# Enhancing parking efficiency: An innovative vehicle scheduling algorithm

Noman Gul [1], Asad Masood Khattak [2], Muhammad Imran Taj [3], Nagarajan Chandrashekaran [2], Bashir Hayat [1], Awais Ahmad [1]

[1] Centre for Excellence in IT, Institute of Management Sciences, Hayatabad, Peshawar, Pakistan
[2] College of Technological Innovation, Zayed University, UAE
[3] College of Interdisciplinary Studies, Zayed University, UAE

noman.gul@imsciences.edu.pk, asad.khattak@zu.ac.ae, muhammadimran.taj@zu.ac.ae, nagarajan.chandrashekaran@zu.ac.ae, bashir.hayat@imsciences.edu.pk, awaisahmaad@gmail.com,

***Abstract*—Vehicle Parking queues in smart cities are typically managed in a first come, first serve manner. These queues are sorted on the basis of vehicle arrival time and neglect crucial vehicle information and the size of the parking area. Vehicle information consists of the vehicle's nature, size, type, etc. Established parking systems allow any vehicles with reservation, and hence different heavyweight and unsuitable vehicles, to enter into congested roads, causing unnecessary traffic jams and inconvenience for the public. To overcome the above-mentioned issues, this research study proposes an efficient and robust vehicle scheduling algorithm known as Priority Vehicle Scheduler (PVS). The scheduler arranges vehicles based on their nature, size, and other properties. The proposed algorithm is compared with the traditional algorithm First Come First Serve (FCFS) and Shortest Job First (SJF) in terms of three parameters using a detailed simulation. These parameters are the degree of congestion, environmental pollution and throughput. The simulation results show that the proposed algorithm performs better in all three parameters, thus keeping heavy and loaded vehicles outside the congested roads and prioritising emergency vehicles.**

***Keywords: PVS, fog computing, cloud, IoT***

## I. Introduction

The vehicle parking system is an integral part of the intelligent transport system and is crucial in mitigating traffic jams and traffic clogging [1]. The increase in the number of vehicles on roads due to the flow of people from rural areas to urban areas generates massive traffic on roads, resulting in a polluted society with health and social problems. The transport system designed for a city should accomplish the basic objectives of traffic and pollution reduction [2]. In smart cities, the objectives of reduced traffic jams and smooth traffic passages are achieved by providing dedicated slots for vehicles in parking areas. In Smart Parking systems (SPS), vehicle drivers reserve a slot in the parking area before placing vehicles on roadways [3]. The parking areas are available to drivers on a single click through web or mobile applications. The applications are updated in real-time. Each time a vehicle leaves a parking slot, data is updated in the cloud server in real-time, letting other vehicle users reserve a slot in advance. If a driver gets a reservation, he moves his vehicle to the concerned location and occupies his slot. Traffic management in such a manner reduces the chances of jams, standstill traffic, and clogging conditions [4]. Moreover, vehicle users come to know about the crowd situation in a particular place and can choose the best time to visit a place. The advantages of Smart parking systems are reduced traffic congestion, optimized space utilization, enhanced safety, and a convenient way of payment of parking fees [5]. Smart Parking systems use different types of scheduling algorithms to provide reservations. In most cases, these reservations are based on a first come, first serve basis. The vehicles that reserve the space first are allowed to enter and occupy a parking slot first. The scheme best fits and is utilized when all vehicles are of the same size, type, status, etc. [6].

The vehicle scheduling algorithm is critical in smart parking systems for managing numerous operations such as vehicle entry, slot reservation, exits, and maintaining a balance among parked vehicles. It decides which vehicles receive reservations in specified parking slots and the order in which they are assigned. To optimize this process, several well-known scheduling algorithms have been used, including First Come First Serve (FCFS), Shortest Job First (SJF), Round Robin (RR), Ant Colony Optimization, Simulated Annealing, and Deadline Scheduling. FCFS prioritizes based on arrival time, SJF reduces waiting times, RR assures equitable allocation, Ant Colony Optimization replicates ant behavior, Simulated Annealing investigates optimal solutions, and Deadline Scheduling handles urgent parking needs. The selection of an appropriate algorithm significantly impacts the efficiency and satisfaction of consumers, making it essential for arriving at the right choice that is appropriate for the specific requirements of a smart parking system [7].

