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Optimizing Emergency Video Delivery in Connected Vehicular Networks Using a Genetic Approach

*Sarra Benzerogue[a], Abdelatif Sahraoui[b], Makhlouf Derdour[c], Abdellah Kouzou[d]

[a]MISC Laboratory, University of Abdelhamid Mehri, Constantine 2, Constantine, Algeria
[b]LAMIS Laboratory, Echahid Cheikh Larbi Tebessi University, Tebessa 12000, Algeria
[c]LIAOA Laboratory, University of Larbi Ben M'hidi, Oum El Bouaghi, Algeria
[d]LAADI Laboratory, University of Djelfa, Djelfa, Algeria

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ABSTRACT

Real-time streaming of multimedia content in vehicular networks presents various challenges, including rapidly changing network topology, lack of global vision, and fluctuating traffic conditions. To address these challenges, this paper proposes a genetic algorithm-based method to optimize emergency video streaming in Vehicular Fog Computing (VFC) environments. This approach enables adapting video transmission during road incidents without requiring prior network knowledge, while optimizing resource utilization and reducing latency. Routing reliability and efficiency are ensured through TCP for intra-frame and UDP for inter-frame transmissions. Experimental results show that the proposed streaming mechanism significantly outperforms traditional GA-based routing, with notable improvements such as reduced End-to-End Delay (E2ED) and increased throughput. Additionally, gains were observed in path discovery time, load management and processing time.

تحسين نقل الفيديو في حالات الطوارئ عبر شبكات المركبات المتصلة باستخدام نهج قائم على الخوارزميات الجينية

*سارة بن زروق[a] و عبد اللطيف صحراوي[b] و مخلوف دردور[c] و عبد الله كوزو[d]

[a] مختبر MISC، جامعة عبد الحميد مهري، قسنطينة ، قسنطينة، الجزائر
[b] مختبر LAMIS، جامعة الشهيد الشيخ العربي التبسي، تبسة ، الجزائر
[c] مختبر LIAOA، جامعة العربي بن مهيدي، أم البواقي، الجزائر
[d] مختبر LAADI، جامعة الجلفة، الجلفة، الجزائر

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الملخص

تدفق الوسائط المتعددة في الوقت الحقيقي في شبكات المركبات يواجه العديد من التحديات، بما في ذلك التغير السريع في بنية الشبكة، وانعدام الرؤية الشاملة، والتقلبات في ظروف المرور. لمواجهة هذه التحديات، يقترح هذا البحث منهجية تعتمد على خوارزمية جينية لتحسين بث الفيديو في حالات الطوارئ ضمن بيئات الحوسبة الضبابية للمركبات (VFC). تتيح هذه المنهجية تكييف عملية بث الفيديو أثناء الحوادث المرورية دون الحاجة إلى معرفة مسبقة بالشبكة، مع تحسين استخدام الموارد وتقليل زمن التأخير. يتم ضمان موثوقية وكفاءة التوجيه من خلال استخدام بروتوكول TCP لنقل الأطر الداخلية وUDP للأطر الخارجية. أظهرت النتائج التجريبية أن آلية البث المقترحة تفوقت بشكل كبير على التوجيه التقليدي القائم على الخوارزميات الجينية، مع تحقيق تحسينات ملحوظة مثل تقليل زمن التأخير من البداية إلى النهاية (E2ED) وزيادة الإنتاجية. كما لوحظت مكاسب في وقت اكتشاف المسارات وإدارة الأحمال وتقليل زمن المعالجة.

1. Introduction

The increasing use of personal vehicles and the development of modern road infrastructure have led to a significant increase in road accidents. This alarming situation highlights the imperative to improve road safety [1]. In this context, vehicular network connectivity is emerging as a promising research field to enhance safety and traffic services through the dissemination of emergency notifications and warnings [2]–[4]. Nevertheless, current text-based communication systems in conventional networks face difficulties in effectively communicating critical information to passengers, emergency responds, and drivers, prompting them to take preventive measures such as reducing speed or changing of management [5].

In recent years, video transmission in vehicular networks has attracted

*Sarra Benzerogue:
E-mail addresses: sarra.benzerogue@univ-constantine2.dz, (A. Sahraoui) abdelatif.sahraoui@univ-tebessa.dz
, (M. Derdour) derdour.makhlouf@univ-oeb.dz, (A. Kouzou) kouzouabdellah@ieee.org
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increasing interest, becoming both a popular and crucial research area. The integration of video streaming is now essential for the services envisaged in these networks [6]–[8]. Indeed, the importance of video streaming is not limited to a simple fad; it contributes significantly to the improvement of the user experience in vehicles, in particular by facilitating the seamless sharing of navigation information [9].

