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A Survey on Video Streaming in Multipath and Multihomed Overlay Networks

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ABSTRACT The focus of this survey is to study the protocols, mechanisms, and the latest standards proposed in the literature for improving the performance and quality of video content in multipath and multihomed overlay networks. Multipath is a broader term, but in the context of this survey, we define multipath as enhancing network routing technique by using various paths that are not necessarily completely disjoint. Multipath can furnish a variety of advantages such as reliability,connection persistence, increased perceived throughput and load balancing. On the other hand, multihoming is the ability to use multiple network interfaces when connecting to the Internet to increase reliability, resilience, and performance. Most existing surveys are specialized in one specific domain area related to multipath or multihoming. This study covers the research proposals at the different layers/sublayers of an overlay network from transport to the application and extends to cover the latest technologies like machine learning, Fog and Mobile Edge computing, VR 360 video, and the Internet of Multimedia Things (IoMT). As such, our work tries to be as comprehensive as possible to relate multipath and multihoming research solutions for video streaming to the current and emerging video streaming technologies.

INDEX TERMS Internet of Multimedia Things, multihoming, multipath, mobile edge computing, fog computing, VR 360 video.

I. INTRODUCTION

Video streaming represents the major part of Internet traffic, and has increased massively over the last decade. *MarketsandMarkets* forecasts the global video streaming market to grow to 70.05 billion USD by 2021 [1]. Besides, 80% from the Internet traffic will be video traffic by the year 2020 [2]. Despite advances in video compression techniques, processing power, and increased bandwidth, researchers and scientists still struggle to cope with unprecedented user demands for Quality of Service and Experience (QoS and QoE).

Basically, clients expect to watch the video with an acceptable level of QoE, which is a customer-focused performance measurement. Indeed, QoE is all about the experience that the end users have when watching video streams and their satisfaction with it. Mok *et al.* [3] measure the QoE of HTTP (HyperText Transfer Protocol) based Video Streaming based on the relationship among three levels of QoS (from user, application and network perspectives). QoS refers to the performance of a network such as a packet loss, bitrate, throughput, availability, transmission delay, jitter, goodput, latency, error rates, and the probability of uptime/downtime.

Many video streaming protocols have been introduced in the past few years and most of them have faced many challenges or limitations to be widely deployed in the Internet. For instance, RTP/UDP (Real Time Protocol/User Datagram Protocol) is an application layer protocol that uses the connectionless protocol UDP at the transport layer and supports some advanced multimedia functionalities such as multicast but RTP/UDP packets are blocked by most firewalls since it is considered as less secure to be used than TCP (Transmission Control Protocol) which is connection-oriented. While the mostly used transport layer protocol TCP provides reliable communications, it is not designed to take care of the quality of service parameters of multimedia communication. Besides, most of the video streaming traffic is based on a best effort Internet, which does not enable QoS routing for many reasons, such as the distributed management of autonomous systems and the business relationship between network providers. The most widely deployed

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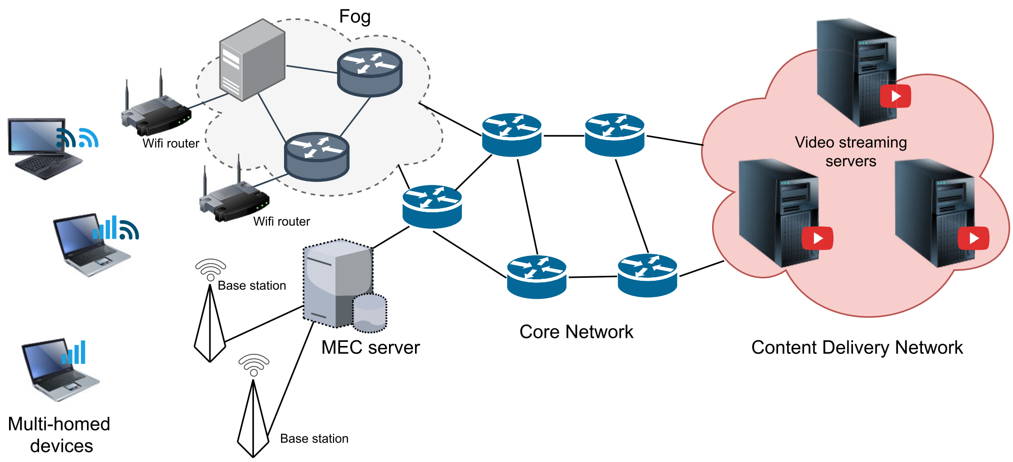

FIGURE 1. **Multi-homed overlay networks.**

routing protocols at the network layer are designed to ensure a best-effort delivery of content without any guarantee on data loss and quality degradation. Then, the designers of the routing and transport layer protocols have not considered the characteristics of the real-time video streaming applications at that time.

Recently, the urgent need to provide acceptable QoS and QoE on the Internet led to enhance existing standards dynamic adaptive streaming over HTTP (DASH) [6] also called MPEG-DASH. DASH, same as Apple's HTTP Live Streaming (HLS) [7], can work on conventional HTTP web servers. MPEG-DASH video streams are made available in several qualities, each encoded at a different bitrate. DASH selects the optimal quality to be streamed according to the client's reception conditions. As a result, DASH can reduce re-buffering and match video qualities to the network status.

Moreover, Content Delivery Networks (CDNs) was needed to cope with the huge video consumption on a large scale. CDN is an overlay network of distributed servers deployed at many geographical locations. Users can access video contents from CDN servers that are the best to their location (i.e., based on geographic proximity or application utility function) instead of downloading it from one central server. Enterprise video streaming companies like YouTube, Netflix, and Hulu have implemented their dedicated CDNs for distributing video contents to their enormous users. However, they are designed as proprietary systems, and there is no standard way or blueprint to construct. Similar to CDN, Cisco introduced the concept of Fog computing in 2012 to address the challenges of conventional cloud computing IoT applications [8].

