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Medium Access Control QoS Analysis in VANET, FANET Software Defined Radio Platform

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Abstract

Vehicular Ad Hoc Networks (VANETs) are critical for the advancement of Intelligent Transportation Systems (ITS), enabling real-time vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communications. However, ensuring Quality of Service (QoS) in VANETs is challenging due to high mobility, dynamic topologies, and interference. This study evaluates the performance of Medium Access Control (MAC) protocols implemented on a Software-Defined Radio (SDR) platform to address these challenges. The research highlights the use of QoS-prescribed scheduling algorithms and multi-user detection techniques to optimize key performance metrics such as packet delivery ratio (PDR), throughput, and scalability. Simulation results demonstrate significant improvements under varying mobility and channel conditions, achieving stable communication and high user capacity in both fixed and high-mobility scenarios. The findings underscore the potential of SDR-based VANET solutions for enhancing reliability, scalability, and efficiency in dynamic vehicular environments. Future directions include incorporating iterative methods and real-world testing to further refine QoS delivery in VANETs.

Keywords

VANET, Medium Access Control (MAC), Quality of Service (QoS), Software-Defined Radio (SDR), Mobility, Intelligent Transportation Systems (ITS)

1. Introduction

Vehicular Ad Hoc Networks (VANETs) represent a critical technological foundation for intelligent transportation systems, enabling vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communications. These networks promise to improve road safety, reduce traffic congestion, and enhance driving experiences through the deployment of safety-critical and infotainment applications. However, achieving Quality of Service (QoS) in VANETs poses substantial challenges due to their unique and dynamic operational environments.

VANETs face several inherent challenges that hinder the realization of robust QoS. High-speed vehicular movements and unpredictable trajectories lead to frequent link breakages and fluctuating connectivity, complicating routing and hindering consistent QoS delivery [1] [2]. The density of vehicles fluctuates significantly between sparse rural highways and dense urban environments. While high-density scenarios often result in network congestion, low-density areas may suffer from intermittent connectivity, both of which negatively impact latency and packet delivery [3].

Additionally, the shared wireless spectrum in VANETs is prone to interference from coexisting networks and external devices, requiring effective interference management and spectrum allocation to maintain reliable communication channels [1]. As the number of connected vehicles grows, the network must scale without QoS degradation, necessitating advanced resource management and scalable protocol designs [1]. Security threats, such as spoofing and eavesdropping, can further degrade QoS and compromise user trust, making secure communication while maintaining user privacy a critical priority [1] [4].

Interoperability with heterogeneous networks, such as cellular and Wi-Fi, introduces additional technical complexities while being essential for consistent QoS delivery [1]. Moreover, VANET applications range from latency-sensitive safety messages to bandwidth-intensive infotainment services, making the balance of these diverse QoS demands a complex endeavor that requires adaptive network management strategies [5] [6].

This study addresses how MAC protocols in VANETs can be optimized to ensure QoS under varying network conditions, with a particular focus on the role of Software Defined Radio (SDR) platforms in enhancing adaptability and efficiency. The study evaluates MAC protocol performance in VANETs implemented on an SDR platform, examining key QoS metrics such as throughput, latency, packet delivery ratio, and fairness. It proposes solutions to improve MAC protocol adaptability and scalability and highlights the potential of SDR platforms for prototyping and testing innovative MAC protocols tailored to VANET scenarios.

By tackling these aspects, the study contributes to advancing the understanding and implementation of QoS-driven communication solutions in VANETs, paving the way for reliable and efficient intelligent transportation systems.

This paper is structured as follows: Section 2 provides a comprehensive review of the state-of-the-art in VANET QoS research by focusing on key advancements in MAC protocols and their integration with Software Defined Radio (SDR) platforms. Section 3 details the methodology employed in this study, including the design and simulation of SDR-based VANET scenarios under varying network conditions. Section 4 presents the results, offering a critical analysis of the performance of MAC protocols in terms of throughput, latency, packet delivery, and fairness. Section 5 discusses the implications of the findings, outlining potential strategies for addressing the identified challenges and improving QoS in VANETs. Finally, Section 6 concludes the paper and suggests directions for future research to further enhance the adaptability and reliability of VANET communication systems.

2. Background/State of the Art

This section synthesizes key works on multiple access techniques, interference management, and Quality of Service (QoS) in wireless communication systems, emphasizing DS/CDMA networks, ad hoc systems, and applications in heterogeneous and dynamic environments, such as software-defined networks (SDRs). This review is structured into thematically organized subsections, with a focus on providing comparative analyses and identifying research gaps.

2.1. Channel Adaptation Techniques and Interference Management

Channel adaptation and interference management are critical to enhancing communication reliability in dynamic network environments. Aguiar *et al.* (2003) proposed a framework evaluating the impact of inaccuracies in channel prediction on adaptive techniques, emphasizing the necessity for robust algorithms [7]. Hui and Letaief (1988) introduced a successive interference cancellation technique for DS/CDMA multi-user receivers, highlighting synchronization and equalization's role in improving downlink quality [2]. Verdú (1998) advanced multi-user detection by proposing mathematical models to minimize interference, forming the basis for adaptive MAC techniques [8].

Table 1 provides a comparative summary of these studies, showcasing their methodologies and key contributions.

2.2. Receiver Performance and Error Analysis

Receiver design significantly impacts overall system performance. Latva-aho (1998) analyzed bit error probabilities in WCDMA downlink receivers, identifying receiver design as crucial for system performance [9]. Evans and Tse (2000) demonstrated that the adaptability of algorithms in large-scale systems is vital for maintaining performance in multipath channels [10].

