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Advancements in Machine Learning Techniques for Enhanced Resource Management in VANET Communication: A Comprehensive Survey

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Abstract- *The expansion of the Internet of Things in the form of autonomous vehicles and Vehicular Ad Hoc Networks (VANETs) necessitates methodical resource management to guarantee dependable and smooth communication between vehicles and infrastructure. The employment of machine learning algorithms, as a remedy to challenges associated with resource allocation and optimization in VANETs, has been on an upsurge. This survey paper provides an extensive review of emerging works aimed at applying machine learning approaches in improving resource management for VANET communications. The paper is divided into several sections that present particular aspects about Machine Learning including supervised learning, unsupervised learning, and reinforcement learning. There are also certain areas where these methods have been applied such as dynamic spectrum access, congestion control, routing optimization, quality-of-service provisioning etc. This survey is expected to be useful for researchers who wish to get an understanding about how machine learning can enhance resource management in VANET communication system.*

Keywords—Vehicular Ad Hoc Network, VANET, Ad-hoc On-Demand Distance Vector (AODV)

I. INTRODUCTION

Vehicular ad hoc networks (VANETs) started as a potential technology that facilitates the connection of vehicles and infrastructure with different applications like traffic management, safety warnings, and infotainment services. Nevertheless, managing resources efficiently in order to overcome such challenges is not easy due to decentralization and dynamism of VANETs thereby making it difficult for traditional methods to cope with fast-changing and unpredicted vehicle environment. Therefore, there’s a need for innovative solutions that can improve communication reliability and performance given the traditional approach struggling in this area.

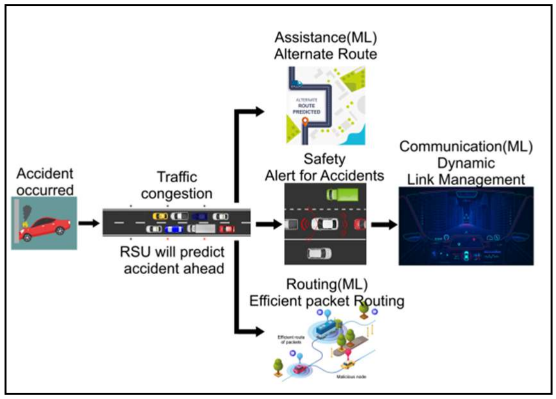


Fig 1.1 Process flow of VANET based applications

Recently, machine learning techniques have become popular as an important solution to these issues and also help in resource management optimization of VANETs. Machine learning algorithms are ideal for enhancing resource management within various VANET solutions because they learn patterns from data which enables them make better decisions.

Moreover, when it comes to resource management in VANETS, supervised learning approaches like neural networks or decision trees have been employed to classify traffic conditions, while unsupervised learning methods like clustering and anomaly detection have been utilized for identifying network anomalies and optimizing resource allocation. Moreover, reinforcement learning approaches enable vehicles to learn optimal communication strategies through interaction with the environment, leading to adaptive and self-optimizing VANET communication systems.

The purpose of this survey paper is to sum up the most recent developments in converting machine learning methods for improving resource management in VANET communication. Through systematic categorization and analysis of the existing literature, we intend to clarify the sorts of machine learning techniques used, their roles in VANETs, and what problems they may pose as well as opportunities. The research hopes to improve the knowledge of implementing ML techniques to enhance VANET performance especially with respect to resource allocation using this novel technology so that other people can have a look at it and build on it later.