The performance and QoE enhancements brought by Dash and CDN can be significantly boosted through multihoming (see Fig. 1). Multihoming permit a client to access the Internet through multiple network cards and probably through multiple Internet Service Providers (ISPs) in order to increase some metric (e.g., reliability, resilience, and performance), if one connection fails due to any reason, the connection will fail over to another connection. Most importantly, multihoming offers bandwidth aggregation by allowing an Internet session to simultaneously use multiple connections. Multihoming research is on the rise as the majority of computation devices like smartphones, laptops, and others are multi-interfaced wireless devices such as Wi-Fi,3G and 4G.

Over the last decade, video streaming in multihomed overlay networks has been prevalent due to several advantages. Researchers tried to implement multihomed overlay networks in different protocol stack layers, which are the network, transport and application layer. Naturally, overlay networking is a virtual network that is built on top of another network, without any additional infrastructure usually by using software to create layers of network abstraction that can be used to run virtualized network layers to provide or support new services. The overlay network's purpose is to add missing features or improves performance [58] and security [59] without a complete redesign of the network. Examples of overlay network deployments include virtual private networks (VPNs), content delivery networks (CDNs), and voice over IP (VoIP).

Being present in multiple locations, the video content can be simultaneously retrieved by the user via multiple Internet paths. The limit of TCP design to support multiple interfaces paved the way to the adaptation of many transport layer protocols such Multipath TCP (MPTCP) [4] and Stream Control Transmission Protocol (SCTP). We can think of Multipath TCP (MPTCP) as an upgrade of TCP where TCP connections are connected using multiple paths while Stream Control Transmission Protocol (SCTP) employs multihoming as a redundant service when a network interface becomes unreachable [5].

This survey is organized as follows. We discuss in Section 2, multihomed multipath solutions related to the transport layer focusing on Quick UDP Internet Connection (QUIC), Stream Control Transmission Protocol (SCTP), and MultiPath TCP (MPTCP). In Section 3, the paper examined a variety of application-layer solutions such as adaptive solutions including DASH and other adaptive algorithms, video encoding solutions, mobile wireless video streaming, and general multipath solutions. Section 4, focused on Video Streaming Platforms including Content Delivery Networks (CDNs) and Video distribution giants like YouTube and Netflix. In addition, this section covers the critical role of emerging multimedia solutions like the Internet of Multimedia Things (IoMT), Fog Computing architecture,Mobile Edge Computing,and 360 VR Video Streaming. Finally, the conclusion and some discussions are presented in Section 5.

II. TRANSPORT-LAYER SOLUTIONS

Researchers figure out that they can implement multihoming in the transport layer instead of depending on the network layer devices such as the router. The Internet Engineering Task Force (IETF) predicts that more than 90% of internet traffic will be transferred via TCP [9]. TCP is, indeed, the dominant transport layer protocol used on the Internet. It offers a connection oriented, reliable delivery,and error-checked delivery of byte streams. The idea is to modify the connection endpoints during the currently established TCP sessions. Unfortunately, TCP does not support multihoming. TCP session between endpoints cannot change, and it is bound to a single IP address. Therefore, TCP by design cannot support multiple network interfaces simultaneously. This section will focus on the most well-known multihoming solutions using the transport layer and submitted to IETF such as Stream Control Transmission Protocol (SCTP) [11], MultiPath TCP (MP-TCP) [12], and Quick UDP Internet Connection (QUIC).

A. QUICK UDP INTERNET CONNECTION (QUIC)

QUIC is a user space transport protocol designed by Google. QUIC introduces the usage of UDP for downloading web applications instead of using the traditional TCP. It considers, indeed, using a specific design for connection setup that integrates transport protocol and TLS functions to minimize Round-Trip Time (RTT) [62]. QUIC starts by reducing connection latency of the initial TCP handshake mechanism, using one RTT to establish the first-time connection by combining the transport and crypto handshake. Also it permits to resume the connection between the client and the previously requested server using 0-RTT connection establishment. [61]. QUIC supports multiplexing features, where requests from the same client are multiplexed over a single UDP connection, with some optimizations that permits the client from processing packet of different streams with presence of packets lost in another stream [13] which reduce the effect of Head-Of-Line (HOL) blocking problem that occurs in video streaming over TCP. Besides, QUIC provides two levels of flow control: stream and connection-level mechanism. With stream-level flow control, the receiver specifies the number of bytes on each stream, which avoid a single stream to consume all buffer resources. The buffer at the receiver side is adjusted to combine all streams on a same connection using the connection-level flow control [60].

B. STREAM CONTROL TRANSMISSION PROTOCOL (SCTP)

SCTP is a transport layer standard that incorporates multihoming into its core design. Similar to UDP, the message-oriented data transfer is an essential feature of SCTP. It also provides reliable transmission control as TCP but added new additional features, such as congestion avoidance, multihoming, and unordered delivery of packets. SCTP is connection-oriented, but it extends the SCTP endpoints by providing a list of multiple IP addresses in combination with an SCTP port. The association spans across all possible combinations of source/destination that can be generated from the lists of each endpoint. For example, at host initialization, a list of IP address-port pairs provided between the communicating hosts. One address selected for the primary path and alternate addresses are used as backup paths for packet retransmission in any failure case.

Wallance and Shami [5] published a comprehensive review of using stream control transmission protocol (SCTP) for multihomed users taking in comparison handover management and concurrent multipath transfer. In the end, they concluded that the future is for the cross-layer activities and that it should play an essential role in the transport layer multihoming.

In order to deal with video content, SCTP is extended to Partial Reliability extension (PR-SCTP) to support retransmission reliability for video streaming applications.PR-SCTP permits to use different retransmission mechanisms at the application layer to each packet before transmission, thus they can determine a maximum interval for retransmissions before ignore the packet. This solution provides a trade-off between reliability and delay for multimedia content in unstable networks, and better quality is achieved than in cases where traditional transport protocols are used. [63].