The vehicles parked in the parking area may be homogenous or heterogeneous. Homogenous means they are the same in properties, while heterogeneous means they are different from each other. The vehicles selected for parking are not homogenous in terms of properties but heterogeneous. The heterogeneous mode of parking area gives rise to various issues like the flow of irregular traffic, entry of heavy and loaded vehicles on roads, and unavailability of space for emergency vehicles [8]. The process significantly affects the performance of smart parking systems as the same conditions of jams and standstill occurs due to mismanagement of parking systems and in-efficient algorithms in parking software [9]. Figure. 1 demonstrates a generalized smart parking system model connected through Fog and cloud computing. It highlights the architecture, connectivity, and user interaction for real-time parking management and data processing.

This research study proposed an efficient scheduling algorithm, namely PVS, to overcome issues arising from vehicles' heterogeneity. Apart from reservation parameters, the algorithm uses other parameters like size, type and status to select a vehicle for parking. It also assigns priority to each vehicle. The vehicles bearing priority flags are given preference as compared to other vehicles.

2835-5776/24/$31.00 ©2024 IEEE
DOI 10.1109/IRI62200.2024.00027


Fig. 1. Generalized smart parking scenario in a smart city envoirenment

The algorithm design assists parking software to allocate space to vehicles as per their properties and in such a manner that the chances of traffic jams and traffic cessation are eliminated and smooth traffic flow is ensured. The simulation study demonstrates that our proposed priority vehicle scheduler has the capacity to benefit the smart parking system in management. In order to eradicate traffic jams, traffic clogging and minimize pollution, there is a dire need of structured approach to traffic parking related issues. The conventional algorithms did not consider the structure size, type and priority during offering reservation while these are considered as main features in vehicle entry and exit to a specific place. The proposed algorithm provides guide map for the parking of vehicles.

The major contributions of the proposed research study can be summarized as follows:

- This research study proposed an efficient task-scheduling algorithm for smart parking systems. The algorithm uses Priority Vehicle Scheduler (PVS) to sort and provide vehicle reservations as per their properties.
- This research study briefly elaborates on smart parking systems. The limitations of current parking systems, its disadvantages and how to overcome the issues of smart parking.
- This research study introduces priority flags for vehicles with special status. Vehicles like ambulances, military etc require priority status for parking. The same priority is achieved using flag indicator.

In traditional algorithm like FCFS and others, the parking space is allotted on First come first serve basis, if a non-emergency vehicle reserve a place in area which is most probably captured by emergency vehicles, then the algorithm allow it. The proposed study restricts the vehicles to park at any place rather it provides a specified area/location for its parking. The PVS algorithm offers a more integrated and dynamic approach, ensuring real-time adjustments and reservations, which can enhance efficiency and adaptability.

The rest of the paper is organized as section-II discusses the related work done in smart parking systems in the domain of scheduling algorithms. Section-III provides the motivation and section -IV demonstrates the proposed protocol along with its working. Section-V discusses the results achieved during the proposed protocol's evaluation, while section-VI concludes the current research study and provides future directions.

## II. Related work

The concept of integration of Smart Parking systems in smart cities is explored extensively. Some research studies incorporate SPS, each with a different implementation paradigm. The major objective of all these studies is to nourish a healthy and pollution-free environment with reduced traffic congestion and problems, establishing a convenient transportation system for the public.

Authors in [10] proposed an SPS that makes use of FCFS and round-robin scheduling algorithms. The algorithm divides the scheduling process into two phases. At first, the vehicles are entered into the queue, and in the second phase, they are employed for load balancing. The algorithm assigns time slots to vehicles in a queue based on their position, ensuring balanced opportunities and outperforming predecessors. Rosli et al. [11] Focus on the most common parking issues in congested cities, such as security concerns, traffic congestion, and particularly for vulnerable groups. The study provides a smart parking allocation system prototype that prioritizes user categories such as women, pregnant women, disabled, and typical users. The electric vehicles (EVs) gain popularity as a green alternative, the possibility of EV Smart Parking Lots (SPLs) emerges. These research studies [12], [13] offer a self-scheduling approach for SPLs, which ensures equal access to mobile charging stations while optimizing energy management via several components. These developments represent an important move towards smarter, more sustainable urban areas.

The safety of smart parking systems is supreme, requiring the use of powerful object detection techniques. Deep learning (DL) based algorithms have proven useful in real-time object recognition; however, attention has been focused on the multi-detection of pedestrians, cars, and traffic signs. [14] compares Faster-RCNN and SSD models for these critical detection tasks across multiple versions, addressing the requirement for detailed assessment criteria and introducing the TraPedesVeh dataset. The results demonstrate the superiority of the Faster-RCNN model with the Inception backbone, which promises improved safety and efficiency in smart parking systems. Shubham et al, [15] focus on using fog computing to build a responsive smart, automated parking system that reduces latency and ensures real-time decision-making. This system optimizes resource management and improves the entire parking experience. The study at [16] proposes an advanced smart parking system based on matching theory that addresses the issue of assigning parking places in congested urban locations. This system includes a prior reservation mechanism to control large traffic volumes and a dynamic parking fee structure to balance parking utilization while maximizing profit for parking operators.

