

Video Streaming Over Vehicular Ad Hoc Networks: A review

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Abstract— The future holds great promise for vehicular networks to reach the same level of widespread use as smartphones have today. Future vehicles will link multiple sensors to advanced onboard processing systems, enabling them to connect with surrounding vehicles and roadside infrastructure through the necessary communication channels. The research community now focuses on video streaming in VANETs because it enables safety applications, traffic management, and entertainment services. The dynamic nature of vehicular environments makes it difficult to provide video streaming services with high quality, reliability, and low latency. The survey examines modern technological developments, current obstacles, advanced solutions, and unaddressed research problems in this field through a systematic analysis.

Keywords—Video streaming, Vehicular Ad-Hoc Networks (VANETs), research challenges, wireless networks

I. INTRODUCTION

Vehicular Ad Hoc Networks (VANETs) enable vehicles to communicate with each other (Vehicle-to-Vehicle, V2V) and with roadside infrastructure (Vehicle-to-Infrastructure, V2I) wirelessly without relying on fixed network support. With the rise of embedded cameras and connected cars, real-time video streaming in VANETs can enhance driver assistance, surveillance, and entertainment systems. Yet, supporting robust video delivery in VANETs is non-trivial. Rapidly changing connectivity network topologies, inconsistent wireless, bandwidth fluctuations, and stringent latency requirements challenge traditional streaming solutions. This paper reviews advancements and persisting hurdles in video streaming over VANETs [1]. Choosing the video source as a bottleneck in video transmission since the high mobility and dynamic topology of VANETs. Not only would the wrong provider cause excessive communications to repeatedly stop and start, but in the absence of any mechanism to reject invalid video pieces, precious bandwidth would be wasted also. To resolve the problem, a new video source decision scheme is proposed and called CDOV (cluster and dynamic overlay based video delivery over VANETs) [2]. In VANET, high-quality video streaming services try to offer safety and infotainment applications to the users. With the dynamic network topology and the rapid mobility of a moving vehicle, the video streaming service should achieve elastic and continuous vehicle information updates in order to playback interactive real-time views for nontrivial sceneries on roads [3]. Vehicular Ad-Hoc Networks (VANETs) have garnered significant attention from both industry stakeholders and government entities alike due to

their vital and critical applications in the realms of safety and traffic efficiency [4]. The sense of urgency for implementing such advanced systems is ever increasing as a response to the unprecedented rise in traffic congestion, alarming road accidents, and unacceptably high rates of fatalities on the roads. For the successful and effective deployment of numerous applications within VANETs, there are various challenges that need to be thoroughly addressed [5]. Given the critical nature of such traffic-related applications, coupled with the emergence of new and advanced smartphones that are capable of both observing the vehicular environment and processing video data in real time, the utilization of video data over VANETs has emerged as a topic of significant attention recently [6].

The implementation of such sophisticated systems will empower roadside infrastructures to effectively monitor traffic behavior and make more informed decisions to better control road traffic based on thorough analysis of real-time video data [7]. Within these systems, the dynamic multi-hop dissemination of video data from vehicles to a large number of additional vehicles operating under the highly dynamic and unpredictable environments characteristic of vehicular traffic presents a major challenge that must be carefully tackled [8].

In this context, numerous methodologies have been proposed that leverage the radio communication capabilities of vehicles to construct dissemination frameworks capable of ensuring reliable video delivery in highly dynamic VANET environments across diverse applications. While these approaches have sought to address several designs, challenges associated with vehicular video dissemination, they have not yet been examined through systematic and comprehensive study. Such an investigation is essential for researchers, engineers, and academics to obtain a holistic overview of the current state of the art, as well as to identify unresolved research gaps and open challenges in this domain [9-15].

II. RELATED WORK

Video streaming over Vehicular Ad Hoc Networks (VANETs) has garnered significant attention due to its potential applications in Intelligent Transportation Systems (ITS), including traffic safety, real-time surveillance, and infotainment services [1]. However, the unique characteristics of VANETs, such as high node mobility, intermittent connectivity, dynamic topology, reliability and low latency of video transmission are significantly impacted by heterogeneous wireless environments [3].