C. MultiPath TCP (MPTCP)

IETF's working group created MultiPath TCP (MPTCP) [64] to use multiple interfaces simultaneously. MultiPath TCP goal is to increase the throughput by using multiple interfaces simultaneously and improve path failure by switching to other paths while used path is down. Also, the multipath approach should remove the burden on congested paths. The working group wanted the MPTCP to be compatible with the application layer and transparent to middle boxes. MPTCP solution uses multiple IP addresses in a single TCP session by using multiple paths which enables the use of resource pooling efficiently. A stable implementation of multipath TCP in the Linux kernel at [14] claiming to be the fastest TCP connection with multipath TCP by achieving $51.8 Gbit/second$ with multipath TCP.

C. James at [65] explores weather MPTCP is suitable for video streaming over DASH using a set of experiments with different network conditions. These experiments show that network conditions determine if MPTCP is beneficial or not. Indeed, while constant bandwidth on the two paths results in improving video quality, bandwidth fluctuations harm user experiences. Several studies proposed to improve video streaming using MPTCP. Priyadarshini and Rekh [15] proposed transmitting video over multiple paths in parallel using wireless networks. They stated that the wireless network is more useful when using MultiPath TCP. Their results show an increase in the speed of video transmission using Multipath.

Matsufuji *et al.* [16] proposed packet scheduling at server side for injection video stream packets into multiple paths. They have characterized MPTCP performance with the default and proposed path schedulers when streaming video content on two wireless paths. Their results show that injecting packets at the path with the largest packet credits yields better video performance.

MPTCP is currently hard to implement and could suffer from network middle boxes, forcing MPTCP connections to fall back to standard TCP. It requires a kernel update on both client and server and a new algorithm to overcome many obstacles to make it deployable on the internet [17].

III. APPLICATION-LAYER SOLUTIONS

A. ADAPTIVE SOLUTIONS

1) DYNAMIC ADAPTIVE STREAMING OVER HTTP (DASH)

HTTP Adaptive Streaming was implemented in Microsoft Silverlight Smooth Streaming (MSS) [67] proposed by Microsoft in 2008, then in HTTP Live Streaming (HLS) [66] proposed by Apple in 2009, then in Adobe HTTP Dynamic Streaming (HDS) [68] proposed by Adobe in 2010. All these protocols didn't success to implement and introduce the HTTP Adaptive Streaming as complete and compatible solution until MPEG (Moving Picture Expert Group), in collaboration with 3GPP, propose MPEG-DASH (Dynamic Adaptive Streaming over HTTP, ISO/IEC 23009-1) as an international standard accredited, approved by MPEG and ISO. In January 2011, this technology became a Draft International Standard then it was published in April 2012 and has been revised in 2014.

In this section, application-layer solutions are video stream applications that best utilize the multihomed solutions and improve the quality of experience of video streaming. Video streaming over the internet uses the TCP protocol as the most widely deployed approach. However in recent years, dynamic adaptive video streaming over HTTP like MPEG-DASH [6] introduced to offer smooth streaming without interruption. It works by detecting end-user bandwidth and CPU power in real time and switching to different video stream quality. The client video player switches between different encoding streams depending on the network conditions, while the server side encodes a single video into multiple bitrates. A media presentation description (MPD), stored at the server, contains the locations of various segments of a particular content with different bitrates and screen resolutions. The client video player will request the MPD file from the server and based on these different parameters; it will choose the best video bitrate and decode them. As a result, MPEG-DASH client can seamlessly adapt to changing network conditions with little buffering and improved QoE.

Researchers discovered an opportunity to combine DASH in the application layer with multihomed solutions in other layers. A cross-layer solution is introduced in [18] to integrate DASH over Multipath TCP for video streaming; based on different setups and using only QoE as the leading performance indicator. The results are elaborated based on different setups; some of them with MPTCP adds to the performance and others, where TCP is considered outperforms MPTCP. In general, they concluded that DASH and MPTCP work well together. However, MPTCP performance depends on many factors. For example, MPTCP performance depends on links' delays and bandwidth and how they are combined. The highest MPTCP performance occurred when there is a low delay and high bandwidth (strong link) and the lowest when there are a high delay and low bandwidth (weak link).

Poliakov *et al.* [21] proposed a new NS-3 [19], [20] distribution model that packages implementation and NS-3 MPTCP implementation as part of the effort on simulating a large-scale multipath-enabled video delivery system. Their test results produced a stable distribution based on version NS-3.19 that is suitable for evaluating the performance of different measurements while using MPEG-DASH over MPTCP.

Chen *et al.* [22] introduced MSPlayer a client-based video streaming,that doesn't require any alteration at the TCP stack, and exploits various video sources just as network paths through various interfaces. MSPlayer uses multiple interfaces (Wi-Fi and LTE) simultaneously to request video segments from different YouTube servers. They compared the performance of standard YouTube players and MSPlayer based on pre-buffering, re-buffering phases and available bandwidth. The size of the requested segment over each path is dynamically adapted based on network variation. However, this approach suffers from out-of-order problems and the robustness of video streaming is not evaluated in mobile scenarios.

More ongoing efforts to extend MPTCP to support DASH, another example is Han *et al.* [23] where a multipath framework with the awareness of the network interfaces is proposed, under MP-DASH, to improve the efficiency of video streaming without degrading viewer QoE. The basic idea about MP-DASH is to choose the best way to split the segment over multiple paths based on the existing DASH algorithms (throughput-based and buffer-based). The results show that this approach reduces cost (mobile data usage and energy consumption) without any side effects to QoE. However, no comparison results were provided for the MP-DASH player compared with other adaptive video players in the same category.

Recently, much interest directed to Virtual Reality (VR) services, particularly 360 VR videos. 360 VR video is video captured in all direction from a specific point, known as spherical video where the viewer can see the panorama in 360 degrees during playback. One of the challenges for streaming VR videos is high bandwidth requirements because most of m360-degree videos have been encoded at 4K resolution.

