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Research Article

CNN-Based Smart Parking System Using VANET: A Novel Intelligent Transportation System Framework

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Abstract

Urban traffic congestion and inefficient parking management have emerged as major challenges in modern smart cities due to the rapid growth in the number of vehicles and increasing urban population density. In many metropolitan regions, drivers spend a considerable amount of time searching for vacant parking spaces, which leads to excessive fuel consumption, increased traffic congestion, environmental pollution, and driver frustration. Conventional parking systems primarily rely on manual supervision or sensor-based infrastructure, which often involves high operational costs, limited scalability, delayed response times, and inefficient utilisation of parking resources. These limitations highlight the urgent need for intelligent, automated, and real-time parking management solutions capable of supporting future smart transportation environments.

This paper proposes a novel Smart Edge-based Vehicle Parking System (SE-VPS) that integrates Convolutional Neural Network (CNN)-based image classification, Vehicular Ad-Hoc Networks (VANETs), and edge computing technologies to develop an efficient and intelligent parking management framework. The proposed system utilizes surveillance cameras installed in parking zones to continuously capture parking area images. These images are processed locally using an edge server equipped with a trained CNN model capable of accurately detecting parking occupancy and classifying vehicles into categories such as Light Motor Vehicles (LMVs) and Heavy Motor Vehicles (HMs). Based on vehicle classification and parking availability, the system allocates appropriate parking slots dynamically and efficiently.

The proposed architecture consists of several interconnected components including Parking Side Units (PSUs), Road Side Units (RSUs), On-Board Units (OBUs), edge servers, and a centralized Traffic Management Bureau (TMB). PSUs monitor parking slot occupancy and communicate parking status information to the edge server. RSUs facilitate Vehicle-to-Infrastructure (V2I) communication by transmitting parking updates, congestion information, and routing guidance to nearby vehicles. OBUs installed within vehicles receive real-time parking information and assist drivers in navigating toward available parking slots. The Traffic Management Bureau supervises system coordination, authentication mechanisms, congestion monitoring, and communication management to ensure secure and efficient system operation.

The integration of VANET communication with edge computing enables low-latency information exchange and real-time decision-making within highly dynamic vehicular environments. Unlike conventional cloud-based parking systems, the proposed edge-based framework performs image processing and parking occupancy analysis locally, thereby reducing communication delays, bandwidth consumption, and dependency on centralized cloud infrastructure. This localized processing significantly improves response time and system scalability, making the framework suitable for large-scale smart city deployments.

The CNN model employed in the proposed system is trained using parking lot image datasets under

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varying environmental and lighting conditions to ensure robust performance and high classification accuracy. Experimental analysis of the proposed framework targets vehicle classification accuracy above 96%, precision exceeding 95%, and image processing time below 50 milliseconds per frame. These performance metrics demonstrate the capability of the system to provide fast and reliable parking management services in real-time urban traffic environments.

The proposed SE-VPS framework aims to minimize driver parking search time, reduce unnecessary vehicle movement, decrease fuel consumption, and lower carbon emissions associated with urban traffic congestion. Additionally, the intelligent parking allocation mechanism improves parking space utilization and enhances the overall efficiency of urban transportation infrastructure. The proposed system contributes toward the development of sustainable smart city ecosystems by integrating artificial intelligence, edge computing, and vehicular communication technologies into a unified intelligent parking management solution.

KEYWORDS: Smart Parking, VANET, CNN, Intelligent Transportation System, Edge Computing, IoT, Vehicle Classification.

1. INTRODUCTION

The rapid expansion of urban populations has created a severe strain on city infrastructure, particularly in the domain of vehicle parking. Studies indicate that drivers in major cities spend an average of 8 to 14 minutes searching for a parking space, contributing to traffic jams, increased carbon emissions, and driver frustration. With millions of vehicles added to global roads each year, solving the parking problem has become a critical component of the smart city agenda.

Vehicular Ad-Hoc Networks (VANETs) have emerged as a powerful communication technology that enables vehicles to exchange data with each other and with roadside infrastructure in real-time. When combined with Convolutional Neural Networks (CNNs) — a proven deep learning technique for visual recognition — VANETs offer a strong foundation for building intelligent, automated parking systems that operate without human intervention.