Several studies have focused on addressing these challenges. For instance, proposed a dynamic video source decision scheme called CDOV (Cluster and Dynamic Overlay-based Video Delivery over VANETs) to overcome the bottleneck caused by selecting an inefficient video source in highly mobile environments. Their approach improves the reliability and efficiency of video delivery by leveraging clustering techniques and overlay networks. The architecture of CDOV is illustrated in Fig. 1 where infrastructure units are positioned along the roadside. The system is composed of three types of nodes: RSUs/infrastructures, cluster heads, and cluster members, enabling both Vehicle-to-Vehicle (V2V) and Vehicle-to-Infrastructure (V2I) communications. As depicted in the figure, the top layer consists of cluster heads that oversee their respective cluster members. These cluster heads are capable of participating in both V2V and V2I communication modes.

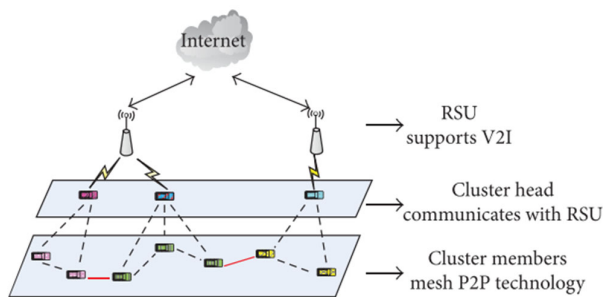


Fig. 1. Architecture of CDOV [2].

Proposed a low complexity and hardware friendly H.265/HEVC encoder specifically designed for vehicular environments. This encoder aims to reduce computational overhead while maintaining acceptable video quality under fluctuating network conditions. Quality of Service (QoS) and Quality of Experience (QoE) are critical aspects in video streaming over VANETs. Benmir et al. [18] reviewed existing QoE/QoS correlation models and highlighted the need for adaptive bitrate streaming (ABR) and error-resilient protocols to handle jitter, packet loss, and variable latency. When we get the emergency-related frames, we will use them for the next phase, securing all that data via Blockchain, as shown in Fig. 2. Recent studies such as Awais et al. [19] have explored deep learning-based approaches combined with blockchain technology to enhance security and optimize QoE in 5G-enabled VANETs.

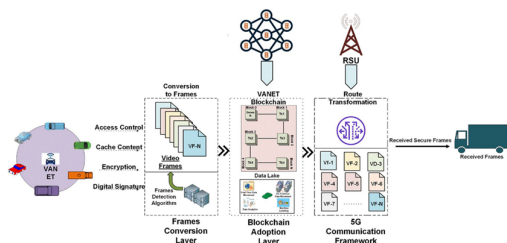


Fig. 2. Block Diagram of Proposed Model [19].

Routing and forwarding mechanisms have also been extensively studied. Lindeberg et al. [20] analyzed congestion control techniques for low-latency video streaming in mobile Ad Hoc networks, while Al-Maliki and AL-Asadi [21]

evaluated end-to-end delay in road-based routing protocols using snake optimization algorithms. Emerging technologies like edge computing, machine learning, and 5G have been integrated into VANET architectures to improve performance [22]. Surveyed vehicular edge computing frameworks that offload processing tasks to nearby nodes or roadside units (RSUs), reducing latency and improving real-time analytics [23]. Provided a detailed review of next-generation video streaming solutions for vehicular networks, emphasizing the role of AI-driven predictive models and multi-access edge computing (MEC) as shown in Fig.3 the architecture of vehicular networks.

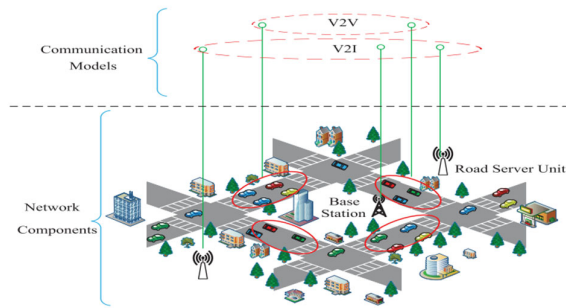


Fig.3. Architecture of Vehicular Networks [17]

Security remains a key concern, especially for safety-critical applications [68]. Outlined privacy and authentication challenges in VANETs, while Naveed et al. [67] proposed blockchain-based solutions to ensure data integrity and traceability in video dissemination. Despite these advancements, several open research issues persist, including seamless handover between heterogeneous networks, efficient resource allocation in sparse topologies, and robust security mechanisms for distributed video sharing.

