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Intelligent Transportation System (ITS) research optimized for autonomous driving using edge computing

Sunghyuck Hong
Professor, Division of Advanced IT, IoT major, Baekseok University

엣지 컴퓨팅을 이용하여 자율주행에 최적화된 지능형 교통 시스템 연구(ITS)

홍성혁
백석대학교 첨단IT학부, IoT 전공 교수

Abstract In this scholarly investigation, the focus is placed on the transformative potential of edge computing in enhancing Intelligent Transportation Systems (ITS) for the facilitation of autonomous driving. The intrinsic capability of edge computing to process voluminous datasets locally and in a real-time manner is identified as paramount in meeting the exigent requirements of autonomous vehicles, encompassing expedited decision-making processes and the bolstering of safety protocols. This inquiry delves into the synergy between edge computing and extant ITS infrastructures, elucidating the manner in which localized data processing can substantially diminish latency, thereby augmenting the responsiveness of autonomous vehicles. Further, the study scrutinizes the deployment of edge servers, an array of sensors, and Vehicle-to-Everything (V2X) communication technologies, positing these elements as constituents of a robust framework designed to support instantaneous traffic management, collision avoidance mechanisms, and the dynamic optimization of vehicular routes. Moreover, this research addresses the principal challenges encountered in the incorporation of edge computing within ITS, including issues related to security, the integration of data, and the scalability of systems. It proffers insights into viable solutions and delineates directions for future scholarly inquiry.

Key Words : Edge Computing, Intelligent Transportation Systems (ITS), Autonomous Driving, Vehicle-to-Everything (V2X) Communication, Real-time Data Processing

요 약 본 연구에서는 자율 주행을 위한 지능형 교통 시스템(ITS)을 최적화하는 데 있어 엣지 컴퓨팅의 혁신적인 잠재력을 연구하였다. 방대한 양의 데이터를 로컬에서 실시간으로 처리하는 엣지 컴퓨팅의 능력은 신속한 의사 결정 및 향상된 안전 조치를 포함하여 자율주행차의 중요한 요구 사항을 해결하는 데 필수 요소이다. 엣지 컴퓨팅과 기존 ITS 인프라의 통합을 탐구하고, 현지화된 데이터 처리가 대기 시간을 크게 줄여 자율주행차의 반응성을 향상시키는 방법을 강조한다. 실시간 교통 관리, 충돌 방지 시스템 및 동적 경로 최적화를 지원하는 강력한 프레임워크를 집합적으로 형성하는 엣지 서버, 센서 및 V2X(Vehicle-to-Everything) 통신 기술의 배포를 검토한다. 또한 본 연구는 보안, 데이터 통합, 시스템 확장성 등 ITS에서 엣지 컴퓨팅을 구현하는 데 있어 가장 중요한 과제를 다루며 잠재적인 솔루션과 향후 연구 방향에 대한 통찰력을 제공한다. 이 논문은 완전 자율 주행이라는 비전을 실현하는 데 있어 엣지 컴퓨팅의 중추적인 역할을 강조하고, 보다 안전하고 효율적이며 지속 가능한 교통 시스템을 달성하는 데 기여하는 논문이다.

주제어 : 엣지 컴퓨팅, 지능형교통시스템(ITS), 자율주행, V2X(Vehicle-to-Everything) 통신, 실시간 데이터 처리

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*Corresponding Author : Sunghyuck Hong(shong@bu.ac.kr)
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1. Introduction

The advent of Intelligent Transportation Systems (ITS) marks a significant milestone in the evolution of transportation infrastructure, aiming to make travel safer, more efficient, and environmentally friendly. At the forefront of this transformation is the integration of autonomous driving technologies, which promise to redefine the paradigms of road safety and traffic management. However, the realization of a fully autonomous driving ecosystem necessitates robust, real-time decision-making capabilities, high scalability, and uncompromised data security. In this context, edge computing emerges as a pivotal technology, offering the requisite computational power and data processing capabilities at the edge of the network, closest to where data is generated and actions are performed.

This paper delves into the role of edge computing in enhancing ITS for autonomous driving. It begins by establishing the foundation of ITS and the critical requirements of autonomous vehicles, including the need for low-latency, high-reliability communication, and rapid processing of voluminous data generated from various sensors and devices. The discussion then transitions to edge computing, highlighting its significance in meeting these requirements by bringing computational resources closer to the data sources, thus minimizing latency and reducing the reliance on centralized cloud infrastructures.