II. REVIEW OF LITERATURE

Resource allocation in (VANETs) Vehicular Ad Hoc Networks has been a subject of extensive research due to the dynamic and challenging nature of vehicular environments. However, in VANETs, the traditional methods are often unable to cope with high levels of dynamism and that is why researchers are now exploring new techniques such as machine learning. The conventional resource management for vehicle network requires computation by a central controller which also allocates resources. However, the networks are very dynamic so it may take time before all information is sent to the central controller for policy optimization resulting in short term allocation policies and delays. This leads to higher communication overhead and additional communication time. Moreover, this process takes time leading to changes in network topology that shorten policy validity periodsConsequently, there is a growing need for decentralized resource allocation mechanisms. A decentralized deep reinforcement learning (RL) algorithm has been developed for Vehicle-to-Everything (V2X) communication, where each vehicle calculates and optimizes band and radio power levels for channel sharing via both Vehicle-to-Infrastructure (V2I) and Vehicle-to-Vehicle (V2V) links. Additionally, researchers have explored leveraging enabling technologies such as Mobile Edge Computing (MEC) and Software-Defined Networking (SDN) to achieve a distributed network structure. Machine learning methods have been investigated to address challenges in these enabling technologies, such as intelligent offloading tasks in MEC systems. Similarly, network slicing, which can benefit V2X systems with heterogeneous Quality of Service (QoS) requirements, presents challenges for further research, including service provisioning. In summary, there are ample opportunities for exploration in distributed V2X systems empowered by next-generation mobile networking technologies.

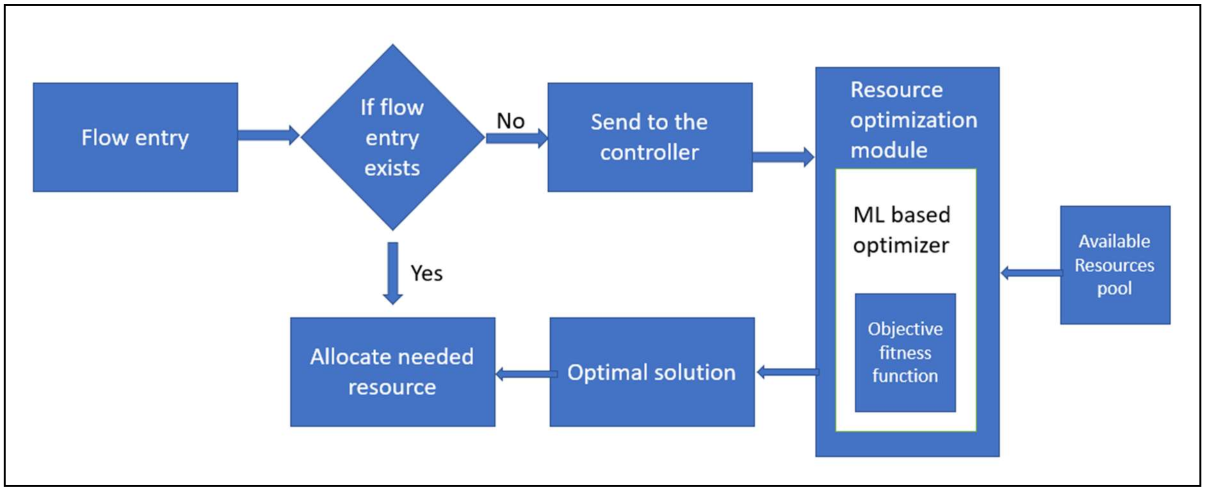
One of the important thing regions in which gadget mastering strategies had been implemented is in dynamic spectrum get admission to (DSA) for VANETs. Liang et al. [3] proposed a reinforcement getting to know-primarily based method for spectrum allocation in VANETs, wherein cars research most desirable spectrum get right of entry to techniques via interplay with the surroundings. The take a look at established stepped forward spectrum usage and decreased interference by using dynamically allocating spectrum resources based totally on vehicular site visitors' styles and channel situations. Another vital factor of resource management in VANETs is congestion control. Machine learning techniques have been applied to expect and alleviate congestion in vehicular networks. For instance, Khan et al. [4] hired a help vector machine (SVM) classifier to are expecting traffic congestion in VANETs based totally on vehicular speed and density. By proactively rerouting vehicles away from congested areas, the proposed approach efficaciously decreased packet loss and progressed community throughput. Routing optimization is every other place where system learning techniques have proven promise in improving resource management in VANETs. Song et al. [5] proposed a deep reinforcement studying-based totally routing algorithm for VANETs, wherein motors examine greatest routing techniques via trial and blunders. The observe established enhanced packet delivery ratio and decreased cease-to-cease delay in comparison to conventional routing protocols, highlighting the effectiveness of reinforcement gaining knowledge of in optimizing VANET routing. Furthermore, gadget mastering techniques were carried out to first-rate-of-provider (QoS) provisioning in VANETs. Zhang et al. [7] proposes a gadget studying-primarily based method for dynamic useful resource allocation in VANETs. The authors make use of a combination of supervised and reinforcement getting to know techniques to optimize spectrum usage, mitigate interference, and improve overall network performance. Through the knowledge of optimal resource allocation strategies from the environmental feedback, vehicles autonomously modify the communication parameters to the maximum possible extent, thus the network performance is improved, which results in a better reliability and efficiency in the vehicular environment. In conclusion, the application of machine learning methods in VANET communication systems seems to be a great opportunity for the improvement of resource management. In this way, the machine learning models can use the historical data and the real-time data to distribute the resources, to forecast the traffic patterns, to optimize the routing and to provision the QoS to enhance the network efficiency and reliability in dynamic vehicular environments.

