Real-Time Video Streaming in MPT-GRE Multipath Networks

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***Abstract*— Real-time video streaming over a multipath system enhances the quality of video delivery by diminishing packet loss, latency, and congestion, which eventually improves service quality and user experience. This paper addresses technical issues related to multipath routing, including path selection, packet scheduling, and path matching, and proposes solutions such as MPT-GRE. The effectiveness of MPT-GRE is assessed using recognized metrics such as PSNR, SSIM, and MSE, which are used to quantify differences in video quality. The paper aims to explore challenges and solutions in real-time video streaming over multipath networks, mainly focusing on MPT-GRE, while also quantitatively assessing the impact of streaming on video quality. In this paper, we selected a set of videos with different resolutions and specifications from the Waterloo Streaming QoE Database. The study measures how video quality assessment metrics influence streamed video through a network using the MPT-GRE communication library and demonstrates the efficiency of real-time video streaming using MPT-GRE. This paper presents evidence that MPT-GRE improves high-resolution video streaming, leading to a smoother and more reliable experience. These enhancements are validated using metrics such as PSNR, SSIM, and MSE, demonstrating the effectiveness of MPT-GRE in maintaining high video quality in multipath network environments.**

Keywords—PSNR, SSIM, MSE, MPT-GRE, Streaming, Tunnel.

I. INTRODUCTION

Real-time video streaming has grown across multiple digital domains, including entertainment, telecommunications, and distant collaboration applications. However, traditional single-path networks frequently experience reliability and performance issues, particularly in dynamic and complex network environments. Furthermore, multipath networks capitalize on the simultaneous use of various paths and offer a viable option for improving video streaming resilience and efficiency by benefiting network variety and redundancy [1]. Nonetheless, properly implementing multipath routing in real-time video streaming offers several technological challenges that necessitate novel solutions and optimizations.

Multipath networks are a potential model that could ensure video streaming is flexible and efficient during network communication. On the other hand, it faces technical challenges. Although multipath routing boosts performance by providing reliability and high throughput, selecting the best path, as well as scheduling of packets and fairness of resource sharing among paths, are technically challenging. Thus, network optimization, congestion control, and technology development solutions to utilize multipath characteristics are required. The throughput in a multipath network is higher than that of a single path. Therefore, multipath networks such as the MPT-GRE library can provide a robust and efficient solution for video streaming. The MPT-GRE library contains a tunnel, and its transmission speed is approximately equal to the sum of the speeds of the two paths. [2], [3].

One of the priorities of network developers interested in real-time video streaming is to ensure that the quality of experience (QoE) remains at its highest levels. Network infrastructures face challenges in video communication due to limited bandwidth and packet loss, resulting in reduced video quality, rebuffering, and reduced throughput. All of these factors significantly impact the QoE of real-time video streaming [4]. An alternative method to enhance QoE is to utilize multipath communication. Multipath architectures are becoming increasingly popular due to the increased usage of mobile devices with multi-interfaces that allow users to simultaneously connect to different types of networks, such as Wi-Fi, 4G, and 5G. The delay, packet loss, and bandwidth limitations are the primary factors contributing to poor-quality video streaming experiences. The use of multipath techniques helps overcome these drawbacks and improve video streaming quality [5]. MPT-GRE ensures uninterrupted data delivery by utilizing alternative paths when one becomes congested or fails. This mechanism is essential for real-time video transmission to prevent buffering and quality issues. MPT-GRE also aggregates bandwidth from multiple paths, improving overall throughput, particularly for high-definition video streaming.

This paper aims to demonstrate the efficient ability of video streaming in real-time via the tunnel of the MPT-GRE multipath network by comparing video streamed through a single path to video streamed through an MPT-GRE tunnel. It also aims to show that the tunnel's throughput aggregation can significantly enhance video streaming quality.

II. RELATED WORK

The research studies on video streaming in the switching and routing infrastructure have become very important in decreasing the effect of communication system breakdowns during data transmission. Another conceptual solution for network breakdowns can be the application of multipath communication technologies.

Almási et al. [6] investigated how the MPT-based multipath communication environment responds to network breakdowns. Through empirical analysis, they evaluated the resilience of the MPT "GRE in UDP" based multipath communication environment in mitigating the adverse effects of network breakdowns on video stream transmission.