To overcome these limitations, research in this field focuses on delivering richer and more relevant content to improve road safety. Among these advances, video streaming stands out as an essential service, providing accurate information on traffic conditions and enabling users as well as authorities, such as firefighters and ambulances, to intervene more effectively. Furthermore, their safety is becoming a priority. However, despite its potential benefits, reliable video content delivery in vehicular networks still faces challenges, such as bandwidth constraints, the dynamic nature of network topologies, and the lack of a global view of the network [11], which affects the Quality of Service (QoS) and Quality of Experience (QoE) for multimedia applications [12].

This study addresses the complex challenge of efficient video content delivery in vehicular networks. Traditional routing protocols struggle to adapt to a dynamic environment, resulting in packet loss, increased latency, and degraded video quality [13]. To address these issues, we propose a novel routing strategy optimized for video streaming in complex traffic scenarios. The solution takes into account network scalability by leveraging distributed computations performed by Fog servers located near incidents. By leveraging a genetic algorithm [14], our approach also integrates an advanced pheromone trail model and directional guidance mechanisms, thereby providing significant improvements for vehicle navigation in intelligent transportation systems.

The paper is structured as follows: Section 2 presents the motivations and contributions, emphasizing the need for QoS-driven adaptive routing and proposing a novel Vehicular Fog Computing (VFC) architecture. Section 3 reviews related work on Genetic Algorithm (GA)-based routing protocols and identifies limitations addressed by the proposed solution. Section 4 formulates the problem, defines the objective function, and integrates QoS and mobility metrics. Section 5 describes the proposed methodology, detailing the VFC architecture, adaptive multi-path routing using GA, and video coding with H.264/SVC. Section 6 evaluates the proposed mechanism through simulations, comparing its performance to traditional GA-based approaches using metrics like E2ED and throughput. Section 7 concludes the paper by summarizing findings and proposing future directions.

2. Motivations and Contributions

Real-time video routing with QoS in vehicular networks is particularly challenging due to the constantly changing network topology. Routing in this context involves not only finding a route from a source to a destination, but also ensuring that the route meets specific QoS requirements that are essential for reliable and timely delivery of emergency videos. To support QoS, the service can be characterized by a set of measurable and predefined service requirements, such as maximum delay, minimum bandwidth, and maximum packet loss rate. Therefore, selecting the best available path(s) is a crucial decision that directly impacts the reliability and timeliness of video delivery in emergency situations. Therefore, this paper proposes a novel video routing mechanism in a vehicular fog computing architecture, aiming to minimize latency and improve QoS, thereby enhancing the overall QoE.

To address the dynamic nature of vehicular networks and bandwidth limitations, we leverage the multi-objective capabilities of GA [15]. Our approach considers multiple measures to select stable paths, balance network load, and optimize bandwidth utilization, thereby reducing the risk of failure in the event of a transmission error. The integration of fog computing provides dynamic management of network resources, enabling real-time adjustments of video transmission. This not only optimizes bandwidth and reduces packet loss, but also improves network resilience through distributed processing and storage, mitigating the risk of single points of failure. Genetic algorithms are suited to high mobility contexts and dynamic environments. It is noted that GAs is able to find sufficiently feasible solutions [16]. The proposed mechanism uses the GA to generate exploratory "chromosomes" representing road segments, navigating in the network on predetermined iterations. Its main innovation lies in its adaptability, dynamically adjusting the number of genetic agents to efficiently adapt to network changes. This feature allows the discovery of optimal routes according to various network criteria.

It is crucial to emphasize the adequacy between the operations of GA and the communication scenarios of vehicular networks, due to their similarity in routing tasks. The proposed approach stands out for its adaptability and robustness for routing in vehicular networks, addressing their specific challenges while exploiting advanced algorithmic strategies. This allows to improve video streaming in emergency situations, ensuring efficient and reliable multimedia delivery, essential for optimal management of critical scenarios involving connected vehicles. The main contributions of this work are summarized as follows:

1. Propose a VFC architecture for adaptive video routing in case of emergency to preserve critical network parameters (latency, throughput, transmission time, etc.).