This paper presents the design and methodology of a Smart Edge-based Vehicle Parking System (SE-VPS). The system uses CNN-based vehicle classification, VANET communication protocols, and edge server management to offer drivers accurate, real-time guidance to available parking slots. The key advantages of this approach include reduced dependency on physical sensors, lower infrastructure cost, improved accuracy, and scalability across large urban environments.

1.1 Vehicular Ad-Hoc Networks (VANET)

VANETs are a specialised category of Mobile Ad-Hoc Networks (MANETs) designed for vehicles and transportation infrastructure. In a VANET environment, every vehicle acts as a dynamic node that can communicate with neighbouring vehicles (Vehicle-to-Vehicle, or V2V) and with fixed infrastructure units along the road (Vehicle-to-Infrastructure, or V2I). These networks are self-organising, requiring no permanent base station, making them highly suitable for dynamic urban environments.

VANETs support the Intelligent Transportation System (ITS) by enabling real-time data sharing about road conditions, vehicle positions, parking availability, and traffic density. The key challenge in VANET-based parking applications is ensuring secure, low-latency communication while accommodating the high-speed mobility of vehicles and the frequently changing network topology.

1.2 Role of CNN in Smart Parking

Convolutional Neural Networks (CNNs) are a class of deep learning models specifically designed to process grid-like data such as images. CNNs automatically learn spatial features — edges, shapes, textures — through successive layers of convolution, pooling, and fully connected operations. In the context of smart parking, a CNN model can be trained on parking lot images to distinguish between occupied and vacant spaces, as well as to classify vehicle types (LMV vs. HMV) for optimised slot allocation.

The integration of CNNs into a VANET-based parking system allows for camera-based detection without the need for expensive ground sensors at every parking bay. A single camera per zone, combined with an edge server running the CNN inference engine, can monitor dozens of spaces simultaneously, making the system both cost-effective and scalable.

CNN-based image processing also improves the accuracy and reliability of parking occupancy detection under varying environmental conditions such as low lighting, shadows, rain, and partial vehicle occlusion. The model continuously learns from training datasets and can be further optimized using real-time parking data to enhance classification performance. In the proposed SE-VPS framework, the CNN inference process is executed at the edge server level, enabling low-latency decision-making and rapid communication of parking updates to nearby vehicles through VANET infrastructure. This intelligent integration of deep learning and vehicular communication significantly enhances automation, operational efficiency, and real-time responsiveness within smart parking environments.

2. LITERATURE SURVEY

The research landscape in smart parking and VANET-based transportation systems has grown rapidly in recent years. This section summarises key studies that have influenced the design of the proposed SE-VPS framework. Table 1 provides a consolidated overview of the reviewed literature.

Several researchers have explored the integration of Internet of Things (IoT), Artificial Intelligence (AI), edge computing, and vehicular communication technologies to improve parking management efficiency and urban mobility. Existing studies mainly focus on parking occupancy detection, traffic congestion reduction, intelligent routing, and real-time vehicular communication. However, many current approaches still face

limitations related to scalability, infrastructure cost, communication latency, security, and efficient vehicle classification. The literature review highlights these research

gaps and demonstrates the need for an intelligent, low-latency, and scalable parking management framework such as the proposed SE-VPS system.

