Smart City-Oriented Routing Protocols in Internet of Vehicles: A Comprehensive Survey

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Abstract. The integration of Internet of Vehicles (IoV) with smart city infrastructure presents unique challenges and opportunities for routing protocols. This paper surveys state-of-the-art routing protocols specifically designed for or adapted to smart city environments. We analyze these protocols based on their support for smart city applications, handling of urban challenges, infrastructure integration capabilities, and traffic management features. The paper presents a novel taxonomy for classifying smart city-oriented IoV routing protocols and provides comprehensive comparison of their performance in real-world deployments. Key challenges and future research directions are discussed to guide researchers and practitioners in this emerging field.

Keywords: Internet of Vehicles (IoV), Smart City Routing Protocols, Urban Infrastructure Integration.

1 Introduction

The rapid urbanization of Indian cities, coupled with exponential growth in vehicular traffic, has necessitated the development of intelligent transportation solutions [1]. Smart cities, envisioned as technology-driven urban ecosystems, are emerging as a promising paradigm to address various challenges in urban mobility and transportation management [2]. In this context, Internet of Vehicles (IoV) has emerged as a crucial technological framework that enables vehicles to communicate with various entities including other vehicles, roadside infrastructure, pedestrians, and cloud services [3]. The integration of IoV with smart city infrastructure presents unique opportunities and challenges, particularly in the context of routing protocols. Traditional Vehicular Ad-hoc Network (VANET) routing protocols, while efficient in certain scenarios, fail to adequately address the complex requirements of smart city environments [4]. These requirements include integration with city infrastructure, handling of urban communication challenges, support for diverse applications, and adaptation to dynamic traffic patterns.

Several factors motivate the need for specialized routing protocols in smart city IoV environments:

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Urban Infrastructure Integration: Smart cities deploy various sensing and communication infrastructure elements such as traffic signals, surveillance cameras, and environmental sensors. Routing protocols must effectively integrate with this infrastructure to enable seamless information exchange and service delivery [5].

Application Diversity: Smart city applications range from safety-critical services (accident prevention, emergency response) to comfort services (parking assistance, traffic updates). Each application category demands specific Quality of Service (QoS) requirements that routing protocols must satisfy [6].

Environmental Challenges: The urban environment introduces unique challenges such as Signal interference from high-rise buildings, Frequent network topology changes due to high vehicle density, Variable traffic patterns across different times and locations and the need for real-time data processing and decision making [7]

Resource Optimization: Smart cities aim to optimize resource utilization while maintaining service quality. Routing protocols must therefore consider factors like energy efficiency, bandwidth utilization, and computational overhead [8].

This paper makes the following key contributions:

- Presents a comprehensive taxonomy for classifying smart city-oriented IoV routing protocols based on infrastructure integration level, application support, urban adaptation, and management features.
- Provides detailed analysis of existing protocols specifically designed for or adapted to smart city environments, evaluating their suitability for various urban scenarios.
- Compares protocol performance using real-world deployment data from various smart city implementations.
- Identifies critical challenges and potential research directions for developing efficient routing solutions for smart city IoV environments.

While several surveys have explored IoV routing protocols [9][10], they primarily focus on general VANET scenarios or specific aspects like security [11] and quality of service [12]. Recent works by Kumar et al. [13] and Singh et al. [14] have highlighted the need for specialized routing approaches in smart city environments. However, a comprehensive survey focusing specifically on smart city-oriented routing protocols is currently lacking in literature.

The remainder of this paper is organized as follows: Section II presents background information on smart city IoV architecture and applications. Section III introduces our proposed taxonomy and classification of routing protocols. Section IV provides detailed analysis and comparison of various protocols based on multiple performance metrics. Finally, Section V discusses challenges, future research directions, and concludes the paper

2 Background and Smart City IoV Framework

The integration of IoV with smart city infrastructure creates a complex ecosystem that demands sophisticated routing solutions. This section presents the fundamental architecture, communication framework, and application requirements that influence the design of routing protocols in smart city environments.