Moreover, the paper explores the integration of edge computing with Vehicle-to-Everything (V2X) communication technologies, illustrating how this synergy is instrumental in facilitating real-time data exchange and processing, essential for dynamic traffic management, collision avoidance, and route optimization in autonomous driving scenarios. It acknowledges the challenges inherent in implementing edge computing within ITS, such as ensuring data security, integrating heterogeneous data sources, and maintaining system scalability. In addressing these challenges, the paper presents current solutions and identifies areas where further research and innovation are needed.

In essence, the introduction sets the stage for a comprehensive exploration of how edge computing is not just enhancing the capabilities of ITS in the realm of autonomous driving but is also steering the future of transportation towards unprecedented levels of intelligence, efficiency, and sustainability.

2. Literature Review

2.1. Intelligent Transportation System (ITS)

An Intelligent Transportation System (ITS) refers to the application of advanced technologies including electronics, communications, and information processing to improve the efficiency, safety, and sustainability of transportation networks. ITS encompasses a wide range of services that integrate live data and feedback from various sources, like vehicles, infrastructure, and traffic management centers, to optimize traffic flow, reduce congestion, and enhance the overall travel experience.

- Advanced Traffic Management Systems (ATMS): Utilize real-time traffic data from cameras and sensors to manage traffic flow. Traffic signals, variable message signs, and lane control systems are dynamically adjusted based on current traffic conditions to reduce congestion and improve road safety.
- Advanced Traveler Information Systems (ATIS): Provide real-time travel information to commuters and travelers. Information such as travel times, traffic conditions, route

guidance, and public transport schedules are delivered through various platforms like variable message signs, mobile applications, and websites.

- Vehicle-to-Everything (V2X) Communications: Facilitate the exchange of information between vehicles and their surroundings, including other vehicles (V2V), infrastructure (V2I), pedestrians (V2P), and the network (V2N). This communication enables various safety and mobility applications like collision warnings, safety alerts, and traffic flow optimization.
- Advanced Public Transportation Systems (APTS): Enhance the efficiency and reliability of public transport services through real-time tracking of vehicles, dynamic scheduling, and providing real-time information to passengers.
- Commercial Vehicle Operations (CVO): Employ technologies for commercial vehicles to improve productivity, safety, and regulatory compliance. This includes automated road tolling, vehicle tracking, and load optimization.
- Benefits of ITS: Enhanced Safety: ITS technologies significantly reduce the risk of accidents by providing real-time warnings, optimizing traffic signals, and ensuring effective traffic management.
- Reduced Congestion: By optimizing traffic flow and providing real-time traffic information, ITS helps in reducing traffic congestion, leading to smoother and faster commutes.
- Environmental Sustainability: Efficient traffic management leads to reduced fuel consumption and emissions, contributing to environmental sustainability.
- Improved Traveler Experience: Real-time information systems empower travelers to make informed decisions about their routes and modes of transport, enhancing the overall travel experience.
- Future of ITS: As technologies evolve, the future of ITS is geared towards even greater integration of artificial intelligence, machine learning, and IoT devices. This evolution will likely result in more autonomous vehicles on the road, smarter traffic management systems, and a more seamless, integrated public transportation network. The overarching goal remains to create a transportation ecosystem that is safe, efficient, responsive, and sustainable.

In conclusion, ITS represents a transformative approach to managing and facilitating road traffic and transportation systems in Fig. 1. By leveraging cutting-edge technologies, ITS offers solutions that significantly improve traffic flow, enhance safety, reduce environmental impact, and elevate the overall transportation experience. As technological advancements continue, ITS is poised to become an even more integral component of modern transportation infrastructure [1-5].