III. CLASSIFICATION OF MACHINE LEARNING ALGORITHMS FOR RESOURCE

Management in VANETs: Machine learning algorithms are the core of the resource management in Vehicular Ad-hoc Networks (VANETs). The mechanisms that aid in the optimization of VANET communication, such as dynamic spectrum access, congestion control, routing optimization, and quality-of-service provisioning are the algorithms used for these purposes. Here, we classify machine learning algorithms suitable for resource management in VANETs based on their characteristics and applications: Here, we classify machine learning algorithms suitable for resource management in VANETs based on their characteristics and applications:

1. Supervised Learning Algorithms: Supervised learning algorithms are the ones that are trained by the labeled data to make predictions or decisions. In the context of VANET resource management,

Figure 1.2 Machine learning-based optimization high-level view for resource allocation.



supervised learning algorithms are employed for tasks such as: a) Traffic Prognosis: Traffic prognosis which involves the prediction of traffic patterns and congestion levels using historical data and external factors like weather conditions and special events. b) Quality-of-Service Prediction: Network performance metrics for instance, latency, packet loss, and throughput are predictable and thus the resources are allocated to be according to the QoS and to optimize it. c) Spectrum Allocation: Planning the spectrum bands and choosing the best frequencies for the communication is a way of predicting the available spectrum bands and selecting the most suitable ones to reduce the interference and to maximize the bandwidth utilization.

2. Unsupervised Learning Algorithms: It is the algorithms which are left to work on their own to find the patterns and structures in unlabeled data without any direct instructions. In VANET resource management, unsupervised learning algorithms are applied for tasks such as: Cluster Analysis: the cars are grouped according to their spatial and temporal closeness to each other so as to find the traffic hot spots and the congested roads. b) Anomaly Detection: Detecting the abnormal behavior or the events in VANETs, which are the malicious activities or the sudden changes of traffic flow, is what constitutes identifying abnormal behavior or events in VANETs. c) Resource Allocation: The system of resource allocation that is not static, but depends on the state and demand of the network, as well as the bandwidth, power, and spectrum, that is, basing on the actual network condition and demand without the training data. Examples of Unsupervised Learning Algorithms: K-means Clustering, Hierarchical Clustering, Density-Based Spatial Clustering of Applications with Noise (DBSCAN), Isolation Forest, Autoencoders are the most popular methods for anomaly detection in the field of Artificial Intelligence.

3. Reinforcement Learning Algorithms: Reinforcement learning algorithms, on the other hand, allow an agent to learn the best actions by the means of interaction with the environment and the feedback which consists of the rewards or the penalties. In VANET resource management, reinforcement learning algorithms are utilized for tasks such as:

a) Routing Optimization: The transfer of data should be made by adaptive routing strategies that dynamically select the most efficient paths based on the current network conditions.

Table 1: Classification of covered work utilizing ML methods with algorithm summary

b*) Spectrum Management:* Adapting the spectrum access policies and transmission parameters to maximize the network throughput while at the same time minimizing the interference. Examples of Reinforcement Learning Algorithms: Q-learning, Deep Q-networks (DQN), Policy Gradient Methods, Actor-Critic Methods, PPO.

