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Review Article

Optimizing QoS Provisioning in Vehicular Ad-Hoc Networks: A Comparative Study

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A B S T R A C T

Vehicular Ad-Hoc Networks (VANETs) play a crucial role in enabling intelligent transportation systems (ITS) by providing real-time communication between vehicles and infrastructure. Quality of Service (QoS) provisioning is a critical challenge in VANETs, given their dynamic nature, high mobility, and varying communication conditions. This article provides a comparative study of various QoS optimization techniques in VANETs, focusing on their performance, scalability, and efficiency in meeting the diverse requirements of vehicular communications. The study evaluates existing QoS models, protocols, and strategies, identifying the strengths and weaknesses of each approach and offering insights into their practical applications.

Keywords: Vehicular Ad-Hoc Networks (VANETs), Quality of Service (QoS), Routing Protocols, Resource Allocation, Vehicular Cloud Computing

Introduction

Vehicular Ad-Hoc Networks (VANETs) are a specific subset of Mobile Ad-Hoc Networks (MANETs), designed to enable communication among vehicles (V2V), and between vehicles and roadside infrastructure (V2I). VANETs are an essential component of Intelligent Transportation Systems (ITS), which aim to enhance road safety, improve traffic flow, and provide various other services, such as infotainment, navigation, and autonomous driving assistance. The network facilitates critical real-time applications, including collision avoidance, emergency alerts, and traffic management, which rely on constant, high-speed data exchange between vehicles and infrastructure nodes.[1]

VANETs operate in highly dynamic environments where vehicles are constantly moving at varying speeds, and communication is subject to frequent topological changes. This high mobility, along with other challenges such as limited bandwidth, intermittent connectivity, and signal attenuation due to physical obstacles, makes the provisioning of Quality of Service (QoS) a complex task. QoS in VANETs refers to the network's ability to consistently deliver a certain level of performance for various applications, which often have diverse and strict requirements in terms of latency, bandwidth, reliability, and throughput.

Ensuring reliable QoS in VANETs is challenging due to the following factors:

- **High Mobility and Dynamic Topology:** As vehicles travel at high speeds and change routes frequently, the network topology can change rapidly, leading to intermittent or broken communication links. This mobility complicates the establishment of stable communication paths required for QoS-sensitive applications.
- **Limited Bandwidth:** The available spectrum for communication in VANETs is often shared with other wireless technologies, which results in bandwidth limitations. In dense urban environments, this can further exacerbate network congestion and reduce the effectiveness of real-time services.

- **Propagation and Interference:** Signal quality in VANETs can be affected by environmental factors such as urban canyons, weather conditions, and interference from other wireless devices. These issues can result in data loss or delays, undermining the network's ability to meet QoS requirements.

For these reasons, maintaining QoS in VANETs involves a delicate balancing act between various performance metrics, including packet loss, delay, jitter, throughput, and fairness. Different vehicular applications have different QoS requirements: safety-critical applications, such as collision avoidance and emergency alert systems, require ultra-low latency and high reliability, while infotainment services may prioritize higher throughput and less stringent delay constraints.[2]

Given the challenging nature of QoS provisioning in VANETs, various strategies have been proposed to optimize network performance under dynamic conditions. These strategies include innovations in routing protocols, resource management techniques, traffic prioritization, and cross-layer optimization. However, each of these approaches comes with its own set of strengths and weaknesses. For example, traditional routing protocols may not effectively handle the highly dynamic topologies of VANETs, while more advanced techniques, such as QoS-aware routing and cross-layer optimization, can introduce additional overhead and complexity.[3]

This article delves into these different QoS provisioning strategies in VANETs, providing a comprehensive review of their effectiveness in real-world scenarios. By evaluating the performance of existing models and protocols under various conditions, this study aims to highlight the most promising approaches for ensuring reliable and efficient communication in VANETs. The article also discusses the emerging trends in VANET research, such as the integration of machine learning and vehicular cloud computing, which hold significant potential for further enhancing QoS in these networks.