Specifically, the author issued Wi-Fi 3G vertical handovers across different scheduled and unexpected breakdowns. The results seem to lean towards the uninterrupted scalability of TCP flow transmission of video streams through scheduled breakdowns. At the same time, there is a slight level of stuttering because of unexpected breakdowns. The same type of video stream transmission using unbuffered UDP depends on the level of failure, although the results are slightly worse. Differences in streaming paths' speeds and delays in scheduled breakdowns are bound to lead to high reordering in packet transmissions, with the video stream quality having the most significant impact and audio synchronization being the second most affected. Despite these challenges, video stream transmission persists, albeit with observable errors that stabilize after a brief period. Overall, this study underscores the potential of MPT-based multipath communication in enhancing the robustness of video stream transmission against network breakdowns.

ZHANG et al. [7] presented a framework for transmitting real-time video traffic through multiple paths. The focus is on implementing congestion control and packet scheduling algorithms. Traditional methods like AIMD are unsuitable for real-time video as they cause sharp rate reductions upon packet loss, resulting in delays. Implementing congestion control at the application layer can address this issue. However, it is challenging to ensure fairness among flows sharing a bottleneck. The study experimented with GCC, QUIC-BBR, WebRTC-BBR, and Delay-BBR, which showed varying performance. Delay-BBR seems promising with bandwidth fairness and lower loss rates, but it comes with a higher delay.

The authors [8] developed models for Multiple Description MD streaming over multiple paths and proposed a multi-path selection method based on these models. This method selects a set of paths, maximizing overall client quality under various constraints. Simulation results using MPEG-2 demonstrate significant average peak signal-to-noise ratio (PSNR) improvements (ranging from 0.73 to 6.07 dB) when intelligently selected multiple paths are utilized compared to shortest or maximally link-disjoint paths. Furthermore, end-users benefit from a more continuous quality experience with streaming. Our approach also addresses the architecture and mechanisms for implementing multi-path streaming over a conventional IP network.

The researchers [9] developed the Bandwidth-Efficient Multipath Streaming (BEMA) protocol to address the limitations of traditional throughput-oriented and content-agnostic multipath video transport protocols to handle the high bandwidth and delay sensitivity of real-time video streaming. BEMA includes priority-aware data scheduling and forward error correction for reliable transmission. The Exata simulations evaluations for real-time H.264 video streaming demonstrate that BEMA improves video peak signal-to-noise ratio, end-to-end delay, and bandwidth utilization for high-quality real-time video streaming in diverse wireless networks.

The authors [10] introduced a real-time media transmission method called VN-based multipath switching (VNMPS), designed for the Vector Network (VN), a connection-oriented network with multipath capabilities. The paper discusses the concepts and features of the Vector Network, presents a model for network nodes, and demonstrates through OMNeT Simulator experiments that VNMPS can reduce packet loss and end-to-end time delay.

This paper distinguishes itself by focusing on MPT-GRE for real-time video streaming. It thoroughly examines technical challenges associated with multipath techniques and provides a detailed quantitative assessment of video quality improvement using recognized metrics such as PSNR, SSIM, and MSE. This differentiates it from the multipath transport solutions and evaluations presented in [7][8][9][10].

III. Challenges of Real-Time Video Streaming

Real-time video streaming in multipath networks faces several challenges due to the stringent requirements of delivering continuous video content with minimal delay and high quality. Network congestion can lead to packet loss, increased latency, and reduced available bandwidth, affecting the quality of real-time video streaming. Variability in available bandwidth across different network paths further complicates the delivery process. Furthermore, the delay in sending and receiving video packets is critical for real-time streaming applications. High latency can result in buffering or playback interruptions, impacting user experience. On the other hand, the jitter, the variation in packet arrival times, can also cause synchronization issues and affect video quality [11], [12].

