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IP VIDEO COMPRESSION COMPARISON FOR SMARTPHONES IN BIG DATA ERA

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Abstract

Recent advances in smartphones make it easy for the end-users to handle complex videos on their phones and take advantage of a variety of video streaming services. The massive volume of video data on the Internet, in turn, adds up to the big data problem. This is the result of the fact that there are a lot of different kinds of information in video contents. Therefore, the video codec algorithms are applied as a solution to reduce the size of video files by removing redundant information while maintaining video quality. On the other hand, video processing on smartphones requires high bandwidth mobile networks among which, LTE and 802.11ac are the two most common. However, due to the special requirements and the complexity inherent in the mobile networks and also due to the different level of capability and complexity involved in the video compression algorithms, the issue is further extended as an inefficient codec algorithm can directly constrain the performance of the mobile networks. Therefore, it is crucial to identify the requirements, potential benefits, and behavioural differences of the video codecs in LTE and 802.11ac networks prior to applying them by video content providers. To contribute in this direction, this work presents a codec-oriented reference model to investigate the performance of the three most common compression algorithms including HEVC, H.264, and MPEG-4 over LTE and 802.11ac networks. The NS3 simulation tool is used to implement the model and FFmpeg and Evalvid open-source tools are used for transmission of real video traffic. Depending upon the requirements, the model assists the video service providers to determine a more efficient video compression algorithm for the corresponding mobile network.

Keywords: 802.11ac, Big data, Evalvid, FFmpeg, LTE, Video codecs.

1. Introduction

Smartphones are rapidly becoming a vital factor in today's life. The significant advancements in hardware capabilities of the smartphones and a variety of mobile applications available in the app stores including Apple store and Google play store have led to extremely rapid growth in the number of smartphone's subscribers. On the other hand, among all the services provided for the subscribers, posting videos on the web and accessing online videos over the Internet via smartphones, as an ever-growing demand, continue to be a challenging task in the mobile phone market and industry. It is expected that the majority of the traffic delivered over the Internet will be video contents and will be over 80% of all Internet traffic [1]. The huge volume of video traffics are exchanged over the Internet via different sources such as over-the-top (OTT) services including YouTube, Netflix, and Hulu, contents on social media networks such as Facebook and Instagram, and live feed surveillance cameras [2]. Consequently, video contents are now relevant to parts of big data applications [3] such as big data video analysis [4].

The amount of video traffics on the networks is influenced by different factors including the size of each video file [1]. On the other hand, the uncompressed video files consume a large amount of storage, transmission time, and bandwidth, which increase the resource utilization [5] in the resource-constrained devices such as smartphones. Therefore, before transmission, the video compression techniques are applied to the video contents to remove redundant information, decrease the individual size of each video file, and also guarantee the perceptual quality of the delivered videos.

There are different types of video compression algorithms, each with different level of capability and complexity. The most common video codecs MPEG-4, HEVC, and H.264 compression algorithms are among the. The fourth suite moving pictures experts group (MPEG-4) has sub-divisions called parts, which are further sub-divided into layers. The parts are used instead of starting a new suite. Currently, the MPEG-4 has about 30 parts each with different technology while MPEG-4 part 2 and part 10 are the most common today. The MPEG-4 part 2 is called H.263 and the MPEG-4 part 10 is called H.264. This work refers to MPEG-4 part 2 as MPEG-4 to be distinguishable from the other parts. Moreover, the MPEG-H is a new suite in which, part 2 is called high-efficiency video coding (HEVC) or H.265 [6-9].

The MPEG-4 algorithm is a low bitrate encoding solution for medium-quality video conferencing. The video bitrate shows how much data can be stored in one second of the video file. Internet applications such as flash videos on YouTube and Google videos, video conferencing, and video telephony along with IP multimedia systems (IMS) originally use this algorithm [6]. In contrast, the H.264 algorithm is able to provide a high level of quality at a lower bitrate than the MPEG-4. The H.264 algorithm is the current standard for live and on-demand video streaming [7]. Furthermore, the HEVC is the newest algorithm, which can provide high-resolution video at a half bitrate of the H.264 [8]. Using this codec, the video is supported at 4096×2160 pixels (4K) at a frame rate of 60, while at the lower resolutions, it can even have a frame rate of 120 [9].

Because these codecs differ in several ways, they can provide a different level of video quality. Furthermore, because distinct structures of the mobile networks demand different requirements, the performance of the codecs relies on the type of the network they are applied to. Taken all these into account, we present a codec-oriented reference model in which, the video delivery is performed through the video server to the smartphones in downlink direction over the long-term evolution (LTE) cellular network and 802.11ac Wi-Fi network. The main contribution of the reference model is to implement different video compression algorithms over both LTE and 802.11ac network to identify their performance and assist the video service providers to determine the right codec for the right network accordingly.

In order to achieve these, the model takes into account three major considerations. First, the compression algorithms attempt to reduce the bandwidth but this, on the other hand, can result in complex dependency creation among the video blocks and frames [6]. Secondly, both the LTE standard and wireless channels are error-prone [10, 11]. Thirdly, the compressed video contents are both error-sensitive and time-critical [10]. Consequently, it is highly important to determine right video compression algorithm to achieve an acceptable video quality and satisfy delay requirements [11], otherwise, the mobile users are more likely to experience video playback issues including significant deterioration in the performance, slow upload-download time, and choppy video.