In [24], an adaptive bandwidth-efficient 360 VR video streaming system based on DASH protocol. It consists of using Spatial Relationship Description (SRD) to realize dynamic viewport-aware adaptation technique based on the user's viewing viewport where the highest quality is assigned for tiles in the viewport, and lower qualities are assigned to the other tiles. The results save up to 70% of bandwidth on such type of streaming without much noticeable quality effects.

2) OTHER ADAPTIVE ALGORITHMS

Jiang *et al.* [25] present a FESTIVE algorithm in HTTP-Based Adaptive Video Streaming for enhancing fairness, efficiency, and stability. In this paper, they addressed the problems of multiple players sharing the bottleneck link over HTTP video streaming. According to the paper, fairness is when multiple players are watching the video content from a server, which is considered as a shared server and want to ensure the fairness of accessing the server from all players, or another case where those players are sharing the same path to a server and the fairness ensure how to share in a fair way the network resources of the shared link for all players. Efficiency is the ability of players to watch the video segment at the highest representation according to available network throughput depends on the adaptation algorithm to maximize users' Quality of Experience (QoE) in real time. Stability is the ratio between the sum of all quality switches detected during the streaming and the sum of all bitrates which were selected by the player. Players prefer to have stability in quality instead of having quality switching frequently. The FESTIVE algorithm is a client-side rate adaptation algorithm in terms of fairness, efficiency, and stability. Before deciding the quality of the next segment, the algorithm calculates the average harmonic mean of bandwidth for the previous 20 chunks is calculated to determine the best quality taking into consideration the stability by avoiding frequent quality switching. Compared to the closest alternative, FESTIVE enhances stability by 50%, fairness by 40%, and efficiency by 10%. Furthermore, FESTIVE success to enhance the QoS by increasing the bandwidth and available set of bitrates for several client players sharing a bottleneck. Moreover, FESTIVE doesn't require modifications at server-side or network infrastructure.

Mao *et al.* [26] propose PENSIEVE, a machine learning approach to generate adaptive bitrate (ABR) algorithms using reinforcement learning (RL) [27] by training a neural network model that determines the quality of the next requested chunks based on client measurements. PENSIEVE learns a quality adaptation logic instantly without any prior knowledge. As a result, the system automatically learns ABR algorithms that adapt to a wide range of environments and QoE metrics. As inputs, this system monitors and learn from bandwidth samples, playback buffer occupancy, and video chunk sizes. The paper compared PENSIEVE to latest ABR algorithms using real-world experiments with a wide variety of network conditions, QoE metrics, and video properties. PENSIEVE outperforms the compared algorithms with enhancements in average QoE of 12% to 25%.

B. VIDEO ENCODING SOLUTIONS

The video stream encoded with standards like H.264/AVC [28] or H.264/SVC [29] permit dealing with bandwidth variations. Scalable Video Coding (SVC) is an extension of the H.264/Advanced Video Coding (AVC) standard with some additional scalability features. A subset video bitstream is derived from the larger video as a low-quality representation of the original content, and require less bandwidth for transmission. In addition to temporal scalability (low frame number) presents in H.264/AVC, H.264/SVC provide spacial (multiple spatial resolutions) and quality (single spatial resolution but at different qualities) scalability. The SVC encoder is more efficient to AVR.

Elgabli *et al.* [30] proposed a multipath video streaming mechanism in the application layer based on SVC. They used TCP instead of MPTCP, proposing a multi-path in the application layer where each layer of a chunk is fetched using one of the connections. They used Adaptive SVC streaming because it has been shown to provide better adaptiveness and scalability than adaptive bitrate streaming (ABR) [31]. Their approach requires no modifications to the server side and avoid any problems with middle boxes. Then, the streaming algorithm decides which link to use for fetching. Besides, they proposed an online algorithm where several challenges including bandwidth prediction errors are addressed.

In addition to H.264 video coding standards, the High-Efficiency Video Coding (HEVC) could provide up to 50% reduction in bandwidth compared to H.264 standards. Corbillon *et al.* [32] proposed a cross-layer MPTCP scheduler for nonadaptive video streaming to prioritize video packets. They propose an adaptive mechanism, at the application layer, to select the segments and uses MPTCP as a transport protocol. The main objective is to minimize the number of packets which arrive out of order. Working at the application layer permit to estimate the playback deadline, thus, it prevents from sending any video segments which will not arrive in time. They wanted to solve the problems of MPTCP, no feedback available, by improving the interaction between the application and the transport layer. After the scheduler that the requested segment will arrive on time, the additional proposed feedback will permit the MPTCP to determine which path can be used to transmit the segment. The cross-layer scheduler explores the interaction between the application and transport layers for flow scheduling decisions in MPTCP. Their results show that the cross-layer scheduler algorithm outperforms the traditional scheduler. Even though their cross-layer scheduler is simple, it shows a performance gain in terms of video quality. However, the solution only studied the server side of the problem without any client implementations.

C. MOBILE WIRELESS VIDEO STREAMING

In recent years, mobile wireless video streaming over the internet shows exponential growth. Wu *et al.* [15] present a video quality driven solution called quality-Driven Multi-Path TCP (ADMIT) for multihomed video transmission over multiple wireless networks (cellular and Wi-Fi). ADMIT is an analytical framework based on MPTCP. It proposes a reliability-aware flow rate allocation. The paper describes the process of selecting the appropriate access networks and adding a Forward Error Correction (FEC) coding adaptation scheme to minimize the effective packet loss rate. By maximizing the FEC coding and the rate allocation, ADMIT outperforms the reference transport protocols in terms of video PSNR (Peak Signal-to-Noise Ratio), end-to-end delay and goodput. ADMIT is, indeed, more suitable for streaming high-quality mobile video in heterogeneous wireless networks with multihomed terminals. However, the paper does not address the well-known problems of MPTCP such as network middle boxes and TCP modifiers.