2. Implement a path selection control mechanism based on two discovery strategies (local and global).

3. Propose a video streaming mechanism with adaptive QoS, whose objective is to maintain stable video transmission quality.

These contributions form an integrated solution that optimizes the efficiency and reliability of video streaming in vehicular networks. Multimetric path selection, dual discovery strategies, and cross-layer collaboration with load balancing ensure optimal routing and fast and reliable video delivery, meeting the challenges of dynamic vehicular environments.

3. Related Work

This section explores innovative approaches to improve routing efficiency in vehicular environments. These approaches use GA mechanisms to address challenges such as selecting optimal routes based on QoS, deploying Road Side Units (RSUs) efficiently, and adapting routes to changing network conditions. Each approach aims to improve the way vehicles communicate and navigate, ensuring reliable data transmission and improving driver safety, as explained below:

Arbaoui et al. [17], seek to solve the challenges of efficient network resource management with network slicing technology, while optimizing the overall performance of vehicular applications. This approach is distinguished by its ability to adapt to vehicle mobility and rapid changes in network conditions, thus providing a robust solution to improve critical communications in vehicular networks. Saleet et al. [18], propose an intersection-based geographic routing protocol, named QoS Support in Delay Tolerant Vehicular Ad Hoc Networks. It aims to determine the optimal road intersection to route packets to the Internet gateway. The selection problem is formulated as a constrained optimization problem, considering QoS parameters such as connectivity probability, E2ED, and Hop Count (HC). To address this, the authors proposed a genetic algorithm (GA) to find an optimal or near-optimal route between vehicles and the Internet gateway. Wille et al. [19], propose a routing protocol, named G-NET, based on the Dynamic Source Routing (DSR) protocol enhanced with genetic algorithms. G-NET retains the reactive nature of DSR, while benefiting from the periodic route optimization via genetic algorithms. The protocol uses population evolution to improve routing quality, by reducing path latency and providing alternative routes in case of route failure. Cheng et al. [20], presented a genetic algorithm-based sparse coverage for an urban vehicular network, focusing on traffic monitoring and management through statistical analysis. The proposed approach aims to optimize RSU deployment based on traffic hotspots and geometric attributes of road segments. It works in three phases: clustering road network regions into hotspots, determining RSU deployment locations using buffer operations, and transforming the BSC problem into a maximization problem solvable by a genetic algorithm. Muniyandi et al. [21]., introduced the Genetic Optimized Location Aided Routing Protocol for VANET Based on Rectangular Estimation of Position. The proposed protocol employs a dynamic rectangular zone that adjusts with node mobility, filtering unreliable Global Positioning System (GPS) data to enhance accuracy. It optimizes route discovery by GA, specifically tuning the time-out variable for optimal performance. By reducing the search space, it minimizes route discovery messages, while the GA-driven selection process ensures robust route selection by rejecting weak GPS data, thereby improving route accuracy. Bello-Salau et al. [22], introduced the Improved Genetic Algorithm-based Route Optimization Technique (IGAROT), which presents a novel routing metric assessing communication link suitability between nodes. The IGAROT enhances routing efficiency in VANET by determining optimal routes for effectively communicating road anomalies between vehicles. The protocol replaces traditional GA selection methods with a K-Means clustering approach, initializing the population with randomly distributed vehicles in the VANET. This strategy forms initial solutions and generates subsequent generations by selecting non-overlapping chromosome clusters using elitism selection probabilities. IGAROT dynamically adjusts cluster sizes within the population to improve performance. By detecting road anomalies, the IGAROT protocol enhances driver navigation on abnormal roads, potentially reducing accidents. Notably, IGAROT currently lacks QoS metrics such as delay, Packet Delivery Ratio (PDR), and throughput in its evaluation. Future implementations should integrate IGAROT into real-time VANET communication systems to further validate its effectiveness. Zhang et al. [23], developed the Genetic Algorithm Based QoS Perception Routing Protocol for VANET, a location-based routing protocol aimed at ensuring QoS. Addressing link failures and unsuccessful packet transmissions between vehicles, GABR dynamically selects the next hop intersection and employs a carry-forward strategy for data packets. The proposed solution integrates destination localization by seeking a connected path from source to destination. Initially employing Intersection Based Routing (IBR), the protocol then sequentially applies a genetic algorithm to derive an optimal QoS path. Performance analysis highlights its capability for real-time information transmission and adaptability to topology changes, despite challenges in programming complexity and search speed of the genetic algorithm. Hadded et al. [24], introduce the Adaptive Weighted Clustering Protocol (AWCP), which employs the Non-dominated Sorting Genetic Algorithm version 2 (NSGA-II) for multi-objective optimization. AWCP aims to enhance network stability by optimizing stable cluster structures, data delivery rates, and reducing clustering overhead. Extensive simulations demonstrate that AWCP, optimized with NSGA-II, outperforms other techniques across various metrics. However, challenges such as scalability, computational overhead, and real-world deployment remain. In contrast, Sharma et al. The work in [25] uses the Adhoc On-Demand Distance Vector (AODV) protocol, a reactive method suitable for on-demand routing. While effective in route discovery, AODV may introduce delays in route rediscovery, posing challenges in dynamic VANET environments where rapid adaptation is crucial. The primary metric for path selection in AODV is hop count, which may not always ensure optimal routes for multimedia streaming. Alternatively, the authors in [26] develops a genetic algorithm-based multi-path routing system tailored for VANET video transmission. This system aims to enhance performance by selecting multiple paths based on latency and reliability metrics. Despite improvements in video transmission, it faces obstacles such as high computational demands and scalability issues, impacting its feasibility in larger networks.