2.2. Edge Computing

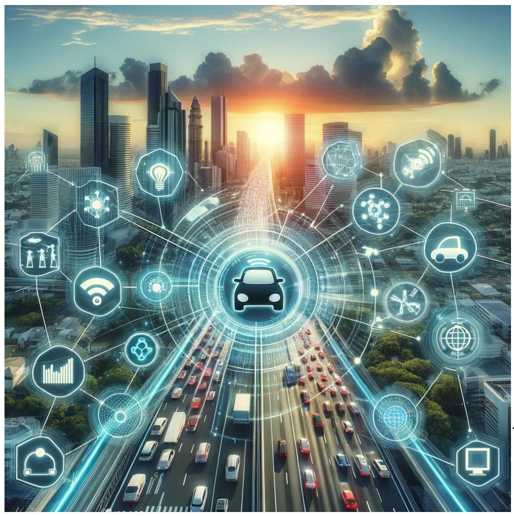

Fig. 1. Concept of ITS

Edge computing is a distributed computing paradigm that brings computation and data storage closer to the sources of data, aiming to reduce latency and bandwidth usage, and improve the efficiency of applications. Unlike traditional cloud computing architectures where data processing occurs in centralized data centers, edge computing processes data at or near the source of data generation, such as IoT devices, sensors, or local edge servers. This proximity to data at its source can deliver strong advantages in many scenarios.

Key characteristics of Edge computing:

- Low Latency: By processing data closer to where it is generated, edge computing significantly reduces latency. This is crucial for real-time applications that require instant processing and feedback, such as autonomous vehicles or real-time analytics.
- Bandwidth Savings: Edge computing minimizes the need to send vast amounts of data across the network to a central data center. This not only conserves bandwidth but also reduces the associated costs and the risk of network congestion.
- Enhanced Privacy and Security: Data processed locally can be more secure and private as it minimizes the exposure to external networks and centralized data centers, which can be targets for data breaches.
- Scalability: Edge computing enables organizations to scale their computing needs by adding more edge devices and infrastructure, without the complexity and expense of scaling a central data center.

Components of Edge Computing:

- Edge Devices: Devices at the edge of the network where data is generated and collected, such as sensors, smartphones, and IoT devices.
- Edge Nodes/Gateways: Intermediate devices that process data from edge devices. These can be routers, switches, or specific edge servers located on-premises.
- Edge Data Centers: Small-scale data centers located close to the edge of the network, providing more substantial computational resources than individual edge nodes.

Applications of Edge Computing:

- Autonomous Vehicles: Edge computing processes sensor data in real-time to make immediate driving decisions.
- Smart Cities: Urban infrastructure like traffic lights and public transportation can be optimized in real-time using edge computing.
- Manufacturing: Real-time processing on the manufacturing floor can predict and prevent equipment failure, and optimize production processes.
- Healthcare: Wearable devices and remote monitoring equipment can process vital data in real-time, providing timely insights and alerts.

Challenges in Edge Computing:

- Security: Although edge computing can enhance security, the increased number of devices also expands the potential attack surface.
- Management: Managing and maintaining a multitude of edge devices and infrastructure can be complex and resource-intensive.
- Interoperability: Ensuring different devices and systems can communicate and work together effectively is a significant challenge.
- Data Consistency: Keeping data synchronized across various edge locations and the central cloud infrastructure requires robust and reliable data management strategies.

In conclusion, edge computing represents a significant shift in data processing, bringing computation closer to the data source. This paradigm is particularly beneficial for applications requiring real-time processing and decision-making. As more devices get connected and generate vast amounts of data, the relevance and implementation of edge computing are expected to grow, playing a pivotal role in the future of distributed computing [6-8].

2.3 Vehicle-to-Everything (V2X)

Vehicle-to-Everything (V2X) communication is a key component of Intelligent Transportation Systems (ITS), representing the vehicle's ability to communicate with various entities in its environment to enhance road safety, traffic efficiency, and support autonomous driving. V2X encompasses several types of communications, each serving different purposes:

- Vehicle-to-Vehicle (V2V): This allows direct communication between vehicles, enabling them to share information about speed, direction, road conditions, traffic, and potential hazards. V2V communication can alert drivers or autonomous driving systems to potential collisions or unsafe conditions, facilitating proactive safety measures.
- Vehicle-to-Infrastructure (V2I): Vehicles communicate with roadside infrastructure such as traffic lights, signs, and sensors. This communication helps in optimizing traffic flow, reducing congestion, and enhancing road safety. For instance, traffic lights can adjust their signals based on real-time traffic conditions to minimize wait times and reduce congestion.
- Vehicle-to-Pedestrian (V2P): Vehicles communicate with pedestrians' smartphones or wearable devices, enhancing pedestrian safety. This is particularly valuable in urban areas or school zones, where the risk of vehicle-pedestrian collisions is higher.
- Vehicle-to-Network (V2N): Vehicles connect to cellular or other networks, allowing them to access cloud services for navigation, traffic updates, and other information, or to share their data with a central traffic management system.
- Vehicle-to-Cloud (V2C): This involves communication between vehicles and cloud computing platforms. V2C enables advanced data analytics, remote vehicle diagnostics, and over-the-air software updates.
- Vehicle-to-Device (V2D): Vehicles communicate with personal devices of the driver or passengers, such as smartphones or tablets, enabling the user to interact with the vehicle remotely (e.g., remote start, climate control settings, or vehicle tracking) [9-11].