Boldrini *et al.* [33] tries to answer the following question: Which wireless network can offer the best performance based on the quality observed by end users between the multiple available wireless networks?. To answer this question, the paper laid the foundations based on two main steps: (1) define QoS/QoE parameters; and (2) define the network selection algorithm. Received Signal Strength Indicator (RSSI),Bit Error Rate (BER) and Signal-to-Interference Ratio (SIR) are QoS parameters, while the throughput, delay, jitter, frame error rate, collision rate are network parameters. When defining the network selection algorithm, the authors examined the game theory [34] as the widely adopted solution in the absence of central processing, and absence of cooperation between users. They also reviewed a machine learning algorithm [35] to address the problem of power allocation and best network selection mechanism. The authors focused their efforts on improving the Multi-Armed Bandit (MAB) Framework [36]. Multi-Armed Bandit (MAB) used extensively in statistics and machine learning. The basic idea of MAB is a system of m arms (machines), each having an unknown distribution of the reward with an unknown mean. In MAB, any player can be chosen among different arms to maximize a reward that can be used to model the above problem. The new Multi-Armed Bandit (MAB) model is called muMAB which introduced two algorithms and referred to as muUCB1 and MLI. The results show that the performance of the proposed algorithms depends mainly on the Probability Density Function (PDF) of the reward received on each arm. They switched between the two algorithms depending on the performance of Probability Density Function (PDF). mnUCB1 elected for the arms with similar mean rewards, while MLI elected when the arm is significantly more rewarding than others. In Summary, their solution depends on an adaptive method to select the best algorithm based on the reward of each arm using the Probability Density Function (PDF).

Wu *et al.* [37] explore parallel transmission over the heterogeneous wireless network. They exploited the multihoming feature of mobile devices depending on the stream control transmission protocol (SCTP) at the transport layer and using Concurrent Multipath Transfer (CMT). The authors claimed that the existing CMT implementation could not efficiently leverage the limited wireless resources to improve the perceived video quality to end users. They extend a content-aware CMT (CMT-CA) solution that emphasized by the irregular frame-level scheduling by identifying the video frame parameters. The content-aware CMT (CMT-CA) solution partitioned into two steps; First, they developed an analytical framework to minimize the total distortion of parallel video transmission over multiple wireless access networks. Second, they introduced a joint congestion control mechanism and data distribution scheme based on quality evaluation and Markov decision process (MDP) [38]. Their experimental results better quality by reducing video peak signal-to-noise ratio (PSNR) and delay, and increase throughput.

Sun *et al.* [39] proposed multipath multi-tier 360 video streaming solutions in 5G networks. In heterogeneous wireless networks, the high capacity demand, in such streaming services, can be well delivered with low cost in 5G in comparison to WiFi connection.Their simulation is controlled by real 5G network and user Field-of-View (FoV) that can be utilized to lead the design of future 360 video streaming systems in 5G wireless networks. They illustrate that the use of 5G network as the strong support of mobility and collaboration can reach higher QoE in the proposed 360 video streaming solutions.

D. GENERAL MULTIPATH SOLUTIONS

Multihoming requires at least one endpoint to have multiple network interfaces, which could not be suitable for some implementations. On the other hand, overlay networks use multipath between endpoints within the application layer without the need to modify the underlying network. Concurrent multipath transmission (CMT) techniques could be a viable solution to some implementations. CMT depends on multiple concurrent paths to enhance QoS and improve network throughput.

Liu *et al.* [40] present a multipath multimedia transport protocol, which exploits path diversity over overlay network called multipath UDP (MPUDP) that acts as middleware between the application and transport layer. The application interacts with MPUDP through socket API, and MPUDP manages multiple TCP/UDP flows. MPUDP is a session-based protocol that allows applications to transmit and distribute data over multiple flows. The MPUDP multipath framework forms an overlay network and consists of three logical entities: the user agent, the relay controller, and the relay server. The relay controller functionality is to manage the overlay network topology. The Relay server forwards data packets to the next hop based on a local routing table. When the sender (user agent) initializes a transmission

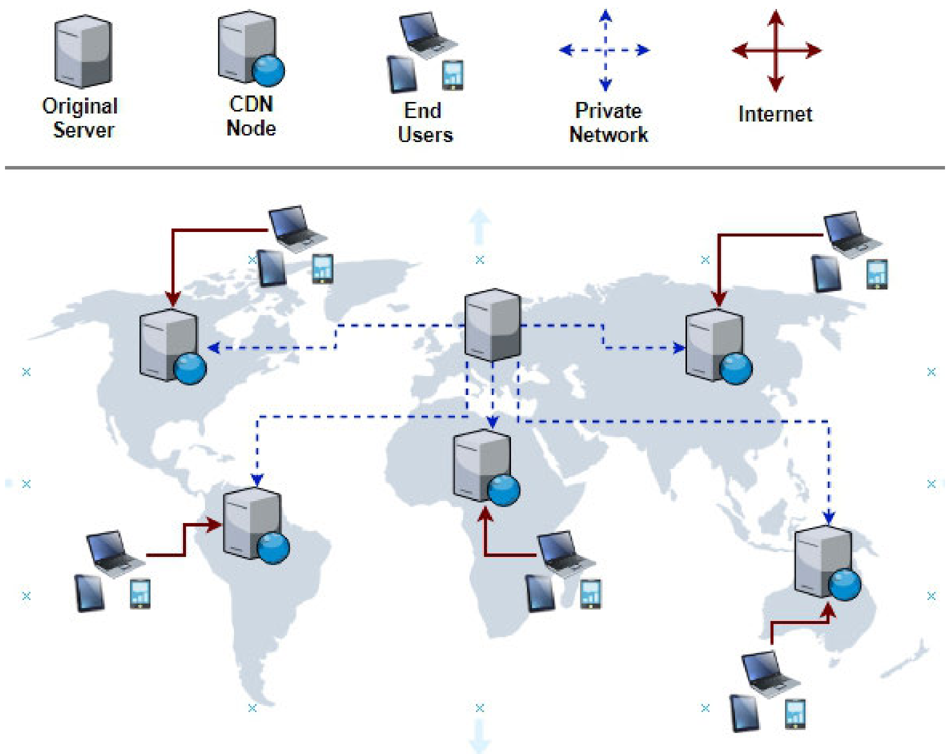

FIGURE 2. Content delivery networks (CDNs).

session, it requests from the relay controller to allocate multiple paths which allow the sender to select paths with minimum utilization of load weight to transmit the packet.