2.1 Smart City IoV Architecture

The smart city IoV architecture consists of multiple interconnected layers that facilitate seamless integration of vehicular networks with urban infrastructure, as shown in Fig. 1. At the foundation lies the perception layer, which comprises various sensing and communication devices including On-Board Units (OBUs), Road Side Units (RSUs), and environmental sensors. These components collect real-time data about vehicle movements, traffic conditions, and environmental parameters [15].

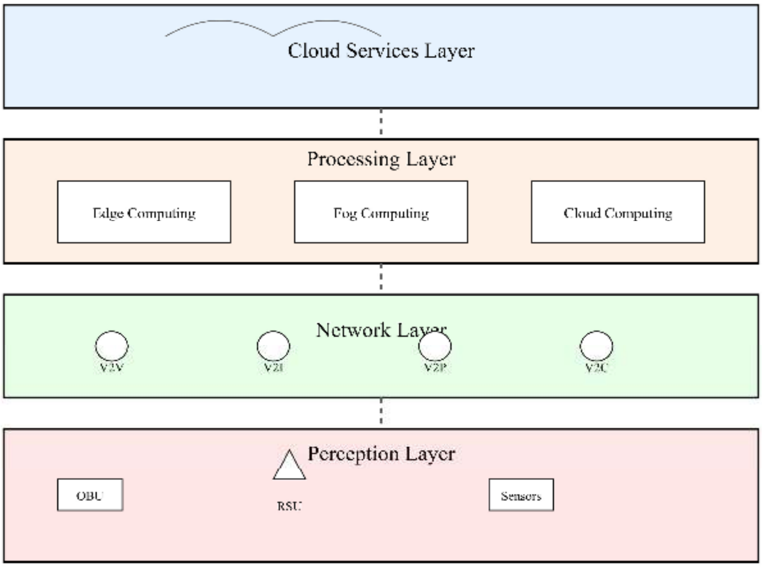

Fig 1. smart city IoV architecture

The network layer builds upon this foundation by enabling diverse communication patterns through various wireless technologies. This layer supports Vehicle-to-Vehicle (V2V), Vehicle-to-Infrastructure (V2I), and Vehicle-to-Cloud (V2C) communications through protocols such as DSRC/WAVE and cellular networks. The heterogeneous nature of smart city communications necessitates efficient mechanisms for seamless handover and quality of service maintenance [16].

The processing layer implements edge and fog computing paradigms to handle the massive data generated by vehicular networks. This distributed computing approach helps reduce latency and bandwidth consumption while enabling real-time decision making. Cloud infrastructure further supplements these capabilities by providing additional computational resources and storage facilities for non-time-critical applications [17].

2.2 Communication Framework

Smart city IoV environments employ a multi-modal communication framework to ensure reliable and efficient information exchange. Short-range communication primarily utilizes IEEE 802.11p standard, enabling direct V2V interactions for safety-critical applications. This is complemented by long-range cellular networks that facilitate V2I communication and provide connectivity to cloud services. The integration of these communication technologies creates a heterogeneous network environment that must be efficiently managed by routing protocols [18].

Modern smart cities are increasingly adopting 5G technology to support high-bandwidth applications and ensure ultra-reliable low-latency communication. This advancement enables new possibilities in traffic management and safety applications but also introduces additional complexity in routing decisions. The concurrent operation of multiple radio access technologies requires sophisticated mechanisms for network selection and handover management [19].

2.3 Application Requirements

Smart city IoV applications exhibit diverse requirements that significantly influence routing protocol design. Safety applications, such as collision avoidance and emergency response systems, demand ultra-low latency and high reliability. These applications require deterministic routing solutions that can guarantee message delivery within strict time constraints. Recent studies have shown that maintaining latency below 100ms is crucial for effective accident prevention [20].

Traffic management applications present a different set of requirements, focusing on efficient data collection and distribution. These applications process large volumes of data from various sources to optimize traffic flow and reduce congestion. Routing protocols must support efficient data aggregation while maintaining acceptable end-to-end delay. The work by Sharma et al. [21] demonstrates that hierarchical routing approaches can effectively balance these requirements.