Providing reliable quality of service for real-time video streaming requires mechanisms to prioritize video traffic over other data types and maintain sufficient network resources to meet performance requirements. However, conducting QoS guarantees becomes complex in networks that suffer from variations in traffic loads and network conditions. In these conditions, packet loss is expected due to congestion, transmission errors, and link failures. Real-time video streaming protocols must incorporate error resilience techniques, such as forward error correction (FEC) and retransmission mechanisms, to mitigate the impact of packet loss and maintain video quality [13] . In traditional networks,

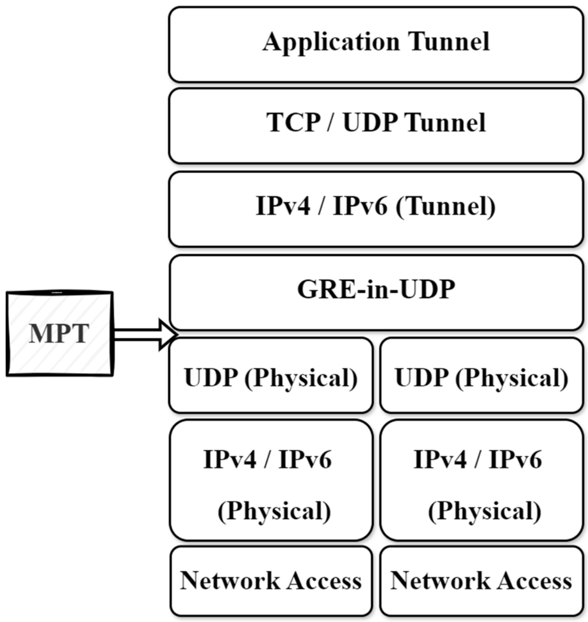

Fig. 1. The Conceptual Architecture of MPT-GRE [12].

if a single link for data transmission breaks due to congestion, hardware failure, or other issues, the video streaming service may be disrupted or even halted until the problem is resolved.

The need for improvements in video streaming quality that aid reliability and improve user experience has encouraged researchers to continue research and development to address these challenges through the use of multipath techniques and a range of innovative techniques, protocols, and optimization strategies specifically designed to meet the specific requirements of real-time video streaming applications.

IV. THE ARCHITECTURE OF MPT-GRE NETWORKS

Contemporary IT devices often have multiple network interfaces, but only one interface is typically used in communication sessions due to limitations in the TCP/IP protocol stack. This limitation is caused by identifying communication endpoints via an IP address and TCP or UDP port number. However, using multiple interfaces at the same time could improve user experience by increasing throughput and adding network failure resilience. MPT-GRE is a network layer solution that enables tunneling over multiple paths through the GRE-in-UDP specification. One significant feature of the MPT-GRE library is that the tunnel IP version and path IP version remain independent, making it suitable for IPv6 transition purposes. The MPT-GRE stands out from similar protocols such as Multipath TCP (MPTCP) and Huawei's GRE Tunnel Bonding Protocol. MPT-GRE works as a router, directing packets across different networks between tunnel endpoints and establishing multipath site-to-site connections[14]. MPT-GRE uses UDP in the underlying layer to take advantage of its simplicity and efficiency. It is based on GRE-in-UDP encapsulation, where GRE (Generic Routing Encapsulation) packets are encapsulated within UDP packets. This method combines the flexibility of GRE tunneling with the transport properties of UDP. The layered architecture of MPT is illustrated in Fig. 1. It extends the GRE-in-UDP framework to support multiple physical paths. Unlike MPTCP, MPT uses UDP at the underlying layer, relies on GRE-in-UDP, and provides a tunnel IP layer that is compatible with both UDP and TCP. Huawei's GRE tunnel bonding protocol has a similar goal to MPT, seeking to bond access to wired and wireless networks within customer premises. However, it uses GRE (not GRE-in-UDP), which has less support in ISP networks than UDP and restricts the number of physical interfaces to two.

V. WATERLOO STREAMING QOE DATABASE

The Waterloo Streaming QoE Database III (SQoE-III) [15] contains a video collection that significantly improves the quality of experience (QoE) after streaming video. It consists of 20 original videos and 450 streamed videos. The database comprising 20 high-quality videos at a resolution of 1920×1080 was selected to cover a wide range of content, including humans, plants, natural scenes, architectures, screen content, and computer-simulated scenes. All videos have a duration of 10 seconds. The videos are formatted and processed using a set of algorithms. Different conversions with special features considered 13 different network conditions necessary to evaluate video streaming performance. Subjective assessments conducted by 34 individuals provide a valuable understanding of user perceptions of streaming quality. SQoE-III is distinguished by its sheer size, variety, and comprehensive evaluation of the streaming experience, which makes it a valuable resource for researchers and practitioners. Figure 2 shows snapshots of the original video sources. It is worth noting that the SQoE-III data was created using different source ranges and distortion methods to ensure a natural representation of real-world strategies.