Challenges in QoS Provisioning in VANETs

- **High Mobility:** One of the most defining characteristics of Vehicular Ad-Hoc Networks (VANETs) is the high mobility of vehicles. Vehicles in a VANET move at varying speeds, ranging from slow-moving urban traffic to fast-moving vehicles on highways. This leads to frequent changes in the network topology, as the relative positions of vehicles and infrastructure nodes constantly shift. As a result, communication links between vehicles, and between vehicles and roadside units, can be established and broken in quick succession. Such rapid changes in topology lead to frequent link failures, packet loss, and a dynamic communication environment, all of which make it difficult to maintain stable connections that are crucial for QoS-sensitive applications. For example, applications like safety warnings (e.g., collision avoidance or emergency alerts) and real-time traffic management depend on continuous communication, which becomes a challenge in high-speed, constantly changing networks. High mobility also complicates routing, as traditional routing protocols that depend on stable network structures struggle to maintain the desired performance metrics in such dynamic environments.[4]
- **Bandwidth Constraints:** Bandwidth is a critical resource in VANETs, and its efficient management is key to ensuring QoS, especially in scenarios where multiple vehicles are competing for limited resources. VANETs typically operate in shared spectrum environments, where the available bandwidth is shared among all vehicles and infrastructure nodes. The limited bandwidth becomes even more problematic in high-density traffic areas, such as urban environments, where a large number of vehicles are trying to communicate simultaneously. This congestion can result in network bottlenecks, increased latency, and reduced throughput, especially for bandwidth-intensive applications such as infotainment or video streaming. In contrast, safety-critical applications (e.g., accident avoidance, collision detection) require guaranteed bandwidth with low latency to function properly. This creates a significant challenge for VANET designers, as they must develop efficient bandwidth allocation techniques that prioritize time-sensitive traffic without overwhelming the network. Furthermore, interference from other wireless devices and environmental factors like weather conditions or signal obstructions can further reduce available bandwidth, compounding the problem of bandwidth scarcity.[5]
- **Dynamic Topology:** The topology of VANETs is inherently dynamic, due to the continuous movement of vehicles. As vehicles enter and exit communication range, and as they change lanes or travel along different routes, the network topology shifts rapidly. This dynamic nature complicates the implementation of traditional QoS mechanisms that are often designed for more stable and predictable networks. Conventional protocols typically assume relatively stable communication paths and rely on a fixed network structure, which does not hold in the highly dynamic and transient topology of VANETs. In addition, the mobility of vehicles can cause route disruptions, leading to increased packet loss or delivery delays, which directly affect QoS. As the topology changes, the challenge is to ensure that the QoS parameters (such as delay, jitter, and bandwidth) remain within acceptable thresholds, even when the

network's structure is constantly changing. Adaptive mechanisms that can reconfigure routing paths in real-time, based on the changing topology, are essential to maintaining QoS in such environments.[6]

- **Latency and Delay Tolerance:** Many of the applications in VANETs, particularly those related to safety, are extremely sensitive to latency and require real-time communication. For example, in collision avoidance systems, even a millisecond of delay can be the difference between an accident and a safe maneuver. Emergency alert systems also require ultra-low latency to ensure that crucial information is delivered to drivers without delay. In contrast, non-safety applications such as infotainment or traffic updates may tolerate some delay. Traditional QoS models, which are designed for more stable networks, may not be suitable for the stringent low-latency requirements of time-critical applications in VANETs. High mobility, bandwidth constraints, and dynamic topologies contribute to increased latency, making it challenging to meet the real-time requirements of vehicular communication. Moreover, the varying delay tolerance of different types of applications adds another layer of complexity. Ensuring that safety-critical communications are delivered with minimal latency, while non-essential traffic can tolerate some delay, requires effective traffic prioritization and resource allocation mechanisms, which must be able to respond dynamically to the ever-changing conditions of VANETs.
- **Interference and Signal Propagation Issues:** VANETs operate in highly variable environments where interference and signal propagation issues are common. Factors such as the physical layout of the environment, including urban canyons, tunnels, and mountainous terrain, can obstruct or degrade signal transmission. Moreover, weather conditions, such as rain, fog, or snow, can negatively impact signal quality, leading to higher error rates and unreliable communication. As VANETs depend heavily on wireless communication for vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) exchanges, signal degradation can result in significant delays, loss of packets, or even the inability to establish communication links. This issue becomes even more pronounced when multiple vehicles in close proximity attempt to transmit data simultaneously, leading to interference and reduced network capacity. Effective interference mitigation and signal propagation models are needed to address these challenges and ensure that communication in VANETs remains robust and reliable, even in challenging environments.[7]
- **Scalability and Network Density:** The scalability of VANETs is another critical challenge. As the number of vehicles in the network increases, the potential for congestion and interference also grows. In densely populated urban areas, the volume of vehicles may lead to network congestion, with vehicles competing for the same communication resources. Traditional routing protocols and QoS mechanisms often struggle to scale efficiently with the increasing number of vehicles, leading to performance degradation. The ability of the network to handle a large number of vehicles while maintaining optimal QoS parameters, such as low latency, high throughput, and minimal packet loss, is a key concern. Furthermore, as the density of vehicles fluctuates in different areas (e.g., rural vs. urban environments), VANETs must be able to adapt dynamically to these changes in traffic patterns, ensuring that the network remains scalable and can meet the QoS needs of all users.
- **Security and Privacy:** Security and privacy concerns also play a significant role in QoS provisioning for VANETs. As these networks facilitate communication between vehicles and infrastructure, they are vulnerable to various security threats, including unauthorized data access, tampering with messages, and denial-of-service attacks. Security mechanisms designed to protect the integrity of data exchanges can introduce additional overhead, potentially affecting network performance and QoS. Additionally, privacy concerns related to vehicle tracking and the sharing of location data must be addressed without compromising the QoS requirements of applications. Ensuring that security and privacy mechanisms do not interfere with the timely delivery of safety-critical data while maintaining the privacy of users is a complex challenge that requires careful balancing.