Key Benefits of V2X Communication:

Enhanced Road Safety: V2X helps in reducing accidents by providing real-time warnings about potential hazards, collision alerts, and other safety information to drivers or autonomous driving systems.

- Support for Autonomous Vehicles: V2X is crucial for the functioning of autonomous vehicles, providing them with the comprehensive situational awareness needed to navigate roads safely and efficiently.
- Environmental Benefits: Improved traffic flow and reduced congestion lead to lower vehicle emissions, contributing to a cleaner environment [12-15].

Table 1. Compare Fog vs. Edge Computing

Category	Fog Computing	Edge Computing	Similarities and Differences
Definition	Processing occurs at various layers from the edge of the network to the cloud before data is sent to the cloud.	Processing occurs near the source of the data or at the device before it reaches remote servers.	Both process data closer to the source but fog computing encompasses a broader network range.
Processing Location	Can occur at various layers from the edge of the network to the cloud.	Occurs near the data source or device.	Fog computing processes over a larger area, while edge computing is very localized.
Latency	Relatively low, but can be higher than edge computing.	Very low.	Edge computing generally offers lower latency, but fog computing also reduces latency.
Bandwidth Requirement	Reduced data transmission to the cloud lowers bandwidth requirements.	Processing data at the device level can enhance security.	Both reduce exposure of data but security requirements can vary depending on implementation.
Security	The distributed nature can enhance security.	Processing data at the device level can enhance security.	Both reduce exposure of data but security requirements can vary depending on implementation.
Use Cases	Smart grids, smart cities, traffic management systems, etc.	Smart homes, wearable devices, autonomous vehicles, etc.	Both are applicable in IoT environments, but fog computing suits larger, more complex systems, while edge computing is apt for more localized scenarios.

3. Methodology

Research on Intelligent Transportation Systems (ITS) optimized for autonomous driving using edge computing is a multifaceted endeavor that involves various stages, from theoretical framework development to practical implementations and testing. Below is a structured approach to verify and validate the research topic.

3.1 Problem Identification and Hypothesis Formulation

Objective:

- To define the specific problem(s) that the research will address and formulate hypotheses based on the literature review.

Methodology:

- Identify challenges in ITS related to autonomous driving that could be addressed by edge computing (e.g., latency in decision-making, data processing challenges).
- Formulate hypotheses about how edge computing can optimize ITS for autonomous driving.

4. Conclusion

This paper underscores the critical role of edge computing in revolutionizing Intelligent Transportation Systems (ITS) for autonomous driving. It illuminates how edge computing's capacity for local, real-time data processing directly addresses the immediate needs of autonomous vehicles, such as swift decision-making and heightened safety. By integrating edge computing with ITS, the research highlights the substantial reduction in latency, enhancing the responsiveness of autonomous vehicles through the deployment of edge servers, sensors, and advanced V2X communication technologies. The synergy of these components supports real-time traffic management, collision avoidance, and dynamic route optimization. The paper also navigates through the challenges of implementing edge computing in ITS, including security, data integration, and scalability, while proposing potential solutions and directions for future research. Significantly, the exploration of edge computing's interplay with breakthrough technologies like 5G, AI, and machine learning accentuates its indispensable role in advancing ITS. Conclusively, the paper emphasizes that edge computing is pivotal in materializing the vision of fully autonomous driving, marking a substantial stride towards safer, more efficient, and environmentally friendly transportation systems.

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홍 성 혁(Sunghyuck Hong) [종신회원]

- 2007년 8월 : Texas Tech University, Computer Science (공학박사)
- 2012년 3월 ~ 현재 : 백석대학교 첨단IT학부, IoT 전공 주임 교수
- 관심분야 : 핀테크, 딥러닝, 블록체인, 사물인터넷 보안
- E-Mail : shong@bu.ac.kr