In summary, the overlay network allows path quality evaluation and dynamic data distribution which maximize path utilization. The paper presents simulation results to show that MPUDP can exploit the benefits of multipath transport. However, the paper does not compare these results with other multipath techniques such as MPTCP. In addition to the problem of initial delay acquired from path quality evaluation and data distribution.

IV. MULTIHOMING AND MULTIPATH IN VIDEO STREAMING PLATFORMS

A. VIDEO DISTRIBUTION NETWORKS

Due to the accelerating speed of streaming high video quality, Content Delivery Networks (CDNs) (Fig. 2),was proposed to enable persistent and reliable content delivery to global users. A CDN consists of a set of distributed network of servers that are implemented at many geographical locations. The objective is to permit client players to watch the video from the CDN servers that are based on the nearest geographic location or an application utility function (e.g., delay, jitter, bandwidth, loss rate), thus provide high performance and availability. Related to this survey, we are concerned with multihoming and multipath CDN context. Multihoming is a promising approach to enhance the performance of video content delivery. Kua *et al.* [41] studied the impact of different network factors, including the dynamicity of the network and its topology, on the performance in dynamic flow scheduling, in a multihoming CDN. Their approach is to identify the effect of different parameters and formulate a new mechanism for best flow scheduling based on a combination of different parameters. Results notice 90% throughput enhancement in comparing the traditional solution.

Adhikari *et al.* [42] propose a measurement-based adaptive CDN selection strategy based on Netflix and Hulu video CDN infrastructure which are the global eiders in providing video streaming content. The paper claims that both platforms assign the preferred CDNs to a video request without considering the network conditions and optimizing the user perceived video quality. The authors, also, stated that server selection mechanisms are independent of the location and the time. The results demonstrate that this selection mechanism does not reach the best possible QoE to the users. Netflix launched its own Content Delivery Network called "Open Connect" and permits ISPs to connect their network with Netflix CDN for free at common Internet exchanges. Böttger *et al.* [43] extensively studied the infrastructure of Netflix "en Connect" providing a complete large-scale measurement study with over 500 locations worldwide. However, some significant ISPs still refuse to connect with Open Connect due to business concerns. However, we think that a significant player like NetFlix and Hulu always innovate new proprietary CDN designs and network infrastructures, which could make the test conditions obsolete.

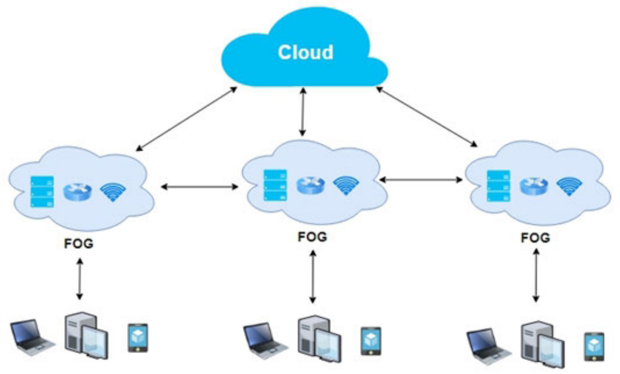

FIGURE 3. Fog computing architecture.

Nikravesh *et al.* [44] paper tries to improve the interplay between multipath and CDN server selection. Based on DNS infrastructure, the selection of a suitable server may affect the quality while another server is available on another path. In other words, when using multipath, choosing the best CDN server is complex and could lead to different network performance degradation. The DNS infrastructure consists of sending initial DNS request by only one path without taking into consideration the other paths. Also, their emulation shows that many factors (MPTCPs scheduling algorithms, network characteristics of a diver path) affect the selection mechanism which can lead to affect the network performance. The paper proposes improvements to make CDN server selection multipath aware by adding protocol support that allows the CDN to learn that the client is using multipath. Besides, they proposed that CDN distinguish between paths based on transfer amounts. It uses the path with minimum latency for small transfers while for large transfers it maximizes the total bandwidth by calculating the weighted sum for all paths bandwidth. However, only general solution guidelines are given without specific detailed implementation.

Video distribution giants like YouTube, Hulu, and Netflix uses a global infrastructure for streaming video by installing their CND servers at the backbone of Internet Service Providers around the world, to provide high-availability and performance video content delivery. QoE monitoring and assessment for giant video distribution is a sophisticated measurement of performance, which is very challenging to be estimated at the network core. Casas *et al.* [45] tries to answer the question if the current mobile network is providing the right QoE for watching YouTube videos. They indicate the received video degradation level based on the ratio between the video's total stall length and the total length of the video playbacks, which can provide approximate QoE. They validate their prosed model based on lab and field measurements. A machine learning approach proposed by Petrangeli *et al.* [46] called YouQ to estimate QoE-relevant metrics for YouTube by extracting features from the stream of encrypted packets, using simple features such as throughput, packet sizes, and packet times. The machine learning models for QoE classification are calculated by collecting data of all the traffic features per video session. However, the accuracy of the predicted QoE values is rather coarse due to frequent pattern adaptation made by the YouTube service. More heuristics based on machine learning could be implemented to avoid such problems.

