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Research Paper

Experimental performance analysis of multipath TCP path characteristics in streaming UHD HEVC-dash over wireless networks

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Abstract

The multiple interfaces in modern devices today have given great promise in enhancing multimedia service delivery over wireless networks. However, the IP coupled nature of the TCP/IP protocol inhibits the simultaneous use of these interfaces. Multipath TCP (MPTCP), a protocol undergoing IETF standardization has been developed to simultaneously use multiple interfaces for service delivery over the Internet. In this paper, we studied the effect of MPTCP paths characteristics in streaming Ultra High Definition, High Efficiency Video Codec (UHD HEVC-DASH) while connected to multiple wireless access points. The findings though specific instead of general, reveal that under balanced and unbalanced network paths, MPTCP offers good Quality of Experience (QoE) compared to SPTCP. However, with variability in latency, and packet loss between paths, MPTCP underperforms compared to SPTCP in terms of video buffering in the unbalanced network case, and high packet retransmission rate in either balanced or unbalanced network paths.

Keywords: *DASH; MPTCP; HEVC; QOS; Throughput; RTT; UHD.*

1. Introduction

The Internet is a global interconnection of networks to enable communication and sharing of resources, ranging from hardware, software, or services between devices. These interconnections between end hosts are realized via a structured protocol stack known as the Transmission Control Protocol/Internet Protocol (TCP/IP). In present times, traffic over the Internet has increased exponentially, with wireless and mobile devices estimated to account for over sixty three percent (63%) in the year 2021 [1]. This high surge of traffic results from the large chunk of video data transmitted over the internet [2]. Thus to decrease the traffic condition on the Internet, Internet Service Providers (ISP) and video content generators are under pressure to devise means of providing good quality of service to consumers at minimal cost.

In the streaming industry Ultra High Definition, High Efficiency Video Codec-Dynamic Adaptive Streaming over HTTP (UHD HEVC–DASH) is gaining recognition among researchers and content developers as an alternative codec for good quality video. This codec seeks to reduce video size and bit rate, giving rise to lower transmission cost and better quality video streaming. Based on the network status, requested video chunks of various lengths are transmitted at different quality level via HTTP. This means that various segments of video need to be downloaded, buffered, and displayed. Though HEVC-DASH from the content generators' perspective is a step in delivering quality multimedia services over wireless networks, the variable bandwidth nature of wireless networks poses a challenge to streaming quality over the Internet. As such, methods of increasing bandwidth becomes paramount [2].

Among multiple methods of increasing network bandwidth, one that has great promises and gains interest among network and communication engineers is the use of Multipath Transmission Control Protocol (MPTCP). It increases network capacity and gives resilience in communication through seamless handover in the presence of connection failure. Because this protocol is yet to be standardized and evaluated in multiple application environments, substantial deployment on devices is yet to be achieved.

With HEVC-DASH using TCP and MPTCP operating at layer four of the TCP/IP stack, it is pertinent to evaluate the interaction between both principles. This paper uses quality of service parameters to investigate the effect of MPTCP path characteristics on the quality of UHD HEVC-DASH streaming as a mobile device moves and connects to multiple access points. The rest of this paper is structured as follows. Section 2 gives a background of HEVC-DASH and MPTCP. Related works are discussed in Section 3, while experimental design is explained in Section 4. Results and discussions are presented in section 5. Finally, conclusion and future research directions are discussed in section 6.

2. Dash streaming

The manufacturing of consumer digital devices in the 21st century is increasing rapidly every year. This poses a constant need for content and video creators to devise techniques to deliver services to numerous consumers using these devices. To support streaming, video generators have resorted to the use of various streaming protocols as alternatives. Prominent among many are HTTP/TCP and RTP/UDP [3].

RTP/UDP technique employs RTP or RTCP at the application layer and the best effort delivery of UDP at the transport layer [3]. Though video transmission using broadcast and multicast are possible in RTP/UDP streaming technique, the high intensive resource control on the sender's session and the blockage of RTP by middleboxes, poses a challenge to streaming using these system of protocols. These shortcoming in RTP/UDP based streaming have made

HTTP/TCP based protocols to be preferred. HTTP/TCP streaming improves scalability in delivery of multimedia contents and traverses through middleboxes without been blocked [three]. These advantages of HTTP/TCP based streaming have made many multimedia content creators over the years resort to Adaptive Bitrate Streaming (ABS) in delivering services to their consumers. However streaming solution that employ ABS like Microsoft smooth streaming, Adobe dynamic streaming, and Apple HTTP Live streaming are vendor based. To overcome this propriety restriction, a standard that is vendor neutral becomes necessary. Prominent among ABS standard is DASH [4].