The rest of this work is organized as follow. Section 2 provides the related work. Section 3 presents the model along with the simulation parameters and scenarios. In Section 4 we evaluate the performance of the model on the basis of the results. Finally, conclusions are drawn in Section 5.

2. Related Works

According to statistics, the proportion of mobile video files will increase from 15% in 2016 to about 75% by 2020 [12]. The authors mentioned that cellular networks are suited for providing personalized service because of their high flexibilities and rich interaction. Additionally, with the increase of available bandwidth and bandwidth efficiency, 5G has the promise of supporting mass data transmission. However, it is difficult even for 5G to meet the video demands in the highly-dense area. Therefore, to resolve the high demand for bandwidth a model is presented for LTE networks. However, the model does not take into consideration the video compression algorithm effects for saving the bandwidth while 802.11ac wireless network is not investigated in this regard.

Bi et al. [13] focuses on 3D video and mentions that the 3D video has been introduced to home through 3DTV, 3D gaming and 3D movies along with developing different codecs for 3D video. Since the 3D video stream consists of both colour and depth, the 3D video delivery requires higher bandwidth. They mention that emerging LTE and 802.11ac standards provide significant bandwidth improvements for delivery of the video sequences. Thus, they present a model for 3D video delivery in heterogeneous networks including LTE and 802.11ac in presence of H.264 video codec and one UE and two wireless stations. The throughput, delay, and PSNR are evaluated only for H.264 codec while other types of video codecs are not implemented and evaluated.

Lin et al. [14] mentioned that according to the study of Cisco, mobile data traffic will grow from 2014 to 2019 and reach 24.3 EB per month by 2019. To develop an effective solution for video transmission, they present a mobile cloud video transmission algorithm based on game theory in wireless networks. However, LTE cellular networks and video compression algorithms are not investigated. The demand for video traffic in wireless networks is highly rising soon [15]. The authors present a model to show how to transmit HEVC compressed video over wireless channels with the aid of large-scale MIMO techniques. The results to evaluate the efficiency of the codec are obtained in terms of throughput and PSNR. However, the LTE cellular networks and efficiency of the other video compression techniques are not studied. According to Pal and Vanijja [16], different characteristics of the HEVC codec's quality for mobile devices in the 802.11ac network are also investigated.

Zeng et al. [17] mentioned various advantages of an efficient video codec to help reducing information redundancy, delaying processing, enhancing the robustness, improving the visual perception of quality, and increasing the compression ratio. They develop software in the win32 environment to investigate and compare the efficiency of the H264 and HEVC video codecs using FFmpeg, sdl2.0 function library, and MFC package. However, LTE and 802.11ac are not used in their work. Using the H.264 video codec, the delivery of 4kUHD videos over 802.11ac networks is evaluated by Adeyemi-Ejeye et al. [18] in term of packet loss. The results show that using H.264 codec in 802.11ac network can provide an acceptable level of quality if the transmission range is not more than 10 m.

Based on the current works, there is no comparable study to investigate different characteristics of the video codecs over cellular LTE and 802.11ac networks. Since the video compression algorithms differ in characteristics and requirements, and since the smartphones are resource-constrained, a low-power and high-performance video compression algorithm can significantly improve the performance of mobile networks. Considering the characteristics of the video compression algorithms and those of the LTE and 802.11ac standards together will lead to selecting the more efficient video compression algorithm for the network which in turn, provides the advantages of effective video file delivery with a smaller size for the smartphones users.

3. Implementation of the Model

The reference model includes two separate parts: implementation and simulation. For this reason, we divide the procedure of the model into two four steps. Steps 1, 2, and 4 are regarding the implementation part and step 3 is related to the simulation part.

- Simulation part: simulation of the model is done using the NS3 tool and the corresponding network devices and topologies are created. Ten smartphones, a packet data network gateway (PGW), an eNodeB, an access point, and a video server are created. The ten smartphones are equipped separately with both LTE and 802.11ac network interface cards (NICs). First, we activate the LTE NICs of the smartphones for the whole process of requesting and receiving video files in the cellular network, and then we activate the 802.11ac NICs of the smartphones to repeat the whole process again in Wi-Fi network. When the LTE NICs are activated, the smartphones are connected to the eNodeB, which in turn is connected to the packet data network gateway (PGW). The PGW connects the smartphones to the video server over the Internet for serving the video file with the pre-determined codecs. Through this structure, the ten smartphones send their video requests at the same time to the video server and then they receive the requested video file (step 3). On the other hand, when the 802.11ac NICs are activated, the smartphones are connected to the wireless access point which in turn, is connected to the video server. Like LTE, in this structure, the ten smartphones send their video requests at the same time to the video server and then they receive the requested video file (step 3). The aim is to measure the performance and compare the behaviour of the two networks separately.

- Implementation part: in this part, the real video files to be transmitted in downlink direction by video server and received by smartphones are generated. The model is able to generate and transmit real video traffic in the network for which, it employs two open-source software called Evalvid [19, 20] and FFmpeg [21]. The Evalvid is a video quality evaluation framework that contains a set of tools to generate traffic. It is also able to regenerate the original sent file from the received file to compare them and evaluate the quality of the received file over the networks. The FFmpeg, on the other hand, includes a set of libraries and programs to perform a variety of functions on files, among which, the model employs the encoding and decoding functions over the video files.