III. TRANSMISSION IN VANETS

Vehicle networks are a highly mobile network scenario, consisting of a wide and rapidly varying distribution of nodes, which are vehicles using the same radio networking technology. The purpose of such networks is to provide Vehicle-to-Vehicle (V2V) and Vehicle-to-Infrastructure (V2I) wireless message dissemination, supporting various safety, mobility, and commercial applications [24]. These mobile Ad Hoc networks, distinguished by a relative mobility of 130km/h and urban conditions, introduce additional challenges over the standard mobile Ad Hoc networks, such as rapid changes in topology, density, and vehicular speed following Poisson distributions [22]. Development of new VANET protocols and solutions demands a thorough consideration of these specific characteristics, since technologies and solutions which perform well in a stationary or pedestrian environment are unlikely to scale to the unique challenges posed by critical vehicular environments [25].

A VANET is a communication network that is composed for a number of transmitting vehicles and a number of road stationary units with an aim to offer vehicles new intelligent applications. Such networks are expected to powerfully impact entertainment, comfort, traffic safety, and efficiency [16]. For instance, vehicles equipped with a wireless video sensor can share a video feed of a traffic incident in the highway or request

from their peers a video feed of a hazardous intersection. Multimedia communications and streaming videos might be very useful in VANETs for traffic management applications or for provision of entertainment and advertising services. The wide usage of video streaming services in vehicular networks for safety or efficiency purposes introduces a new challenge in video transmission and in video communication in VANETs. The latter represents a significant interest area in scientific research due to the wide usage of video streaming service [26]. Video streaming from vehicles creates new opportunities and application for vehicles to use real-time video for providing traffic management [23]. Also the vehicles could send a video feed of an hazardous intersection in order to warn cars approaching the intersection [27].

Video feed could also be an important source of information for traffic management. On the other hand, video streaming is a very challenging area of research in vehicular networks for several reasons. Abnormality in the network topology due to high speed of nodes and obstacles in a vehicular context like tunnels and highways increase the difficulty of streaming video [28].

Streaming video from moving vehicles in a real-time manner is very challenging in vehicular networks because video streaming takes a consistent number of packets from a consistent time period. As the extent of mobility in vehicular networks is higher, video frames could be received out of order, thus a video frame could not be received at all as it is discarded from the buffer of the source vehicle [29].

Recent Advances in Video Coding Techniques Real-time video transmission over vehicular Ad Hoc networks (VANETs) is critical for intelligent transportation systems (ITSs), improving the emergency responses' effectiveness for road safety applications. Currently, more and more mobile devices with in-car cameras are emerging, and the active video transmission from fixed-installed cameras is also in a large number [30]. It is shown that the taxi-based smart system can significantly improve the accuracy of traffic state prediction at the urban road network level, and road traffic accidents detected on the highway can be effectively reduced by warning vehicles approaching the incident [31].

An application-aware routing metric, considering different dissimilarity of the video contents and mobility patterns, as well as the prediction of bandwidth, is proposed to enhance the quality of experience (QoE) for scalable video streaming over VANETs. However, though extensive efforts have been made to study the issues of video streaming over VANETs, the performance of video codec to support the real-time video transmission over the VANETs is quite lacking. It is known that in real-time applications, the processing and power consumption of the video codec is crucial, as it should be possible on low-cost hardware and must avoid huge energy consumption.

The H.265/HEVC is designed to achieve better coding performance than its predecessor H.264/AVC [29]. Many recent works have been proposed to reduce the encoding complexity of the HEVC encoder. During the past few years, some fast algorithms of coding unit (CU) size decision and prediction unit (PU) mode decision for H.265/HEVC encoding have been proposed. Most of the proposed fast algorithms act in a picture-based or block-based manner [17].