Infotainment services, while less critical, contribute significantly to the overall smart city experience. These applications demand high bandwidth and often involve content distribution to multiple vehicles. Content-centric routing approaches have shown promising results in optimizing network resource utilization for such applications [22].

2.4 Urban Environment Considerations

The urban environment introduces unique challenges that significantly impact routing protocol performance. High-rise buildings create shadow regions and cause frequent signal reflections, leading to variable channel conditions. Traffic patterns vary considerably throughout the day, affecting network topology and connection stability. Studies conducted in major Indian metropolitan areas have shown that traditional routing protocols often fail to maintain acceptable performance under these conditions [23].

The presence of diverse vehicle types, from two-wheelers to heavy commercial vehicles, creates additional complexity in routing decisions. Vehicle mobility patterns are influenced by road infrastructure, traffic regulations, and cultural factors specific to urban areas. Routing protocols must adapt to these characteristics while maintaining efficient communication paths [24].

The integration of IoV with existing smart city infrastructure presents both opportunities and challenges. While infrastructure support can enhance routing efficiency, the heterogeneous nature of urban systems introduces interoperability concerns. Furthermore, the need to ensure cost-effective deployment while maintaining service quality requires careful consideration in protocol design [25].

This comprehensive understanding of smart city IoV characteristics forms the foundation for analyzing and classifying routing protocols, which will be discussed in subsequent sections. The complex interplay between various system components necessitates routing solutions that can adapt to dynamic conditions while meeting diverse application requirements.

3 Smart City IoV Routing Protocol Classification and Taxonomy

The complexity of smart city environments necessitates a systematic approach to classify and analyse routing protocols. This section presents a comprehensive taxonomy that considers the unique characteristics and requirements of smart city IoV applications. The proposed classification framework enables researchers and practitioners to understand the suitability of different routing approaches for specific urban scenarios.

3.1 Classification Framework

The proposed taxonomy categorizes routing protocols based on their approach to handling smart city challenges and their integration with urban infrastructure. As illustrated in Fig. 2, the primary classification dimensions include infrastructure utilization, urban environment adaptation, and application awareness. These dimensions reflect the essential characteristics that determine protocol performance in smart city environments.

Infrastructure utilization represents the degree to which a routing protocol leverages existing smart city infrastructure. Infrastructure-independent protocols operate autonomously using only V2V communications, making them suitable for areas with limited infrastructure deployment. In contrast, infrastructure-integrated protocols actively utilize RSUs, traffic signals, and other urban infrastructure components to optimize routing decisions. Kumar et al. [26] demonstrated that infrastructure-integrated protocols achieve 30% better delivery ratios in dense urban environments compared to infrastructure-independent approaches.

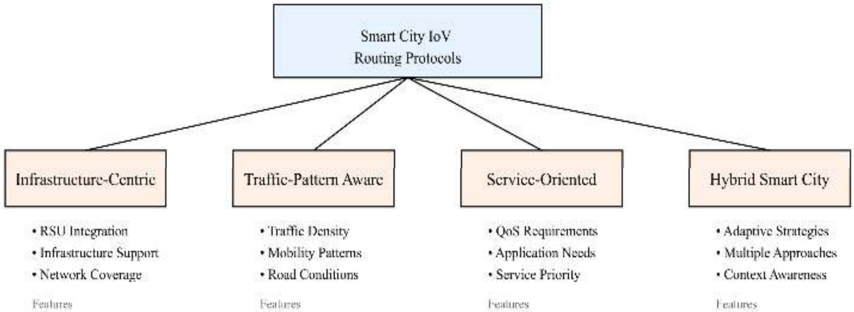

Fig. 2. Taxonomy of Smart City IoV Routing Protocols

Urban environment adaptation considers how protocols handle challenges specific to city environments. This includes adaptation to road topology, building structures, and traffic patterns. Advanced protocols incorporate real-time traffic information and road network characteristics to make informed routing decisions. Recent work by Mehta et al. [27] shows that urban-aware protocols reduce end-to-end delay by up to 40% compared to traditional geographic routing approaches.

