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Energy Efficient and Throughput Oriented Route Optimization Models in the Internet of Vehicles: A Survey

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ABSTRACT

The Internet of Vehicles (IoV) has emerged as a promising paradigm that integrates vehicles, communication technologies, and the Internet to foster intelligent transportation systems. To fully exploit the potential of IoV, efficient route optimization models are crucial to optimize energy consumption while ensuring high throughput. This survey paper aims to provide a comprehensive analysis of existing research on energy-efficient and throughput-oriented route optimization models in IoV. The primary objective of this survey is to categorize and evaluate various route optimization techniques that focus on enhancing energy efficiency and throughput in the IoV context. We present a systematic review of literature, encompassing academic papers, conference proceedings, and technical reports up to the time of this research. By examining the state-of-the-art approaches, we identify the underlying principles, strengths, and limitations of each method. The survey first delves into the foundational concepts of IoV and their significance in modern transportation systems. We elucidate the challenges faced in IoV route optimization concerning energy consumption, data transformation, bandwidth contention, and network congestion. In the main body of the survey, we classify existing route optimization models based on their energy efficiency and throughput-oriented objectives. The energy-efficient category encompasses methodologies that aim to minimize a node's energy consumption and extend its battery life, considering factors such as the routing process involved (massage broadcasting and rebroadcasting), link state, and traffic flow patterns. On the other hand, the throughput-oriented category focuses on maximizing information transformation and ensuring low latency during operational time. Furthermore, we identify open challenges and research gaps in the field of energy-efficient and throughput-oriented route optimization for IoV. These gaps pave the way for future research directions, which can lead to the development of more robust, scalable, and adaptive routing solutions. By evaluating the strengths and weaknesses of various approaches, we aim to inspire researchers, engineers, and entrepreneurs to develop innovative solutions that enhance energy efficiency, maximize throughput, and foster the realization of a smarter and more sustainable transportation ecosystem.

Keywords:

Internet of vehicles; Reinforcement learning; Machine learning; Routing; Throughput

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1. Introduction

The Internet of Vehicles (IoV) represents a revolutionary paradigm that amalgamates cutting-edge information and communication technologies with modern transportation systems [1]. At its core, IoV envisions a highly interconnected network where vehicles, road infrastructure, and various smart devices collaborate seamlessly to enhance the overall efficiency of transport systems [2]. This interconnectedness enables vehicles to communicate with each other (V2V), with infrastructure (V2I), and with the internet (V2X), facilitating the exchange of real-time data and information. Such data exchanges empower vehicles with enhanced situational awareness, enabling them to make informed decisions, avoid potential hazards, and optimize their routes dynamically [3].

In modern transportation systems, the significance of IoV lies in its potential to revolutionize road safety, traffic management, and overall mobility [4]. By leveraging IoV technologies, vehicles can detect and respond to critical events much faster than conventional systems, reducing the risk of accidents and fatalities significantly [5]. For instance, through V2V communication, vehicles can share information about their speed, position, and intentions, enabling them to anticipate and avoid collisions in complex traffic scenarios. Additionally, IoV facilitates advanced driver assistance systems (ADAS) that can automatically brake, steer, or provide warnings to drivers, mitigating the impact of human error on road safety [6]. Moreover, the data generated and collected through IoVs enables sophisticated traffic management strategies [7]. Traffic authorities can leverage real-time information to analysis traffic flow, identify congestion hotspots, and deploy dynamic traffic control measures to optimize the overall traffic flow. This not only reduces travel time for individual commuters but also contributes to reduced fuel consumption and emissions, leading to a more sustainable and eco-friendly transportation ecosystem [8]. Furthermore, IoVs play a pivotal role in enabling the development and implementation of smart mobility services [7]. Ridesharing, carpooling, and automated fleet management systems can be efficiently orchestrated through IoVs, optimizing resource utilization, and reducing the overall number of vehicles on the roads. As a result, urban congestion can be mitigated, and cities can pave the way for more pedestrian-friendly spaces and greener urban environments [9].