These diverse challenges highlight the need for innovative solutions to effectively provision QoS in VANETs. Addressing these challenges requires a multifaceted approach that incorporates adaptive protocols, dynamic resource allocation, intelligent traffic management, and advanced interference mitigation techniques. By overcoming these challenges, VANETs can unlock their full potential to support the wide range of applications that are critical for the future of intelligent transportation systems.

QoS Provisioning Strategies in VANETs

Various approaches have been proposed to optimize QoS in VANETs. These approaches can be broadly categorized into the following:

Routing Protocols

Routing protocols are at the heart of any Vehicular Ad-Hoc Network (VANET), as they enable the establishment and maintenance of communication paths between vehicles. Given the highly dynamic nature of VANETs, the choice of an appropriate routing protocol is crucial for optimizing Quality of Service (QoS). The routing protocol directly influences various QoS parameters, including latency, packet loss, throughput, and overall network efficiency. In VANETs, where vehicles are constantly moving at varying speeds and communication links are subject to frequent disruptions, selecting a protocol that can handle these challenges effectively is essential. Here, we explore several key routing strategies employed in VANETs, along with their impact on QoS performance:

Geographic Routing

Geographic routing protocols rely on the location information of vehicles to make forwarding decisions, thus simplifying the routing process. In these protocols, vehicles forward packets based on their own position and the position of the destination vehicle. One of the most well-known geographic routing techniques is Greedy Forwarding, where each vehicle forwards packets to the neighbor that is closest to the destination. This approach has the advantage of reduced delay since it directly uses the geographical proximity of vehicles to select forwarding paths, without requiring the maintenance of extensive route tables or complex routing metrics.[8]

However, geographic routing faces significant challenges in certain scenarios. A well-known issue is the occurrence of "local minima," where a vehicle may not have any neighbors closer to the destination than itself, effectively trapping the packet in a local region. This can lead to packet loss or delay, especially in areas with low vehicle density or in congested environments where vehicles are not aligned along optimal forwarding paths. While geographic routing can reduce communication overhead, it may not always guarantee reliable QoS, particularly in urban environments with dense traffic or where vehicles are spread out in a non-linear manner. Additionally, geographic routing does not take into account the quality of the communication link, which can result in unreliable transmissions under certain conditions (e.g., signal interference or propagation issues).

Position-Based Routing (PBR)

Position-Based Routing (PBR) is an enhancement over basic geographic routing protocols. By utilizing the position information from GPS systems, Position-Based Routing protocols, such as Greedy Perimeter Stateless Routing (GPSR), help maintain more stable routes. In GPSR, vehicles use GPS data to forward packets in the direction that is closest to the destination, similar to greedy forwarding, but with additional mechanisms to handle situations where geographic routing may fail (such as when a vehicle is in a local minimum).

PBR protocols generally offer better scalability and adaptability in dynamic environments due to their ability to make routing decisions based on real-time location updates. These protocols are especially effective in scenarios where vehicles move at high speeds, as the routing decisions are always based on current vehicle positions. However, the challenge of handling high mobility persists, especially in densely populated areas where the vehicles' relative positions are constantly changing, and network topology is highly volatile. The routing protocol must adapt quickly to ensure low latency, minimize packet loss, and maintain efficient throughput. Moreover, while PBR protocols benefit from reduced overhead due to the lack of centralized route management, they may still struggle in areas with sparse vehicle density or where there is insufficient position information, leading to inefficiencies in route discovery and data forwarding.[9]

Cluster-Based Routing

Cluster-based routing approaches aim to improve the efficiency and scalability of VANETs by dividing the network into smaller, manageable clusters. In Cluster-Based Routing, vehicles within a cluster communicate directly with each other, while a Cluster Head is responsible for managing inter-cluster communication. This approach reduces the overhead associated with route maintenance by localizing routing decisions within clusters. Protocols such as Hierarchical Clustering Routing (HCR) leverage this method to enhance QoS by reducing the number of routing entries that need to be updated and by improving scalability as the network grows.