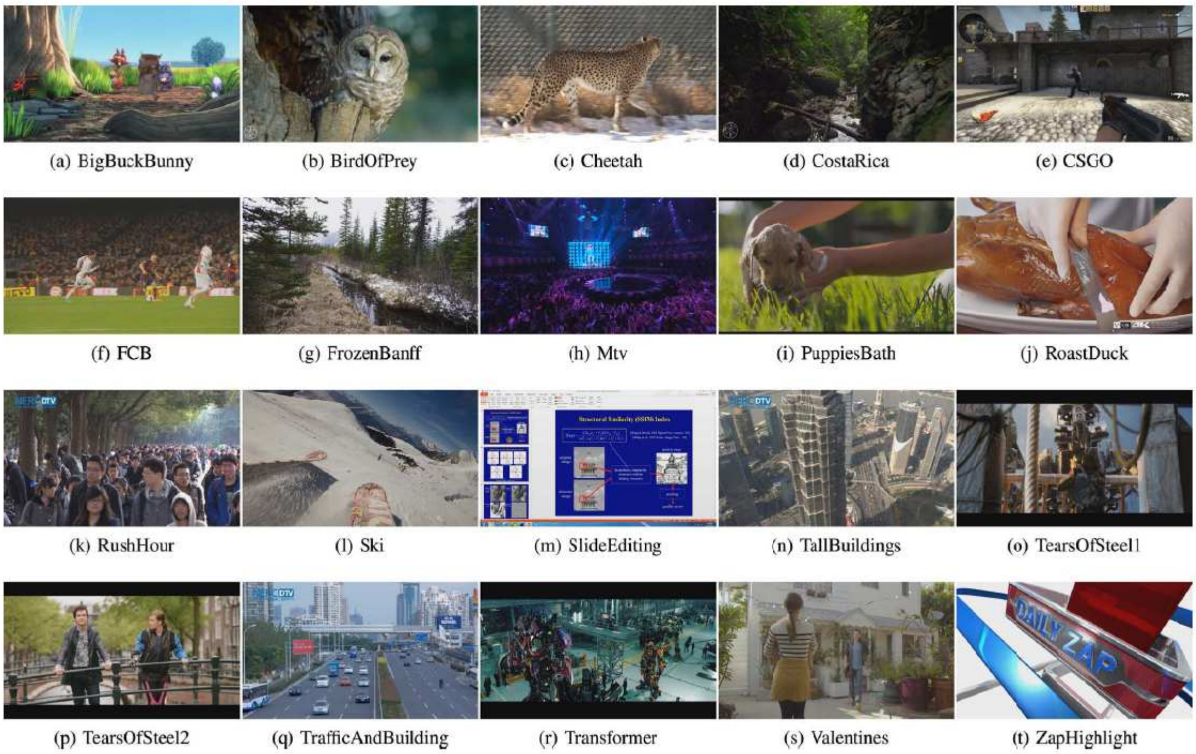

Fig. 2. The Snapshots of video sequences of Waterloo Database [13].

VI. VIDEO QUALITY ASSESSMENT METRICS

Video quality assessment metrics are essential tools to evaluate the fidelity and perceptual quality of video content. One such metric is the Peak Signal-to-Noise Ratio (PSNR), which measures the strength of the signal against noise interference. This provides insights into the level of distortion that occurs during compression or transmission[16].