The advent of autonomous vehicles is another area where IoVs' significance shines. As self-driving vehicles become more prevalent, they heavily rely on IoV technologies to communicate with other vehicles, infrastructure, and pedestrian devices, ensuring safe and coordinated movement [10]. Additionally, IoVs facilitate over-the-air (OTA) updates, allowing autonomous vehicles to receive software upgrades and critical safety patches, further enhancing their capabilities and security [11]. In conclusion, IoVs foundational concepts and their significance in modern transportation systems stem from their ability to foster a highly connected, data-driven, and intelligent mobility ecosystem [12]. By promoting real-time data exchanges and communication among vehicles, infrastructure, and the internet, IoVs have the potential to revolutionize road safety, optimize traffic management, and lay the groundwork for sustainable and efficient transportation [13,14]. As the world moves towards smarter cities and more advanced transportation solutions, IoVs will continue to play a crucial role in reshaping the way we move, commute, and interact with our surroundings [15]. Moreover, the Efficiency of the network depends upon effective communication among participating devices, but in a dense network, communication becomes a serious challenge, which ultimately degrades network performance [16]. Additionally, communication becomes highly important when continuous routing information is required for the mobile network [17], It’s because mobile devices require timely information otherwise it may cause major damage even life loss [18].

Despite its promises, the IoVs landscape is fraught with challenges that pose significant obstacles to its seamless implementation. Among these challenges, routing is one of them.

Routing grasps special attention in this regard, but the realization of an efficient and reliable routing system in IoV is not without challenges, key factors are here. The mobility of vehicles leads to constantly changing network topologies, making it challenging to establish and maintain stable routes [19]. Also, IoV applications often require real-time data transmission, particularly for safety-critical systems such as collision avoidance. Routing aims to Minimize communication latency and packet delay is crucial to ensure timely information dissemination which is crucial one [20]. With the proliferation of connected vehicles, routing solutions must handle a rapidly increasing number of vehicles and data packets efficiently, which becomes cumbersome in highly dense networks. because the main cause associated with routing is its overhead [21]. Routing overhead in IoV refers to the additional data and control packets generated and consumed during the process of routing messages between vehicles and infrastructure [22]. As vehicles move dynamically and frequently change their positions, traditional routing protocols may face difficulties in maintaining up-to-date and efficient routes. The constant exchange of routing information imposes a burden on the communication network, leading to increased latency, reduced bandwidth, and congestion, which can undermine the effectiveness of IoVs applications. This overhead has a direct impact on the degradation of network throughput and heavy utilization of energy resources unnecessarily (wastefully). Proactive, reactive, Hybrid Routing Protocols, and Machine Learning-Based Routing algorithms are some possible solutions to address routing challenges. Despite its potential, the IoV ecosystem is susceptible to throughput degradation, which can significantly impact the reliability and performance of critical applications. Several key factors contribute to this degradation are the growing number of connected vehicles and the vast amount of data generated resulting in network congestion, causing delays and packet loss in data transmission. In some advanced and traditional routing protocols' complex implementation architecture, communication overhead is created which is the major cause of throughput degradation. Limited operating bandwidth and network congestion are other parameters that cause degraded network performance. Suitable implementations of protocols are required to gain high throughput.

While the IoV holds the promise of transforming mobility and transportation, it also presents several energy efficiency challenges that need urgent attention, which are presented here,

With the integration of sophisticated technologies and continuous data exchange, IoV leads to increased energy consumption in vehicles [23]. Connected vehicles require a continuous power supply to maintain communication, process data, and support advanced features, impacting overall fuel efficiency and vehicle range for electric vehicles [24]. The processing and communication of vast amounts of real-time data in IoV demand considerable computational power and communication resources. This data overhead places an additional burden on the vehicle's energy resources, potentially leading to higher energy consumption [25]. Seamless IoV operations require robust and reliable network connectivity. However, maintaining network coverage across vast geographical areas can be challenging, leading to signal losses and energy inefficiencies when vehicles struggle to establish and maintain connections [26]. The integration of emerging technologies, such as autonomous driving and edge computing, adds complexity to IoV systems. Ensuring their energy-efficient implementation becomes crucial to maximize the benefits of these technologies while minimizing their environmental impact [26]. To address the energy efficiency challenges of IoV and ensure its sustainable growth, various potential solutions must be explored, which are here. Power Management Strategies (Implementing intelligent power management strategies that optimize energy consumption based on the node's operational requirements can significantly enhance energy efficiency.), Energy-Aware Communication Protocols (Developing energy-aware communication protocols that prioritize critical data and minimize unnecessary data transmissions can reduce the energy overhead in IoV systems.)