One of the key benefits of cluster-based routing is that it enables better network management by limiting the scope of communication to smaller areas, which reduces the risk of congestion and packet collisions. Cluster heads can also implement QoS strategies, such as prioritizing certain types of traffic or controlling the flow of data within and between clusters, thus optimizing overall network performance. This centralized management within clusters can improve the efficiency of data delivery, reduce delay, and ensure reliable communication for time-sensitive applications like safety messages.[10]

However, the challenge lies in maintaining the stability of clusters in highly mobile networks. As vehicles move in and out of clusters, frequent changes in cluster membership can occur, potentially disrupting communication and reducing the stability of the routing process. Moreover, the task of selecting a cluster head must consider factors such as vehicle mobility, available resources, and network conditions, adding complexity to the protocol. If the cluster head changes too frequently, or if the head does not have sufficient resources to manage the cluster efficiently, it may degrade the QoS of the network.

Hybrid Routing Protocols

To address the limitations of pure geographic, position-based, or cluster-based approaches, Hybrid Routing

Protocols combine the strengths of different routing strategies to optimize QoS. For instance, some protocols combine the stability and scalability of cluster-based approaches with the efficiency of position-based routing. These hybrid protocols can dynamically select the most suitable routing strategy based on the current network conditions, vehicle density, and application requirements. By adapting to the environment, hybrid protocols can ensure better QoS, particularly in heterogeneous networks with varying traffic and mobility patterns.[11]

Hybrid approaches can also mitigate the weaknesses of individual strategies, such as the local minimum problem in geographic routing or the instability of clusters in highly mobile environments. These protocols dynamically switch between routing techniques based on factors like network load, mobility, and the criticality of the communication (e.g., whether the data is safety-critical or not). The ability to adapt in real-time provides a promising solution to the challenges posed by the dynamic nature of VANETs, but it also introduces additional complexity in terms of protocol design and real-time decision-making.[12]

The choice of routing protocol is a key factor in optimizing QoS in VANETs, and each approach comes with its own advantages and challenges. Geographic routing is efficient and simple, but struggles with issues like local minima and congestion. Position-based routing offers better scalability and adaptability but requires high mobility and sufficient position data to function effectively. Cluster-based routing helps reduce overhead and improve scalability but faces challenges in maintaining cluster stability. Hybrid routing protocols aim to leverage the strengths of multiple techniques, providing a more adaptable solution but at the cost of increased protocol complexity.

To achieve optimal QoS in VANETs, it is essential to select or design routing protocols that can dynamically adapt to the varying network conditions, prioritizing traffic based on application needs, and ensuring that latency, packet loss, and throughput remain within acceptable levels. As VANETs continue to evolve, further research is needed to improve these protocols, particularly in areas such as resource management, congestion control, and the integration of emerging technologies like machine learning and cloud computing.[13]

Resource Allocation

In Vehicular Ad-Hoc Networks (VANETs), optimizing resource allocation is critical to meet the diverse demands of various vehicular communication applications. Given the limited resources (e.g., bandwidth, processing power, storage) in these networks, it is essential to ensure efficient utilization to provide Quality of Service (QoS) for time-sensitive applications like safety warnings, traffic management, and autonomous driving. Resource allocation strategies are designed to optimize network performance, minimize congestion, and ensure that critical data can be transmitted reliably and with low latency. Effective resource management requires the coordination of multiple factors, such as bandwidth availability, power consumption, network topology, and the quality of communication links. Below, we explore key techniques for resource allocation in VANETs:

Channel Assignment Algorithms

Channel assignment is one of the most important aspects of resource management in VANETs. With multiple vehicles communicating over shared radio frequencies, interference and congestion can significantly degrade network performance. To mitigate these issues, channel assignment algorithms play a vital role in ensuring that vehicles are assigned appropriate communication channels based on traffic demands and environmental conditions.[14] One common technique is Dynamic Spectrum Access (DSA), which allows vehicles to dynamically select underutilized spectrum bands for communication. DSA enables efficient use of the available frequency spectrum by allowing vehicles to access channels that are not currently being used by others. This reduces interference, increases available bandwidth, and ensures that critical applications have sufficient resources for data transmission. DSA systems are designed to adapt in real-time to changing network conditions, making them ideal for the dynamic nature of VANETs.

Cognitive Radio (CR) networks are another promising solution for channel assignment in VANETs. Cognitive radios are capable of sensing their environment to identify unused spectrum and can automatically switch to the best available channel based on the network's traffic requirements. This not only improves bandwidth utilization but also ensures that vehicles can avoid interference from other communication systems (e.g., Wi-Fi, cellular networks), which is particularly important in urban environments where signal congestion is common. The use of CR networks in VANETs can lead to more efficient spectrum management, reduce congestion, and improve the overall QoS for both safety-critical and non-critical applications.[15] However, the deployment of DSA and CR in VANETs comes with challenges, such as the need for fast spectrum sensing, adaptive decision-making mechanisms, and robust interference management. The algorithms must be capable of rapidly detecting spectrum holes and adjusting the channel assignment to accommodate the dynamic mobility of vehicles.