IV. Role of Machine Learning in Spectrum Sensing and Allocation:

1. Congestion Control: The traffic caused by vehicle-to-vehicle (V2V) communication networks is the main reason for the congestion, therefore the reliability of the communication is reduced, the traffic efficiency is decreased and the whole network performance will be affected. The VANETs, due to the fact that they are constantly changing, therefore traffic density, road conditions, and network topologies are all changing rapidly, hence the congestion problem is even worse. Among the other disadvantages of congestion, the loss of packets, the increase of latency, and the communication delays can be found. These problems hinder the development and the effectiveness of vehicular safety applications and other services that depend on VANET communication.

2. Routing Optimization: The reconstruction of the routes is the key issue in the Vehicular Ad-hoc Networks (VANETs) to make the communication between the vehicles and the infrastructure components efficient and reliable. The VANETs characteristics which are mainly the rapid changing of network topologies, high mobility, and the traffic conditions that are changing so fast, require us to use the routing protocols that are robust enough to adapt to dynamic environments and at the same time to minimize the communication overhead.

3. Learning-Based Traffic Pattern Recognition: Machine learning algorithms are able to learn from the past traffic data to find the patterns that recur and the areas that are known for the traffic congestions. Through the recognition of the possible congested areas in advance, the machine-learning-based routing protocols can beforehand reroute vehicles to the areas that don't hold congested and at the same time the traffic will be distributed onto the alternative routes.

Application Category	**Task**	**Utilized ML algorithms**	**Core ML method utilized**	**Open challenges specific to V2X**
Mobility Management	Mobility Prediction	Probabilistic models, NNs	Supervised Learning	Accurate but fast future position prediction required to support other predictive tasks

	Handover Optimization	Q-learning. Fuzzy Q-learning, Ulti-armed bandits, Support Vector Machine(SVM), NNs,K-nearest Neighbors(K-NN)	Supervised Learning RL	Seamless handover required with handover time restriction due to high mobility
Routing	Routing decision, user association	Kernel-based learning NNs, Q-learning, user association Multi-armed bandits	RL	Routing in vehicular HetNet according to differentiated QoS requirements
Resource Management	Channel, power, and joint radio resource management Computing Management	Q-learning, Convolutional Supervised Learning RL NN (CNN), Deep Q-learning	Supervised Learning RL	Resource allocation based on differentiated QoS requirements; System architecture design;
Energy Efficiency	Base station switch off	Q-learning, Heuristic	RL	Algorithmic scheduling optimization at a regional central control or on an individual gateway device-level; Large-scale system combining infrastructure with EV real-world deployable ML. methods
	Infrastructure and/or Electric Vehicle (EV) energy efficiency through scheduling	Q-learning. Deep Q-learning		

4. Quality-of-Service Provisioning: QoS provisioning is the necessary thing in VANETs to facilitate the reliable and efficient communication, especially for the applications which are safety-creditable and multimedia services. Serving as the qualitative parameters like the latency, packet loss, throughput, and reliability, QoS parameters influence the performance and effectiveness of VANET applications directly. Thus, the QoS provisioning is very important for the assurance of the user experience and the support of the different communication aims in the

VANETs. Courts found that in most minimal drinking cases far less than direct harm was shown, which discloses that such anomalous drinking can be an individual altitude. Safety Applications: Quality of service is the most important thing for the applications that are really important for VANETs, like the systems that help to avoid crashes and the emergency messages between the vehicles. These applications demand the low-latency and high reliability communication to guarantee the timely and the accurate information exchange between the vehicle and the infrastructure components

V. OPEN RESEARCH CHALLENGES:

Vehicular Ad-hoc Networks (VANETs), through the use of Machine learning, can be efficiently managed, hence, the machine learning is a great tool for the management of resources in VANETs. Still, a number of problems are facing the way in which it is applied and its efficiency in the field.