- PSNR is expressed in decibels (dB) and compares the peak signal power to the power of the noise, thus quantifying the level of degradation introduced during compression or transmission. It is computed as the ratio of the maximum possible pixel value squared (usually 255 for 8-bit images) to the mean squared error between the original and processed images, as shown in Equation 1:

$$PSNR = 10.\log_{10}\left(\frac{MAX^2}{MSE}\right) \quad (1)$$

- Structural Similarity Index Measure (SSIM), in contrast, comprehensively measures the structural similarity between two images by evaluating luminance, contrast, and structure. It ranges from -1 to 1, where 1 indicates perfect similarity. The SSIM index is calculated using a comprehensive formula that includes the mean, variance, and covariance of the original and processed images, represented by μx, μy, $\sigma x2$, $\sigma y2$, and σxy. The SSIM index formula is as Equation 2:

$$SSIM(x, y) = \frac{(2\mu x\mu y + c1)(2\sigma xy + c2)}{(\mu_x^2 + \mu_y^2 + c1)(\sigma_x^2 + \sigma_y^2 + c2)} \quad (2)$$

Where c1 and c2 are constants are used to stabilize the division when dealing with a weak denominator.

- Mean Squared Error (MSE) evaluates the average squared difference between corresponding pixels of the original and processed videos, offering a quantitative measure of reconstruction accuracy. MSE, often used alongside PSNR and SSIM, represents the average squared difference between the pixels of the original and processed images. It is calculated by averaging the squared differences in overall pixel positions. as shown in Equation 3:

$$MSE = \frac{1}{mn}\sum_{i=0}^{m-1}\sum_{j=0}^{n-1}(I(i,j) - K(i,j))^2 \quad (3)$$

Where I and K represent the intensity values of the corresponding pixels in the original and processed images, and m and n are the dimensions of the images.

These metrics enable objective comparisons between encoding methods, aiding informed decision-making in video processing applications such as video compression, streaming, and transmission optimization.

VII. EXPERIMENTAL TEST ENVIRONMENT

A. *Hardware and Infrastructure Setup*

A test system for measuring and analyzing video streaming in the multipath network was created, as shown in Fig. 3. Here are the specifications of the two Dell PowerEdge R620 servers that were used.

- 4x8 GB 1333MHz DDR3 SDRAM.
- Two 6-core Intel Xeon E5-2620 processors clocked at 2.00 GHz.
- Network Interface Card (NIC): Intel quad-port Gigabit Ethernet controller, of which two ports were used for the examination.

The two interfaces were connected via a Cisco Catalyst 3550 switch with a 10Mbps transmission limit. Two independent physical paths were constructed between the interfaces (eth1, eth2), where the experimental network's IP address can also be seen in the figure. The MPT-GRE software enabled the tunnel (tun0). Both servers ran the Ubuntu 22.04.4 LTS (Jammy Jellyfish) / Linux operating system. This experimental design aims to assess the efficacy of the MPT-GRE tunnel in real-time video streaming by calculating performance evaluation of video streaming quality employing video from the Waterloo streaming QoE database via conducting some quality metrics for streamed video, like PSNR, SSIM, and MSE.

B. *MPT Software Configuration*

The MPT software setup requires a 64-bit version, especially the version mpt-gre-lib64-2019.tar.gz, which can be

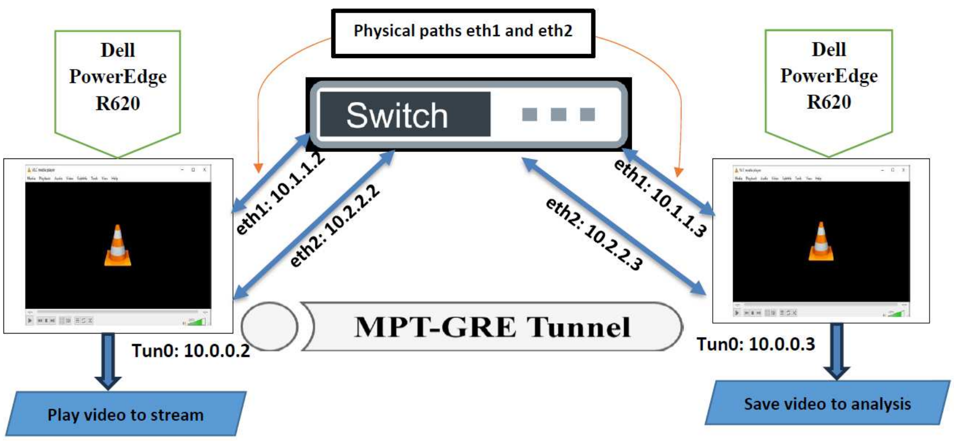

Fig. 3. Network Topology of Real-Time Video Streaming.

found in [17]. Two files are in the MPT installation directory, and modifications are needed to the configuration. The first file, conf/interface.conf contains general interface information such as local command UDP port number, interface number, acceptance of remote requests, and specifics regarding tunnel interfaces, including name, maximum transfer unit, and IPv4 address with the prefix length. Similar configuration methods were applied to the interface of the second server.