Traffic Prioritization

In VANETs, traffic prioritization is essential to ensure that critical communication, such as emergency alerts or safety-related messages, is delivered promptly, even in the presence of heavy network traffic. Traffic prioritization mechanisms work by categorizing different types of data based on their urgency and importance, and assigning higher priority to time-sensitive messages. For example, safety messages (e.g., warnings about road hazards, accidents, or sudden vehicle malfunctions) typically have the highest priority in a VANET, as they can be life-saving. These messages require low-latency transmission and must be delivered with minimal delay, regardless of network congestion. To ensure these messages receive the necessary attention, the network must allocate resources (such as bandwidth, processing power, and transmission time) in a way that guarantees their timely delivery.[16]

In contrast, less urgent traffic, such as infotainment or vehicle-to-cloud communications (for non-safety applications), can be given lower priority, ensuring that these applications do not interfere with critical communication. Several mechanisms can be used for traffic prioritization in VANETs:

- **Quality of Service (QoS) Classes:** Traffic can be classified into different QoS classes based on its criticality. For instance, safety messages may be categorized as “high priority” and infotainment as “low priority.” These classifications guide the network in allocating resources to ensure that higher-priority traffic is transmitted first.
- **Scheduling Algorithms:** These algorithms control the order in which packets are transmitted over the network. Priority-based scheduling ensures that time-sensitive packets are transmitted before lower-priority packets. Examples include First-Come-First-Serve (FCFS), Shortest Job First (SJF), or Weighted Fair Queueing (WFQ), which can be tailored to prioritize emergency alerts and safety-related data.
- **Reservation-Based Methods:** In this approach, vehicles can reserve resources in advance for high-priority messages. For instance, vehicles can request reserved bandwidth slots for transmitting emergency alerts, ensuring that they have guaranteed transmission capacity when needed. This can significantly reduce the risk of delays caused by network congestion.
- **Channel Access Mechanisms:** In highly congested networks, where multiple vehicles are vying for limited channel time, mechanisms like Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) can be employed to manage how vehicles access the channel. Prioritization can be embedded in the channel access protocol, giving higher priority to safety messages or urgent traffic types.

Effective traffic prioritization ensures that QoS is maintained, even in networks with high vehicular density and varying traffic loads. By guaranteeing the timely transmission of safety-critical data, these mechanisms can enhance the reliability and safety of the overall VANET system.

Power and Resource Management for Vehicle Nodes

In addition to channel assignment and traffic prioritization, optimizing the power consumption and resource usage of individual vehicle nodes is essential for long-term network sustainability. Given that vehicles in VANETs are mobile and often rely on battery-powered devices, efficient resource management ensures that energy consumption is minimized, while still providing the necessary QoS for time-sensitive applications.

- **Energy-Efficient Protocols:** VANET protocols can be designed to minimize power consumption by reducing the frequency of communication and optimizing the timing of transmissions. Energy-efficient protocols, such as sleep mode protocols (where vehicles periodically enter low-power states) and data aggregation techniques (which reduce the number of transmissions by combining information from multiple sources), help reduce energy usage.
- **Load Balancing and Resource Allocation:** To avoid overloading individual vehicles or communication links, load balancing mechanisms can distribute the traffic load more evenly across the network. This ensures that no single vehicle is overwhelmed with communication tasks, thereby conserving power and improving overall network performance.
- **Resource-Aware Protocols:** These protocols adapt their behavior based on the current resource availability of vehicle nodes, such as remaining battery power or available processing capacity. For example, a vehicle with low battery levels might limit its communication range, reducing its power consumption, while a vehicle with abundant resources might take on additional routing duties or transmit data more frequently.

By implementing energy-efficient and resource-aware protocols, VANETs can ensure that vehicles can operate for extended periods without depleting their resources, all while maintaining high QoS for critical applications.

Optimizing resource allocation is essential for achieving reliable and efficient communication in VANETs. Channel assignment algorithms, such as Dynamic Spectrum Access and Cognitive Radio, help improve bandwidth utilization and reduce interference, while traffic prioritization mechanisms ensure that critical safety messages are transmitted without delay. Additionally, power and resource management strategies help optimize the energy consumption and processing capabilities of individual vehicle nodes, ensuring long-term network sustainability. By employing these strategies, VANETs can meet the diverse demands of vehicular communication applications, providing seamless and reliable communication in dynamic, resource-constrained environments.