The number of parking spaces available for vehicle parking is less in number. This deficiency enables researchers to encourage private parking spaces and the sharing of parking spaces with car drivers, thus meeting the demand and supply paradigm. The CHs defined uses Auto Regressive Moving Average (ARMA) for predicting the arrival of the next task. Similar protocols for task scheduling are explored in research studies at [17], [18]. All these studies and proposed algorithms significantly improved the parking issues but did not address some of the challenging problems. These issues are as follows.

- The algorithms permit entry of all vehicles regardless of their size and type. E.g., if a heavy and loaded vehicle reserves a slot in the parking area near markets and crowded spaces. It is accommodated without any preconceptions. The entry of loaded vehicles in such places creates an imbalance in road traffic, causing traffic jams and difficulty for other small vehicles to adjust.
- The algorithms did not provide a mechanism for directing inappropriate vehicles to specific parking areas. E-g ideally, heavy vehicles should be parked outside the crowded areas so that it does not affect traffic flow and its adverse effects on traffic congestion should be mitigated.
- The algorithms did not prioritize different types of vehicles. Vehicles like ambulances, fire brigades, military & police are often deployed in crowded places and locations like hospitals, markets, etc. They are usually accommodated in parking places to keep smooth traffic flow. In case of non-availability of parking slots, the vehicles may not be accommodated, and they are usually parked on roads, causing inconvenience for the public.

All these issues are vital for the resolution of traffic-related problems like congestion, clogging, standstill, etc. This research study proposed an efficient task scheduling algorithm for effectively handling vehicles of all sizes and nature.

## III. Motivation

This research study addresses a critical aspect of an intelligent transport system known as a vehicle parking system. Mismanaged vehicle parking systems have a significant implication on the environment and public health as they cause traffic jams and clogging which result in anxiety, depression and other health problems [19]. There have been certain research studies on how to improve the management of vehicle parking system and get the best out of it, but certain issues still need to be addressed. These issues relate to the nature, type and size of vehicles entering the parking area. This research study tries to resolve the issue by proposing an efficient vehicle scheduling algorithm, PVS. All vehicles are offered reservations on the basis of their size, nature and condition. E.g, heavy traffic is usually parked outside the city because of its size. If such vehicles apply for reservation in cities the Parking system will automatically direct the vehicle to the nearest parking for loaded and heavy traffic. The algorithm enables the establishment of uniform parking areas. Each vehicle has a specific parking place with a particular priority, thus eliminating inadvertent traffic congestion.

## IV. Proposed Algorithm

This section briefly discusses the workings of the priority vehicle scheduler, a vehicle scheduling algorithm. The algorithm envisions a crowded parking area divided into different parking slots, each with a specific size, a Fog layer, and a Cloud layer. Cameras capture images of the parking slot and identify filled and vacant positions in the parking area.

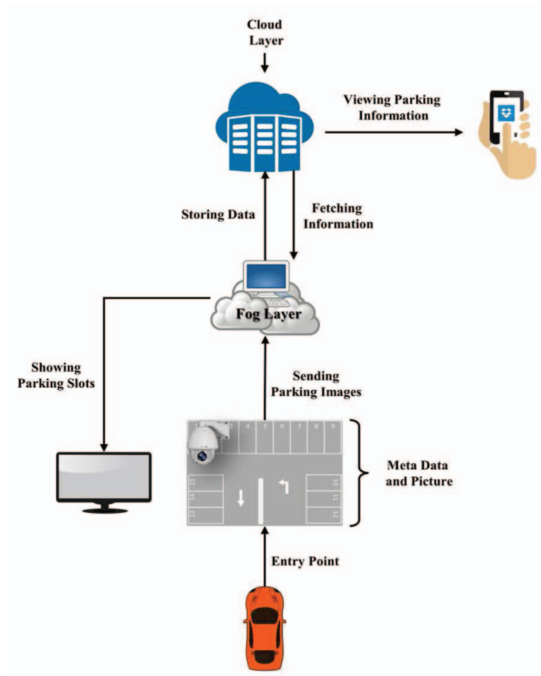


Fig. 2. Workflow of smart car parking System from entry point to showing on screen and viewing on web application