Table 1: Summary of Related Work in Smart Parking and VANET Systems

Author(s) & Year	Method / System	Key Finding	Accuracy
Almalki & Ragab (2025) ^[1]	YOLOv8 Deep Learning	Smart parking in sustainable cities; improved resource use	~99%
Vijayalakshmi <i>et al.</i> (2025) ^[2]	LSTM-based IDS for VANET Parking	Detects DDoS attacks in smart parking systems	~97%
Bohra <i>et al.</i> (2023) ^[3]	V2X + AI/ML Review	ML improves safety, routing, and driver awareness in VANETs	Review
Alsheikhy <i>et al.</i> (2022) ^[4]	CNN + Image Processing	Automated space detection using a single camera, no sensors needed	>97%
Canli & Toklu (2021) ^[5]	LSTM-based Mobile App	Predicts occupancy using real-time + historical data	High
Kanan <i>et al.</i> (2020) ^[6]	IoT Sensor + VTD	Low-cost real-time monitoring with auto payment	High
Mettupally <i>et al.</i> (2019) ^[8]	CNN + Big Data	Grid layout of parking via GPS and deep learning	High
Lookmuang <i>et al.</i> (2018) ^[10]	IoT-based Guidance	Guides users to slots; reduces congestion inside parking areas	Good

Table 1: Literature Review Summary

Almalki and Ragab (2025) ^[1] demonstrated that advanced deep learning models such as YOLOv8 can achieve nearly 99% accuracy in parking space detection, positioning AI as central to the future of smart city parking. Vijayalakshmi *et al.* (2025) ^[2] extended this to VANET-integrated systems, demonstrating that LSTM-based intrusion detection can secure smart parking networks against DDoS attacks with approximately 97% accuracy.

Earlier works by Alsheikhy *et al.* (2022) ^[4] and Canli and Toklu (2021) ^[5] established the feasibility of CNN and LSTM-based parking systems, respectively, achieving accuracy rates above 97%. Kanan *et al.* (2020) ^[6] showed that IoT-based low-cost sensor systems can monitor parking in real time and enable automatic billing, while Mettupally *et al.* (2019) ^[8] combined CNN with big data analytics to create a grid-based GPS parking guidance app.

Despite these advances, most existing systems focus on occupancy detection alone and do not address vehicle classification, dynamic re-routing in congested conditions, or edge-server-based architecture for low-latency operation. The proposed SE-VPS bridges these gaps by integrating CNN classification, VANET communication, and edge computing into a unified framework.

3. RESEARCH PROBLEM AND MOTIVATION

Urban parking management suffers from several unresolved challenges that limit the effectiveness of existing systems:

- Drivers spend excessive time searching for parking, wasting fuel and increasing emissions.
- Most systems rely solely on occupancy detection and do not classify vehicle types, leading to inefficient slot usage when HMVs occupy LMV bays and vice versa.
- Existing IoT sensor-based systems require hardware at each parking bay, resulting in high installation and maintenance costs.
- Traditional systems lack real-time dynamic re-routing when a parking facility is full.
- Security threats such as DDoS attacks on VANET-connected parking infrastructure are often not addressed.
- Most systems are not scalable to multi-level, multi-zone parking complexes in large cities.

These limitations significantly reduce the efficiency, reliability, and scalability of current parking management infrastructures. In highly populated urban areas, the inability to provide real-time parking guidance and intelligent slot allocation contributes directly to traffic congestion and poor transportation management. Additionally, centralized cloud-dependent architectures often introduce communication delays and bandwidth overhead, making them unsuitable for time-sensitive vehicular environments. The absence of efficient security and authentication mechanisms further increases the vulnerability of parking systems to cyberattacks and unauthorized access.

These gaps motivate the development of the SE-VPS system, which uses camera-based CNN detection, VANET communication for real-time updates, and edge servers for low-latency decision-making all without requiring sensors at every individual parking bay. The proposed framework aims to provide a scalable, secure, and intelligent parking solution capable of supporting future smart city transportation infrastructure while improving parking efficiency, reducing operational costs, and enhancing overall urban mobility.

4. RESEARCH AIM AND OBJECTIVES

4.1 RESEARCH AIM

The primary aim of this research is to design, develop, and validate a novel Intelligent Transportation System (ITS) for smart parking using VANET and CNN-based vehicle analysis that can accurately classify vehicles, allocate parking spaces, and dynamically re-route traffic in real-time.

4.2 SPECIFIC OBJECTIVES

- To count the total number of vehicles entering and exiting a parking facility in real time using vehicular analytics and VANET communication.
- To classify vehicles into Light Motor Vehicles (LMVs) and Heavy Motor Vehicles (HMVs) using a trained Convolutional Neural Network model applied to camera images.
- To intelligently allocate parking slots based on vehicle type, distance from destination, driving time, and real-time congestion data from the Traffic Management Bureau.