The ten smartphones and video server are all equipped with the Evalvid framework in the reference model. The Evalvid video server sends the video files to smartphones as Evalivid clients. The Evalvid framework contains a library called mp4trace that generates the final video trace file to be transmitted to the destination. The ten smartphones act as Evalvid clients to request a video file from the video server, which in turn acts as the Evalvid server to transmit the requested video file to all ten smartphones.

Step 1

A pre-preparation step in the model is performed before transmitting the real video file from the video server to the smartphones. This pre-preparation step aids to create the desired encoded video trace file from a raw video source. According to the National Science Foundation [22], for this purpose, the Akiyo yuv raw video file with 300 frames is selected and downloaded. Then, the raw video file is used as the input to the FFmpeg tool three times each with a different codec. At this point, three new yuv files, encoded with MPEG-4, H.264, and HEVC codecs, are created all with 352×288 resolution, 64k bitrate, and 30 frames per second (FPS). The FFmpeg has applied again over the three encoded files to create three different.m4a files from which, three mp4 files are created using the MP4Box tool. The next step in the model is using the Evalvid framework to produce three different.*st* trace files. The trace files contain all the relevant information for transmission of the video packets with four columns. The frame number, frame type, frame size, and the total number of packets needed to send out the frame are placed in the columns of one to four respectively. All this information helps to determine how to transmit and receive the video files.

Step 2

The .st video files are placed in the video server. As the server, the clients send their request messages to it as a sign of requesting the video file. Upon receiving the ten video requests from the ten smartphones, the video server is responsible to transmit the .st file encoded first with MPEG-4 codec. The .st file is delivered to the smartphones through the corresponding core networks, either the LTE or 802.11ac. The process again is repeated for the H.264 and HEVC codecs.

Step 3

Now, the reverse process is done by the smartphones to convert back the received .st file to playback the original raw yuv video. The transmission time is set according to the time length of the video, which is 14s for the selected video in the model. Finally, the results are collected for all the three codecs over both LTE and 802.11ac networks separately in terms of throughput, delay, packet loss, and jitter for the entire video transmission time process. In the context of video streaming:

- Throughput refers to the connection speed at which, the video files can be sent to the users. It is a critical parameter because if it is not high enough, lower-quality video files are received by mobile users.
- Delay refers to the time it takes to deliver a single frame of video file to the users. being real-time, the video files are sensitive to high delay, which directly affect the quality.
- Jitter, as the amount of variations in the delay of sending the consecutive frames of the video file, needs to be minimized otherwise degrade the quality of the video streaming.
- Packet loss ratio shows the percentage of the lost video packets. As the ratio increases more lost packets happen, which in turn affect the final received video file.

Figure 1 summarizes the model and the corresponding details. Moreover, the video implementation parameters, simulation parameters common between LTE and 802.11ac, simulation parameters specific to LTE, and simulation parameters specific to 802.11ac networks are presented in Tables 1 to 4, respectively.

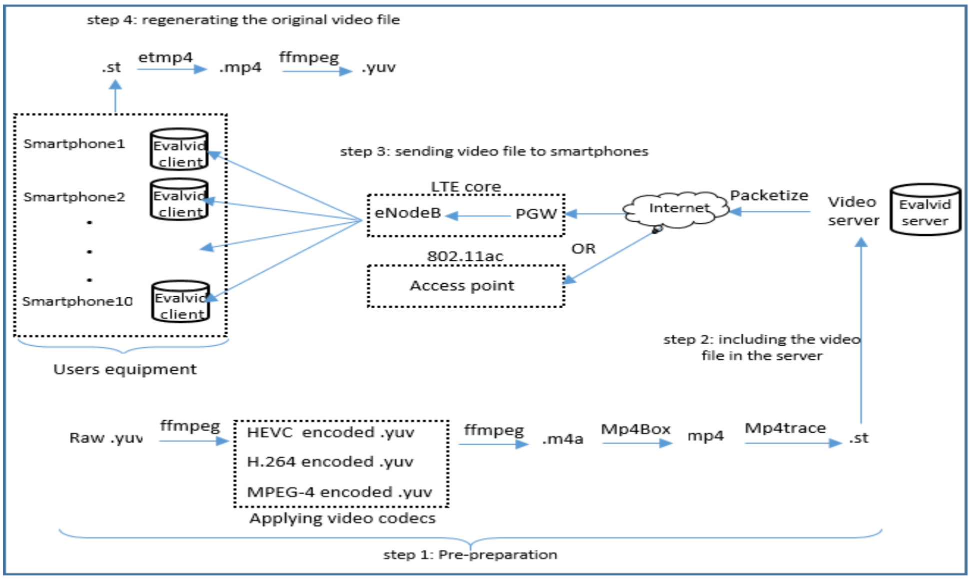

Fig. 1. Proposed reference model.

Table 1. Video implementation parameters.

Parameters	Values
Software	FFmpeg
	Evalvid
Video codecs	HEVC
	H.264
	MPEG4

Table 2. Common simulation parameters for both LTE and 802.11ac.

Parameters	Values
Network type	LTE
	802.11ac
Number of Evalvid clients	10 smartphones
Number of Evalvid server	1
MTU	1500B
Performance metrics	Throughput
	End-to-end delay
	Packet loss ratio
	Jitter

Table 3. LTE simulation parameters.

Parameters	Values
Number of resource blocks	100
Channel width	20 MHz
RLC mode	UM
Modulation algorithm	64QAM
Coding rate	5/6
LTE specific elements	1 eNodeB
	1 PGW

Table 4. 802.11ac simulation parameters.