DASH as well as other ABS methods use Server and Client perspective to deliver content. The multimedia files stored on the server are of two types: the segments and media presentation description [5]. The streaming information such as location of segments and corresponding versions, video resolution and bitrate etc are held in the MPD. As shown in Figure 1, streaming session begins by the request of MPD from the server by the client. Based on the information received from the MPD, segments are serially requested through HTTP GET request, decoded and played. The quality of streamed video content is a function of the network condition. Bandwidth adaptation method used in DASH streaming depends on the media players and the adaptation algorithm such as look ahead rate, harmonic mean, and those based on fuzzy techniques [6-8].

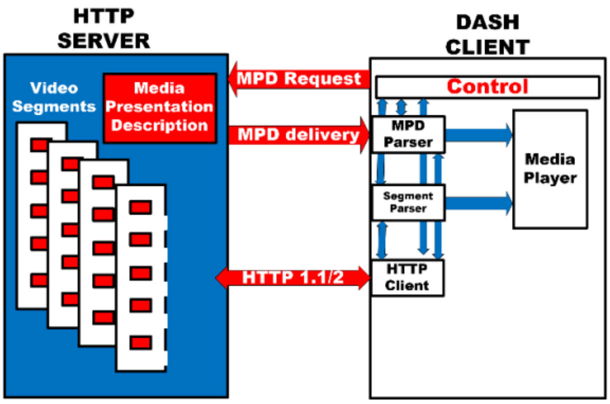


Fig. 1: DASH Operational Architecture.

2.1. Quality of experience parameters affecting DASH streaming

In evaluating quality of DASH streaming, two evaluation approaches are employed. These are objective and subjective approaches. The objective evaluation look at the underlaying network characteristics, while the subjective is based on users' perception. Quality of Experience has been defined as a subjective method of evaluating how well the underlaying network satisfy users' requirement. These features are functions of the users' perception, and their interaction with the service provided [9]. The QoE parameters affecting DASH streaming are startup delay, buffering/stalling, throughput and quality switch.

The start-up delay is the time between request of the first segment and start of the actual playback. This might comprise the client and server processing time, network latency, etc. In general, this parameter depends on the case under study.

Stalling is characterized by playback stoppage or freezes during streaming. This is caused by low buffering or buffer underruns. The playback is resumed after the media has re-buffered. It is clearly understood that wireless network experience variable bandwidth, thus in DASH streaming, switches in quality bitrate are usually experienced. This is usually adopted in DASH streaming so as to avoid buffer depletion during streaming [9]. The throughput or the download rate is a parameter measured in bits/seconds. This signifies the rate at which video segments are downloaded from the video server. A higher value means better QoE and a lower value means negative impact on the QoE. To evaluate these parameters, we used MPTCP path characteristics like network delay, packet loss, and network bandwidth as influence factors. Rather than using Mean Opinion Score (MOS) to obtained the effect of those factors on QoE, we used the statistics obtained from underlaying network condition and observed the effect on the streaming media player as used in [2].

2.2. UHD HEVC

With various techniques and methods of streaming multimedia content on the rise, different video compression techniques and standards used to enhance and ease delivery of video to users is also getting attention of content providers [10]. HEVC also known as H265 is a new video codec developed by the combined ingenuity of the Joint Collaborative Team on Video Coding (JCT-VC), with its first standard available to the public in 2013 [11]. With the new coding system incorporated in HEVC's I-, P- and B-frames, more coding efficiency is achieved.

HEVC coded video sequence is specifically divided into smaller intervals referred to as Group of Pictures (GOP). Structure and feature are detailed in [12]. Though HEVC has high complex structure [13], [14], and on the process of being incorporated into media devices [13], its high compression performance and reduction in file size and bitrate offers promise of less bandwidth utilization [11].This lower bandwidth utilization has attracted many content generators to HEVC for video delivery over the internet. With HEVC giving great optimization in file size and bandwidth, the compressional problem of Ultra High Definition has a solution. UHD offers high pixel resolution, high frame rate (HFR) of about 50 to 120 frames per second, and colour fidelity for high dynamic range imaging.[15]

2.3. Multipath TCP

While HEVC and DASH hold great advantages in streaming video, the inherent side effect of playback deadline [16], and slow start present in TCP greatly affects DASH request scheme and streaming quality [17]. Furthermore, the unstable nature of bandwidth in wireless networks poised added challenges. To cope with some of these challenges, MPTCP becomes a promising alternative. MPTCP is a protocol undergoing IETF standardization. It extends TCP by splitting a single TCP flow into subflows, allowing simultaneous transfer of data via multiple interfaces [18].