Adhikari *et al.* [47] tries to reveal Netflix architecture and its performance strategies and propose a new CDN selection mechanism. They investigate the architecture of Netflix and improve its CDN performance. Surprisingly, Netflix always binds a user to one CDN server, regardless of the available throughput between the user and the server even when the other CDNs can achieve better QoE. They run a set of bandwidth measurements while using three Netflix CDNs. Results show that choosing the best CDN, based on bandwidth availability, lead to an average enhancement up to 12% in comparison with the static CDN assignment. However, the study could be obsolete now as Netflix is continuously changing the underlying CDN infrastructure and selection algorithm. For future work, the study recommends adapting of rate-adaptive streaming technologies (e.g., DASH) for from simultaneously using multiple servers to enhance QoE.

B. FOG COMPUTING ARCHITECTURE

Fog computing [48] Fig.2 is a decentralized architectural design that enables mobile devices to execute computationally intensive tasks directly at the network edge. The term coined by Cisco to whereby the former typically refers to bring the power of cloud computing closer to the location where services are instantiated. For example, commercial edge routers have the potential to become new servers to provide services at the network edge.

Zhu *et al.* [49] present a study to improve video performance with edge servers in the Fog computing architecture. The paper describes a series of video applications that can potentially benefit from a fog computing architecture, ranging from intelligent caching and adaptive streaming for video content delivery to interactive virtual desktop infrastructure(VDI) and real-time video analysis. The paper shows how to increase video performance by applying intelligent caching at the edge for video content delivery. The fog computing platform can be utilized to offer just-in-time video analytics based on schedules and proximity of consumers. As a result, fog computing architecture opens up new avenues for video applications. This will reduce the computational load from mobile clients, reduce the communication burden on wireless networks, and improve response time compared with traditional cloud network.

C. MOBILE EDGE COMPUTING

Due to power resources limitations of the mobile user equipment and the delay that occurs by offloading the application to centralized cloud (CC), European Telecommunications Standards Institute (ETSI) proposes a solution known as Mobile edge computing (MEC) [70]. The MEC brings the network of cloud servers, storage and processing resources, closer to the mobile device, which results in benefits to mobile operations, service providers and end users. [72], [73]. From user perspectives, mobile devices have certain limitations (battery, memory and processor) and mobile applications are requiring more and more kind of processing (image and speech processing). MEC solution permit users to use the resources of Mobile Edge Server (MES) to compute the complex operations instead of using the local resources of mobile users. MEC permits services providers to gather information from the users, which can be used for security and safety purposes. Also MEC acts as an IoT (the Internet of Thing) gateway, to aggregate and deliver services between IoT devices with minimum latency required in various protocols. Yue Li at [69] propose a video streaming architecture based on MEC and compatible with DASH Standard. The paper presents an Integer Linear Programing (ILP) formulation for the problem addressed as network selection in heterogeneous wireless networks. Then, use the heuristics algorithm to solve the problem while optimizing the QoE. Firstly, a network selection algorithm is used to specify which network is the most suitable for each client. Then, a local and global optimization of resources are used to prevent a user from fulfilling the resource utilization, which maximizes the QoE-fairness across all clients, and to improve the QoE.

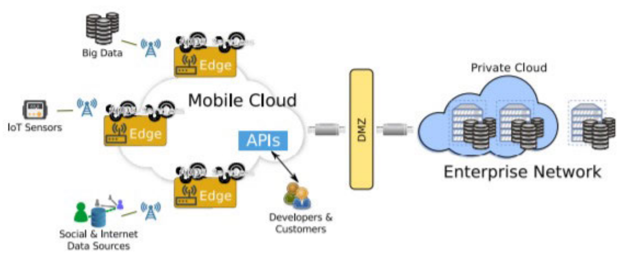

FIGURE 4. **Mobile edge computing architecture.**

D. INTERNET OF MULTIMEDIA THINGS (IoMT)

Recently, a group activity called the Internet of MultiMedia Things (IoMT) (general architecture illustrated in Figure 4) created by the MPEG International Standardization Group (ISO/IEC SC29 WG11) to standardize the communication between multimedia things and humans [50], [51]. The idea is to take advantage of all smart heterogeneous multimedia things to deliver multimedia content by collaborating and interacting between multimedia things.Balan *et al.* [52] focused on using LISP (Locator Identifier Separation Protocol) [53] for multihoming and load-balancing purposes. LISP is a network architecture that separate IP addresses into two numbering entities: the Endpoint Identifiers (EID-s) and Routing Locators (RLOCs) [54]. The purpose of EID to identify connected network nodes and RLOCs identifies locations by using IPv4 and IPv6. The separation of LISP identity and locations allows mobility and pave the way for multihoming implementation. The paper focused on video streaming by implementing an IoT gateway that runs on IBM Watson IoT framework and using Raspberry Pi as hardware.

In [55], the authors used Open Overlay Router (OOR) as public open source LISP implementation. Multiple mobile operators used simultaneously for multihoming. In a nutshell, the paper demonstrated multihoming for IoMT by having multiple parallel mobile connections with LISP multihoming, load-balancing, and using several multimedia WebRTC streams simultaneously. However, the testing environment cannot be verified or controlled as they stated that the measurement of the LISP multihoming performance is custom designed and not accurate. Furthermore, the test methodology is not complete because it doesn't study the impact of adaptive bitrate streaming.

Floris and Atzori [57] present QoE management aspects of IoMT applications and define a layered QoE model aimed at evaluating and estimating the overall QoE, mostly multimedia data is involved. The QoE model consists of four general layers; (1) Real-World Objects (RWOs): this is the physical IoT devices. (2) Virtualization layer: Virtual Objects (VOs) to add functionality to the physical devices (3) Aggregation layer: Composite Virtual Objects (CVOs) capable of implementing services that Virtual Objects (VOs) cannot accomplish. (4) Application layer: manage requested services required by the IoT application. The validation of the model is performed with gathered data from an IoT vehicle application, containing sensors, and camera data. The data sources are streamed and displayed to end users, which then subjectively assign a QoE rating score.