Provided a fast-encoding complexity method based on the probabilistic graphical model, and the difference of the characteristics of the picture is explored offline. H. Fatemidokht et

al. [32] presented algorithms including CU early termination and CU early skip methods to reduce the redundant computing of inter-prediction in H.265/HEVC based on the CU analysis method. But all those methods cannot achieve a better trade-off between the encoding efficiency and the encoding complexity. To ensure a lower coding complexity and a better coding efficiency, three novel methods including early CU split, early CU termination, and search range adjustment to reduce the computation complexity for H.265/HEVC. The experimental result shows that the proposed algorithm can outperform the previous works with respect to both the speed and the RD performance. A low-complexity and hardware-friendly encoder is designed to allow the video transmission to automatically adapt to the VANETs environment.

IV. CHALLENGES IN VIDEO TRANSMISSION OVER VANETs

VANET network has allowed information exchange between vehicles. The current trend in the automotive industry is to enable vehicles and roads (navigation systems, integrated sensors, positioning transceivers, communication devices, etc.) to make the transport infrastructure more efficient and safer and to make passengers more accessible. These reasons have made VANET an attractive subject both in field of research and applications [18]. In this regard, routing plays an important role in determining which node (vehicle) will send the incoming video packets to selected destinations [16]. A framework for routing video packets that considers relative speed and distance between nodes is improved. The formulae for calculating the relative distance and speed of the chosen next hop are established [3]. The video packets are transmitted from different choices of sources into the destination node. The delay of the video packets is lessened, and the bandwidth usage is optimized by selected source nodes, as compared to the other schemes [33]. Video streaming abilities over VANETs are vital for new services. Nevertheless, providing reliable QoS control video streaming over this kind of network remains a challenging task due to high mobility, frequent vehicle disconnection, packet jitter, and end-to-end delay [16]. Video communication in VANETs encompasses various modes, including vehicle-to-vehicle (V2V), vehicle-to-infrastructure (V2I), and vehicle-to-everything (V2X) [35]. Each mode has unique challenges and solutions to enhance video streaming quality [36]. V2V communication focuses on enhancing video quality through routing protocols and cooperative communication [37]. V2I communication aims to improve real-time video streaming and address interference issues [38]. V2X communication integrates both V2V and V2I to enhance overall traffic safety and efficiency [39]. Video streaming in VANETs faces significant challenges, related to latency, reliability, and security due to the dynamic nature of vehicular networks [40]. High mobility and limited bandwidth complicate video streaming [41, 42]. Real-time applications require ultra-low latency to ensure safety [43, 44]. The need for high-quality video content for infotainment applications increases the complexity of resource allocation [45, 46]. However, few studies have been proposed on video streaming that consider the strict requirements of video in QoS terms in VANET networks. Therefore, there are some techniques for improving video streaming and key along with their challenges.

1. Adaptive Bitrate Streaming (ABR): The causes is dynamically adjusts video quality based on network conditions, the advantages is to enhances user experience

- and ensures efficient bandwidth usage, disadvantages is implementation complexity and potential latency issues [36].
2. Error Resilience Techniques: The causes are implements methods such as Forward Error Correction (FEC) to recover lost packets, the advantages is increases the reliability of video streams, and disadvantages is adds overhead in terms of bandwidth and processing [47].
 3. Content Delivery Networks (CDN): The causes to utilizes distributed servers to cache and deliver video content efficiently, the advantages to reduces latency and improves scalability, and disadvantage to dependency on third party services [7].
 4. Multi-Channel Transmission: The causes is to employs multiple channels for simultaneous video transmission, the advantages is to enhances throughput and reduces congestion and disadvantages to increased complexity in managing channels [48].
 5. Cross-Layer Optimization: The caused is integrates application and network layers for efficient resource usage, the advantages is maximizes performance across different layers and disadvantages is complex due to the requirement of deep integration [49].
 6. Machine Learning Approaches: The causes is utilizes ML algorithms to predict network conditions and optimize transmission, the advantages to adaptive with potential for improvement over time and disadvantages need training data and face overfitting challenges [8].
 7. Network Coding: The causes is combines data streams to reduce redundancy and improve throughput, the advantages is to enhances capacity and robustness and disadvantages is complexity in encoding and decoding process [35].
 8. Vehicular Edge Computing: The causes is offloads processing to nearby vehicle or edge servers for real-time analysis, the advantages is reduces latency and offloads network traffic and disadvantages is requires reliable connectivity between vehicles [22].
 9. Delay Tolerant Networking (DTN): The causes is implements techniques to handle intermittent connectivity in VANETs the advantages is suitable for highly dynamic environments and disadvantages is may introduce latency and requires buffer management [50].
 10. Quality of Service (QoS) Management: The causes is to ensures specific performance metrics for video streams, the advantages is guarantees user performance metric, and disadvantages is needs careful planning and resource allocation [51].