Parameters	Values
Modulation coding scheme	VHTMcs7
Aggregation mechanism	A-MPDU (default)
Physical channel width	20MHz
Number of 802.11ac AP	1
802.11ac specific elements	1 access point

4. Performance Evaluation of the Model

The proposed model is implemented, and the results are obtained in terms of throughput, delay, packet loss, and jitter. The results of the comparative analysis of the MPEG-4, H.264, and HEVC video codecs over the LTE and 802.11ac networks are presented in this section.

4.1. HEVC video codec

At the pre-preparation step of the model, the first video codec to experiment is the HEVC, which is provided in this section. The results of implementing the HEVC codec to assess its performance over the LTE and 802.11ac networks in terms of throughput, loss ratio, delay, and jitter are demonstrated in Figs. 2 to 5 respectively.

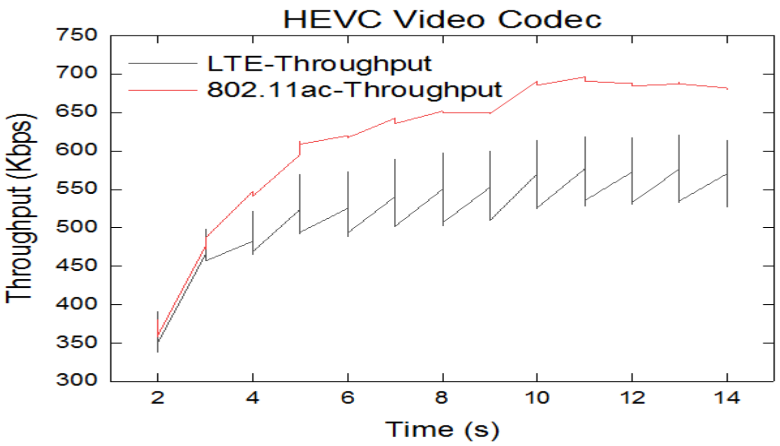

Fig. 2. HEVC video codec throughput in LTE and 802.11ac.

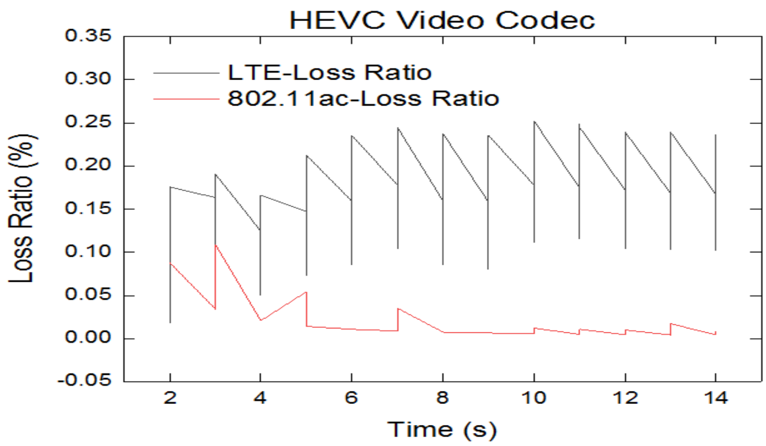

Fig. 3. HEVC video codec loss ratio in LTE and 802.11ac.

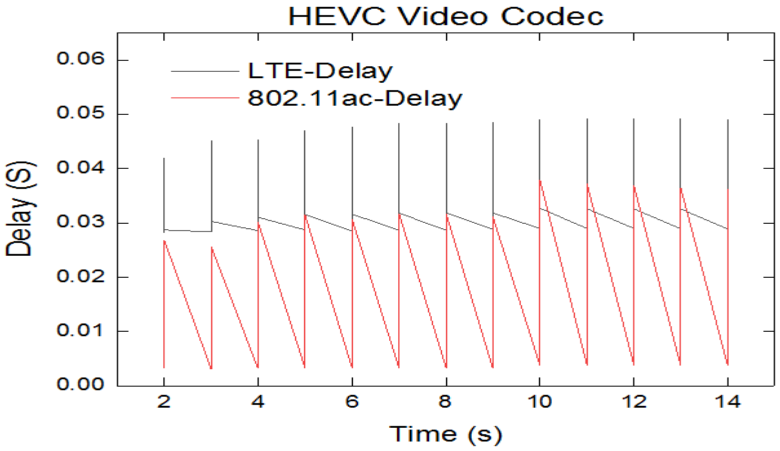

Fig. 4. HEVC video codec delay in LTE and 802.11ac.

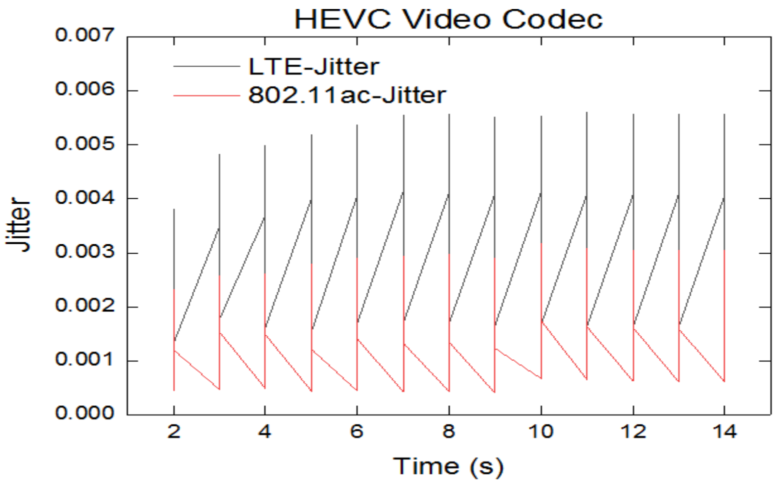

Fig. 5. HEVC video codec jitter in LTE and 802.11ac.

