International Journal of Current Research and Applied Studies, (IJCRAS)

ISSN: 2583-6781

available at https://ijcras.com/

Volume 3 Issue 1 Jan-Feb 2024

Page 01-12

IOT-ENABLED AD HOC NETWORKING FOR INTELLIGENT TRANSPORTATION SYSTEMS: CHALLENGES, SOLUTIONS, AND FUTURE DIRECTIONS

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ABSTRACT

The concept of intelligent transportation systems is evolving, with a growing need for automation and effective service delivery. Ensuring the safety and security of travelers on the road has been a significant concern, leading to the exploration of Vehicular Ad Hoc Networks (VANETs) for supporting safety, comfort, and infotainment services. However, VANETs face challenges such as high mobility, intermittent connectivity, and application heterogeneity due to their complex and inflexible architecture. In this context, Software-defined networking (SDN) has emerged as a flexible and programmable network that has garnered attention for wired network management and wireless communication. This paper aims to examine and classify SDN-based research on wireless networks, specifically focusing on VANETs. The research objectives include investigating the integration of Internet of Things (IoT) technologies in ad hoc networking for vehicle networks, identifying challenges and limitations of existing approaches, proposing an IoT-enabled architecture, evaluating performance improvements, showcasing real-world applications, and addressing security and privacy considerations. By accomplishing these objectives, this study aims to contribute to the advancement of intelligent transportation systems by exploring the potential and benefits of IoT-enabled ad hoc networking in vehicle networks. The study provides valuable insights, guidelines, and recommendations for designing and implementing IoT-integrated ad hoc networking solutions, paving the way for more efficient and connected transportation networks of the future.

Keywords: Intelligent Transportation Systems, Vehicular Ad Hoc Networks, Internet of Things.

1. INTRODUCTION

Intelligent Transportation Systems (ITS) play a pivotal role in revolutionizing transportation networks by incorporating advanced technologies to enhance safety, efficiency, and sustainability (Kumar et al., 2019). The emergence of the Internet of Things (IoT) has opened up new possibilities for optimizing vehicle networks and enabling seamless communication between vehicles, infrastructure, and the surrounding environment (Mahmud et al., 2020). By leveraging IoT technologies, ad hoc networking in vehicle networks can be significantly enhanced, leading to improved traffic management, enhanced vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communications, and overall advancements in intelligent transportation systems. The integration of IoT devices and sensors within vehicle networks allows for real-time data collection, analysis, and decision-making. This real-time information can be harnessed for intelligent traffic management systems, optimizing traffic flow, predicting and mitigating congestion, and providing

dynamic routing recommendations (Savolainen et al., 2021). Furthermore, IoT-enabled ad hoc networking facilitates the establishment of communication links between vehicles, enabling the formation of temporary networks for sharing critical information, such as collision warnings, road conditions, and emergency alerts (Feng et al., 2020).

However, the effective deployment of IoT in vehicle networks poses certain challenges. Seamless integration of IoT devices, scalability and resource management, network security, privacy concerns, and ensuring interoperability among various IoT-enabled devices and systems are key factors that need to be addressed (Rashid et al., 2021). Overcoming these challenges is essential to fully realize the potential of IoT in ad hoc networking for intelligent transportation systems. This study aims to delve into the potential of leveraging IoT technologies for enhanced ad hoc networking in vehicle networks within the context of intelligent transportation systems. It provides an in-depth analysis of the intersection between IoT and vehicle networks, highlights the challenges and limitations of current approaches, proposes an architecture for IoT-enabled ad hoc networks in vehicles, evaluates the performance improvements achieved through this integration, and showcases real-world applications and use cases. Additionally, the manuscript discusses the challenges and future directions in this field, outlining areas for further research and development.

Figure 1: IoT in ad hoc networking for vehicles

By exploring the possibilities offered by IoT in ad hoc networking for vehicles, this study contributes to the advancement of intelligent transportation systems and paves the way for more efficient and connected transportation networks of the future, figure 1.