1. Data Heterogeneity: VANETs are generating a large and changing data streams of diverse kinds such as the vehicular mobility patterns, traffic conditions and environmental factors. The combination and processing of the different data from various sources are the main problems that the machine learning algorithms encounter when they are trying to build and predict the behavior of the network.

2. Limited Training Data: The problem of the lack of labeled training data for machine learning models in VANETs is tough to overcome since there are very few real-world datasets and the cost of data collection is high. The scarce training data can be the obstacle for the performance and the generalization of machine learning algorithms in the management of VANET resources.

3. Complexity of Vehicular Environment: The vehicle environment is always changing and unpredictable. This means that the network topology, traffic densities and communication dynamics are always in a constant state of flux, which machine learning algorithms find challenging to adapt to new conditions and also to make decisions at an emergency situation.

Issues Such as Scalability, Security, and Real-Time Processing**:**

*1. Scalability***:** Certain projects and interests are only solved in a classroom atmosphere, thus hindering the students' ability to improve and obtain knowledge that they cannot produce elsewhere on their own. Scalability: Scalability is a big issue in the use of machine learning in VANETs, especially when it is about the large-scale deployment with a lot of vehicles and infrastructure elements. The main issues related to scalability, such as the efficient distribution of computation and communication tasks, and the optimization of resource utilization in resource-constrained environments, are mentioned above.

2. Security: Security in VANETs is very crucial to ensure against the possible malicious attacks, privacy breaches, and the unauthorized access to the sensitive information. The specialists in the field of machine learning should take into account the difficulties that are related to adversarial attacks, data poisoning, and model vulnerabilities in order to ensure the reliability and the protection of the communication of the VANET.

3. Real-Time Processing: Real-time processing is indeed the key to a well and timely decision-making and the rapid and efficient response for VANET resource management. Machine learning algorithms should be able to cope with the stringent latency requirements and work efficiently in resource-limited environments in order to support real-time applications like collision avoidance and emergency response.

VI. OPPORTUNITIES FOR FUTURE EXPLORATION:

1. Dynamic Resource Allocation and Optimization: Afterwards, the research can go on to the development of the modern machine learning algorithms for the dynamic resource allocation and the optimization of the VANETs. These algorithms should be able to adjust the communication parameters, such as spectrum access, power control, and routing decisions, in real-time, depending on the network conditions and the traffic dynamics to ensure that the resources are used in the best possible way and the quality of service is provided. 2. Edge Computing and Distributed Learning: There is a chance to investigate the use of edge computing and distributed learning techniques with machine learning for decision-making and distributed resource management in VANETs. 3. Blockchain for Secure and Decentralized Communication: Blockchain technology is suitable for improving security, privacy, and trust in VANET communication. Later researches can study the combination of blockchain with machine learning techniques for the safe and decentralized data sharing, authentication and access control in VANETs. 4. Collaboration between Academia, Industry, and Policymakers: The Necessary, collaboration opportunities between the academia, industry, and the policymakers are of great importance in the development of VANET communication and in solving the real-world issues. 5. Interdisciplinary Research and Innovation: Future exploration in the VANET resource management by means of machine learning should be carried out in a multidisciplinary spirit, involving collaboration from different fields, such as computer science, engineering, transportation and data analytics.

VII. CONCLUSION:

Thus, this research has given us the key information about the role of machine learning in developing resource management in Vehicular Ad-hoc Networks (VANETs). Main findings suggest that the usual methods are not suitable for the changing network conditions, scalability issues, and resource utilization is not optimal. Necessity is the mother of invention and the development of intelligent devices demanded the use of computerized information of the invention. The use of machine learning in VANETs can result in the intelligent allocation of resources, proactive congestion control and the optimal Quality-of-Service provisioning. Clearly, the machine learning has the ability to change VANET communication, to make the communication more reliable, and to improve the users' experiences. Thus, an appeal to do more research and to come up with new ideas is needed in this fast-changing field. The experts, industry partners, and policymakers are advised to move forward with the development of algorithms, develop new technologies, collaborate across disciplines, and take advantage of the standardization efforts to achieve the full potential of machine learning in VANET resource management and reach the next level of intelligent and adaptive vehicular networks.

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