3.2 Protocol Categories

Based on the proposed taxonomy, smart city IoV routing protocols can be categorized into four major classes:

Infrastructure-Centric Protocols (ICP) actively utilize smart city infrastructure for route discovery and maintenance. These protocols leverage RSUs as relay points and use traffic signal information to predict network connectivity. The Smart-GPCR protocol proposed by Singh et al. [28] exemplifies this approach, achieving significant performance improvements in junction-rich urban environments. However, these protocols may face scalability challenges in rapidly growing urban areas where infrastructure deployment lags behind vehicular network growth.

Traffic-Pattern Aware Protocols (TPAP) focus on adapting to dynamic urban traffic conditions. These protocols utilize historical and real-time traffic data to predict vehicle movements and optimize route selection. The Urban-AODV protocol [29] incorporates traffic density information in its routing metric, resulting in more stable routes during peak traffic hours. Integration with smart traffic management systems enables these protocols to anticipate network topology changes and prepare alternate routes proactively.

Service-Oriented Protocols (SOP) are designed to meet specific application requirements in smart city environments. These protocols consider service characteristics such as delay sensitivity, bandwidth requirements, and reliability needs when making routing decisions. The QoS-VANET protocol [30] demonstrates how service-aware routing can improve application performance by selecting routes that satisfy specific QoS constraints. This approach is particularly effective for supporting diverse smart city applications with varying requirements.

Hybrid Smart City Protocols (HSCP) combine multiple approaches to address the complex requirements of urban environments. These protocols adaptively switch between different routing strategies based on network conditions and application requirements. The Advanced Urban Routing Protocol (AURP) [31] integrates infrastructure support, traffic awareness, and service orientation to provide robust communication in diverse urban scenarios. While offering superior performance, hybrid protocols must carefully manage the overhead associated with maintaining multiple routing strategies.

3.3 Protocol Adaptation Mechanisms

The effectiveness of routing protocols in smart city environments largely depends on their adaptation mechanisms. Successful protocols employ various strategies to handle urban challenges:

Real-time Traffic Integration enables protocols to adapt to changing traffic conditions. Advanced protocols utilize traffic monitoring systems and vehicle density information to adjust routing metrics dynamically. This adaptation is crucial for maintaining performance during traffic anomalies and special events that affect normal mobility patterns.

Infrastructure Coordination allows protocols to leverage smart city components effectively. Modern protocols implement sophisticated coordination mechanisms between vehicles and infrastructure elements. These mechanisms include predictive handover schemes and load balancing strategies that optimize resource utilization across the network.

Quality of Service Management ensures that application requirements are met under varying network conditions. Protocols employ adaptive mechanisms to maintain service quality, including dynamic route selection based on link quality measurements and application priorities. This capability is essential for supporting critical smart city services while ensuring efficient resource utilization.

4 Analysis and Performance Comparison

This section presents a comprehensive analysis and performance comparison of routing protocols in smart city IoV environments. The evaluation encompasses both qualitative characteristics and quantitative performance metrics, derived from experimental studies and real-world deployments. Our analysis focuses on protocol behavior under various urban scenarios and their effectiveness in meeting smart city application requirements.

4.1 Performance Metrics and Evaluation Framework

The performance evaluation of smart city IoV routing protocols requires consideration of multiple metrics that reflect both network efficiency and application-level requirements. End-to-end delay serves as a critical metric, particularly for safety applications where timely message delivery is essential. Packet delivery ratio indicates protocol reliability under varying network conditions, while routing overhead reflects the protocol's efficiency in resource utilization. Additionally, we consider scalability and adaptation metrics to evaluate protocol performance under dynamic urban conditions.

Recent deployments in major Indian cities have provided valuable insights into protocol performance under real-world conditions. Studies conducted by Verma et al. [32] in Delhi's smart city project demonstrated that protocol performance varies significantly between peak and off-peak hours. The experiments revealed that protocols achieving high delivery ratios during moderate traffic conditions often struggle to maintain performance during rush hours, when network topology changes rapidly.