V. QUALITY OF SERVICE (QoS) METRICS AND QUALITY OF EXPERIENCE (QoE) CHALLENGES

Quality of service (QoS) is the measurement of performance level in a fine granularity quality of service (QoS) enabled network. On the client side, QoS parameters would typically include dropped data packets, end to end delay, jitter, and data rate [49]. Ensuring consistent QoS and QoE is challenging due to variable network conditions. Factors such as fluctuating signal strength, interference, and varying vehicle densities impact the delivery of video content. Adaptive streaming techniques and error-resilient protocols are essential to mitigate these issues [50]. Quality of Service (QoS) and Quality of Experience (QoE) are compared in depth in Table 1, along with their effects and related mitigating techniques.

TABLE I. DETAILS OF (QoS) AND (QoE)

Aspect	Technique Details			
	Causes	Impact on video streaming	Proposed solutions	Ref
Variable Latency	High vehicle mobility and frequent topology variations in VANETs lead to dynamic routing and fluctuating transmission delays.	Causes video buffering, playback delay, interruptions, long startup times, and poor interactivity in real-time video apps	Delay-aware routing protocols, buffer management, edge-based pre-fetching, and edge computing, predictive caching	[31]
Packet Loss	Frequent disconnections and interference in VANETs cause dropped packets	Leads to video frame loss, freezes, and quality degradation	Forward error correction (FEC), packet retransmission, redundancy coding	[52]
Jitter (Delay Variation)	Inconsistent packet arrival times due to congestion and routing changes	Jerky video or unsynchronized video playback, affects real-time applications like video conferencing	Jitter buffers, adaptive playback mechanisms, cross-layer optimization, timestamp reordering, adaptive buffer management	[53]
Throughput Variability	Network throughput changes due to topology, load, and signal quality	Sudden changes in video resolution or playback smoothness	Scalable Video Coding (SVC), Dynamic Adaptive Streaming over HTTP (DASH)	[54]
Heterogeneous Network Conditions	Differences in wireless tech (DSRC, 5G, WiFi) in hybrid VANETs	Uneven video performance across network segments	QoS-aware vertical handoff algorithms, context-aware media delivery	[55]
Resource Limitations	Limited bandwidth, buffer, and compute power in vehicles	Inability to support high bitrate videos or handle sudden demand spikes	Resource-aware scheduling, MEC (multi-access edge computing), fog computing	[56]
Lack of End-to-End Guarantees	VANETs often have no guarantee of end-to-end reliability	Unpredictable performance, especially for live and mission-critical video	SDN-based routing, QoS-aware multipath transport	[21]

VI. LATENCY AND JITTER SENSITIVITY

Real-time video applications, such as live traffic monitoring and emergency response, require low-latency communication. However, achieving low latency in VANETs is challenging due to variable network conditions and processing delays. Additionally, jitters, or the variation in packet arrival times, can disrupt the smooth playback of video streams [58]. The extent to which presents a comprehensive overview of latency and jitter sensitivity in VANET video streaming, highlighting their

impacts, mitigation strategies. Real-time Constraints: Applications such as surveillance and live navigation necessitate extremely low delays due to their real-time nature. To address these issues, implementing real-time communication protocols like RTP/RTCP and deadline-aware transmission in suggested [20]. Routing Path Instability: In dynamic networks, frequent re-routing and increased path setup delays can disrupt video sessions and create delay spikes. Fast re-routing techniques, multipath routing, and geo-routing protocols are recommended solutions to mitigate these issues[57].