An MPTCP connection has one or more subflows, each of which appears like a conventional TCP session to the network. When a session is initiated, MPTCP options are appended to the SYN segments to verify whether the node at the other end of the network has the capability to negotiate a MPTCP token that will distinctly identify this session [19]. Newly created TCP subflows can be linked to this MPTCP session by carrying the previously exchanged token in their three-way handshake. Its TCP-like mode of operation makes it undetected by middleboxes, enabling MPTCP run where TCP runs and thus, suitable for DASH streaming.

To provide quality service delivery MPTCP uses a coupled congestion control, which directs traffic to less congested path: thus spreading congestion across sub-flows and providing efficient resource pooling capacity [20] as shown in Figure 2. More descriptions are given in [21].

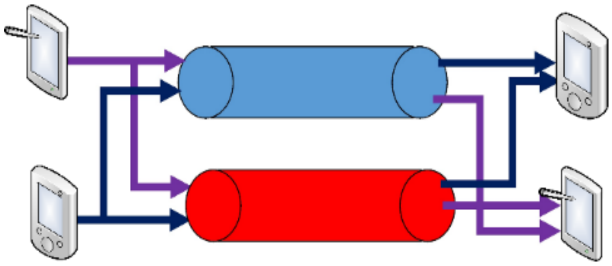


Fig. 2: MPTCP Resource Pooling.

3. Related work

Earlier studies have shown that using MPTCP offers great advantages compared to TCP. In [22], the performance of MPTCP in wireless scenario was investigated The focus was to determine the effect of MPTCP on applications' performance in relation to Round Trip Time (RTT), loss rate, and throughput. Their findings which use cellular and Wi-Fi setup show that MPTCP gives better data transfer when file sizes are larger, and lowers the variance in latency during download of files. This paper extends their research by considering the effect of MPTCP in streaming video services in a mobile environment using wireless network. In [23], a proposed packet scheduling algorithm for MPTCP in wireless network using simulation with Network Simulator 3 (NS3) was employed to analyze the efficiency of MPTCP. Though this finding offer insight into the behaviour of MPTCP in wireless situation, it didn't evaluate MPTCP performance in a mobile environment using real measurements as used in this research.

Unlike other studies which use Ethernet and wireless interfaces to study MPTCP, in [24] purely wireless interfaces were used to evaluate MPTCP. The focus of the paper was to examine how MPTCP coupled congestion control functions with receive buffer size and segment size when a communication device was connected to various Wi-Fi standards in multi-homed networks. Conclusions from the research reveal that the coupled congestion control in MPTCP increases the share of the traffic over Wi-Fi as receiver buffer size increases. This increase as discovered in the paper can only be larger than that on the dedicated links, if the data rate on the Wi-Fi exceeds that on the dedicated link. Though their research and this paper employ the use of wireless networks to evaluate MPTCP, the studies could not assert whether the throughput of MPTCP outperforms that of TCP which this paper investigates.

James et al [2] investigated the overall quality of experience (QoE) when MPTCP is used with DASH for video streaming on the Internet. A LAN network and a Wireless network were used to emulate multipath for evaluation. The finding focuses on the effect of MPTCP paths bandwidth in streaming DASH videos. The research concludes that the variability in bandwidth on the paths plays a key role in the streaming quality offered by MPTCP. This paper extends their research by studying the effect of delay and packet loss on network paths using UHD HEVC-DASH dataset in a mobile environment.

4. Experimental setup

The testbed for the video streaming is a client and server scenario as shown in Figure 3. The server and client are both laptops with Ubuntu 16.04 and kernel implementation of MPTCP v0.92 [25] installed and configured. The server is connected to the Internet via ethernet and Wi-Fi interfaces, while the client uses two wireless interfaces with roaming enabled so as to connect to various access points as it moves away from the server. The video files and the corresponding manifest files are stored on the server while the client is equipped with VLC media player configured to stream and track streaming statistics from the server. To make the client access the video files via HTTP, Apache HTTP server was installed and configured on the server. The dataset used for analysing streaming with MPTCP was the public UHD HEVC-DASH dataset in [15].

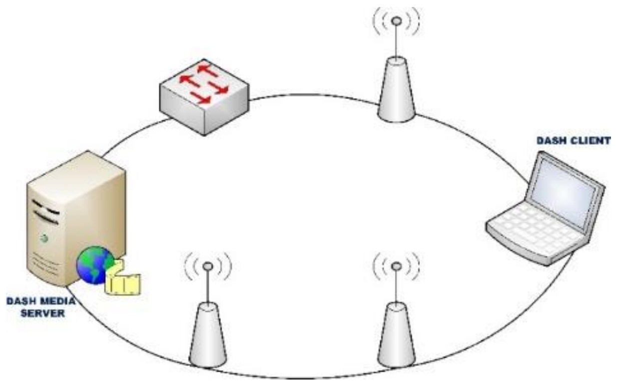


Fig. 3: Experimental Testbed.