The IoMT Vehicle Application IoT multimedia system aimed to monitor the traffic in real-time scenarios, such as the cameras, installed on roads that act as video sensors. Accident alerting, traffic planning, Speed detection, and rash driving are some of the features that such applications can provide. For Example, The application provides up-to-date information to the users to permit them to choose the best route without congestion. On the other hand, the application provides government accurate position of the vehicles for safety reasons (crime detection, road accidents and traffic jams). The Smart Surveillance Application consists of different types of sensors (video cameras, motion and light sensors) located in different sites. Video streams in multimedia internet of things provide public security safety, for example if any accident happens on a street the smart cameras can detect the attack event and report it to the basic central monitoring room and alarm the nearby hospitals for emergency support. The architecture of IoT consists of three layers, starting by the perception layer which is responsible for connecting the sensors to their Virtual Objects (VOs) to measure the QoS network condition and evaluate the QoE for cameras based on video sequences will be used based on the quality of the videos such as bitrate, resolution, and codec. After transmitting the processed information into upper layer via layer interfaces, the network layer is used to receive the processed information provided by the perception layer and

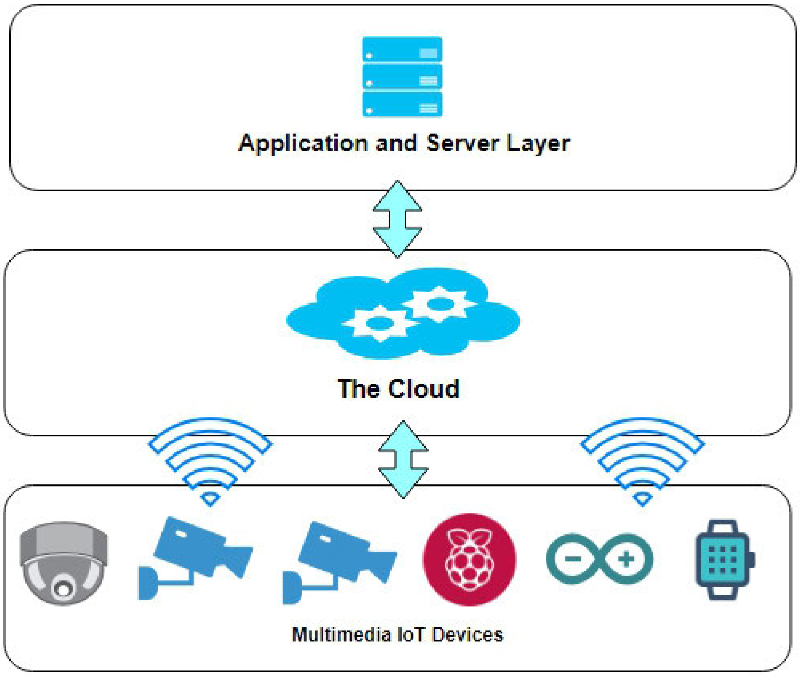

FIGURE 5. Internet of Multimedia Things (IoMT).

determine the routes to transmit the data and information to the IoT applications. The application layer receives the data transmitted and provide required services. The basic idea is to correlate all the cameras and sensors to improve the detection process of the surveillance application. The authors have been able to prove that the QoE metrics obtained from the layered QoE model performed well in controlling the QoE of IoMT applications. However, the authors stated that the major obstacles are the lack of adoption of an IoT architecture by the associated IoT community. The term Quality of Data (QoD) is proposed to evaluate the quality or precision of acquired data by Multimedia-IoT devices, and QoS parameters are considered as influencing factors for QoD. As for future work, many parameters are used to ensure the quality of received video for different application of IoMT and different layered based QoE-aware architecture should be evaluated

V. CONCLUSION AND FUTURE WORKS

This survey toured a wide variety of scientific literature that aimed to enhance QoE for video streaming based on multipath and multihomed overlay networks. We tried to combine research papers on multipath and multihoming as a refined method to exploit the ultimate potential of multiple network interfaces with smart network routing. We revealed that the transport and application layers are currently very active and dominant in the research and industry.

Multihoming research still on the rise as the majority of devices like smartphones and laptops are equipped with multiple network interfaces(like Wi-Fi, Ethernet, and 4G). Unfortunately, challenges still facing the implementation of multihomed solutions. Most Multihoming Operating Systems (OS) implementations are missing or complex to deploy. Also, mobile and wireless devices cannot take full advantages of multihoming due to the energy constraints and higher charge for 4G and 5G networks.

The survey inferred the influence of MultiPath TCP (MPTCP) reflected in the enormous amount of research papers on the topic. MultiPath TCP (MPTCP) use multiple paths to increase network throughput and improve fail-over by switching between paths in case of a path failure. Unfortunately, MultiPath TCP (MPTCP) suffered from network middle boxes, forcing MPTCP connections to drop back to standard TCP.

In the application layer, the dynamic adaptive video streaming over HTTP like MPEG-DASH seems to be the most widely deployed. The survey showed several studies related to DASH and multihomed multipath solutions. One significant advantage of the client-based approach like DASH players is that no modification is required at either the server or the client side. Besides, we presented different studies on machine learning techniques to generate adaptive application algorithms.

We highlighted the critical role of Content Delivery Networks (CDNs) in video streaming and its relation to multipath and multihoming and tried to shed light on video distribution infrastructure giants like YouTube and Netflix. In the future, we expect more improvements to the multipath algorithm and anticipate that more video streaming to move even closer to the network edge through fog computing.

We shifted our focus to more advanced emerging video streaming technologies such as the Internet of Multimedia Things (IoMT), fog computing, and 360 VR Video Streaming. We believe that these new technologies continue to grow and open up new avenues for video streaming and should be the basis of our further work. We want to investigate more on implementation and performance gain of the Internet of Multimedia Things (IoMT) based on multipath and multihoming technologies.

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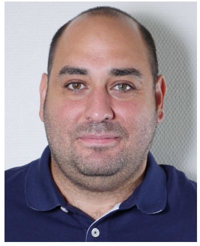

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