1. Congestion-Induced Delay: High node density and bandwidth competition often lead to network congestion, which in turn causes latency spikes and results in out-of-sync audio and video. Utilizing congestion-aware MAC protocols and dynamic bandwidth allocation can alleviate such problems [58].

2. Limited Buffer Handling: In vehicular networks, small or poorly managed buffers may result in packet drops or excessive buffering, leading to playback issues. Adaptive buffer tuning, playback-aware control, and QoS buffer policies are key solutions proposed to handle these challenges effectively [59].

3. Cross-layer Incoordination: The lack of coordination among MAC, transport, and application layers can lead to misaligned delay management strategies and increased jitter. Cross-layer optimization frameworks are advised as a means to overcome these coordination challenges [60].

4. QoE Impact: Latency and jitter significantly affect the user perception of video quality, leading to dissatisfaction, stream abandonment, and low engagement levels. To improve Quality of Experience (QoE), approaches such as QoE-aware streaming, user feedback loops, and machine learning-based latency prediction are recommended [19].

VII. SECURITY AND PRIVACY CONCERNS

VANETs are susceptible to various security threats, including eavesdropping, spoofing, and denial-of-service attacks. Ensuring secure video transmission requires robust authentication, encryption, and trust management mechanisms. However, implementing these security measures must balance the need for low latency and computational efficiency [64-66]. Certainly. Below is a comprehensive Figure 4 that addresses security and privacy concerns in video streaming over Vehicular Ad Hoc Networks (VANETs). It covers the types of threats, their impacts on video streaming, proposed solutions.

VIII. RESOURCE ALLOCATION AND MANAGEMENT

Efficient allocation of network resources, such as bandwidth and buffer space, is critical for seamless video streaming. The dynamic nature of VANETs necessitates real-time resource management strategies that can adapt to changing network conditions and application requirements [16].

We can be comprehensive on Resource Allocation and Management in video streaming over VANETs, highlighting key challenges, their impact, possible mitigation strategies. Efficient allocation of network resources, such as bandwidth and buffer space, is critical for seamless video streaming. The dynamic nature of VANETs necessitates real-time resource management strategies that can adapt to changing network conditions and application requirements [16]. Certainly, we can comprehensive on Resource Allocation and Management in video streaming over VANETs, highlighting key challenges, their impact, possible mitigation strategies. Resource allocation and management are critical factors influencing the performance of video streaming in Vehicular Ad Hoc Networks (VANETs). Several aspects have been identified, each presenting unique

challenges and requiring tailored solutions. One of the most pressing issues is limited bandwidth resources, where shared wireless media must accommodate competing demands from multiple applications. This limitation impedes the ability to support high-quality video streams, particularly during periods of congestion. To address this, dynamic bandwidth allocation and priority-based access control have been proposed [69]. Dynamic spectrum access further complicates communication due to fluctuating channel conditions driven by mobility, interference, and topology changes. These fluctuations often result in intermittent connectivity and degraded performance. Cognitive radio networks and adaptive frequency hopping strategies have been suggested to mitigate these challenges [23]. Computation resource limitations also arise because onboard vehicular units possess limited processing capabilities for real-time video encoding and decoding. Such constraints introduce latency and reduce video quality. Solutions include edge computing, task offloading to Roadside Units (RSUs), or leveraging fog computing [16]. Adaptive video caching and distributed storage across RSUs are proposed strategies to alleviate these issues [41]. Excessive energy usage leads to rapid battery depletion and degraded system performance. Energy-aware scheduling and low-power video encoding algorithms have been recommended as potential solutions [70].