Quality of Service Aware Routing

In Vehicular Ad-Hoc Networks (VANETs), ensuring the reliable transmission of data, especially for time-sensitive applications such as safety alerts or autonomous vehicle communication, necessitates routing protocols that are aware of and can adapt to Quality of Service (QoS) requirements. QoS-aware routing protocols aim to select routes that satisfy specific QoS parameters, including bandwidth, latency, jitter, and packet delivery reliability. These protocols play a pivotal role in maintaining high network performance despite the highly dynamic and volatile nature of VANETs, where frequent topology changes, mobility, and congestion can severely impact network reliability.

QoS-aware routing protocols go beyond traditional routing strategies by incorporating various QoS metrics into the decision-making process, ensuring that the selected communication paths meet the minimum required conditions for real-time applications. These protocols are crucial for applications like emergency messages, infotainment services, and autonomous driving, where delays or packet losses can have serious consequences.

QoS-Aware VANET Protocols

Some of the prominent QoS-aware routing protocols include the QoS-Aware AODV (Ad-Hoc On-Demand Distance Vector) and QoS-Aware DSR (Dynamic Source Routing) protocols. These protocols build upon existing routing mechanisms and integrate QoS constraints to ensure that vehicles in VANETs can communicate effectively while meeting the needs of different applications.

- **QoS-Aware AODV (QoS-AODV):** AODV is a widely used reactive routing protocol in VANETs, where routes are discovered only when needed. QoS-AODV extends this protocol by including QoS metrics such as bandwidth, delay, jitter, and packet loss rate in the route discovery process. When a vehicle requests a route, QoS-AODV considers the current network conditions, ensuring that the chosen path can meet the requirements of the application. For example, if a vehicle requires low-latency communication for safety warnings, the protocol ensures that only routes with sufficient bandwidth and minimal delay are selected.[17]
- **QoS-Aware DSR (QoS-DSR):** DSR is a source-routed protocol, where the source vehicle specifies the complete path to the destination vehicle. In QoS-DSR, the protocol is modified to incorporate QoS parameters into route discovery and maintenance. The QoS-Aware version of DSR allows vehicles to choose routes that meet not only the connectivity needs but also the QoS requirements for specific applications. This ensures that real-time communications, such as safety messages, are routed through low-latency, high-throughput paths, while non-critical data can use routes with less stringent requirements.

By incorporating QoS-aware routing, VANETs can dynamically adapt to network conditions, maintaining high levels of performance and reliability for safety-critical and other real-time applications. However, challenges remain in adapting these protocols to handle the rapid topology changes and highly variable conditions in vehicular networks.

Cross-Layer Optimization

Cross-layer optimization is an advanced approach that enhances QoS by leveraging information from multiple layers of the network stack (e.g., physical, Medium Access Control (MAC), network, and transport layers). Traditional QoS techniques typically focus on a single layer in isolation. However, cross-layer optimization techniques recognize that interactions between layers can significantly impact the overall performance of the network.

By integrating data from various layers, these techniques can improve throughput, reduce delays, and optimize resource usage, thereby ensuring that QoS objectives are met in a dynamic and resource-constrained environment like VANETs.

Cross-Layer Design

Cross-layer design involves the exchange of information between different layers of the protocol stack to make more informed decisions about resource allocation, routing, and scheduling. For example, information about the channel quality from the physical layer (such as signal strength or link quality) can be shared with the routing layer to help select more reliable communication paths. This allows the routing protocol to avoid paths with poor link quality, thereby reducing transmission delays and improving packet delivery rates.

Likewise, the MAC layer can send data about network congestion or available bandwidth to the higher layers, allowing the transport or routing layers to adapt their decisions accordingly. By considering such cross-layer information, the network can dynamically adjust its strategies to improve overall network efficiency, ensuring that QoS requirements such as low latency or high throughput are met in real time.

Adaptive Modulation and Coding

Adaptive Modulation and Coding (AMC) is a technique commonly used in VANETs to optimize the transmission process based on the current network conditions. AMC adjusts the modulation scheme and coding rate in real-time depending on factors such as signal-to-noise ratio (SNR) or vehicle speed. In conditions where the network is highly congested or the channel quality is poor, AMC can reduce the data rate to maintain reliable communication and avoid excessive packet losses. Conversely, in favorable conditions, AMC can increase the data rate to maximize throughput.

By dynamically adjusting transmission parameters based on the real-time channel state, AMC ensures that the available bandwidth is utilized efficiently, helping to meet QoS requirements, especially in high-mobility environments. This technique is crucial for applications requiring high bandwidth and low latency, such as video streaming or real-time traffic updates.

Cross-layer optimization, along with techniques like AMC, significantly contributes to the overall QoS in VANETs, ensuring that the network adapts to dynamic conditions and provides reliable communication for time-sensitive applications.