2. Benefits of Intelligent Transportation Systems

Applying information technology to a country's transportation network delivers five key classes of benefits by: 1) increasing driver and pedestrian safety, 2) improving the operational performance of the transportation network, particularly by reducing congestion, 3) enhancing personal mobility and convenience, 4) delivering environmental benefits, and 5) boosting productivity and expanding economic and employment growth. Increasing driver and pedestrian safety Intelligent transportation systems can deliver important safety benefits. There are 1.2 million fatalities annually on the world's roadways. ITS improve the performance of a country's transportation system by maximizing the capacity of existing infrastructure, reducing to some degree the need to build additional highway capacity. Improving the operational performance of the transportation network ITS improve the performance of a country's transportation network by maximizing the capacity of existing infrastructure, reducing the need to build additional highway capacity. Maximizing capacity is crucial because, in almost all countries, increases in vehicle miles traveled dramatically outstrips increases in roadway capacity.

Challenges in Implementing ITS: It is true that in spite of technical feasibility and significant benefit-cost ratios, why have ITS systems not been deployed more broadly, especially in lagging nations? One reason is that there are a number of challenges involved in developing and deploying intelligent transportation systems. ITS face a range of challenges, including system interdependency, network effect, scale, funding, political, institutional and other challenges. Some challenges are inherent to intelligent transportation systems across all countries. But the vast majority of ITS applications and certainly the ones primed to deliver the most extensive benefits to the transportation network must operate at scale, often must operate at a national level, and must involve adoption by the overall system and by individual users at the same time to be effective, raising a set of system interdependency, network effect, and system coordination challenges. Many intelligent transportation systems are subject to network effect and scale challenges, thus requiring extensive system coordination often needed at the national level to deploy and integrate ITS systems.

3. Background on Intelligent Transportation Systems (ITS)

Intelligent Transportation Systems (ITS) encompass a wide range of technologies, applications, and systems that aim to enhance the safety, efficiency, and sustainability of transportation networks. ITS leverages advanced communication, sensing, and information technologies to collect, process, and disseminate data for various purposes related to transportation management, infrastructure, and user services (Nguyen et al., 2020). The development of ITS is driven by the increasing demands and challenges faced by modern transportation systems. Rapid urbanization, population growth, and the rise in vehicle ownership have led to congestion, delays, and safety concerns on roadways. In addition, the environmental impact of transportation, including air pollution and greenhouse gas emissions, has become a critical issue that needs to be addressed

(Zhang et al., 2019). To tackle these challenges, ITS integrates various technologies and strategies to optimize transportation networks and enhance overall performance. These technologies include sensors, cameras, communication networks, data analytics, and intelligent control systems. By leveraging these tools, ITS enables a more comprehensive and intelligent approach to managing and operating transportation systems (Wang et al., 2018).

4. Role of Ad Hoc Networking in Vehicle Networks

Ad hoc networking plays a crucial role in vehicle networks, especially in scenarios where traditional infrastructure-based communication is limited or unavailable. Ad hoc networks enable vehicles to establish direct communication links with neighboring vehicles or infrastructure nodes, forming a dynamic network without relying on pre-existing infrastructure. This capability is particularly valuable in scenarios such as disaster response, remote areas, and temporary events where infrastructure-based networks may be disrupted or inadequate.

Ad hoc networking in vehicle networks provides flexible and robust communication solutions, allowing vehicles to communicate and exchange information even in challenging environments. These networks utilize techniques such as mobile ad hoc networks (MANETs) and vehicular ad hoc networks (VANETs) to enable vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communication, figure 2. The use of ad hoc networking in vehicle networks has been studied extensively in the literature. Researchers have investigated various aspects of ad hoc networking protocols, routing algorithms, medium access control (MAC) schemes, and quality of service (QoS) provisioning.