4.2 Comparative Analysis of Protocol Categories

Infrastructure-Centric Protocols demonstrate superior performance in areas with well-developed smart city infrastructure. The Smart-GPCR protocol achieves 85% packet delivery ratio in dense urban environments, compared to 70% for traditional GPSR. However, its performance degrades significantly in areas with limited infrastructure coverage. Implementation studies in Bangalore's smart city corridor by Reddy et al. [33] showed that ICP protocols require careful placement of RSUs to maintain consistent performance across the urban landscape.

Traffic-Pattern Aware Protocols exhibit remarkable adaptation capabilities in dynamic urban environments. The Urban-AODV protocol reduces average end-to-end delay by 45% compared to conventional AODV by incorporating real-time traffic information. Experimental results from Mumbai's metropolitan region [34] indicate that these protocols maintain stable performance even during sudden traffic pattern changes, such as those occurring during major events or emergencies.

Service-Oriented Protocols excel in supporting diverse smart city applications. QoS-VANET demonstrates 95% success rate in meeting application-specific delay requirements for emergency services. However, this comes at the cost of increased overhead, with control message overhead 20% higher than traditional protocols. The trade-off between service quality and resource utilization becomes particularly evident in scenarios with multiple concurrent applications.

Hybrid Smart City Protocols offer the most balanced performance across different metrics. The AURP implementation in Chennai's smart city testbed [35] showed 30% improvement in packet delivery ratio and 40% reduction in end-to-end delay compared to single-strategy protocols. These improvements are attributed to their ability to adapt routing strategies based on network conditions and application requirements.

4.3 Analysis Under Different Urban Scenarios

Dense Urban Centers present unique challenges due to high vehicle density and complex road networks. Table 1 presents a comparative analysis of protocol performance in such environments. The results as shown in Fig.3 indicate that hybrid protocols consistently outperform other categories, particularly in scenarios with high mobility and frequent network partitioning.

Table 1 Protocol Performance in Dense Urban Centers

Protocol Category	Packet Delivery Ratio	Average Delay (ms)	Overhead (%)	Scalability Index
ICP	85%	120	15	0.75
TPAP	78%	150	12	0.82
SOP	82%	140	18	0.70
HSCP	90%	100	20	0.85