Video codec used was H.265 and media encapsulation format was MP4. The segments are of lengths 2s, 4s, 6s, 10s, and 20s, with bit rate ranging from 2 Mbps to 20 Mbps. The 6-second video segments, files with 720p, 1080p, and 2160p resolutions were used for evaluation. To corroborate the findings from the VLC media player, TCP dump was used to capture traffic on both interfaces connected to the client.

To study behavior of HEVC-DASH under various QoS parameters, Linux traffic shaping tools(Wonder shaper, tc and netem) were used to emulate two categories of network conditions, balanced and unbalanced respectively. The balanced network has equal path characteristics, while the unbalanced has variable path characteristics as shown in Table 1. The QoE metric considered for evaluation are download rate of segments, startup delay, and stalling.

Table 1: Network Path Characteristics

Balanced network	Packet loss (%)	Latency (ms)	Bandwidth (Mbps)
MPTCP			
Path 1	10	10	15
Path 2	10	10	15
SPTCP	20	10	30
Unbalanced network			
MPTCP			
Path 1	15	15	25
Path 2	5	5	5
SPTCP	10	10	30

5. Results and discussion

5.1. Start-up delay

In this paper we used network latency as a QoS parameter to evaluate initial delay when streaming with MPTCP. The network latency values in Table 1 were used for MPTCP and SPTCP respectively.

It can be deduced from the graph shown in Figure 4 that SPTCP and MPTCP in the balanced network have similar buffering time, while MPTCP in the unbalanced network performs worst. As packets are being transmitted over different subflows, the latency difference in the unbalanced case makes packets on the subflow with lower latency to wait for packets on the path with higher latency. This results to unordered arrival of packets at the client side. This phenomenon makes the DASH client in the unbalanced case take a longer time with more buffering stalls, as reflected in Figure 4.

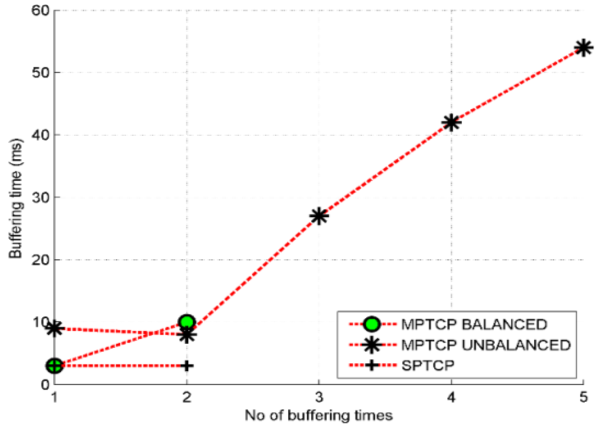
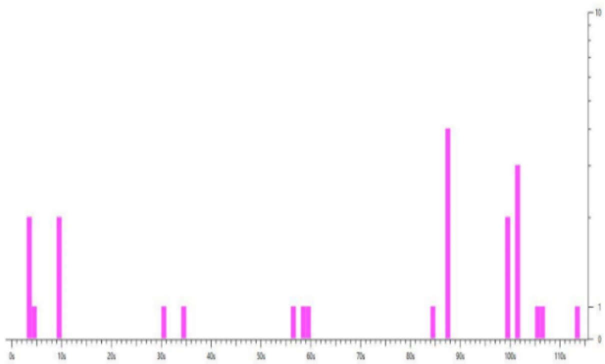


Fig. 4: Buffering Delay Comparisonmptcp Balanced: Avg = 6.5ms MPTCP Unbalanced Avg = 27ms SPTCP: Avg = 3ms.