The Internet of Vehicles holds immense promise for transforming transportation systems into safer, more efficient, and interconnected networks. However, addressing the challenges associated with IoVs is essential to unlock its full potential. Implementing suitable routing protocol and method as per scenario, controlling flooding, and minimizing communication and computational overhead are the possible solutions outlined in this research seek to pave the way for a seamless and secure IoVs ecosystem, ultimately improving the overall driving experience and fostering a more sustainable transportation future.

In this paper, we present a survey of various routing approaches for IoVs. We try to cover most routing techniques and group them into three major categories. The primary goal is to present an in-depth analysis of route protocols and methods used in IoVs for routing optimization, with a focus on contributions and lessons learned for future research. Our survey aims to explore specific routing applications and why routing protocols and models have become such an important factor in improving network throughput and used to enhance network lifetime). Other surveys have a more generalist approach (centralized focusing on logic and implementational scenarios and providing an overall idea).

In essence, this survey includes the following contributing factors:

i. It offers a thorough overview of IoVs, routing, and route optimization techniques, conducted by a team of researchers with experience in a variety of fields, which enhances the analysis.
ii. It provides a qualitative analysis of routing techniques as a starting point for new researchers in this field, based on the context of the scenario that needs to be examined and the desired applications.
iii. It organizes the most recent works concerning the survey according to three main categories of routing (proactive, reactive, and Machine learning base).
iv. All works are analysed and compared, including the techniques used, their unique objectives (since they are all centred on routing), their implementation and evaluation, and their advantages and disadvantages. A summary of the research trends and lessons learned follows this analysis.
v. This survey includes a comprehension section for future researchers and gives directions as well, which shows there is still much work that needs to be done in the field to make it relevant in the long term.

2. Methodology

For manuscripts, The Google Scholar website was primarily used for state-of-the-art search because it completely indexes work (articles, patents, etc.) from various journals, websites, and even archive repositories. The three key terms concerning the survey were routing, optimum routing, energy efficiency, and throughput, we also searched for proactive network lifetime, high packet delivery ratio, proactive routing, reactive routing, machine learning (ML), supervised learning (SL), unsupervised learning (US), and reinforcement learning (RL). In addition, we looked at the closest related works and assessed the contributions of our survey using a survey, overview, and tutorial. Most of the works were released in the last five years. Most works were published during the last three years.

We culled the results directly related to our analysis from thousands of results, the majority of which were published within the last two to three years. With an exponential rise in the use of reinforcement learning-based approaches over the past two years, the growth of publications was particularly pertinent during this time. Since English was the most popular language, we applied filters based on the number of citations to evaluate the most cited articles first. We also paid special attention to articles published in reputable journals (preferably those indexed in JCR).

To find additional pertinent works, we also carefully examined the references of the articles that had already been chosen for the survey.

3. Related Work

3.1 Proactive Routing Approaches

Proactive routing protocols play a vital role in maintaining efficient communication in computer networks by establishing and maintaining routing tables ahead of data transmission in the proactive routing protocol, every node individually maintains a routing table for its neighbours. These tables required regular updating to maintain up-to-date routing information from every node to all other nodes. Optimized Link State Routing (OLSR), Destination-Sequenced Distance Vector (DSDV), Cluster-Based Routing Protocol (CBRP), Wireless Routing Protocol (WRP), Fish-Eye State Routing (FSR), Topology Broadcast based on Reverse-Path Forwarding (TBRPF) are common routing protocols which are using to handle specific challenges.

In the category of proactive protocols [27] purposed. Multi-hop Cellular Networks (MCN) provide connectivity for single as well as for multi-hop communication. The author suggested its application even for hotspot environments like the stock market, stadium, etc. It uses the same frequency band for single as well as multi-hop users. Despite these benefits, MCN faced a few challenges the same data packet was sent twice (one for the single-hop and the other for the multi-hop) which was a waste of transmission power, reception, and computation. Therefore, MCN is not a resource-efficient algorithm since it requires more resources especially the energy of the node to achieve moderate throughput. Another issue is that when the network becomes dense, more and more data packets flood into the network, which causes it to congest the network. Congestion introduces delay into the network, which further compromises the network performance. Mobility is also a critical issue of MCN because mobility causes disturbance routing of the nodes frequently. Furthermore, routing required many resources, which degraded the throughput of the network.