The obtained results imply that transmission of the video file encoded by the HEVC algorithm provides higher throughput over the 802.11ac networks than the LTE and is not affected by the time.

Unlike the constant throughput increasing in the 802.11ac network, the throughput variations are observed in the LTE network for the entire transmission time.

Consequently, the same behaviour is observed for the ratio of the lost packets. The smartphone users in the LTE network, suffer the higher ratio of the lost video packets encoded by the HEVC compared to the users in the 802.11ac network.

Losing the video packets in 802.11ac only happens at the beginning of the transmission while reach zero after handling all the video requests by the video server. In term of delay, both LTE and 802.11ac show high variations.

Delivery of the HEVC encoded video file causes the smartphone users in LTE network experience almost twice average delay compared to when they switch to 802.11ac network.

Further analysis reveals that the average of jitter is also higher in LTE network than 802.11ac. Thus, the above results signify a better performance of the HEVC codec in the 802.11ac network compared to the LTE.

4.2. H.264 video codec

Further analysis is performed in this section to apply the H.264 video compression algorithm over the video file to be transmitted to the smartphones in LTE and 802.11ac networks.

Therefore, at the pre-preparation step of the model, the H.264 codec is utilized to encode the video file before transmission to the smartphones. The throughput, loss ratio, delay, and jitter results are demonstrated in Figs. 6 to 9, respectively.

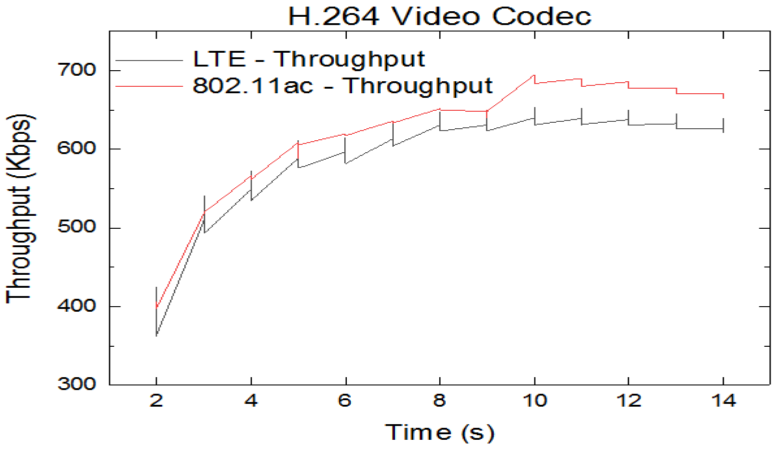

Fig. 6. H.264 video codec throughput in LTE and 802.11ac.

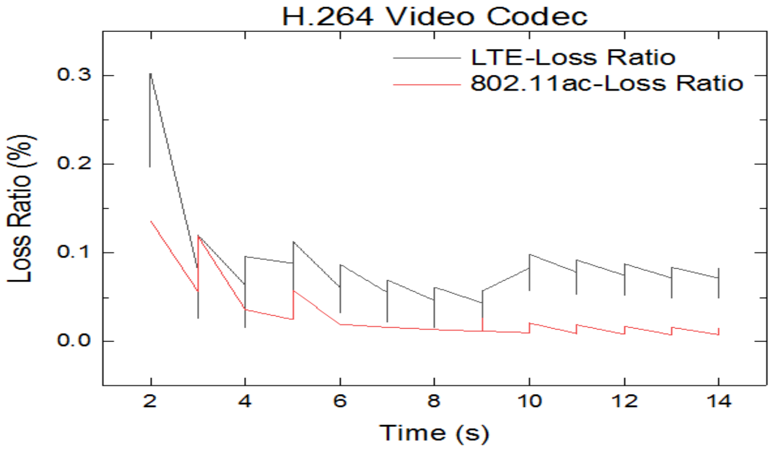

Fig. 7. H.264 video codec loss ratio in LTE and 802.11ac.

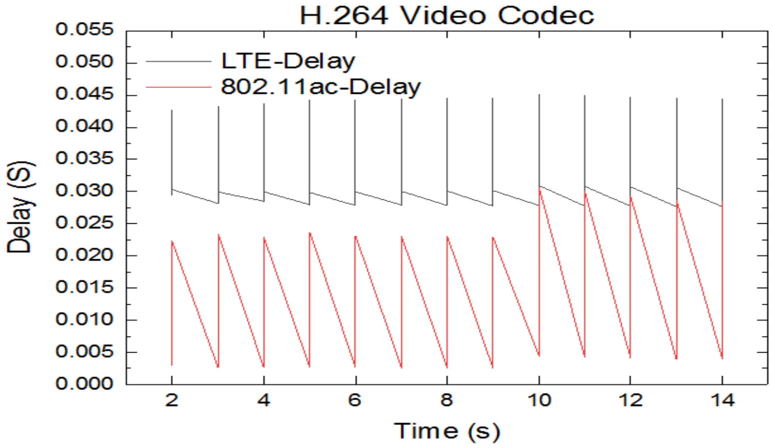

Fig. 8. H.264 video codec delay in LTE and 802.11ac.