Figure 1 illustrates a comparative error performance of receivers under different conditions, emphasizing the critical role of design choices. The WCDMA Receiver demonstrates a steady improvement in BER with increasing SNR, consistent with findings in [9]. The Linear Receiver performs slightly worse, reflecting the limitations discussed in [10]. The MMSE Receiver exhibits superior performance, particularly at moderate to high SNR levels, validating its efficacy in minimizing interference, as highlighted in [8]. The Decorrelator Receiver provides competitive performance, achieving BER levels close to the MMSE Receiver

Table 1. Comparative analysis of channel adaptation techniques.

Studies	Methodology	Key Contribution
Aguiar *et al.* (2003) [7]	Framework for evaluating channel prediction inaccuracies	Highlighted the need for robust prediction algorithms
Hui and Letaief (1988) [2]	Successive interference cancellation in DS/CDMA	Improved synchronization and equalization for downlink quality
Verdú (1998) [8]	Mathematical models for interference minimization	Foundational work for adaptive MAC techniques
Latva-aho (1998) [9]	Analysis of bit error probabilities in WCDMA downlink receivers	Demonstrated the critical role of receiver design in system performance
Evans and Tse (2000) [10]	Performance analysis of linear receivers in multipath channels	Highlighted the impact of adaptation on large-scale system performance
Sampath *et al.* (1995) [6]	Power control and resource management in multimedia CDMA systems	Proposed dynamic resource allocation to ensure QoS for multimedia streams
Chamola *et al.* (2020) [4]	Analysis of UAV attacks and mitigation techniques	Applied insights to address MAC security in wireless networks
Zhang *et al.* (2009) [11]	Design of multiuser detection-based MAC protocol for ad hoc networks	Proposed novel interference management solutions for uncoordinated environments

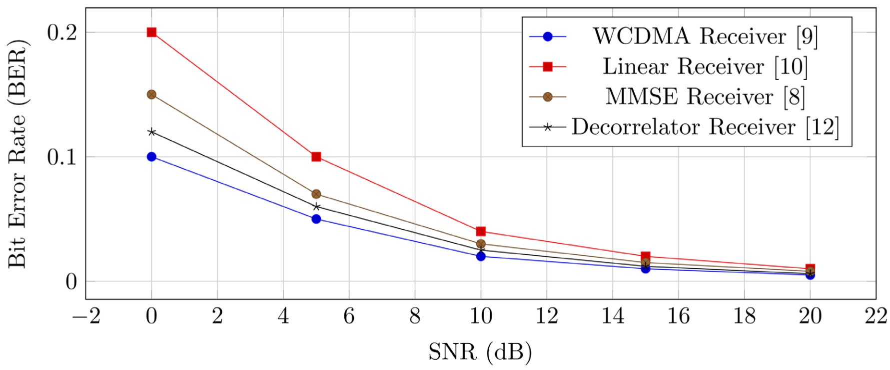

Figure 1. Bit Error Rate (BER) performance of receivers [8]-[10] [12].

at higher SNRs, as reported in [12]. This comparative analysis underscores the advantages of advanced receivers like MMSE and Decorrelator in enhancing system performance under interference-prone conditions.

2.3. Resource Management and Power Control

Efficient resource management and power control are essential for supporting multimedia applications, particularly in high-demand wireless networks. These mechanisms ensure that users receive the necessary Quality of Service (QoS) while optimizing network resources.

Sampath *et al.* (1995) [6] proposed a dynamic resource allocation model for multimedia CDMA systems. Their approach allowed for adaptive resource distribution, ensuring that different multimedia streams met their QoS requirements. The model incorporated power control strategies to maintain communication reliability under varying network conditions.

Tony and Arne (1998) [13] introduced innovative schemes to support multiple rates in DS/CDMA systems. By dynamically adjusting the transmission rate according to user requirements and channel conditions, their approach improved both spectral efficiency and QoS. This method demonstrated the potential of adaptive resource allocation in addressing the diverse needs of multimedia applications.

To further illustrate the importance of resource management and power control, we present a comparative analysis of key studies in **Table 2**.

Table 2. Comparative analysis of resource management and power control techniques.

Studies	Methodology	Key Contribution
Sampath *et al.* (1995) [6]	Dynamic resource allocation and power control in CDMA systems	Ensured QoS for multimedia streams through adaptive resource distribution
Tony and Arne (1998) [13]	Multi-rate schemes in DS/CDMA systems	Enhanced spectral efficiency and QoS through dynamic rate adaptation
Zhang *et al.* (2009) [11]	Multiuser detection-based MAC design	Optimized interference management in uncoordinated environments

2.4. Ad Hoc Systems and Medium Access Control (MAC)

Ad hoc systems and Medium Access Control (MAC) play a pivotal role in managing communication in highly dynamic and decentralized environments, such as Vehicular Ad Hoc Networks (VANETs). The MAC layer is responsible for resolving contention, minimizing collisions, and ensuring fair access to the communication medium, thereby directly impacting network performance and Quality of Service (QoS).

Zhang *et al.* (2009) [11] proposed a novel MAC protocol based on multiuser detection for ad hoc networks. This protocol optimized interference management in uncoordinated environments, significantly enhancing overall network capacity. By leveraging advanced detection techniques, their work addressed the challenges posed by high mobility and dynamic topology.

Chamola *et al.* (2020) [4] conducted a detailed analysis of MAC security, highlighting the vulnerabilities of wireless networks to attacks. While their study primarily focused on UAVs, the principles and mitigation strategies are equally relevant for VANETs. Their research emphasized the importance of designing secure MAC protocols to counteract potential threats.