To constrain the resources, [28] proposed Base-Centric Routing (BCN) which uses a centralized proactive approach. B2S maintains a routing table and provides smart routing information for requesting nodes which is under its coverage. Additionally, near and far users can be handled simultaneously, which improves the BS user handling capacity. Along with these advantages, BCN also faced a few advanced challenges. Each BS can efficiently handle the number of nodes. When the network becomes congested and exceeds that limit, then the routing table becomes larger. To find routing information into a larger table requires more time which is the cause for an extra delay in the network (network scalability issue). Furthermore, the same MCN data packet is sent twice into the network (for remote and near nodes). Every node in close vicinity received two times more packets than edge nodes. Nearby located nodes receive both types of packets and utilize more resources, hence they waste more resources. Another critical challenge is that when a failure occurs in BS, then the entire network chokes (single point of failure).

In [29] proposed a Cellular Based Multi-hop Network (CBMN) that efficiently handles the traffic and provides scalable connectivity for those nodes that are under the coverage of cellular BS. Also same as CBR, CBMN maintains a routing table in BS to avoid computational burden from an individual node. Moreover, CBMN used two transceivers (one for data and one for control packets), which are used to provide high network throughput and maintain routing information at the same time. Along with these mentioned benefits, CBMN also faces few challenges. Each node receives two packets (data and control) all the time, they separately handle these packets irrespective of whether these packets are related to them or not. These processes consume all their resources when these packets are not related to them. Due to BS-centric architecture, network congestion becomes a major issue, and BS is unable to handle that situation. Moreover, in this routing algorithm when BS failed whole the network failed (single point of failure).

3.1.1 Advantages

1. Simple and fast routing with state-forward implementation
2. High route accuracy for a small network
3. Energy efficient, scalable routing, with high throughput in static network deployment

3.1.2 Disadvantages

1. Mobility management can cause routing overhead.
2. Memory saturation occurs in a congested network.
3. Low throughput, high packet drops ratio, more delay, and heavy energy consumption are observed under large-scale mobile networks.

3.2 Reactive Routing Approaches

In [30,31] authors proposed an Ad hoc On-demand Distance Vector (AODV) which was originally proposed in AODV and used routing protocol to enhance the throughput of the network. AODV maintains current route information in its routing table. Also, each routing entry needs to be updated periodically. When any entry is not updated within the expiration time, that entry is removed from the table. So, when data is required to be sent, the source node checks its routing table if a route is found and then otherwise finds a route using a reactive approach. In this way, the AODV protocol performs well when the network is not dense and nodes have low mobility. In that scenario, it provides high throughput by reducing control packets. Also, it selects the shortest path which avoids data path loss and improves the packet delivery ratio. Moreover, it reduces control overhead and uses the shortest path, which leads to improving energy efficiency. Despite these advantages, AODV faced a routing overhead challenge due to the mobility of nodes in dense networks. When the network becomes dense, the routing table requires more control packets which makes the table large and also spends more time on table updating. Meanwhile, when the mobility of nodes increases then the probability of routing table maintenance, updating, and routing finding also increases, which consumes many resources in that scenario.

Dynamic source routing protocol (DSR) was proposed by [32] which also belongs to the category of reactive protocols. Since the initial proposal of DSR in 1996, it has gone through many variations. In DSR when routing is required it creates a route discovery process and only active nodes respond and remain active when required otherwise remain in sleep mode. In this way, DSR is an energy-efficient protocol that minimizes the energy of nodes and networks as well. DSR can be implemented for multi-hop communication in a dense network. The mobility of nodes also does not have much effect on the performance of the network. Besides these benefits, when the network becomes so dense DSR faces the challenges of bandwidth congestion, delay, and low throughput.

To maximize the network throughput in an energy-efficient manner, [33] proposed Energy Efficiency and Achievable Data Rate of Device-to-Device Communications in Cellular Networks (EEDR). In this protocol based on the destination node, by using a reactive routing approach suitable communication mode is used which improves network throughput. Also, near-node transmission power can be reduced, and using BS for multi-hop communication saves the nodes' energy consumption. Along with these benefits, many challenges also degrade network performance. Also using three different communication modes makes the implementation so complex. So, in dense more and more control packets flood into the network which congests the network. Furthermore, when the mobility of nodes increases suitable mode selection and communication create overhead which also degrades the network throughput and uses more energy.

3.2.1 Advantage

i. Can provide high coverage in large-scale networks by using multi-hop communications.
ii. Efficiently hand Mobility up to 15 m/s.
iii. Provide scalable and smart routing under medium and moderate-level mobile networks.