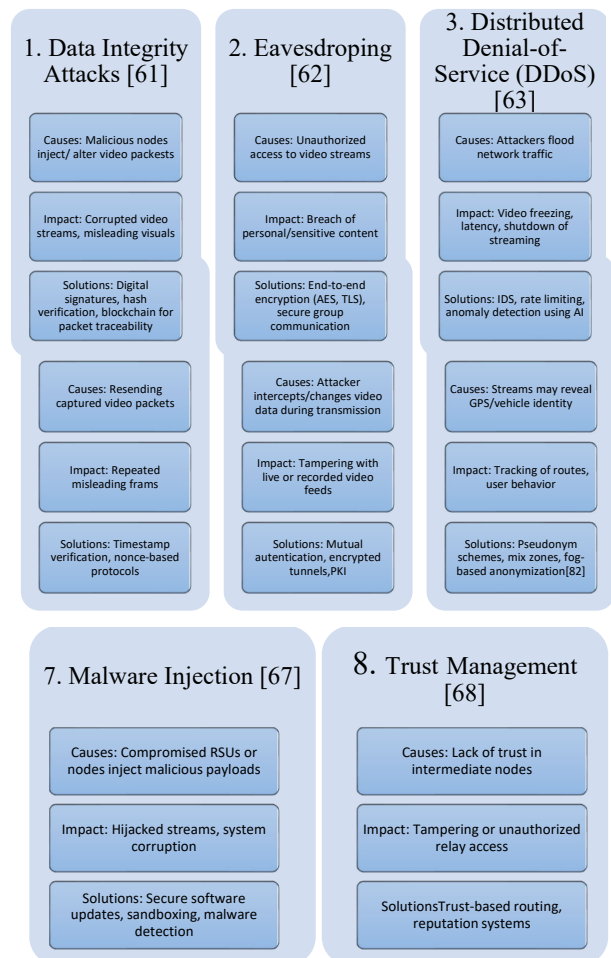


Fig. 4. Addresses security and privacy concerns in video streaming

In terms of Quality of Service (QoS) support, uneven allocation of resources can result in variability in video quality and user dissatisfaction. To overcome this, resource-aware QoS mechanisms, including weighted fair queuing, have been introduced [51]. Finally, AI and machine learning-based resource prediction provides promising solutions to the limitations of traditional methods, which often fail to adapt to rapid changes in demand. AI-driven strategies, such as predictive resource allocation using Deep Neural Networks (DNNs) and reinforcement learning, offer proactive and adaptive resource management [8].

On the other hand, the challenges of integrating emerging technologies (such as 5G, edge computing, AI/ML, blockchain, and IoT) in video streaming over VANETs, along with impacts, solutions. 5G Networks: Inconsistencies in 5G coverage, especially across highways and rural vehicular Ad Hoc networks (VANETs), lead to fluctuating bandwidth and unreliable ultra-low latency in real-time video. Proposed solutions include a hybrid 5G-DSRC architecture, network slicing, and mobility-aware handovers [72].

1. Edge Computing: Edge computing faces uneven deployment of servers and limited Road-Side Unit (RSU) capabilities, resulting in latency spikes when edge resources are unavailable. Dynamic task offloading and hierarchical fog-edge-vehicle architectures are recommended to this mitigate [28].

2. Artificial Intelligence (AI/ML): High training costs and the complexity of real-time inference in resource-constrained vehicles cause delays in adaptive streaming and low-quality decision-making. Lightweight machine learning models and federated learning across RSUs are suggested solutions [73].

3. Internet of Things (IoT): The integration of IoT sensor data with video streams can cause interference and traffic overload, leading to bandwidth congestion and increased packet loss. Priority-aware data scheduling and QoS-aware media fusion are viable solutions [74].

4. Blockchain: High computational and communication overhead in maintaining distributed ledgers delays the validation of video metadata and integrity. Lightweight blockchain solutions and RSU-based consensus protocols are recommended [75].

5. Software-Defined Networking (SDN): Centralized control structures in SDN may result in single-point failures or slow decision-making, impacting traffic management and stream rerouting. Distributed or hierarchical SDN controllers and failover-aware path control address these issues [76].

6. Network Function Virtualization (NFV): Virtualized video processing requires resource isolation, leading to resource contention and stream degradation. SLA-aware resource orchestration and containerization (e.g., Docker) are proposed as solutions.

7. Digital Twin Technology: Synchronizing real-world vehicle dynamics with digital twins in real-time is complex, resulting in delays in predictive analytics and context-aware streaming. Real-time sensor fusion and predictive synchronization models are effective solutions [35]. Addressing these challenges requires a multidisciplinary approach, combining advancements in wireless communication, network protocols, security frameworks, and intelligent resource management. Ongoing research and development efforts are crucial to enhance the reliability and efficiency of video streaming services in vehicular networks [5, 21, 26, 33-35].