The tunnel files are categorized into distinct connection files that include all relevant IP addresses and constant-length data for each MPT-GRE software, thereby establishing the logical path (tunnel). Connections were organized and arranged in the second file, featuring IPv4 over IPv4 connection specifications outlined in the conf/connections/IPv4.conf file. Our prior paper [18] provided detailed descriptions of MPT configuration file settings, which are publicly available on GitHub [19].

C. VLC Software Configuration

To configure VLC for streaming and receiving video over the MPT-GRE tunnel or the single path, we made some adjustments for optimal transmission and playback. Initially, we added the video file to the stream on the source computer. Next, we chose the H.264 video codec and MP3 audio codec for transcoding. We then specified the MPT-GRE tunnel address or first path as the destination IP for streaming with specific port. The HTTP protocol is used for video streaming in both single and multipath. Finally, to save the video received via the tunnel or first path address, we used the recording propriety in VLC at the destination.

To illustrate the experiment in more detail, we adjusted the transmission speed settings for both paths to 10 Mbps using the ethtool command as follows:

```
ethtool -s eth1 speed 10 duplex full autoneg off
ethtool -s eth2 speed 10 duplex full autoneg off
```

The video was played on the sender, a Dell PowerEdge R620 server, using the VLC player. We utilized the HTTP protocol and the H.264 video format for streaming. On the recipient side, the video was received through the tunnel using the IP address 10.0.0.2 and via the single path using the IP address 10.1.1.2. The video was then stored, and then the Python script, which is publicly available on GitHub [20], calculated the average values of the Peak Signal-to-Noise Ratio (PSNR), Structural Similarity Index (SSIM), and Mean Squared Error (MSE).

VIII. Performance Evaluation of Video Streaming Quality

To assess the quality of real-time video streaming through the tunnel of the MPT-GRE network layer multipath communication library, we conducted two scenarios. In both scenarios, we measured video quality before and after streaming through the first path and through the MPT-GRE tunnel.

In the first scenario, we computed the quality metrics for the BigBuckBunny video with different resolutions and bitrates, as illustrated in Table 1.

Analyzing results, as shown in Fig. (4 - 6), involves examining the variations in PSNR, MSE, and SSIM before and after streaming videos of various resolutions and bitrates

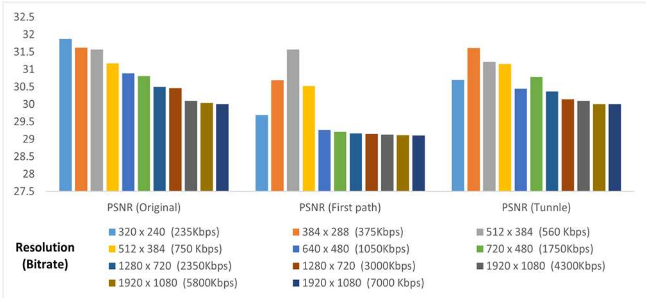

Fig. 4. PSNR Comparison before and after streaming through the single path and MPT-GRE Tunnel.

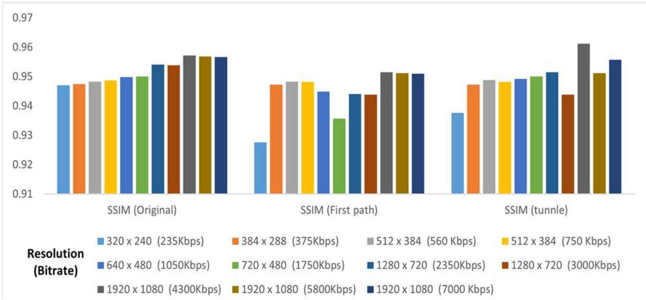

Fig. 5. SSIM Comparison before and after streaming through the single path and MPT-GRE Tunnel.