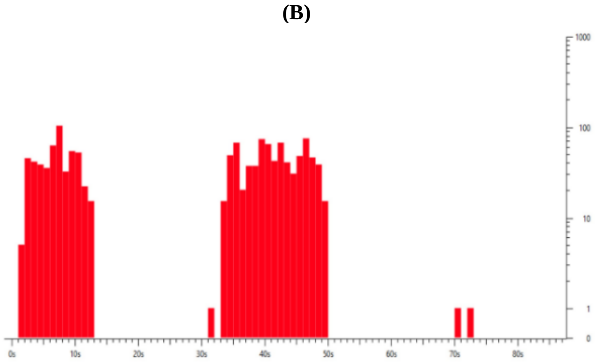
5.2. Stalling

To evaluate stalling, packet loss rate on the network was employed. DASH streaming uses HTTP/TCP system of protocols to deliver packets. Thus, packets that are lost are requested for retransmission by the client. This phenomena affects the buffering level which consequently leads to stalling/freezes. Thus, we used retransmission errors to evaluate packet loss effect on video quality. As in the startup delay analyses, packet loss rate values for balanced and unbalanced networks as shown in Table 1 were used. TCPdump was employed to capture packets on both interfaces of the client. From the results for SPTCP and MPTCP in balanced and unbalanced cases as shown in Figure 5 (a), (b) and (c), it is observed that SPTCP with average retransmission rate of 1 packet per 1s tick interval, outperforms MPTCP in balanced and unbalanced cases with average retransmission rate of 14 packets per 1s tick interval (14 packets/tick) and 9 packets per 1s tick interval (9 packets/tick) respectively. Due to the effect of different path characteristics in MPTCP, high out-of-order data delivery is experienced at the receiver' end. This behaviour overwhelms the receiver buffer at the MPTCP level, leading to more packet drops and high packet retransmission rate observed when using MPTCP in either balanced or unbalanced cases.

(A)



(B)



(C)

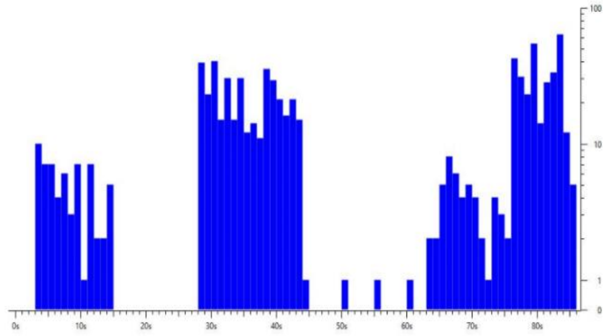


Fig. 5: Packet Retransmission Rate in (A) SPTCP (B) MPTCP Balanced (C) MPTCP Unbalanced

5.3. Download rate

Bandwidth is an essential factor to consider when providing video content to consumers. It is very critical in DASH streaming in which the quality of video depends on the available network bandwidth. To study how bandwidth in MPTCP affects UHD HEVC-DASH streaming, the bandwidth values in Table 1 were used to evaluate the effect of bandwidth on streaming.
The experiment for each network settings was repeated five (5) times and the average download rate for each network scenario as obtained from the media player was calculated. The graph for the segment vs average download rate for each network is shown in Figure 7.
From the graph, it is observed that MPTCP either in the balanced or unbalanced network condition, performs better than SPTCP. This is due to the advantage of path diversity in MPTCP. However, the unbalanced network conditions, when compared to MPTCP in the balanced scenario, show that when variability exists in bandwidth between paths, MPTCP performance in streaming is reduced.

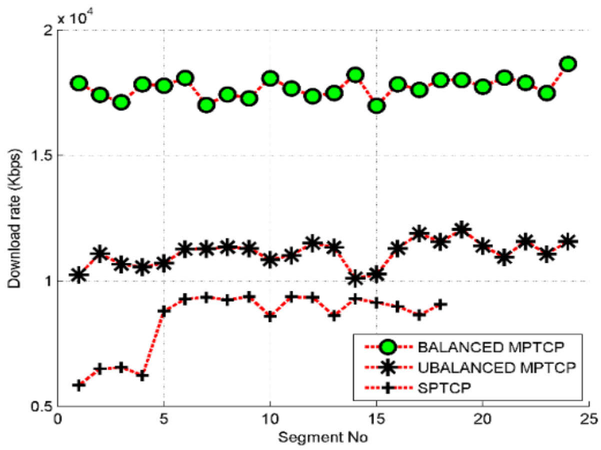


Fig. 6: Download Rate Comparison.

6. Conclusion

In this research, we investigated the effect of MPTCP path characteristics on the streaming of UHD HEVC-DASH over wireless networks. The main aim was to explore how the path characteristics (which are QoS network parameters) affects user's QoE. It was discovered that from the QoS viewpoint, MPTCP under low packet loss rate, gives better streaming quality, by providing higher download rate when in balanced and unbalanced network bandwidth conditions. However, with variability in latency, and packet loss between paths, MPTCP underperforms compared to SPTCP in terms of video buffering in the unbalanced network case, and high packet retransmission rate in either balanced or unbalanced network paths.

Comparing the effect of MPTCP path characteristics on various video codecs such as AVC and SVC will be our future research fcus.

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