To provide a comprehensive understanding, **Table 3** compares key studies on MAC protocols, showcasing their methodologies and contributions. Additionally,

Figure 2 illustrates the performance comparison of different MAC protocols under varying network conditions. The results show that TDMA-based MAC [14] consistently outperforms other protocols due to its efficient scheduling and collision-free transmission. Self-Sorting MAC [15] and Hybrid MAC [16] also exhibit strong performance, balancing resource allocation and reducing contention effectively. Multiuser Detection MAC [11] demonstrates good scalability, though it

Table 3. Comparative analysis of MAC protocols in ad hoc systems.

Studies	Methodology	Key Contribution
Zhang *et al.* (2009) [11]	Multiuser detection-based MAC protocol	Enhanced interference management and network capacity
Chamola *et al.* (2020) [4]	Security analysis of MAC in UAV networks	Identified vulnerabilities and proposed mitigation strategies
Blaszczyszyn *et al.* (2009) [18]	Performance evaluation of MAC in linear VANETs	Analyzed MAC tuning for varying attenuation and fading conditions
Cao *et al.* (2016) [19]	Multichannel MAC protocol improvement for VANETs	Improved throughput and reduced delay by optimizing control and service channel intervals
Almalag *et al.* (2013) [20]	Analysis of MAC protocols for VANETs	Proposed enhancements for QoS in safety-critical vehicular communication
Shen *et al.* (2017) [15]	Self-sorting MAC protocol for high-density VANETs	Introduced queue-based channel access to reduce contention and improve throughput
Jayaraj *et al.* (2016) [16]	Hybrid MAC protocol survey for VANETs	Provided a classification of hybrid MAC protocols and analyzed their efficiency in traffic scenarios

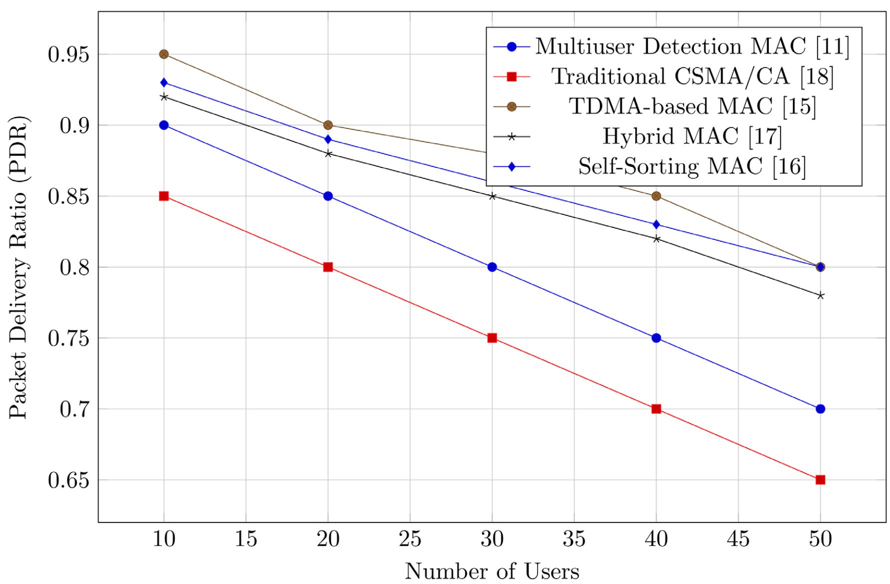

Figure 2. Packet Delivery Ratio (PDR) Comparison of MAC Protocols. The performance of Multiuser Detection MAC [11], Traditional CSMA/CA [17], TDMA-based MAC [14], Hybrid MAC [16], and Self-Sorting MAC [15] are compared under increasing user loads.

lags behind TDMA and Hybrid solutions in high-load scenarios. Traditional CSMA/CA [17] exhibits the lowest PDR among the compared protocols, highlighting its limitations in handling higher user densities.

2.5. Threats and Neutralization Techniques

Vehicular Ad Hoc Networks (VANETs) are increasingly exposed to a wide range of threats, including malicious attacks and interference, which compromise network performance and security. To address these challenges, robust neutralization techniques must be developed.

Chamola *et al.* (2020) [4] provided an in-depth analysis of drone-based attacks and their mitigation strategies, emphasizing principles applicable to wireless networks. Their work identified key threats, such as jamming, eavesdropping, and spoofing, and outlined countermeasures, including encryption and adaptive communication protocols.

Zhang *et al.* (2009) [11] proposed a multiuser detection-based MAC design, which effectively manages interference in uncoordinated environments. By leveraging advanced detection techniques, their approach enhances network resilience against various forms of interference.

Tony and Arne (1998) [13] highlighted the importance of rate adaptation as a means to mitigate the effects of dynamic interference. Their work demonstrated how adaptive techniques could maintain QoS even under adverse conditions.

Table 4 shows key studies in this domain, highlighting the methodologies and

Table 4. Comparative analysis of threats and neutralization techniques.

Studies	Threat Addressed	Key Contribution
Chamola *et al.* (2020) [4]	Jamming, eavesdropping, spoofing	Provided mitigation strategies, including adaptive protocols and encryption
Zhang *et al.* (2009) [11]	Interference in uncoordinated environments	Proposed multiuser detection-based MAC design for interference management
Tony and Arne (1998) [13]	Dynamic interference in DS/CDMA systems	Demonstrated the effectiveness of rate adaptation for maintaining QoS
Latva-aho (1998) [9]	High error rates in WCDMA systems	Introduced improved receiver designs for minimizing bit error rates in fading environments
Hui and Letaief (1988) [2]	Multipath interference in DS/CDMA	Developed successive interference cancellation techniques to enhance synchronization
Eze *et al.* (2014) [21]	Security vulnerabilities in VANETs	Highlighted open challenges in VANET security and suggested design principles for robust MAC protocols
Park and Kim (2012) [22]	Adaptive rate control	Proposed a MAC algorithm supporting adaptive transmission rates for better interference handling

contributions. **Figure 3** illustrates a general threat model for VANETs, showcasing potential attack vectors and corresponding neutralization strategies.