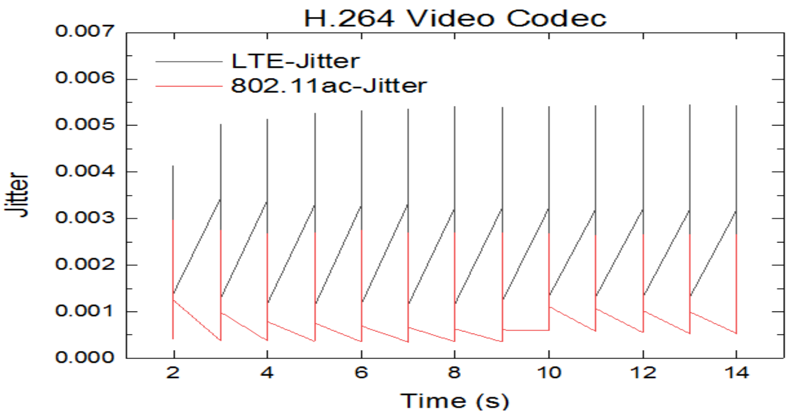

Fig. 9. H.264 video codec jitter in LTE and 802.11ac.

The results show no significant difference between the throughput performance of H.264 codec in the LTE and 802.11ac networks. The throughput in both networks has a constant increase until the transmission of the last frame in the video file. Comparing the H.264 throughput results with those of HEVC reveals that the H.264 throughput is higher than HEVC for both networks. In 802.11ac network, both H.264 and HEVC video codecs achieve the same throughput performance. In contrast, the H.264 shows slightly higher throughput than the HEVC in LTE network. The ratio of the lost packets in the presence of the H.264 codec is very close in LTE and 802.11ac with a slight difference at the beginning of the video transmission which is slightly higher in LTE. Comparing the number of packet loss caused by the HEVC and H.264 implies the higher number for the HEVC codec in both LTE and 802.11ac networks. Thus, when the HEVC codec is used in either LTE or 802.11ac network, the end-users achieve a lower quality of video services in term of a higher number of lost video packets.

Moreover, analysing the delay results confirms higher values for the LTE network than the 802.11ac when H.264 codec is used as the compression algorithm of the video files. On the other hand, the delay caused by the H.264 codec does not show a remarkable difference between LTE and 802.11ac networks compared to those of HEVC codec. The same behaviour is observed for the jitter values. In this regard, the jitter is higher in LTE network compared to 802.11ac while the analysis does not show substantial differences between the H.264 and HEVC codecs. Thus, the results obtained from the implementation of the H.264 video codec reveal two findings. First, the H.264 achieves a better performance than HEVC codec and the second, H.264 achieves a better performance in the 802.11ac network compared to LTE.

4.3. MPEG-4 video codec

In order to compare the performance of MPEG-4 compression algorithm against the HEVC and H.264, this time at the pre-preparation step of the model, the MPEG-4 codec is utilized to compress the video files. The MPEG-4 encoded video file is then transmitted to the smartphones in both LTE and 802.11ac networks upon receiving the video requests. The MPEG-4 codecs performance in terms of throughput, loss ratio, delay, and jitter results are quantified and presented in Figs. 10 to 13, respectively.

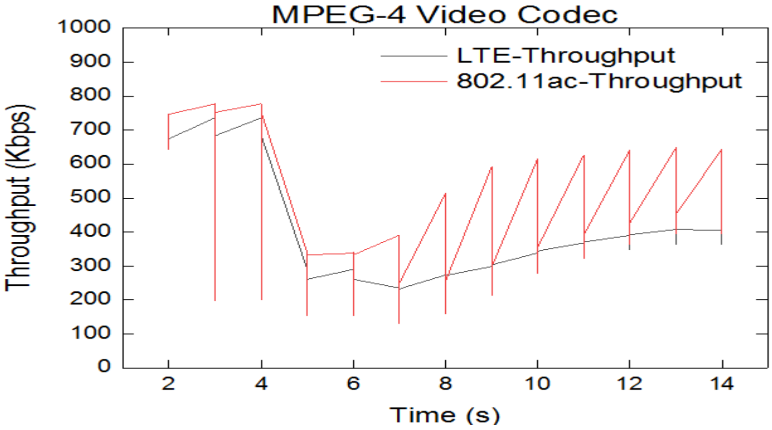

Fig. 10. MPEG-4 video codec throughput in LTE and 802.11ac.

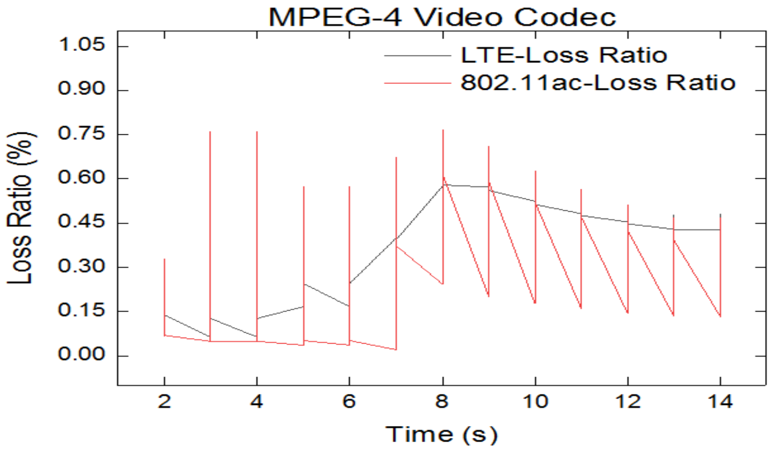

Fig. 11. MPEG-4 video codec loss ratio in LTE and 802.11ac.