4. Problem Statement and Objective Function

The architectural design plays a pivotal role in guaranteeing the successful dissemination of video content, particularly when accounting for QoS requirements. Nonetheless, a failure to align the structure with the intrinsic features of vehicular networks, characterized by high mobility and limited bandwidth, can result in a deterioration of overall performance of video dissemination within the network of vehicles. This, in turn, can adversely impact the stipulated QoS standards for video streaming, consequently influencing the QoE negatively.

To overcome the challenges associated with optimizing the network of a video streaming application within a vehicular network, we introduce an objective function integrated with genetic algorithms. This function is crafted to address multiple objectives simultaneously, encompassing both mobility and QoS parameters. When determining the most efficient routes for video streaming, the objective function considers the routing topology, nodes, interconnecting links, and routing information. The computation of this objective function involves an aggregate function that captures the overall cost associated with each path. This cost is calculated based on weighted criteria, taking into consideration QoS performance metrics and mobility metrics as represented in equation 1.

$$Min(F_{sd}) = min\left(\sum_{i=1}^{n} \quad \left(w_1 \cdot QoS - Metrics_{\ ij} + w_2 \cdot Mobility - Metrics_{\ ij}\right)\right) \tag{1}$$

Subject to:

- $Min(F_{sd})$ **:** is the objective function, aiming to optimize the video stream from the source vehicle (s) to the target emergency vehicle (d) by selecting the optimum path based on QoS performance metrics and mobility metrics.
- n: represents the number of vehicles or nodes in the network.
- i: represents the index of the source vehicle (ranging from 1 to n).
- j: represents the index of the destination vehicle (ranging from 1 to n).
- w_1: is the weight assigned to the QoS performance metrics, specifically, minimum (L_{ij}), between vehicle **i** and vehicle **j** respectively.
- w_2: is the weight assigned to mobility metrics between vehicle **i** and vehicle **j**. To which take the minimum Hop Count (HC_{ij}) and Distance (D_{ij})

5. Optimizing Emergency Video Stream Delivery Using Genetic Approach

This proposal outlines a Vehicular Fog Computing (VFC) architecture designed to enhance video streaming in vehicular networks by decentralizing data processing and storage to the network's edge, thereby reducing latency, minimizing bandwidth use, and improving QoS. It incorporates advanced routing algorithms tailored for video streaming in vehicular networks, using genetic and multi-path routing techniques to select optimal transmission paths, adapt to network changes, and ensure efficient and reliable video delivery. This integrated approach addresses the challenges of video streaming in vehicular environments, promising to boost the efficiency and reliability of traffic management systems and support the development of safer, smarter transportation solutions, as will explain in the follow:

5.1. VFC-Architecture based

This part introduces our proposed VFC architecture, designed to address the challenges of efficiently routing video streams, with a focus on real-time video traffic. The architectural blueprint prioritizes adaptability, efficient management of video transmissions, and the preservation of essential network metrics such as low latency and swift transmission times, which are crucial for scenarios involving road incidents or events.