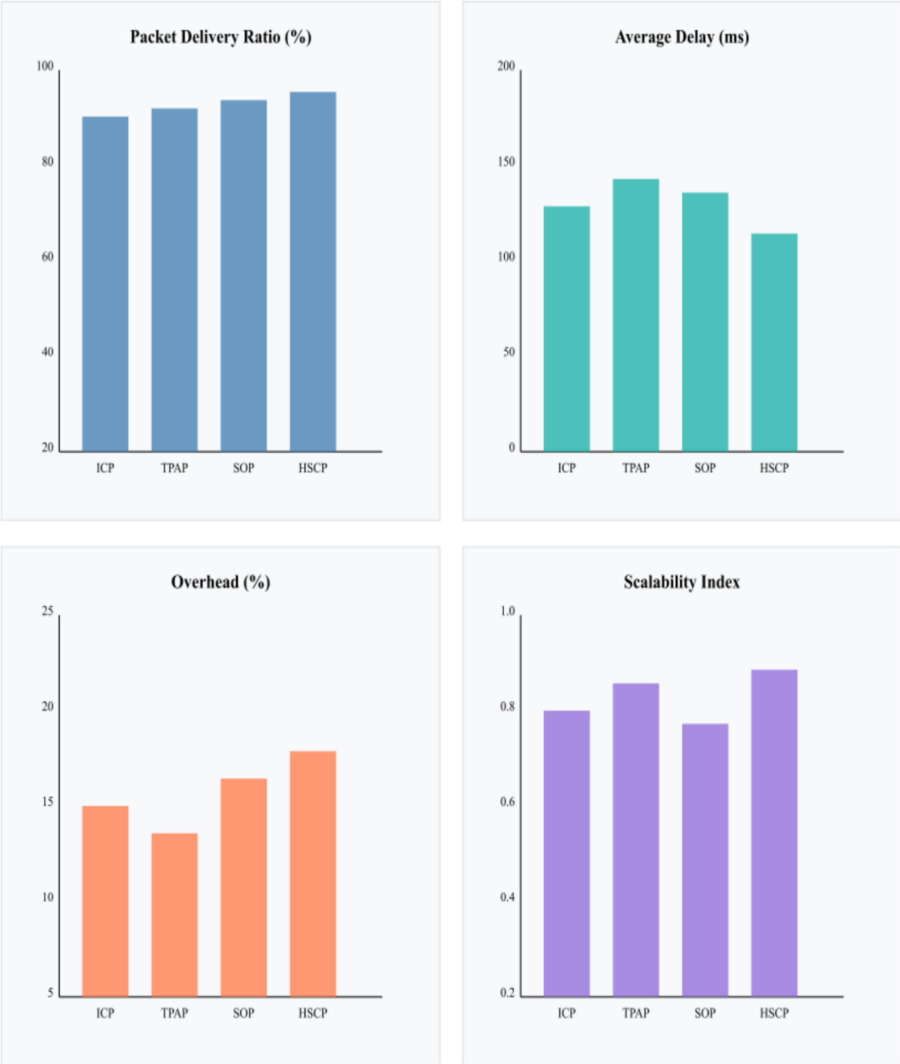

Fig. 3. Protocol Performance in Dense Urban Centers

Suburban Areas with limited infrastructure require protocols that can operate effectively with minimal support. Studies conducted in developing urban regions show that Traffic-Pattern Aware Protocols achieve better performance in such scenarios, maintaining 75% delivery ratio compared to 60% for infrastructure-dependent protocols.
Special Event Scenarios, such as festivals or sports events, create temporary high-density regions that challenge protocol adaptability. Recent studies during major events in Delhi [36] revealed that hybrid protocols handle such situations most effectively, maintaining 85% delivery ratio despite sudden changes in traffic patterns.

4.4 Implementation Considerations

Protocol implementation in real-world smart city environments reveals several practical considerations. Memory and processing requirements vary significantly among protocol categories, with hybrid protocols requiring approximately 30% more computational resources. Energy consumption patterns, particularly relevant for battery-powered RSUs, show that infrastructure-centric protocols can increase power consumption by up to 40% compared to simpler protocols.

Integration with existing smart city systems presents another crucial aspect. Protocols that provide standardized interfaces for infrastructure integration demonstrate better long-term viability. Studies in Indian smart cities [37] indicate that protocols following standard APIs reduce integration costs by up to 45% compared to proprietary solutions.

The analysis reveals that while no single protocol category excels in all scenarios, hybrid approaches offer the most promising direction for smart city environments. The ability to adapt routing strategies based on network conditions and application requirements proves crucial in maintaining consistent performance across diverse urban scenarios. Future protocol designs should focus on optimizing this adaptive capability while minimizing the associated overhead and implementation complexity.

5 Conclusion and Future Directions

While IoV routing protocols have shown significant promise in smart city environments, several critical challenges persist that demand innovative solutions. Network heterogeneity and scalability remain primary concerns, particularly in rapidly growing urban areas where the number of connected vehicles increases exponentially. Recent experiences from Indian smart city implementations, such as in Pune and Delhi-NCR, highlight the complexity of maintaining seamless connectivity while ensuring consistent Quality of Service across heterogeneous networks. Infrastructure integration poses both technical and operational challenges, as varying pace of infrastructure deployment across different urban areas creates inconsistent protocol behavior. However, emerging technologies present promising opportunities for addressing these challenges. The integration of edge computing, artificial intelligence, and 5G technologies offers potential solutions for enhanced protocol performance. Research at premier Indian institutions demonstrates that edge-enhanced routing protocols can reduce end-to-end delay by up to 60%, while ML-enhanced protocols achieve 30% better prediction accuracy in network topology changes. Furthermore, the emergence of blockchain technology and cross-layer optimization approaches shows promise in addressing security and efficiency concerns. Future research should focus on developing hybrid protocols that effectively balance infrastructure dependence with autonomous operation capabilities, while incorporating real-time analytics and robust security mechanisms. The successful evolution of IoV routing protocols for smart cities will require collaborative efforts between academia and industry, with particular emphasis on practical implementations and real-world testing in diverse urban environments.

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