3.2.2 Disadvantage

i. For fast and random mobile devices, routing can cause routing overhead.
ii. Frequent use of the route discovery process can cause resource consumption, moreover, delay and packet drop increase at an exponential rate.
iii. Relatively Complex implementation for smart devices having limited computation power.

3.3 Machine Learning Based Approaches

Scientists initially explained ML methods as a tool for creating predictive models for IoVs. However, numerous applications showed that ML is a rich field that should be understood by those looking to apply it to IoVs to reap the greatest rewards. The use of ML techniques in IOVSs and IoT aims to address a variety of problems and provides enormous benefits in terms of flexibility and accuracy. We describe the need for and impact of ML in IoVs in this section.

Due to the massive number of wireless sensor nodes that are deployed at random in IoVs, designing a network requires considering several crucial factors, including topological deviations, communication link failures, memory limitations on sensor nodes, limited computational capabilities, and distributed management. ML techniques have been successfully used to address several IoVs-related problems, including network delay, traffic congestion by applying prediction methods, smart mobility management by clustering principle, minimizing flooding situations in the network, smart energy conservation strategies, and mitigating routing overhead, also provides a broad summary of the various IoVs challenges that are resolved using ML techniques.

To increase the quality of the service, these difficulties must receive special consideration. By 2025, there will be more connected objects, which raises several challenges that need to be considered [34], including scalability, energy efficiency, security and privacy, smart network management, and long-range communication networks, especially for edge nodes, interoperability, and conglomeration, network overload, and congestion, QoS, and network mobility and coverage [35]. Most of these issues can be solved on a large scale by using machine learning (ML), which also provides benefits to the network. For humans to comprehend and recognize various parameters, such as a voice, a person, an object, and others, learning is a necessary activity. One typically makes a distinction between learning that entails memorization of data and learning by generalization in which we typically construct a model from learned examples to recognize new examples and scenarios [36-39]. For the machines, handling a lot of data is simple, but creating a good model that can accurately identify new objects in a new test is challenging. ML is an effort to comprehend and mimic this learning capability in a synthetic system. Therefore, it would seem appropriate to use methods from this field to find knowledge, model it, and close the semantic gap [40]. ML is a field that straddles several disciplines, including signal and information processing, probability theory, cognitive science, statistics, artificial intelligence, and statistics. Giving a taxonomy of machine learning categories is therefore extremely difficult.

4. Conclusion

This survey clarifies the important factors for improving the functionality and sustainability of vehicular networks. The Internet of Vehicles (IoV) is a paradigm shift that connects vehicles and the Internet to enable seamless communication, data exchange, and wise decision-making. However, the demand for real-time data transmission and the exponential growth of vehicle traffic necessitates effective route optimization methods that balance energy conservation and throughput maximization. Through this survey, we have investigated many route optimization models made to address the problems the IoV presents. To guarantee the best routing choices, these models make use of cutting-edge algorithms, machine-learning strategies, and communication protocols. Notably, energy efficiency has become a major issue because of the direct effects it has on the environmental footprint and general operating expenses of the vehicular network. Numerous methods for energy-efficient route optimization have been examined, including more established artificial intelligence-based methods like deep reinforcement learning and neural networks, as well as more contemporary approaches like genetic algorithms, ant colony optimization, and particle swarm optimization. These strategies aim to reduce the amount of energy used by vehicles while they are traveling while maintaining dependable and low-latency data transmission. The survey also highlights the importance of throughput-oriented routing in the IoV, which is concerned with maximizing data delivery rates and network capacity. Numerous strategies, including load balancing, multipath routing, and traffic-aware routing, have been investigated to meet the throughput needs of various applications and guarantee a stable and effective vehicular network. For the IoV to reach its full potential, the development of energy-efficient and throughput-oriented route optimization models is essential. We can significantly reduce fuel consumption, greenhouse gas emissions, and overall network efficiency by intelligently optimizing routes. Additionally, the effective application of such models will encourage a sustainable and environmentally friendly transportation ecosystem, which will be advantageous to both society and the environment. Researchers and practitioners must collaborate to improve current models and create fresh strategies that can consider the dynamic and heterogeneous nature of vehicular networks as the IoV continues to develop. To promote seamless communication and cooperation among vehicles, infrastructure, and other IoT devices, standardization, and interoperability should also be given priority.

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