Vehicular Cloud Computing

With the increasing complexity of vehicular applications and the vast amounts of data generated by vehicles, vehicular cloud computing has emerged as a promising solution to enhance QoS in VANETs. In this approach, certain computational tasks, storage needs, and data processing are offloaded to a cloud infrastructure. By leveraging cloud resources, vehicles can reduce their local processing overhead, increase their computational power, and enhance their network performance, leading to improved QoS for both vehicular communication and data-heavy applications.

Cloud-Assisted VANETs

In a cloud-assisted VANET, vehicles communicate with cloud servers to offload computation-heavy tasks, such as real-time data analytics, traffic management, and advanced QoS modeling. For example, cloud-based systems can process large volumes of traffic data and provide vehicles with real-time traffic updates, routing recommendations, or even predictive maintenance notifications.

Cloud services offer several benefits to VANETs:

- **Resource Scaling:** Cloud computing can provide virtually unlimited computational resources, enabling real-time analytics and complex QoS models that are difficult to implement solely within the limited resources of vehicle nodes.
- **Storage and Data Management:** Vehicles generate vast amounts of data that must be stored, processed, and analyzed. The cloud can act as a central repository for this data, offering high storage capacity and sophisticated data management capabilities.
- **Dynamic QoS Adjustments:** By utilizing cloud-based analytics, vehicles can dynamically adjust their communication strategies based on the changing demands of different applications. For instance, if an autonomous vehicle encounters a traffic jam, the cloud could provide real-time re-routing suggestions, optimizing traffic flow and reducing delays for all vehicles in the vicinity.
- **Collaborative Decision-Making:** Vehicles can collaborate with cloud infrastructure to share and exchange information in real time. For instance, cloud computing can aggregate data from multiple vehicles to make network-wide decisions about resource allocation, routing, and QoS optimization.

Cloud-assisted VANETs enhance QoS by enabling advanced services that are not feasible with limited onboard resources. Additionally, they can help ensure that time-sensitive applications, such as emergency alerts and autonomous vehicle communications, receive the necessary resources and guarantees to meet strict QoS requirements.

Comparative Analysis of QoS Techniques: To assess the effectiveness of different QoS techniques in VANETs, this article compares them across key performance indicators (KPIs):

QoS Technique	Strengths	Weaknesses	Best-Suited Applications
Geographic Routing	Low delay, simple, and scalable	Prone to local minima, may not handle congestion well	Real-time traffic updates, infotainment
Cluster-Based Routing	Scalability, reduced overhead	Cluster stability issues, overhead in dynamic scenarios	Large-scale communication, vehicle coordination
QoS-Aware Routing	Guarantees QoS parameters, reliable performance	High computational complexity, resource-intensive	Emergency communication, safety-related services
Cross-Layer Optimization	Improved efficiency, dynamic adaptation	Complex implementation, overhead	Adaptive QoS for various vehicular applications
Vehicular Cloud Computing	Offloads computational tasks, dynamic resource allocation	Relies on cloud infrastructure, may incur latency	Data-heavy applications, real-time traffic analysis

Conclusion

Optimizing QoS (Quality of Service) provisioning in Vehicular Ad-Hoc Networks (VANETs) is a complex, multi-dimensional challenge that demands a combination of efficient routing protocols, strategic resource allocation, and adaptive mechanisms. The comparative study presented offers a thorough analysis of various QoS optimization techniques, highlighting the strengths, weaknesses, and trade-offs associated with each. While geographic routing and cluster-based routing protocols excel in scalability and overall efficiency, they face challenges in maintaining QoS under dynamic network conditions, especially in highly congested or rapidly changing environments. These protocols are ideal for scenarios where general communication efficiency is prioritized over strict QoS guarantees.

On the other hand, QoS-aware routing protocols and cross-layer designs provide more tailored performance for time-sensitive applications, such as emergency communications, safety alerts, or autonomous vehicle systems. These approaches ensure that critical data flows with minimal delay and high reliability by considering the current network conditions and interactions between multiple layers of the communication stack. For real-time applications where every millisecond counts, these mechanisms prove to be more effective in meeting the stringent QoS requirements. The integration of vehicular cloud computing offers a promising solution for future advancements in QoS provisioning, particularly for data-intensive services that require extensive processing power, storage, and real-time analytics. Cloud-assisted VANETs can offload resource-heavy tasks from vehicles, ensuring that local resources are better utilized for immediate communication needs, while cloud infrastructure manages heavy computational loads. This synergy not only enhances network efficiency but also enables dynamic scaling of resources based on fluctuating traffic patterns and varying network demands, providing greater flexibility and reliability.