IX. IRREGULAR CONNECTIVITY AND FREQUENT DISCONNECTIONS

The high mobility of vehicles in VANETs leads to frequent topology changes, resulting in intermittent connectivity and frequent disconnections. This instability poses significant challenges for maintaining continuous video streams, as packets may be lost or delayed, leading to degraded video quality. Strategies such as predictive routing and buffer management are being explored to mitigate these issues [1]. Below is a detailed figure (Fig. 5) describing the challenges related to irregular connectivity and frequent disconnections in video streaming over VANETs, including their impacts, potential solutions.

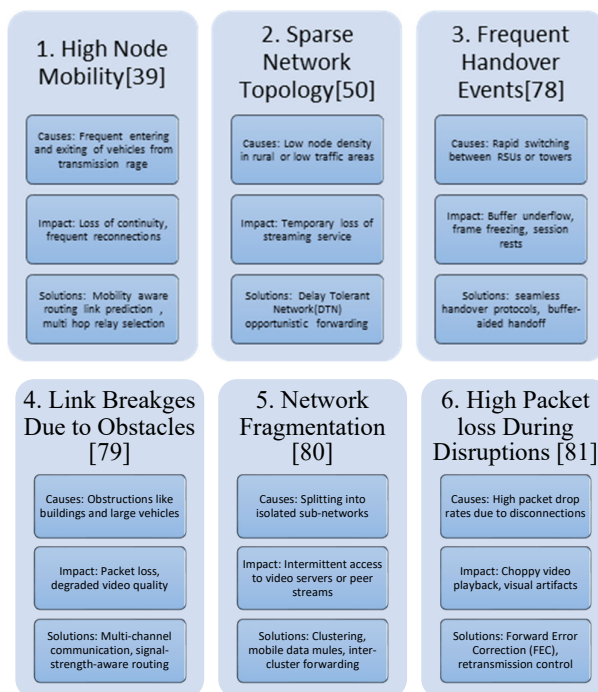


Fig. 5. Describing the challenges related to irregular connectivity

X. REVIEW METHODOLOGY

This study adopted a structured and systematic review methodology to ensure comprehensive coverage and academic rigor in analyzing the challenges and technological trends related to video streaming over VANETs. The methodology followed established systematic review guidelines and consisted of the following steps: Research design and objectives to identify, classify and evaluate the existing challenges, solutions and emerging technologies in VANET based video streaming systems. Specifically, the review was aimed at 1. Categorize the technical, performance and security challenges affecting video transmission in VANETs. 2. Examine the methodologies, protocols, and architecture proposed to mitigate these challenges. 3. Identify research gaps and future directions for real-time, QoE/QoS aware vehicular video communication. Literature search strategy was conducted across major scientific databases, including IEEE Xplore, ScienceDirect, SpringerLink, Scopus, ACM Digital Library and MDPI. Data extraction and coding: each selected study was analyzed using a structured data extraction form containing publication metadata (authors, year, venue). Network type and communication mode (V2V, V2I, V2X). Video codec/streaming method (H.264,

H.265/HEVC, DASH, SVC, etc.). Simulation tools (NS-3, SUMO, OMNeT++, Veins). Evaluated metrics: latency, jitter, packet loss, throughput, PSNR, MOS, and QoE. Reported challenges (e.g., mobility, congestion, interference, resource scarcity, security). Proposed mitigation techniques and corresponding outcomes.

XI. CONCLUSION

In conclusion, while significant strides have been made in enhancing video streaming capabilities in VANETs, the convergence of advanced networking paradigms and vehicular applications continues to present both opportunities and unresolved challenges. Future research should focus on holistic system design, incorporating user-centric QoE metrics, context-aware adaptation, and resilient security frameworks to realize the full potential of connected and autonomous vehicles. This is an important issue for future research should concentrate on developing AI driven, context aware streaming frameworks that dynamically adapt video quality to real time vehicle and network conditions. Integrating 6G enabled V2X communication, edge cloud collaboration, and federated learning will be essential to enhance scalability, security, and latency performance. Finally, lightweight blockchain mechanisms and energy-efficient encoding algorithms must be explored to ensure secure and sustainable video transmission in next generation intelligent transportation systems.

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