Our VFC architecture aims to mitigate the computational load on relay nodes through a decentralized routing strategy, enhancing V2I connectivity with proactive measures. As illustrated in Fig.1, the integration of a fog computing layer with the vehicular network architecture facilitates adaptive video routing. This design minimizes the risks of connectivity disruptions and reduces the frequency of RSU changes, thereby ensuring a smoother video streaming experience.

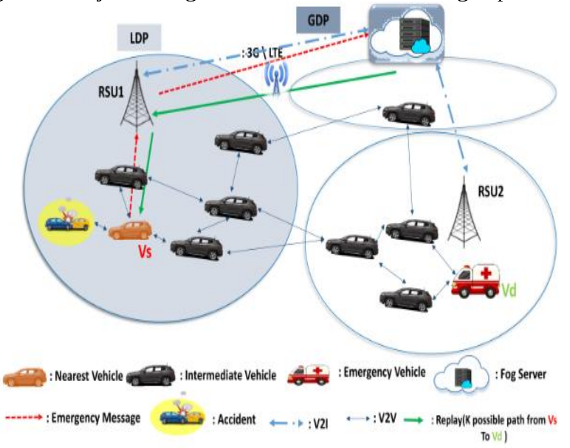

Fig. 1: VFC Architecture

Key Components of the Architecture:

- Vehicular Nodes: it consists of vehicles connected to edge computing infrastructure, particularly emergency vehicles responding to incidents like accidents. These vehicles act as event detectors using cameras and relay nodes for video transmission via V2V communication. This system enhances emergency responses by facilitating quicker detection and transmission of information, potentially saving lives and minimizing damage from road accidents.
- RSU: it acts as intermediate access points, providing connectivity to clusters of vehicles within their coverage area and facilitating V2I communication. This connectivity enables seamless information exchange and data collection, essential for maintaining network connectivity and supporting various vehicular applications.
- Fog Computing Infrastructure: fog computing optimizes streaming routing in vehicular networks by centralizing data processing near its source. This enhances streaming efficiency, especially during emergencies, by dynamically processing and routing data to the appropriate emergency vehicle. This approach supports adaptive information dissemination and improves the security and effectiveness of communications in rapidly changing situations.

5.2. Traffic Management

Several vehicular traffic applications are integrated into the proposed architecture, including:

- Network Traffic: All Vehicles periodically send beacon messages to notify the nearest RSU of their presence. These messages include information for identifying emergency vehicles (ID, Type, Location, Movement Direction, Neighbors' IDs). This data is forwarded to the fog server, while RSUs use it to estimate when vehicles leave their range and maintain a local cache of vehicle statuses. The RSU updates its cache upon receiving a beacon. To ensure current data, the RSU periodically checks vehicle presence by scheduling a timer that expires after **T**, calculated as:

$$T = T_r + T_p \quad (2)$$

where Tr is the time of the last received beacon and Tp is the expected interval between beacons. If the timer expires without a new beacon, the RSU removes the vehicle's record from its cache, ensuring efficient management.

- Vehicular Traffic Control: When a vehicle needs to transmit a video feed to an emergency vehicle, it sends an Emergency Message (EM) to the nearest RSU. The RSU initiates a Local Discovery Process (LDP) to identify suitable emergency vehicles. If no suitable vehicle is found locally, the RSU notifies the fog server to trigger a Global Discovery Process (GDP), coordinating a broader search for response vehicles. This strategy ensures high-quality video transmission and swift emergency response. When a suitable emergency vehicle is identified, the nearest RSU in the LDP or the fog server in the GDP sends a Replay-Packet (N, P). Here, N represents all interested vehicles, and P represents all possible paths from the source vehicle (V_s) to the destination vehicle (V_d). The set of potential paths in the vehicular network N, where Z represents the total number of nodes, is defined in Equation (3).

$$N = \{n_1, n_2, n_s, \dots, n_d, \dots, n_Z\} \quad (3)$$

Here, n_s is the source vehicle, and n_d is the destination vehicle. There are K possible paths connecting n_s and n_d, represented as:

$$P = \{p_1, p_2, \dots, p_K\} \quad (4)$$

where (P_q) represents the (q^{th}) path interconnecting the source and destination nodes. The suitability of these paths for video transmission may vary due to changes in the distance between nodes. Therefore, it is necessary to identify M multi-path options for reliable video transmission

- Mobility Management: As vehicles move between RSU communication ranges, a transfer notification is sent to the new RSU, including the source RSU's IP address and the sequence number of the last received video packet. The new RSU forwards this information to the source RSU, which then continues delivering the remaining video packets to the new RSU. This hierarchical approach ensures efficient selection of optimal QoS paths for video streaming, supporting effective emergency vehicle coordination.