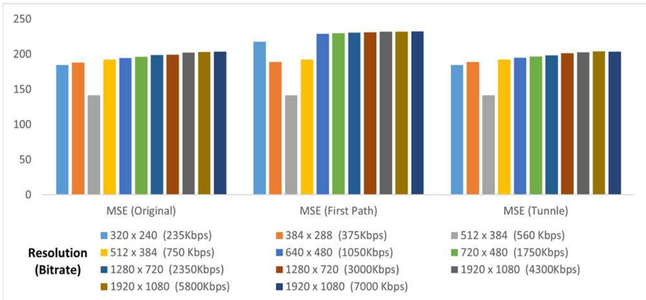

Fig. 6. MSE Comparison before and after streaming through the single path and MPT-GRE Tunnel.

through the single path and the tunnel of the MPT-GRE multipath network. The impact of resolution and bitrate on video quality is significant. The results showed that aggregated tunnel throughput helped maintain video streaming quality better than using a single path. For example, the PSNR of the video streaming with a resolution of 720 x 480 and a bit rate of 1750Kbps through the tunnel was 30.7810 dB, whereas the PSNR of the original video before streaming was 30.8098 dB.

TABLE I. DESCRIPTION OF ENCODING THE BIGBUCKBUNNY.MP4 VIDEO SEQUENCES

Video Name: BigBuckBunny		
Representation Index	***Resolution***	***Bitrate (kbps)***
1	320 × 240	235
2	384 × 288	275
3	512 × 384	560
4	512 × 384	750
5	640 × 480	1050
6	720 × 480	1750
7	1280 × 720	2350
8	1280 × 720	3000
9	1920 × 1080	4300
10	1920 × 1080	5800
11	1920 × 1080	7000

This indicates a difference of 0.0288 from the original video, and the PSNR of the single path was 29.2108 dB, the difference with the single path was 1.599. Furthermore, the SSIM value for the video before streaming was 0.950099362, while its value for the video streamed within the single path and the tunnel was 0.935692353 and 0.950079322, respectively. The MPT-GRE tunnel maintains a higher SSIM than the single path. The difference in SSIM between the two methods is 0.014386969, suggesting that the tunnel provides better quality preservation than the single path. Multipath protocols often introduce some overhead due to the additional processing required to manage multiple paths. This overhead can slightly affect the overall video quality. For example, all PSNR results of the MPT-GRE tunnel are higher than the PSNR results of the single path. Only in the 512x384 (560 Kbps) resolution is the PSNR (First path) slightly higher than the PSNR (Tunnel) where the values (31.57387531 and 31.21375698) respectively, with a simple difference is (0.36011833).

On the other hand, when comparing the MSE values of the video mentioned above, we observe a notable difference between the MSE value for the tunnel and the single path. The MSE values were 196.077941 for the video before streaming, 229.6698142 for the single path, and 196.6698142 for the tunnel.

In the second scenario, we calculated the quality metrics PSNR, MSE, and SSIM for 6 videos at the highest resolution in the database, 1920 × 1080, with a bit rate of 7000Kbps, as depicted in Table [II – IV].

The results in Table II indicate that using the tunnel of the MPT-GRE method is best for preserving video quality for high-resolution video streaming, as indicated by higher PSNR values. While the single path is still usable, it results in more substantial quality loss and might not be suitable for high-quality video applications.

For example, the PSNR values for the video named "Transformer" were 39.6097 dB before streaming, while the PSNR values for the streamed video through the single path and tunnel were 32.8483 dB and 39.6097 dB, respectively. These PSNR values significantly drop (6.76 dB) for the single path, indicating significant quality degradation. On the other hand, the PSNR values of the tunnel show no drop, maintaining the original PSNR, which is a perfect quality.

By analyzing the results in Table III for the same video previously mentioned, these SSIM results show that the MPT-GRE tunnel's streaming is highly effective in maintaining quality. For example, the SSIM value for the video named "Transformer" after streaming through the single path is 0.7967. The difference between the original and the single path SSIM is 0.0175. This difference indicates a reduction of approximately 2.15%, demonstrating a small but detectable degradation in video quality during streaming. However, the SSIM after streaming via the tunnel was the same as the original SSIM, with no degradation in video quality.