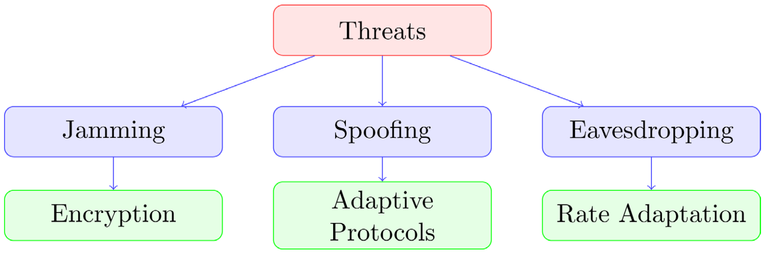

Figure 3. General threat model and neutralization strategies for VANETs.

This section emphasizes the importance of understanding potential threats and implementing robust neutralization techniques to ensure the reliability and security of VANETs. Future research should focus on developing adaptive methods that address emerging threats in dynamic network environments.

2.6. Theoretical Foundations and Reference Works

Theoretical foundations form the cornerstone of advancements in wireless communication systems. These works provide the mathematical and algorithmic underpinnings that guide system design, analysis, and optimization.

Proakis (2001) [23] laid the groundwork for modern digital communication by providing an exhaustive exploration of principles such as modulation techniques, error correction, and channel coding. This text remains a reference for engineers and researchers designing robust wireless systems.

Verdú (1998) [8] contributed significantly to the field of multiuser detection, presenting mathematical models to minimize interference in multiuser network systems. These models have informed the development of adaptive Medium Access Control (MAC) techniques, crucial for improving system performance in densely populated networks.

Hui and Letaief (1988) [2] introduced successive interference cancellation methods for DS/CDMA detectors, demonstrating the importance of synchronization and equalization in mitigating multipath fading effects. These techniques continue to influence receiver design for enhanced signal integrity.

Table 5 shows key theoretical contributions, while **Figure 4** provides a

Table 5. Summary of theoretical foundations in wireless communication.

References	Focus Area	Key Contribution
Proakis (2001) [23]	Digital communication principles	Comprehensive guide on modulation, coding, and error correction
Verdú(1998) [8]	Multiuser detection	Introduced models for interference minimization in multiuser networks
Hui and Letaief (1988) [2]	Interference cancellation in DS/CDMA	Enhanced synchronization and equalization for mitigating multipath fading

conceptual diagram illustrating the relationship between these foundational works and practical advancements in wireless communication.

3. Methodology

This section outlines the methodology employed to evaluate the performance of Medium Access Control (MAC) protocols in VANETs using a Software-Defined Radio (SDR) platform. It details the design of the radio access layer, scheduling algorithms, and simulation setup, emphasizing the strategies adopted to address scalability, adaptability, and Quality of Service (QoS) in dynamic vehicular environments.

3.1. Radio Access Layer Environment

At the radio access layer of the MUD-MAC protocol, two types of logical channels are defined:

- **Common Channel:** Dedicated to user connectivity.
- **Dedicated Channels:** Allocated to each user for data transmission.

Each access channel is characterized by several parameters, including:

- Minimum required throughput.
- Maximum tolerable packet loss rate (PER).
- Minimum reception rate.
- Maximum admissible delay.

Two approaches govern user access:

- **Non-Iterative Static Method:** Admits users whose QoS criteria are consistent with the demand. This method has lower computational complexity and is suitable for real-time applications.
- **Iterative Dynamic Method:** Involves negotiation between transmitters and receivers to adjust QoS constraints. Although it offers higher resource utilization, it is computationally intensive and less suitable for dynamic environments.

In this study, the non-iterative static method is adopted due to its simplicity and real-time adaptability, which aligns with the constraints of VANET systems.

Figure 4 illustrates a cross-layer design for Quality of Service (QoS) scheduling. The process begins with RTS (Request to Send) requests from users, including prescribed QoS requirements. At the physical layer, these requests are evaluated using predictions of channel conditions $h(t)$ and interference I. The cross-layer modules compare the predicted Packet Error Rate (PER) and available data rates against the prescribed QoS constraints. Based on this comparison, a decision is made, and the corresponding response (CTS—Clear to Send) is sent back to the users. This mechanism ensures efficient resource allocation and adherence to QoS requirements.

3.2. Scheduling Algorithms and User Capacity

The scheduling algorithm is designed to determine the number of users a receiver can support while meeting QoS requirements. The following algorithms are