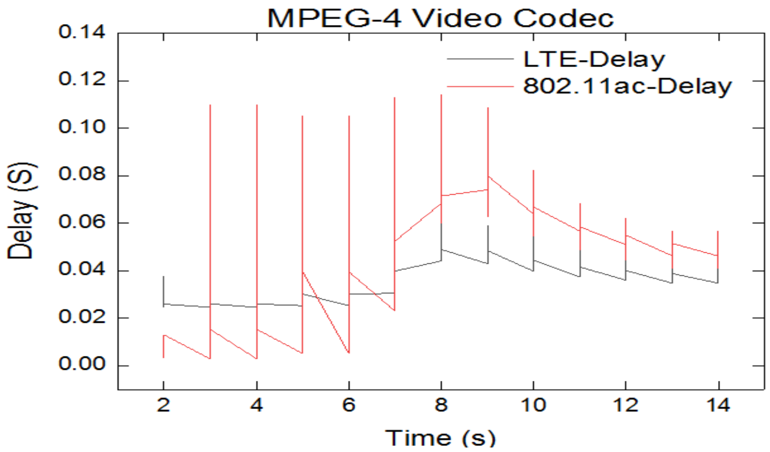

Fig. 12. MPEG-4 video codec delay in LTE and 802.11ac.

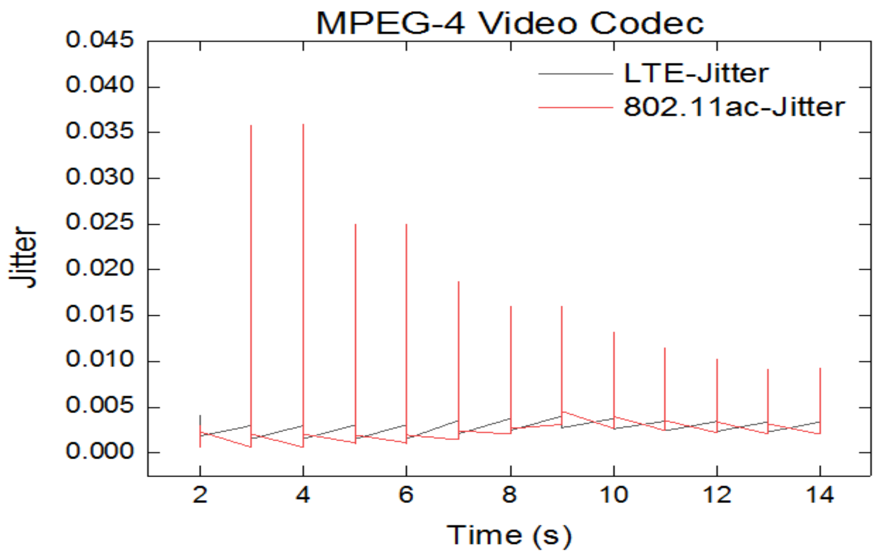

Fig. 13. MPEG-4 video codec jitter in LTE and 802.11ac.

From the MPEG-4 results, it is found that like the HEVC and H.264 codecs, the average throughput is higher in the 802.11ac network than the LTE. The results prove that regardless of exchanging of the video files in LTE and 802.11ac networks, applying the MPEG-4 codec will result in the lowest amount of throughput compared to HEVC and H.264 video codecs.

In this regard, the results show significant throughput reduction for both LTE and 802.11ac networks in contrast to HEVC and H.264 codecs. Furthermore, the packet loss ratio also shows a sudden increase, which results in the delivery of lower quality video services by the MPEG-4 codec, particularly in the LTE network.

In term of delay, the results are different this time. While both HEVC and H.264 codecs show a higher delay in the LTE network compared to 802.11ac, the MPEG-4 results show the opposite. In the LTE network, applying the MPEG-4 video codec causes close delay values as the HEVC and H.264 codecs in the LTE network.

However, the MPEG-4 codec causes a sudden increase in the amount of delay in the 802.11ac network, which is even higher than the values in the LTE network.

The same behaviour is also observed for jitter values so that while the jitter is higher for the HEVC and H.264 codecs in LTE, in case of using the MPEG-4 codec, the jitter is higher in 802.11ac network than LTE. For a better visualization over the correlation between the type of video codecs and the performance of LTE and 802.11ac networks, the summary of throughput, loss ratio, delay, and jitter comparison are provided in Figs. 14 to 17 respectively.

The overall above findings suggest significant performance differences achieved by each codec while using the H.264 codec provides better performance for both LTE and 802.11ac mobile networks.

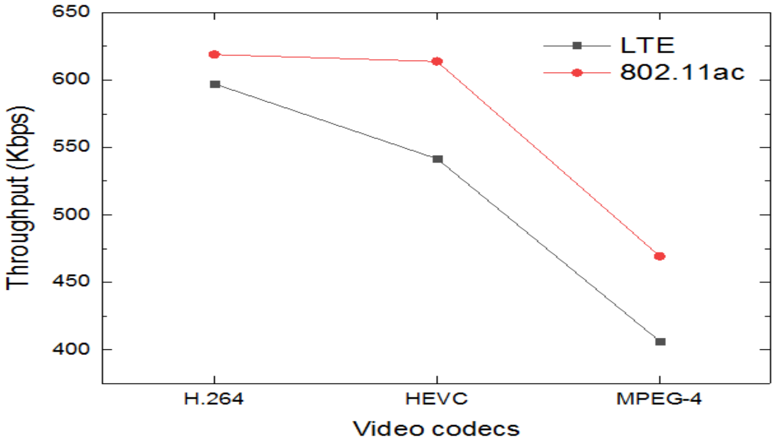

Fig. 14. Throughput comparison of video codecs in LTE and 802.11ac.