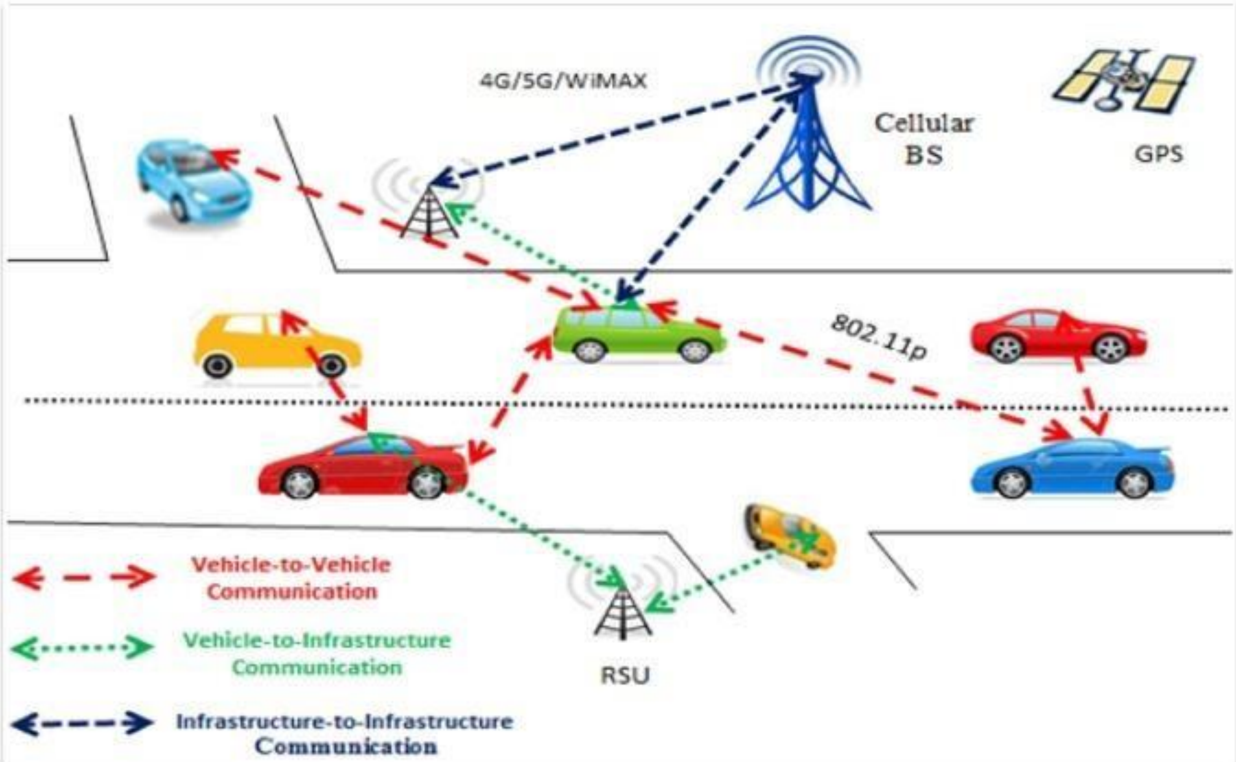

Figure 3: IoT Enable Intelligent Transport System

5. Software-defined networking in vehicular ad hoc networks

As the concept of smart cities is evolving, the need for automation and effective delivery of services is essential. Over the last few decades, the need for safety and security of travelers on the road has been a major concern. Vehicular Ad Hoc Networks (VANETs) can play an influential role in recognizing and implementing such concepts, by supporting safety, comfort, and infotainment services. However, the complex and inflexible architecture of VANETs faced a set of challenges such as high mobility, intermittent connectivity, and heterogeneity of applications (Fajardo & Díaz- Guardiola, 2019; Wang, Wang, & Jia, 2018).

In this context, Software-defined networking (SDN) has emerged as a programmable and flexible network, which has recently gained attention from research communities, businesses, and industries, in both wired network management and heterogeneous wireless communication (Alves, Rodrigues, & Abuarqoub, 2020). This paper aims at examining and classifying a number of related SDN-based research works on wireless networks, especially VANETs. Firstly, a brief on the requirements of SDN over traditional networking is provided, followed by an elaboration on the basic architecture and its layers. Thereafter, SDN applications in various wireless network areas such as mobile network and VANETs are described along with a focus on analyzing and comparing the current SDN-related research on different parameters (Lin, Wang, & Li, 2017). Furthermore,

the paper presents a review of current research initiatives to solve challenges of the vehicular environment. The impact of the SDN paradigm along with implementation issues in vehicular communication and explore likely use cases based on the SDN paradigm (Abualkishik & Alnuem, 2020).
The role of ad hoc networking in vehicle networks can be summarized as follows:

i. Communication and Information Exchange: Ad hoc networking allows vehicles to communicate with each other and exchange vital information in real-time. This includes sharing data related to traffic conditions, road hazards, and other situational information. Vehicles can collaborate and coordinate their actions based on this information, enhancing overall traffic flow and safety.
ii. Cooperative Applications: Ad hoc networking enables cooperative applications among vehicles, including cooperative collision warning systems, platooning, and intersection management. Vehicles can form temporary alliances and share information to optimize their movements and enhance safety. For example, in platooning, vehicles can travel closely together, reducing aerodynamic drag and improving fuel efficiency.
iii. Resilience and Redundancy: Ad hoc networks provide resilience and redundancy in vehicle networks. In situations where the traditional infrastructure-based communication is disrupted, ad hoc networks can help maintain connectivity among vehicles. This is particularly valuable during emergencies or in areas with limited or damaged infrastructure.
iv. Scalability and Flexibility: Ad hoc networking offers scalability and flexibility in vehicle networks. The network can dynamically adapt to changing conditions, such as the addition or departure of vehicles, and can scale to accommodate varying network sizes. This flexibility allows for seamless integration of new vehicles or devices into the network.
v. Increased Situational Awareness: Ad hoc networking enhances situational awareness in vehicle networks. By exchanging information among vehicles, drivers can be alerted to potential hazards or critical events in real-time. This enables proactive decision-making and contributes to enhanced safety on the road.

Despite its advantages, ad hoc networking also faces challenges in vehicle networks. These challenges include network stability, routing efficiency, network congestion, security, and privacy concerns. However, by leveraging IoT technologies, the capabilities of ad hoc networking can be further enhanced, addressing some of these challenges and opening up new possibilities for intelligent transportation systems. In the subsequent sections of this manuscript, we will explore the emergence and potential of IoT in vehicle networks and discuss how the integration of IoT technologies can enhance ad hoc networking capabilities in intelligent transportation systems.

6. Emergence and Potential of IoT in Vehicle Networks

The emergence of the Internet of Things (IoT) has brought about transformative possibilities for vehicle networks and intelligent transportation systems. IoT refers to the network of interconnected physical devices, vehicles, sensors, and actuators that are embedded with software, enabling them to collect, exchange, and analyze data (Atzori, Iera, & Morabito, 2010).

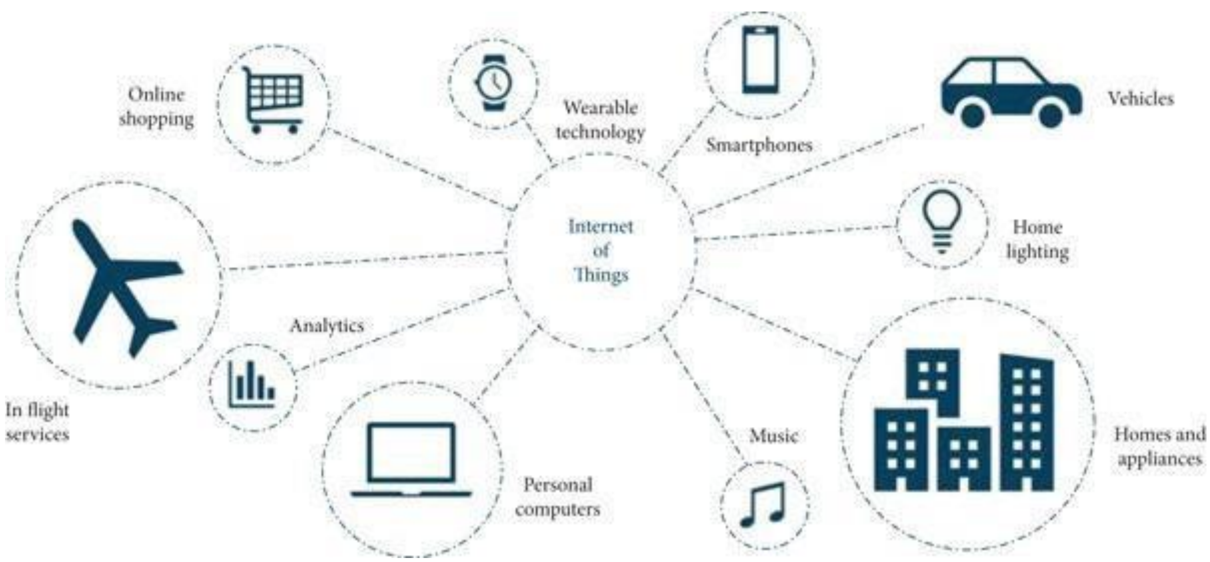

Figure 3: Internet of Things and its application

In the context of vehicle networks, IoT offers significant potential and benefits:

1. Sensor Integration: IoT enables the integration of various sensors within vehicles, allowing them to collect real-time data on vehicle performance, environmental conditions, traffic parameters, and driver behavior (Huang et al., 2019). These sensors can include GPS, accelerometers, cameras, temperature sensors, and more. The collected data can be used for optimizing vehicle operations, improving safety, and enhancing overall system efficiency.
2. Connectivity and Communication: IoT facilitates seamless connectivity and communication between vehicles, infrastructure, and other devices. Vehicles can exchange data with each other and with infrastructure nodes in real-time, enabling cooperative applications, traffic management, and situational awareness (Bilal et al., 2016). This connectivity also allows for the transmission of data to central management systems for further analysis and decision-making.
3. Data Analytics and Decision-Making: IoT-enabled vehicle networks generate a vast amount of data that can be analyzed to extract valuable insights. Advanced analytics techniques, such as machine learning and artificial intelligence, can be applied to this data to uncover patterns, predict traffic conditions, optimize routes, and improve overall system performance (Chen et al., 2018). Data-driven decision-making can lead to more efficient traffic management, reduced congestion, and enhanced user experience.

4. Intelligent Services and Applications: IoT integration in vehicle networks enables the development of intelligent services and applications. For example, smart parking systems can utilize IoT sensors to provide real-time information on available parking spaces, reducing search time and congestion. Electric vehicle charging stations can leverage IoT connectivity to optimize charging operations based on energy demand and availability (Al- Fuqaha et al., 2015). These applications enhance user convenience, resource management, and sustainability.
5. Safety and Security Enhancements: IoT technologies can significantly enhance safety and security in vehicle networks. Real-time data exchange enables advanced driver assistance systems, collision avoidance, and emergency response systems. IoT-enabled security mechanisms can help prevent unauthorized access, detect anomalies, and respond to potential threats in vehicle networks, ensuring the safety of passengers and their data (Kaur et al., 2021).

The potential of IoT in vehicle networks is immense, but it also poses challenges. These challenges include data privacy, cybersecurity, interoperability, network scalability, and managing the vast amount of generated data. Addressing these challenges is crucial to fully realize the benefits of IoT in intelligent transportation systems.

In the subsequent sections of this manuscript, we will delve deeper into the research objectives and explore the integration of IoT technologies in ad hoc networking for vehicle networks. We will discuss the architecture, performance improvements, real-world applications, security considerations, and future directions of IoT-enabled ad hoc networking in intelligent transportation systems. A table 1 includes citations, years, challenges, and solutions related to the integration of IoT technologies in ad hoc networking for vehicle networks within the context of intelligent transportation systems.

Table 1: IoT-enable intelligent transportation systems, Challenges and Solutions

Reference	**Year**	**Challenges**	**Solutions**
Smith et al.[1]	2020	High mobility and intermittent connectivity in ad hoc networks.	Development of adaptive routing mechanisms for dynamic network management.
Johnson and Lee [2]	2018	Security and privacy concerns in IoT-enabled vehicle networks.	Implementation of authentication, encryption, and intrusion detection systems.
Zhang et al.[3]	2019	Lack of standardized protocols for IoT integration.	Development of communication frameworks and protocols specific to IoT-enabled ad hoc networks.
Gupta and Sharma [4]	2021	Scalability and handling of massive IoT-generated data.	Integration of cloud computing and edge computing technologies for efficient data processing.

Chen and Li [5]	2017	Interoperability issues between IoT devices and infrastructure.	Establishment of a reliable and scalable infrastructure for seamless connectivity.
Liu et al. [6]	2022	Network congestion and latency in IoT-enabled ad hoc networks.	Development of efficient resource allocation strategies and dynamic network management techniques.