5.3. Adaptive Multi-Path Routing Using Genetic Algorithm

The process of transmitting video files in vehicular networks involves two key tasks. Firstly, due to the large video volume, the files are converted into frames using the H.264/SVC encoding technique [27]. Secondly, optimal paths between the source and the appropriate destination are selected for lossless video transmission. The vehicular networks identify potential paths, and GA with a latency, HC and D-based fitness function is applied to choose the optimal paths. After this optimization, the actual video transmission takes place, ensuring efficient and lossless data transfer within the vehicular networks.

5.3.1. Video Coding

We incorporate the H.264/SVC video compression standard to enhance the transmission efficiency and optimize video quality. Utilizing the SVC extension of this standard, we enable the creation of video streams that maintain multiple qualities, accommodating diverse network capacities. This extension produces the following types of frames as output:

1) **Intra-frames (I-Frames or Key-frames):** These frames contain complete information and can be decoded independently. In our protocol, I-Frames play a crucial role in ensuring high video transmission reliability. By exclusively utilizing TCP for the transmission of Intra-frames along the primary communication path, we guarantee a consistent availability of vital video information. This approach significantly enhances the overall reliability and quality of the video stream.
2) **Inter-frames (P-Frames and B-frames):** Including P-Frames (Predictive Frames) and B-Frames (Bidirectional Frames), rely on decoded I-Frames or P-Frames for efficient compression. Although crucial for video com- pression, these frames may not be as pivotal in the context of real-time video transmission. Consequently, we employ UDP for their transmission.

5.3.2. Selecting M-Stable paths through GA

This section details our approach utilizing a GA for select M-Stable paths selection, which strategically identifies M optimal paths for the transmission of video streams. This method focuses on the efficient routing of video data from the source vehicle to the appropriate destination, ensuring enhanced reliability and quality of the stream.

1) **Solution encoding:** For selecting the optimal M paths from a total of K available paths. The solution is conceptualized within a [1×M] space, chosen from these K paths. This selection is represented as a set, $\{S_1, S_2, \dots\dots\dots, S_M\}$ where M signifies the number of optimal paths to be identified. The core objective of the optimization algorithm is to ascertain the most effective M paths among the K available, with a focus on ensuring secure and efficient video transmission.
2) **Fitness evaluation:** To enhance the optimization of video streaming in a VFC context, we have developed a tailored fitness function. This function is crucial for selecting multiple paths and takes into account the dynamic nature of vehicular networks, which includes considerations for Latency (L), Hop Count (HC), and a novel Distance (D) metric. The fitness function is formulated as follows:

$$F(p) = \alpha \cdot L + \beta \cdot HC + \gamma \cdot D \quad (5)$$

where F (p) represents the fitness of the path p, with α, β, and γ denoting the weights assigned to latency, hop count, and delay, respectively. This approach facilitates the identification of the most efficient and reliable paths for video transmission, ensuring optimal performance in the dynamic environment of VFCs.

3) **Selection, crossover, and mutation:** The GA utilizes a selection process to choose the best solutions for crossover, aiming to generate a new generation of paths that inherit the advantageous traits of their predecessors. Through strategic crossover and mutation operations, the algorithm fosters the emergence of paths with enhanced fitness scores, thereby

optimizing the route selection process for video streaming in vehicular networks.

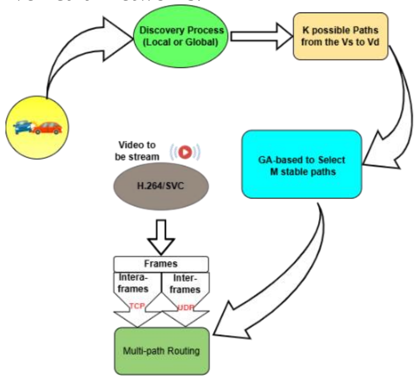

Fig.2: Coding and Transmit the Video

The employment of GA for the selection of optimal paths in vehicular networks introduces a robust and efficient mechanism for video streaming, ensuring high-quality transmission by adapting to the dynamic conditions inherent in such networks.

6. Results and Discussion

This section reviews the performance of the proposed protocol in a simulated vehicular network, focusing on video streaming. It compares results with a GA-based approach to show improvements in delay and throughput.