- To dynamically re-route vehicles to alternative parking facilities in the event that the target parking zone is full, using RSU-assisted guidance.
- To evaluate the proposed SE-VPS using standard classification metrics including Accuracy, Precision, Recall, and F1-Score.

5. RESEARCH METHODOLOGY

This section describes the architecture and operational workflow of the proposed Smart Edge-based Vehicle Parking System (SE-VPS). The system integrates five key components that communicate through VANET protocols and edge computing infrastructure.

The proposed methodology combines Convolutional Neural Network (CNN)-based vehicle classification, real-time vehicular communication, and intelligent parking allocation to provide an automated and efficient parking management

solution for smart city environments. The system is designed to monitor parking availability dynamically, classify vehicles according to their category, and guide drivers toward suitable parking spaces with minimum delay.

By utilizing edge computing and VANET communication, the proposed framework ensures low-latency processing, real-time data dissemination, improved scalability, and reduced dependency on traditional sensor-based parking infrastructure.

5.1 System Architecture

The SE-VPS architecture is built around an edge computing model in which intelligence is pushed closer to the data source (parking zones and road segments) rather than relying on distant centralized cloud servers.

This reduces communication latency and enables real-time decision-making. The five core components of the architecture are described in Table 2.

Table 2: System Architecture Components of SE-VPS

Vehicles with OBU/GPS	Entry/Exit monitoring, sends location & vehicle type
Parking Side Units (PSU)	Manages parking slots, communicates with edge servers
Road Side Units (RSU)	Tracks vehicle movement, reports congestion
Edge Server (SE-VPS)	CNN-based classification, parking allocation, real-time analytics
Traffic Management Bureau (TMB)	Authentication, security, vehicle registration

Table 2: Core Components of the Proposed SE-VPS Architecture

5.2 Communication Model

The SE-VPS operates on a hybrid communication model combining V2V (Vehicle-to-Vehicle) and V2I (Vehicle-to-Infrastructure) modes over 3G/4G networks. When a driver approaches a parking zone, the vehicle's OBU broadcasts its GPS coordinates, vehicle ID, and vehicle type to nearby RSUs. The RSU forwards this data to the edge server, which queries the CNN classification model and the parking database to identify the nearest suitable available slot.

If no slot is available, the edge server calculates alternative routes to nearby parking facilities using congestion reports from the TMB and instructs the RSU to broadcast re-routing guidance to the vehicle. All vehicle registrations and authentications are handled by the TMB through Edge Authentication Units (EAUs), ensuring only authorized vehicles receive parking services.

The proposed communication framework enables continuous real-time interaction between vehicles, parking infrastructure, and edge servers, thereby improving parking management efficiency and reducing communication delays. The edge server performs localized processing of parking data, which minimizes

network congestion and decreases dependency on centralized cloud systems. This low-latency processing capability is particularly important in highly dynamic urban traffic environments where parking availability changes rapidly. Furthermore, the integration of intelligent routing and authentication mechanisms enhances system reliability, improves driver convenience, and strengthens the security of VANET-enabled parking communication. The hybrid communication architecture also supports scalability, allowing the proposed system to efficiently manage large multi-level and multi-zone parking infrastructures in smart city environments.

5.3 CNN-Based Vehicle Classification

The CNN model is the core intelligence of the SE-VPS. It is trained on a dataset of parking lot images captured under various lighting conditions, camera angles, and weather scenarios. The training dataset includes images of LMVs (cars, sedans, SUVs) and HMs (trucks, buses, vans), pre-labeled for supervised learning. Data augmentation techniques such as rotation, brightness adjustment, and horizontal flipping are applied to improve model generalization.