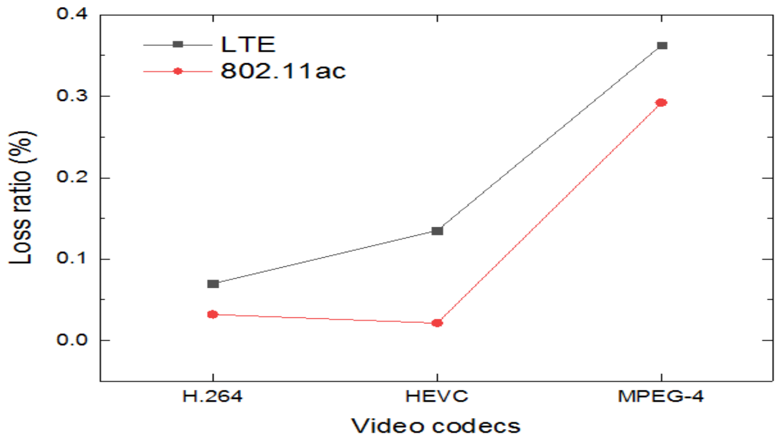

Fig. 15. Loss ratio comparison of video codecs in LTE and 802.11ac.

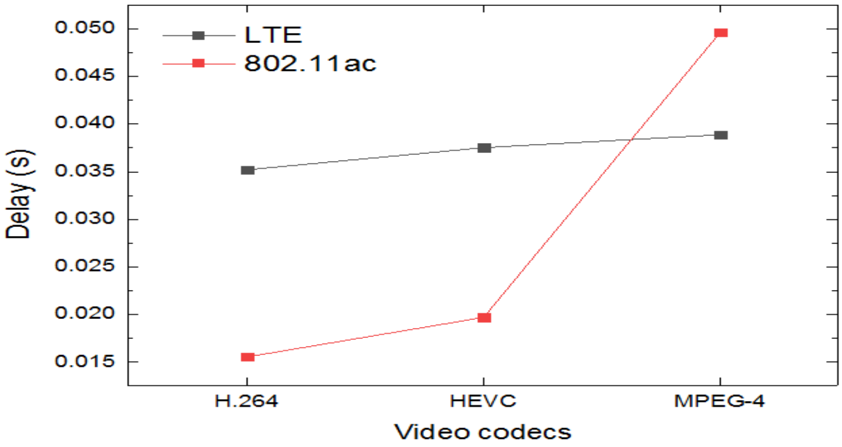

Fig. 16. Delay comparison of video codecs in LTE and 802.11ac.

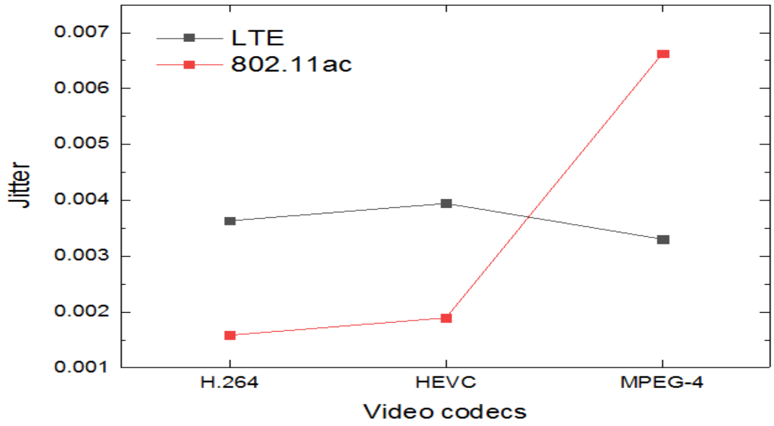

Fig. 17. Jitter comparison of video codecs in LTE and 802.11ac.

5. Conclusions

This work presents a codec-oriented reference model for the performance comparison of the LTE and 802.11ac networks in the presence of three most common video codecs including HEVC, H.264, and MPEG-4. The obtained results reveal major considerations. On average, all the codecs perform better over the 802.11ac compared to the LTE network in terms of throughput, delay, packet loss ratio, and jitter metrics. Further analysis of the results confirms the close performance of the HEVC and H.264 codecs in IEEE 802.11ac network so that applying these codecs does not provide remarkable performance differences for the users of the smartphones. However, the results show the difference is more significant in the LTE network so that using the H.264 provides better performance compared to HEVC. On the other hands, based on the results, the MPEG-4 codec provides the lowest performance for delivery of the video files in both LTE and 802.11ac networks. Thus, comparing the results of the three video codecs, it is concluded that to have a better quality of the video services for the end-users of the smartphones, it is more efficient to utilize the H.264 video codec to encode the video files in the LTE and 802.11ac networks. In this work, the performance of video compression algorithms is determined in LTE and 802.11ac mobile networks. However, the effect on the performance of the 802.11ax mobile network has not been investigated, which will be considered in the future.

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