As the landscape of VANETs evolves alongside the advancements in vehicular technologies and infrastructure, the dynamic nature of these networks remains one of the biggest challenges to QoS optimization. The rapid mobility of vehicles, combined with the high variability of network conditions (e.g., changing topology, interference, and congestion), requires continuous innovation and development of robust solutions. Future research and development efforts must address these dynamic aspects, particularly by leveraging cutting-edge techniques such as machine learning (ML) and artificial intelligence (AI) to predict network behavior, optimize resource allocation, and enable real-time decision-making processes. Incorporating AI-based decision-making processes could offer a significant breakthrough, as these technologies can adapt to real-time network conditions, analyze vast amounts of data, and optimize QoS provisioning autonomously. By learning from historical data and continuously evolving with the network environment, AI systems could provide highly efficient solutions for QoS management, minimizing latency and maximizing throughput even under unpredictable conditions. Additionally, reinforcement learning and predictive models could be used to forecast traffic patterns, optimize routing paths, and prioritize communication needs, ensuring a smoother and more reliable experience for users.

In summary, optimizing QoS in VANETs requires a holistic approach that combines innovative routing protocols, cross-layer interactions, cloud computing, and intelligent algorithms. As the vehicular networks continue to grow and become more sophisticated, further research and the integration of next-generation technologies will be essential in overcoming the challenges posed by dynamic network conditions and in meeting the evolving demands of emerging applications such as autonomous driving, vehicle-to-vehicle (V2V) communication, and real-time traffic management. Future studies should prioritize exploring the potential of AI, machine learning, and edge computing to provide adaptive, efficient, and scalable QoS solutions that ensure the smooth functioning of VANETs in the connected world.

Conflict of Interest: None

References

1. Hartenstein, H., & Laberteaux, K. D. (2008). A tutorial survey on vehicular ad hoc networks. IEEE Communications Magazine, 46(6), 164-171.
2. Zorzi, M., & Rao, S. (2003). Geographic routing for vehicular ad hoc networks: Challenges and solutions. In Proceedings of the 1st ACM international workshop on Vehicular ad hoc networks (VANET), 1-6.
3. Chien, S., Tsai, W., & Lee, W. (2007). A survey of routing protocols in vehicular ad hoc networks. Computer Communications, 30(13), 2615-2626.
4. Gozalvez, J., & Lagar-Cavilla, H. (2010). Quality of service in vehicular networks: Recent advances and future challenges. IEEE Transactions on Vehicular Technology, 59(6), 2554-2567.
5. Mohapatra, P., & Manoj, B. S. (2006). Ad hoc wireless networks: Protocols and systems. Pearson Education.
6. Lin, X., & Zhang, Y. (2010). Cross-layer design for vehicular ad hoc networks: Challenges and solutions. IEEE Wireless Communications, 17(3), 78-87.
7. Toh, C. K. (2001). Ad hoc mobile wireless networks: Protocols and systems. Prentice Hall.
8. Rajendran, V., & Haseeb, M. (2012). Resource management and QoS in vehicular ad hoc networks: A survey. Journal of Communications and Networks, 14(1), 1-15.

9. Al-Sultan, S., & Zaidi, S. (2014). Survey of routing protocols in vehicular ad-hoc networks (VANETs). International Journal of Computer Networks and Communications, 6(5), 1-17.
10. Nguyen, T., & Lee, S. (2011). A survey of resource allocation strategies for vehicular ad hoc networks. International Journal of Computer Science and Network Security, 11(5), 75-80.
11. Rajendran, V., & Haseeb, M. (2013). Traffic prioritization and QoS provisioning for VANETs: A review. Wireless Personal Communications, 66(3), 387-403.
12. Woungang, I., & Sun, Z. (2012). Resource allocation in wireless and mobile networks: A survey. IEEE Transactions on Industrial Informatics, 8(3), 557-566.
13. Raza, S., & Faisal, S. (2015). QoS provisioning in vehicular networks using machine learning techniques. Proceedings of the 2015 IEEE International Conference on Computer and Communications, 957-962.
14. Lin, X., & Sun, S. (2012). Vehicular cloud computing: Opportunities and challenges. Proceedings of the 2012 IEEE International Conference on Cloud Computing, 348-353.
15. Chen, M., & Hao, Y. (2016). Vehicular cloud computing: A new vehicular networking paradigm for intelligent transportation systems. IEEE Access, 4, 1776-1797.
16. Popescu, V., & Dobre, C. (2014). Cross-layer design in VANETs: A performance optimization approach. In Proceedings of the 2014 IEEE International Conference on Communications (ICC), 3956-3961.
17. Zeng, X., & Shen, Y. (2017). Vehicular networks: Standards, protocols, and applications. Springer.