movie trailer and the 0.55 Mbps for the video conference on Adobe Connect as reference data.

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