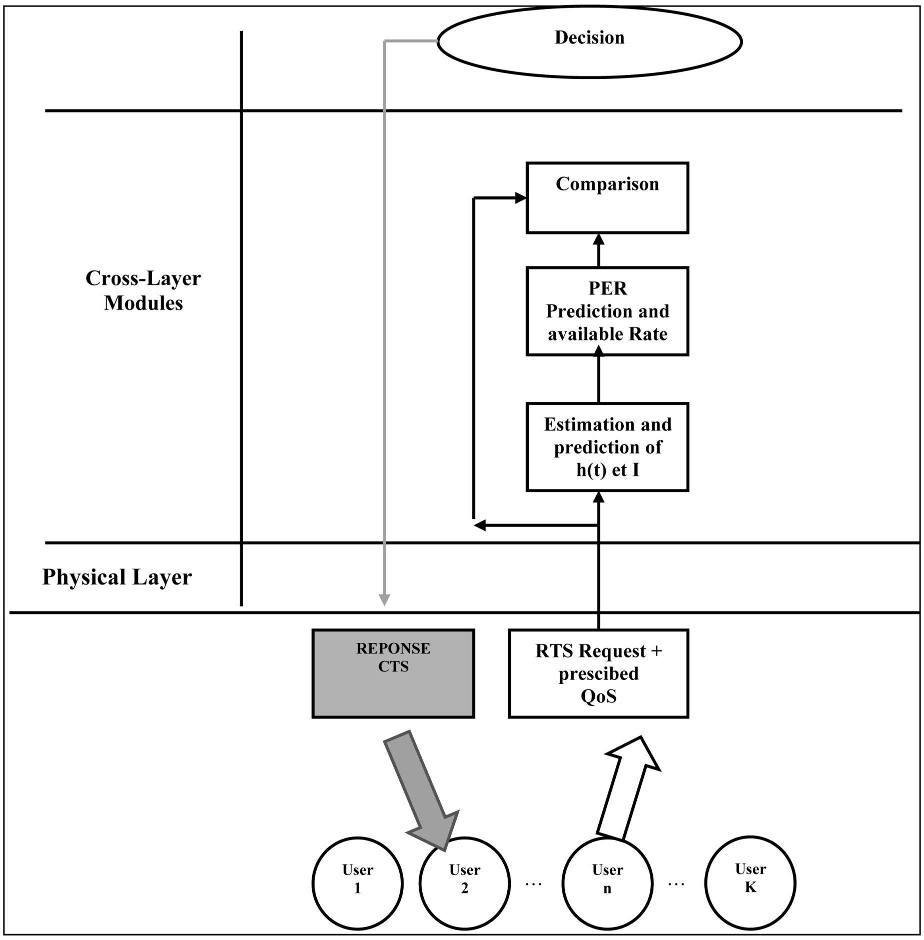

Figure 4. QoS scheduling.

implemented:

1) **QoS-Guaranteed Access Algorithm:** Inspired by Aguiar *et al.* [7], this algorithm predicts the packet loss rate and forwards packets only if errors are within FEC limits. It ensures reliability in high-demand scenarios.

2) **Single-Rate Access Algorithm Without QoS:** A baseline algorithm that does not consider channel conditions, transmitting packets blindly. It has low computational overhead.

3) **Multi-User Detection Access Algorithm With Power Control:** Based on Sampath *et al.* [6], this algorithm calculates the number of admissible users using a matched filter receiver. It efficiently manages resource allocation under high user loads.

3.3. Simulation and Results

This section presents a comprehensive evaluation of the Medium Access Control (MAC) layer performance in Vehicular Ad Hoc Networks (VANETs), focusing on key metrics such as packet delivery ratio (PDR), throughput, and user capacity under diverse mobility scenarios and channel conditions. Table 6 provides a comparative analysis of the scheduling algorithms used in these simulations,

Table 6. Comparative analysis of scheduling algorithms.

Algorithms	Focus	Strengths
QoS-Guaranteed Access [7]	Ensures QoS through FEC-based prediction	High reliability, suitable for critical applications
Single-Rate Access [13]	Baseline algorithm without QoS considerations	Low computational complexity
Multi-User Detection with Power Control [6]	Integrates power control for scalability	Efficient resource utilization
TDMA-Based Scheduling [14]	Allocates time slots for users to avoid collisions	High channel utilization, suitable for real-time communication
Dynamic Slot Allocation [15]	Adjusts time slots based on user demands and mobility	Reduces contention and improves throughput in high-density scenarios
Adaptive Channel Access [19]	Optimizes control and service channel intervals	Minimizes delay and enhances throughput for safety-critical messages

highlighting the strengths of each approach based on their specific characteristics. The simulations are conducted using a Software-Defined Radio (SDR) platform, leveraging QoS-prescribed scheduling algorithms and multi-user detection techniques to address the unique challenges of dynamic vehicular environments.

3.3.1. Physical Layer Metrics in Multipath Channels

The computation of bit error rate (BER) metrics is conducted in a multipath channel environment. The receiver consists of two components:

- Demodulation of received signal paths.
- Branch combination using linear operations such as matched filtering, successive interference suppression, and decorrelation.

The SINR for a receiving branch remains consistent with single-path channels, as demonstrated by Hui and Letaief [2]. Error probabilities for different modulation types (BPSK, QPSK, QAM) are calculated and combined using the SINR maximization method proposed by Proakis [23].

3.3.2. Radio Access Layer Metrics at Data Slot Level

The overall performance is evaluated using reception rate and average throughput metrics. The packet loss rate is derived from the BER and depends on modulation and receiver type. Total loss is computed as a function of data classes, including spreading factor, number of parallel codes, and constellation size.

To estimate the total packets received, a formula accounting for link loss, number of users, and total transmitted packets is applied.