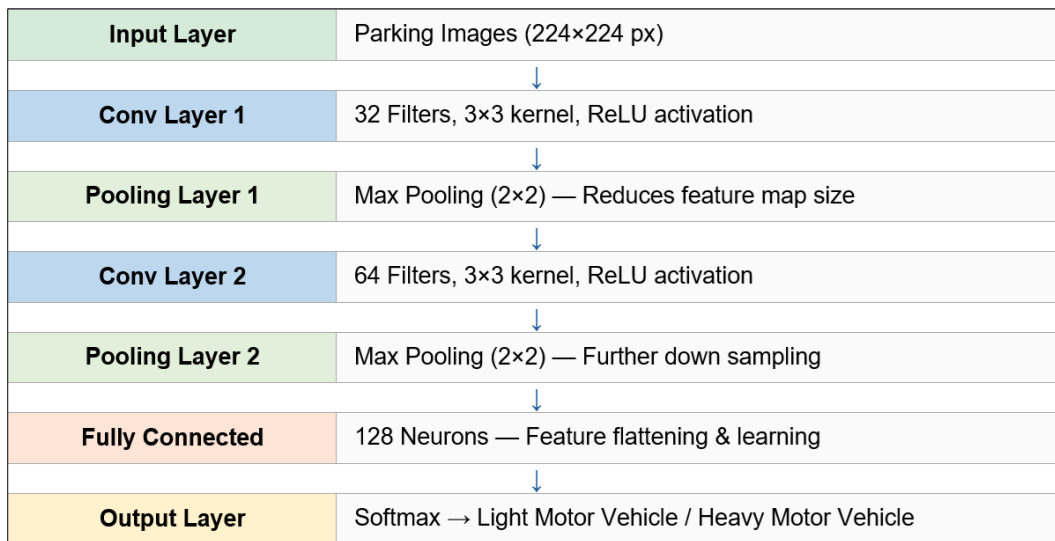


Figure 1: Layer-by-Layer Structure of the Proposed CNN Model

Fig 1: CNN Architecture for Vehicle Classification in SE-VPS

As illustrated in Figure 1, the CNN consists of an input layer accepting 224×224 pixel images, two convolutional-pooling block pairs for hierarchical feature extraction, a fully connected layer for feature aggregation, and a Softmax output layer that produces classification probabilities for each vehicle class. The ReLU activation function is used in convolutional layers to introduce non-linearity and accelerate training. Max-pooling layers reduce spatial dimensions while retaining the most prominent features.

5.4 Parking Slot Allocation Algorithm

Once the vehicle is classified, the SE-VPS executes a multi-factor slot allocation algorithm. The algorithm considers the following parameters for optimal slot assignment:

- Vehicle type (LMV or HMV) to match slot dimensions.
- Walking distance from the allocated slot to the driver's destination.
- Current occupancy level of the parking facility.
- Estimated parking duration based on historical patterns.
- Real-time congestion index reported by the TMB.

The algorithm generates a weighted score for each available slot and assigns the slot with the highest score to the incoming vehicle. The slot status is immediately updated in the edge server database, and the OBU in the vehicle receives confirmation of the allocated slot along with turn-by-turn navigation guidance.

This intelligent slot allocation mechanism improves parking space utilization and minimizes unnecessary vehicle movement

inside parking facilities. By considering multiple real-time parameters simultaneously, the system ensures balanced parking distribution, reduced congestion, and faster parking access for drivers. The automated allocation process also enhances overall operational efficiency and supports scalable parking management in large urban environments.

6. Evaluation and Expected Outcomes

The proposed SE-VPS framework will be implemented and tested using a combination of simulation tools (NS3 for VANET communication) and deep learning frameworks (TensorFlow/Keras for CNN training). A real-world parking lot dataset will be used for model training and validation. The system performance will be measured using the metrics defined in Table 3.

The experimental setup will evaluate both communication efficiency and vehicle classification performance under varying traffic densities and parking occupancy conditions. Multiple simulation scenarios will be created to analyze the scalability, response time, and reliability of the proposed framework in real-time urban environments. The integration of VANET communication and edge-based CNN processing will also be analyzed to determine the effectiveness of low-latency parking guidance and intelligent slot allocation mechanisms. Furthermore, comparative performance analysis with existing parking systems will be conducted to demonstrate the advantages of the proposed SE-VPS architecture in terms of accuracy, efficiency, and operational cost reduction.