Finally, the MSE results are in Table IV. Analyzing the MSE values for the video named "Transformer" after streaming via the single path were 441.7730. The difference between the MSE for the original video and the single path MSE is 118.3305, while the tunnel kept the same MSE as the original video. These MSE results support the previous results from the PSNR and SSIM analysis. Real-time video streaming using the MPT-GRE tunnel method effectively maintains the original video quality.

The PSNR, SSIM, and MSE metrics show that streaming through MPT-GRE is better than streaming through a single path for high-quality video streaming. PSNR measures the quality of the video by comparing the original and transmitted images, with higher values indicating better quality. SSIM evaluates the structural similarity between the original and transmitted images, with values closer to 1 representing higher similarity. MSE calculates the average squared difference between the original and transmitted pixel values, with lower values indicating better quality. These metrics together indicate that MPT-GRE provides a more reliable and higher quality video streaming experience than a single path, reducing errors and maintaining the integrity and clarity of the video content.

TABLE II. PSNR COMPARISON BEFORE AND AFTER STREAMING AT 7000 KBPS BITRATE THROUGH SINGLE PATH AND MPT-GRE TUNNEL

Video Name	*PSNR before Streaming*	*PSNR (Single Path)*	*PSNR (Tunnel)*
BigBuckBunny	31.8745	29.6982	30.6772
BirdOfPrey	31.0678	27.4731	30.0677
CostaRica	29.4287	28.9875	29.3415
SlideEditing	60.9745	57.3846	58.8492
TallBuildings	30.3831	28.3691	30.0752
Transformer	39.6097	32.8483	39.6097

TABLE III. SSIM COMPARISON BEFORE AND AFTER STREAMING AT 7000 KBPS BITRATE THROUGH SINGLE PATH AND MPT-GRE TUNNEL

Videos Names	*SSIM before Streaming*	*SSIM (Single Path)*	*SSIM (Tunnel)*
BigBuckBunny	0.9566	0.9510	0.9557
BirdOfPrey	0.9099	0.8771	0.8999
CostaRica	0.8929	0.8570	0.8733
SlideEditing	0.9858	0.9796	0.9834
TallBuildings	0.9279	0.9110	0.9258
Transformer	0.8142	0.7967	0.8142

TABLE IV. MSE COMPARISON BEFORE AND AFTER STREAMING AT 7000 KBPS BITRATE THROUGH SINGLE PATH AND MPT-GRE TUNNEL

Videos Names	*MSE before Streaming*	*MSE (Single Path)*	*MSE (Tunnel)*
BigBuckBunny	184.5999	217.9941	184.5789
BirdOfPrey	207.6518	300.3752	210.6651
CostaRica	116.8239	136.3514	122.4405
SlideEditing	224.9919	322.9418	258.3786901
TallBuildings	76.9375	102.9581	96.0309
Transformer	323.4425	441.7730	323.4425

IX. CONCLUSION

In this paper, we have dealt with delivering video streams on multiple paths. We have focused on streaming video through the tunnel of the MPT-GRE multipath network layer solution; the throughput of the MPT-GRE tunnel is approximately equivalent with the sum of the throughput of the two paths. This characteristic prompted us to conduct a test on the channel aggregation capability of the MPT library, which offers a multipath solution for the network layer.

Our results show that the MPT-GRE multipath network is efficient and effective in real-time video streaming and receiving. Analyzing the results of these quality metrics proved that the throughput aggregation of the MPT-GRE tunnel can significantly improve video streaming quality in real-time, especially with high-quality videos.

Real-time video streaming through the single path leads to an apparent decrease in PSNR and SSIM values and an increase in MSE values, which indicates a reduction in video quality. When streaming through the MPT-GRE tunnel, the PSNR and SSIM values decrease or increase slightly, and in some cases, the PSNR, SSIM, and MSE values were the same as those of the original video before streaming. So, evaluating video streaming quality using PSNR, SSIM, and MSE metrics indicates that streaming through the MPT-GRE tunnel is better than streaming through the single path in maintaining higher quality in all our measurements.

One of our future objectives is to stream 4k or 8k videos through the MPT-GRE multipath network and then calculate their Quality of Experience (QoE).

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