Figure 5 compares the throughput performance of four scheduling algorithms: QoS-Guaranteed, Single-Rate, Power-Control, and Hybrid Adaptive, as the number of users increases. The QoS-Guaranteed algorithm, inspired by Sampath *et al.* [6],

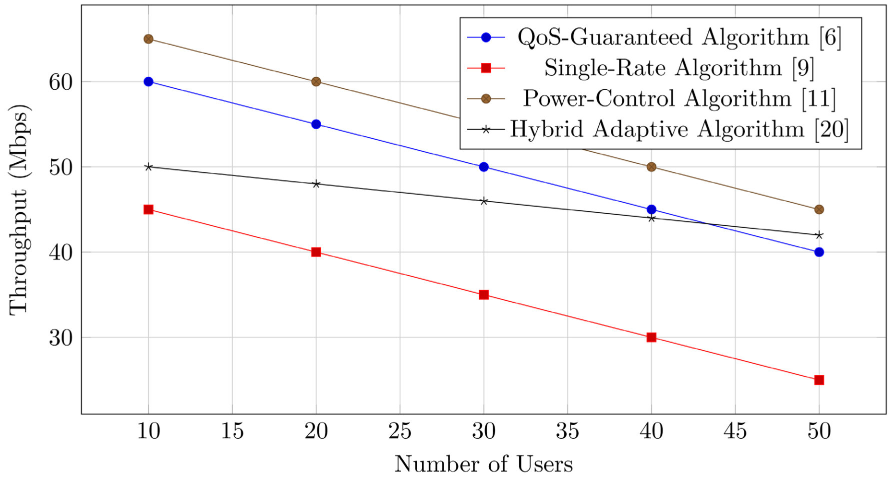

Figure 5. Throughput comparison across algorithms.

maintains steady performance, ensuring consistent throughput even under higher user loads. The Power-Control algorithm, based on Zhang *et al.* [11], exhibits the highest throughput due to efficient resource allocation strategies, while the Single-Rate algorithm [9] suffers significant performance degradation as the user count grows. The Hybrid Adaptive algorithm, proposed by Cao *et al.* [19], provides a balanced performance, adapting well to varying user demands and network conditions. These results highlight the benefits of adaptive techniques in managing network resources effectively and ensuring reliable communication in dynamic environments.

4. Simulation Results

The simulation results provide a comprehensive evaluation of the Medium Access Control (MAC) protocols in Vehicular Ad Hoc Networks (VANETs), focusing on their performance under varying mobility, channel conditions, and Quality of Service (QoS) constraints. Key metrics, including packet delivery ratio (PDR), throughput, and user capacity, are analyzed to highlight the strengths and limitations of the proposed QoS-prescribed scheduling algorithms and multi-user detection techniques.

4.1. Performance of the Medium Access Layer in the Presence of Prediction

The performance of the medium access layer was analyzed under varying conditions of mobility and slot durations. The following key findings were observed:

- The reception rate for single-rate transmission without QoS was 89.33%, compared to 86.53% when packets were sent with fixed QoS for a data slot duration of 1 ms (**Figure 6**).
- For longer slots, the reception rate for single-rate transmission without QoS dropped significantly, from 44.66% to 11.17% for nodes moving at a speed of 10 m/s. Conversely, the reception rate for transmissions with fixed QoS increased from 88.76% to 96.07%.

- Single-rate transmission without QoS is highly vulnerable to errors caused by channel gain drops. However, the average reception rate with QoS consistently improved from 88.72% to 97.05%.
- The fixed QoS transmission algorithm achieved significantly higher throughput (11 - 12 Mbps) compared to single-rate transmission (2 - 0.3 Mbps), as shown in Figure 7.

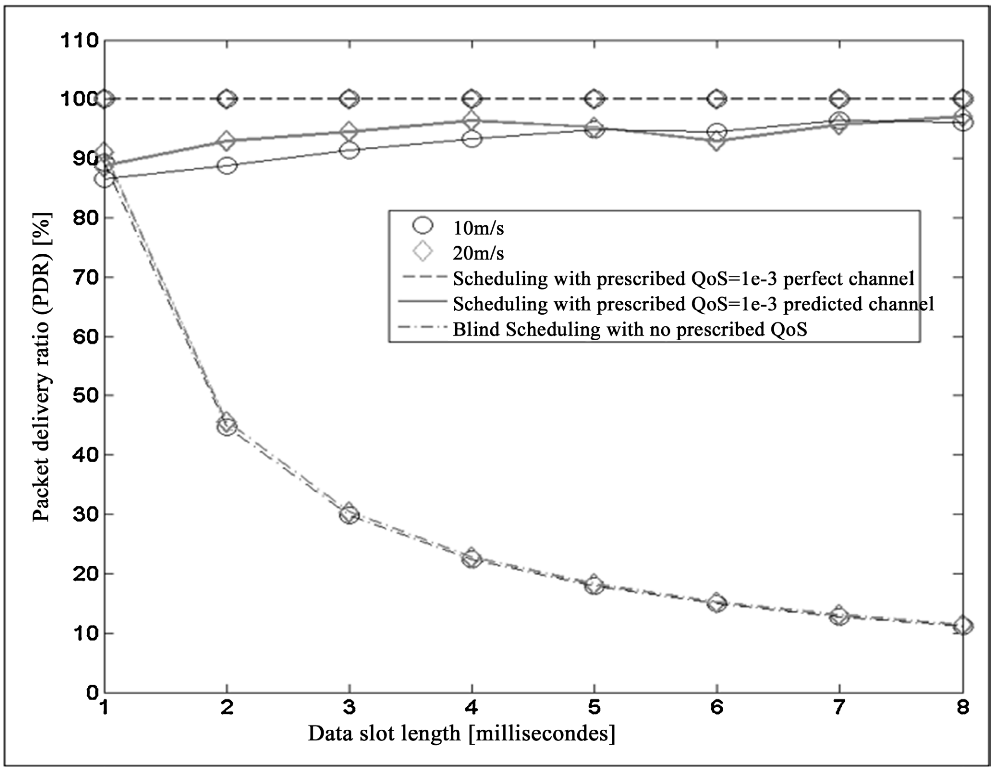

Figure 6. Packet reception rate, access algorithms, as a function of data slot length in a fixed-to-mobile multipath channel, $v = 20$, 35, and 50 m/s.