Table 3: Performance Evaluation Metrics for SE-VPS

Metric	Formula	Description	Expected Value
Precision	$TP / (TP + FP)$	Proportion of correctly predicted positive samples	Target > 95%
Recall (Sensitivity)	$TP / (TP + FN)$	Proportion of actual positives correctly identified	Target > 94%
Accuracy	$(TP+TN) / (TP+TN+FP+FN)$	Overall correct predictions out of all predictions	Target > 96%
F1-Score	$2 \times (P \times R) / (P + R)$	Harmonic mean of Precision and Recall	Target > 95%
Processing Time	Milliseconds per frame	Speed of real-time vehicle classification	< 50 ms

Table 3: Evaluation Metrics with Target Values

The confusion matrix will be used to visualise the classification performance, separating True Positives (correctly classified LMVs), True Negatives (correctly classified HMVs), False Positives, and False Negatives. Training and validation loss curves will be monitored to detect overfitting, and hyper parameters will be tuned accordingly.

6.1 Comparison with Existing Systems

To validate the advantages of the proposed approach, the SE-VPS will be benchmarked against existing parking systems across key dimensions. Table 4 provides a comparative analysis. The comparison focuses on important performance

factors such as real-time responsiveness, detection accuracy, infrastructure dependency, traffic impact, and scalability in large urban parking environments. Existing parking approaches including manual systems, IoT sensor-based systems, RFID-based systems, and traditional image processing methods are analyzed to identify their strengths and limitations. The proposed SE-VPS framework is evaluated against these systems to demonstrate its ability to provide intelligent, low-latency, and cost-effective parking management through the integration of CNN-based vehicle detection, VANET communication, and edge computing technologies.

Table 4: Comparison of SE-VPS with Existing Parking Systems

System Type	Technology	Real-time?	Traffic Impact	Accuracy	Detection Mode
Traditional Parking	Manual	No	High	Low	Manual
IoT Sensor-based	Sensors	Partial	Moderate	Medium	Sensor-based
RFID-based	RFID tags	Yes	Moderate	Medium	RFID reader
Camera + Rule-based	Image Processing	Yes	Low	Medium	Fixed rules
Proposed SE-VPS (CNN)	CNN + VANET + Edge	Yes	Low	High	Automated AI

Table 4: SE-VPS vs. Existing Smart Parking Approaches

As shown in Table 4, the proposed SE-VPS is the only system that combines real-time operation, high accuracy, VANET-based communication, and fully automated AI-driven detection without requiring physical sensors at every bay. This makes it significantly more cost-effective and scalable than sensor-based or RFID-based alternatives. In addition, the use of edge computing enables faster processing and reduced communication latency, which is essential for dynamic urban transportation environments. The CNN-based vehicle classification mechanism further improves parking slot utilization by allocating spaces according to vehicle type and parking requirements. The proposed framework also enhances system flexibility and scalability, making it suitable for deployment in multi-level, multi-zone smart parking infrastructures across modern smart cities.

7. CONCLUSION

This paper has presented the design and methodology of a Smart Edge-based Vehicle Parking System (SE-VPS) that uses Convolutional Neural Networks and VANET communication to deliver intelligent, real-time parking management. The proposed system addresses the major shortcomings of traditional and existing smart parking approaches by introducing CNN-based vehicle classification, edge server intelligence, and dynamic re-routing capabilities.

The SE-VPS architecture is built around five interacting components vehicles with OBUs, Parking Side Units, Road

Side Units, the Edge Server with the CNN engine, and the Traffic Management Bureau all communicating through a hybrid V2V and V2I VANET model. This design ensures low-latency decision-making, real-time slot allocation, and secure vehicle authentication.

Future research directions include extending the CNN model to detect parking violations, integrating electric vehicle charging slot management, and deploying the system in a real-world pilot parking facility. The proposed framework contributes a scalable, cost-efficient, and technically robust solution to one of the most pressing challenges in modern smart city infrastructure.

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