6.1. Simulation Tools Parameters

This section evaluates the effectiveness of the proposed protocol through various experiments in an OMNET++ [28] simulation environment. The study focuses on a video streaming scenario within a simulated VFC environment. The aim is to assess the protocol's ability to handle real-time video transmission during road events, aiming to minimize interruptions and improve QoS and QoE. Additionally, we compare the QoS performance of the proposed mechanism in terms of E2ED and throughput with the GA original based approach. Table 1 summarizes the simulation parameters, including the simulation area, vehicle count, MAC protocol, and communication ranges, chosen to create a realistic environment for evaluating the protocol's performance.

Table 1: Simulation Parameters.

Parameters	Values
Area of simulation	1200 · 1200m2
Number of vehicles	50, 100
MAC protocol	802.11p
Vehicle communication range	500 m
RSU communication range	700 m

6.2. Comparative Performance Metrics

The Table 2 presents a comparative analysis of different approaches for routing in vehicular networks, focusing on key performance metrics and strategies:

Table 2: Comparative Performance Analysis of Ga-Based Original Protocol and Proposed Mechanism

Approaches	Performance metrics			
	50 Nodes		100 Nodes	
	E2ED (s)	Th	E2ED (s)	Th
GA-based Original	6.928	89.886	8.822	87.792
The proposed mechanism	5.5	91	7.5	89

Where:

• K-path Calculation: The proposed approach computes paths via RSUs or FSs. This allows for more stable and reliable routing paths compared to V2V communication, which is more sensitive to frequent topology changes.

• Metric Focus: The inclusion of multiple metrics (latency, hop count, and distance) by our mechanism allows for a more comprehensive optimization, potentially leading to better performance in terms of speed and reliability.

• Path Strategy: The multi-path optimization strategy is likely to enhance the robustness of data delivery, especially critical for emergency video streaming.

• Architecture: The hierarchical VFC architecture supports improved scalability and efficiency by offloading processing tasks to intermediate nodes (RSUs and FS), reducing the burden on individual vehicles and the core network.

• Transport Protocol: By supporting both TCP and UDP, our mechanism provides flexibility in handling different types of data traffic, ensuring that emergency video streams can be delivered reliably (TCP) or timely (UDP), depending on the frame type. The performance of the proposed mechanism routing scheme is evaluated based on key metrics, including End-to-End Delay and throughput: • E2ED: This metric refers to the total time consumed by a video stream packet to travel from the source to the destination through the optimal multi-path.

• Throughput (Th): Throughput measures the total video stream packets received by the destination node relative to the total video packets transmitted by the source node.

Table 3 summarizes the comparative performance of the proposed mechanism routing algorithm against the GA-based original routing scheme in terms of E2ED and throughput for different node configurations.

7. Conclusion and Perspectives

This paper introduces an optimized emergency video stream delivery system in connected vehicular networks using a genetic algorithm approach. The proposed work enhances video transmission by developing a stable multi-path routing protocol based on multi-metric (QoS and mobility metrics). To identify the k possible paths between the source and destination, the system utilizes LDP and GDP for large-scale path discovery. The GA is then applied at the vehicle source to select the optimal paths for multi-path routing in the vehicular networks. The video to be transmitted is converted into frames by using H.264/SVC encoding approach. These frame streams travel through the optimal multi-path routes, utilizing TCP for key-frame transmission to ensure reliability and UDP for inter-frame transmission to ensure real-time delivery. The simulation results of the proposed GA-based multipath routing algorithm are compared with the adaptive multipath scheme and evaluated based on E2ED and throughput. The proposed scheme achieved an E2ED of 5.5 seconds and a throughput of 90. Future work can introduce hybrid optimization algorithms to further increase throughput. In future work, we will consider additional QoS metrics, such as jitter and path discovery time, alongside QoE evaluation metrics like PSNR (Peak Signal-to-Noise Ratio) and MOS (Mean Opinion Score).

Table 3: Comparison of Approaches.

Approach	K-path Calculation	Metric Focus	Path Strategy	Architecture	Transport Protocol
GA-based Original	V2V	Distance	Multi-path	Traditional Vehicular Networks	UDP
Proposed Mechanism	Nearest RSU or Fog Server (FS)	Latency, Hop Count, Distance	Stable Multipath	Hierarchical VFC	TCP and UDP

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