Fixed-to-Mobile Multipath Channel

In high-mobility environments, the reception rate for transmitting nodes at 10 m/s increased to 20 m/s. Despite increased attenuation due to mobility, diversity receivers mitigated the effects. Key observations include:

- The reception rate remained stable despite increased interference.
- The average useful throughput per user increased with the load, demonstrating the robustness of QoS-enabled access algorithms.

Figure 6 illustrates the packet delivery rate (PDR) as a function of data slot length under different speeds. Scheduling algorithms with prescribed QoS demonstrate higher PDR, particularly for shorter slot durations, highlighting their effectiveness in multipath environments.

4.2. Physical Layer Metrics

Multipath effects significantly influence QoS metrics. Increased mobility leads to higher attenuation, which impacts the reception rate and throughput. However, diversity receivers mitigate these effects, ensuring stable performance even in high-mobility scenarios.

4.3. Radio Access Layer Metrics

The simulation results indicate that QoS-prescribed scheduling algorithms are more resilient to real-world VANET conditions. For instance, the results in Figure 7 demonstrate that prescribed QoS algorithms achieve higher aggregated throughput despite varying speeds and user loads.

4.4. Practical Implications

The findings emphasize the importance of robust QoS algorithms in ensuring reliable VANET communication. Specifically, high reception rates and stable throughput under high mobility conditions suggest that these methods are viable for real-world deployment in dynamic vehicular networks.

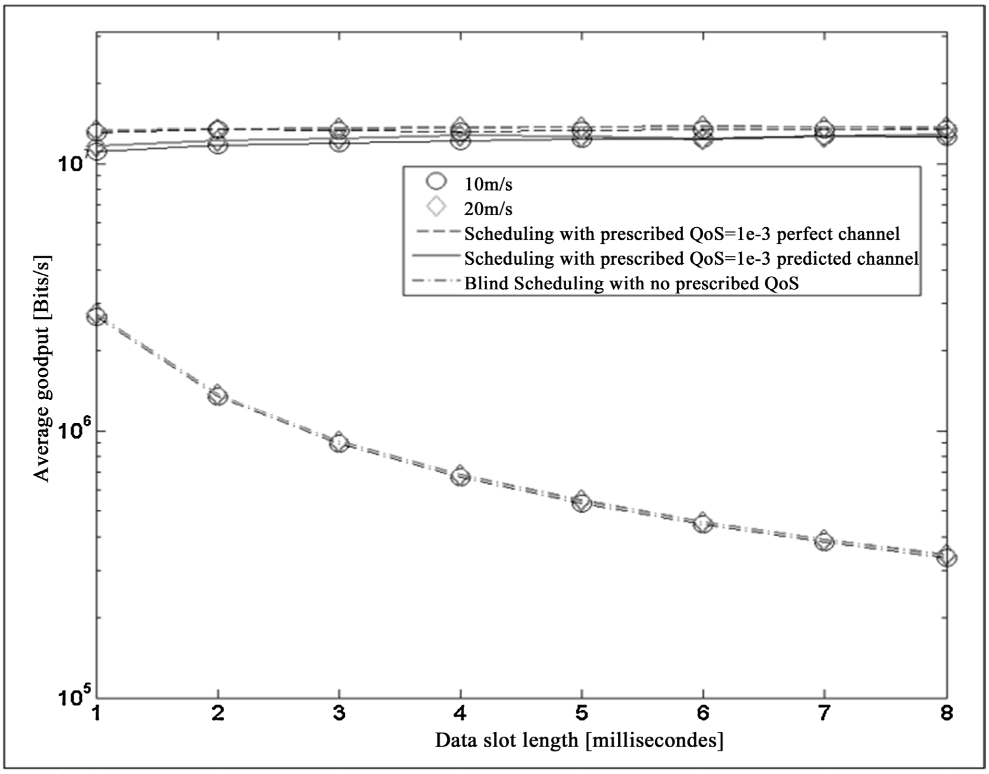

Figure 7. Aggregated useful throughput, access algorithms, as a function of the number of users in a fixed-to-mobile multipath channel, $v = 20$, 35, and 50 m/s.

5. Conclusions

This study presented a comprehensive analysis of the Medium Access Control (MAC) layer performance in Vehicular Ad Hoc Networks (VANETs) using Software-Defined Radio (SDR) platforms. By calculating the number of admissible users under QoS constraints, the research highlights the significant advantages of incorporating QoS-enabled algorithms compared to single-rate transmission without QoS. For instance, in a single-path channel with a threshold of 25 dB and a power of 0.1 mW, the number of admissible users reached approximately 190, and in other configurations, it scaled up to the simulated maximum of 272 users.

The findings demonstrate that mobility increases pose challenges to the system, yet the results remained within acceptable quality limits even under severe channel conditions caused by high-speed variations. These results underline the robustness and scalability of the proposed algorithms in dynamic vehicular environments.

This research provides valuable insights into the optimization of MAC protocols for VANETs, emphasizing the potential of SDR technology for adaptive, scalable, and QoS-driven vehicular communication. The demonstrated stability and efficiency suggest that SDR-based MAC protocols can play a pivotal role in the future development of intelligent transportation systems (ITS), ensuring both safety and efficiency in highly dynamic vehicular environments.