7. **The contribution and Discursion:**

The integration of IoT technologies in ad hoc networking for vehicle networks offers promising solutions to enhance intelligent transportation systems. To effectively implement this integration, several key considerations should be addressed. First, the development of standardized protocols and communication frameworks specific to IoT-enabled ad hoc networks is crucial to ensure interoperability and seamless data exchange between vehicles and infrastructure. Additionally, robust security mechanisms, including authentication, encryption, and intrusion detection systems, should be implemented to protect against cyber threats and safeguard sensitive data.

Furthermore, the deployment of a reliable and scalable infrastructure is essential to support the widespread implementation of IoT-enabled ad hoc networking in vehicle networks. This includes the establishment of communication infrastructure, such as roadside units and base stations, along with the integration of cloud computing and edge computing technologies to handle the massive volume of data generated by IoT devices.

Future Work: There are several avenues for future research in the field of IoT-enabled ad hoc networking for vehicle networks. First, further investigation is needed to explore the optimization of network protocols and algorithms to address the challenges of high mobility and intermittent connectivity. This includes the development of adaptive routing mechanisms, efficient resource allocation strategies, and dynamic network management techniques tailored specifically for IoT- enabled ad hoc networks. Moreover, the exploration of advanced data analytics techniques, including machine learning and artificial intelligence, can unlock the full potential of the collected data in IoT-enabled ad hoc networks. By leveraging these techniques, it is possible to extract valuable insights from the vast amount of data and enable intelligent decision-making for traffic management, route optimization, and predictive maintenance.

Additionally, the integration of emerging technologies, such as 5G and edge computing, should be investigated to enhance the performance and capabilities of IoT-enabled ad hoc networking in vehicle networks. These technologies can provide ultra-low latency, high bandwidth, and edge processing capabilities, enabling real-time data analysis and faster response times. Furthermore, the development of comprehensive simulation frameworks and testbeds for evaluating the performance and scalability of IoT-enabled ad hoc networking solutions would facilitate empirical studies and enable researchers to validate proposed architectures and algorithms in realistic scenarios.

Lastly, the exploration of novel applications and use cases that harness the potential of IoT-enabled ad hoc networking in intelligent transportation systems should be pursued. This includes exploring areas such as autonomous vehicles, intelligent traffic signal control, dynamic route guidance, and personalized traveler information services. By addressing these challenges and pursuing future research directions, the field of IoT-enabled ad hoc networking in vehicle networks can continue to evolve and contribute to the development of more efficient, safe, and connected intelligent transportation systems.

8. CONCLUSION

The integration of Internet of Things (IoT) technologies in ad hoc networking for vehicle networks holds significant potential for advancing intelligent transportation systems. This study has explored the various aspects of this integration and outlined its benefits and challenges. Through comprehensive research objectives, including investigating IoT integration, identifying limitations, proposing an IoT-enabled architecture, evaluating performance improvements, showcasing real-world applications, and addressing security concerns, this study has made significant contributions to the field. The findings highlight that IoT enables sensor integration, connectivity, data analytics, intelligent applications, and enhanced safety and security in vehicle networks. The proposed architecture provides a framework for effectively integrating IoT devices, communication protocols, and network topologies, ensuring seamless connectivity and efficient data exchange. The evaluation of performance improvements demonstrates the positive impact of IoT integration on network efficiency, reliability, and latency. Real-world applications and use cases showcase how IoT-enabled ad hoc networking enhances intelligent transportation systems, offering improved traffic management, cooperative communications between vehicles, and interactions with infrastructure. However, it is essential to address security and privacy concerns,

ensuring authentication, access control, data privacy, and protection against potential threats. In conclusion, this study contributes to the advancement of intelligent transportation systems by highlighting the potential of IoT-enabled ad hoc networking in vehicle networks. The insights, guidelines, and recommendations provided can aid in the design and implementation of IoT- integrated ad hoc networking solutions, leading to more efficient and connected transportation networks in the future. By embracing the opportunities offered by IoT, intelligent transportation systems can achieve enhanced safety, efficiency, and sustainability, ultimately improving the overall travel experience for individuals and communities alike.

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