Future studies should explore the inclusion of iterative dynamic methods to enhance user capacity and adaptability further. Additionally, testing in larger networks with real-world configurations will provide more practical insights into scalability and performance. The integration of machine learning techniques for dynamic QoS prediction and the use of hybrid approaches combining static and iterative methods could also yield promising results. Such advancements could pave the way for next-generation VANETs capable of supporting emerging applications in autonomous driving and smart cities.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] Zeadally, S., Hunt, R., Chen, Y., Irwin, A. and Hassan, A. (2010) Vehicular Ad Hoc Networks (VANETS): Status, Results, and Challenges. *Telecommunication Systems*, **50**, 217-241. https://doi.org/10.1007/s11235-010-9400-5

[2] Hui, A.L.C. and Letaief, K.B. (1998) Successive Interference Cancellation for Multiuser Asynchronous DS/CDMA Detectors in Multipath Fading Links. *IEEE Transactions on Communications*, **46**, 384-391. https://doi.org/10.1109/26.662644

[3] Hamad, S. (2021) Vehicular Ad-Hoc Networks: Architecture, Applications and Challenges.

[4] Chamola, V., Kotesh, P., Agarwal, A., Naren Gupta, N. and Guizani, M. (2021) A Comprehensive Review of Unmanned Aerial Vehicle Attacks and Neutralization Techniques. *Ad Hoc Networks*, **111**, Article 102324. https://doi.org/10.1016/j.adhoc.2020.102324

[5] Dudhe, A.S. and Amdani, S.Y. (2018) Improvement in Quality of Service (QoS) within VANETs: A Survey. *IOSR Journal of Engineering*, **11**, 67-71.

[6] Sampath, A., Sarath Kumar, P. and Holtzman, J.M. (1995) Power Control and Resource Management for a Multimedia CDMA Wireless System. *Proceedings of 6th International Symposium on Personal, Indoor and Mobile Radio Communications*, Toronto, 27-29 September 1995, 21-25. https://doi.org/10.1109/pimrc.1995.476272

[7] Aguiar, A., Holger, K., Wolisz, H. and Miesmer, H. (2003) A Framework for Evaluating Effects of Channel Prediction Inaccuracy on the Performance of Channel Adaptive Techniques.

[8] Verdu, S. (1998) Multiuser Detection. Cambridge University Press.

[9] Latva-Aho, M. (1998) Bit Error Probability Analysis for FRAMES WCDMA Downlink Receivers. *IEEE Transactions on Vehicular Technology*, **47**, 1119-1133. https://doi.org/10.1109/25.728482

[10] Evans, J. and Tse, D.N.C. (2000) Large System Performance of Linear Multiuser Receivers in Multipath Fading Channels. *IEEE Transactions on Information Theory*, **46**, 2059-2078. https://doi.org/10.1109/18.868478

[11] Zhang, J.H., Dziong, Z., Gagnon, F. and Kadoch, M. (2009) Multiuser Detection Based MAC Design for Ad Hoc Networks. *IEEE Transactions on Wireless Communications*, **8**, 1836-1846. https://doi.org/10.1109/t-wc.2008.071449

[12] David, N., Tse, C. and Hanly, S.V. (1999) Linear Multiuser Receivers: Effective Interference, Effective Bandwidth and User Capacity. *IEEE Transactions on Information Theory*, **2**, 641-657.

[13] Tony, O. and Arne, S. (1998) On Schemes for Multirate Support in DS/CDMA Systems. Technical Report. Technical Report No. 14.

[14] Wang, Y. (2011) TDMA-Based MAC Protocols for Vehicular Ad Hoc Networks. *IEEE Communications Surveys & Tutorials*, **4**, 560-578.

[15] Shen, Z., Zhang, X., Zhang, M., Li, W. and Yang, D. (2017) Self-Sorting-Based MAC Protocol for High-Density Vehicular Ad Hoc Networks. *IEEE Access*, **5**, 7350-7361. https://doi.org/10.1109/access.2017.2692254

[16] Jayaraj, V., Hemanth, C. and Sangeetha, R.G. (2016) A Survey on Hybrid MAC Protocols for Vehicular Ad-Hoc Networks. *Vehicular Communications*, **6**, 29-36. https://doi.org/10.1016/j.vehcom.2016.09.003

[17] IEEE (1997) IEEE Standard for Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications.

[18] Blaszczyszyn, B., Muhlethaler, P. and Toor, Y. (2009) Performance of MAC Protocols in Linear Vanets under Different Attenuation and Fading Conditions. 2009 12*th International IEEE Conference on Intelligent Transportation Systems*, St. Louis, 4-7 October 2009, 1-6. https://doi.org/10.1109/itsc.2009.5309672

[19] Cao, S. and Lee, V.C.S. (2016) Improving Throughput of Multichannel MAC Protocol for Vanets. 2016 *IEEE International Conference on Vehicular Electronics and Safety* (*ICVES*), Beijing, 10-12 July 2016, 1-6. https://doi.org/10.1109/icves.2016.7548163

[20] Almalag, M.S., Weigle, M.C. and Olariu, S. (2013) MAC Protocols for VANETs. In: *Mobile Ad Hoc Networking*: *Cutting Edge Directions*, Wiley, 599-618. https://doi.org/10.1002/9781118511305.ch17

[21] Eze, E.C., Zhang, S. and Liu, E. (2014) Vehicular Ad Hoc Networks (VANETs): Current State, Challenges, Potentials and Way forward. 2014 20*th International Conference on Automation and Computing*, Cranfield, 12-13 September 2014, 176-181. https://doi.org/10.1109/iconac.2014.6935482

[22] Park, S. and Kim, N. (2012) Design of MAC Algorithm Supporting Adaptive Transmission Rate on VANET. *Journal of the Institute of Electronics Engineers of Korea*, **49**, 132-138. https://doi.org/10.5573/ieek.2012.49.11.132

[23] Proakis, J.G. (2001) Digital Communications. 4th Edition, McGraw-Hill.