The information is extracted from images of parking slots captured by the camera occasionally. This information is processed and, information regarding the slots is obtained. This information is then transferred to the primary repository of parking, i.e., the fog layer [20]As cameras have limited storage capacities, a fog layer is used to store data. The fog layer has no storage or processing limitations. It stores data temporarily, while for permanent storage, it is transferred to the cloud layer. [21]. The cloud layer is the permanent repository of data. The end-user then accesses the information about the slots through a mobile or web application. Figure 2 illustrates the smart parking system's implementation scenario and process flow. The process continues, and drivers reserve slots for themselves in the parking areas. Each vehicle has a specific size and nature. If the parking area is in front of the hospital, ambulances should be given priority in occupying a slot. If two different vehicles are in run for a single parking slot. Priority may be given to ambulances because of their nature. The algorithm assigns a parking slot to the ambulance while the other vehicle is redirected to the nearest neighbour parking.

Similarly, crowded areas where markets are situated are usually congested. The entry of heavy and oversized vehicles into the area disturbs the whole flow of the vehicles. The parking areas in these places are only for small vehicles and not for heavy traffic. The algorithm assigns a specific priority number of flags to the vehicle based on vehicle size when it registers itself. The priority flag determines the permission to enter or park at a specific instance. When the vehicle wants to apply for a reservation, the algorithm retrieves its information from the database, i.e., its size, nature, history and other information saved by the system. The smart parking system works by first accessing parking area information to determine whether a vehicle fits the eligibility criteria for parking in a specific location or should be directed to another parking spot. Based on this information, the location of the vehicle should be decided, ensuring the best allocation and effective use of parking resources.

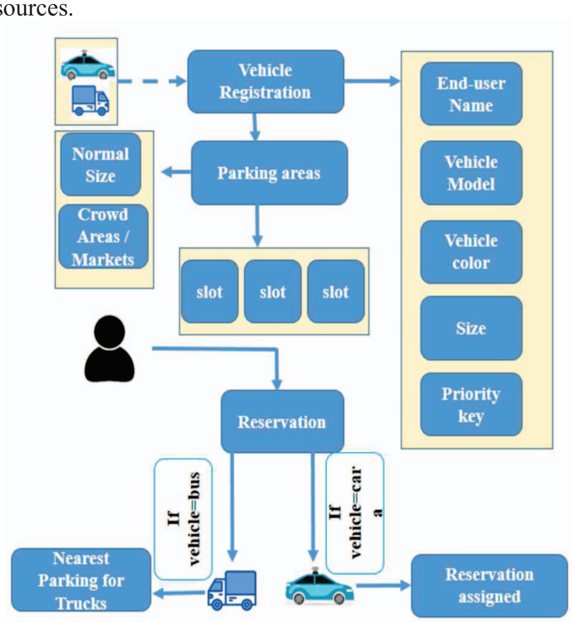


Fig. 3. Flowchart of the PVS System for efficient traffic management

Figure. 3, demonstrates the proposed algorithm's flowchart, where two vehicles of different sizes compete for parking slots in a specific parking area. The parking area is crowded and has markets/shops. Entry of heavy trucks is forbidden in such areas as they will disturb the normal flow of vehicles. The flowchart shows that if we have a heavy vehicle based on its size, parking reservation is denied and redirected to the nearest parking available for these vehicles. In contrast, a small vehicle can enter the parking area because it fits in the area and does not disturb traffic flow. The system is designed so that all vehicles of any nature have their own priority. There are specified parking areas for heavy vehicles. These vehicles did not need to travel around the area instead they are directed to their specified place.

The proposed VPS study utilize a multi-tiered priority system that assigns high priority to ambulances. It assigns medium priority to doctors, patients and lower priority is given to other vehicles. A reservation system for critical users is integrated in the system. Furthermore, the algorithm adjust priorities based on real-time data. This ensures hospital-related vehicles receive necessary parking access without compromising emergency vehicle priorities. Similarly, if we have two vehicles of the same size, they are different in nature. Say, one is an ambulance, the other is a vehicle, and the parking area is near the hospital. The algorithm will consider ambulances for parking rather than ordinary vehicles. This is because emergency vehicles' priority is more significant than ordinary vehicles'. The flow of vehicles minimizes the chances of large vehicles entering congested areas, thus creating disturbance in the normal flow of vehicles and traffic. Besides the issues created when travelling on roadways or overfilled areas, these vehicles also create issues for parking owners. The space consumed by large vehicles is much greater than the space consumed by small vehicles. These two are directly proportional to each other.

$$Size\ of\ Object \propto Space\ Occupied\ by\ Object \quad Eq(1)$$

It shows that if a parking area has space for ten (10) small vehicles, it may have space for five (5) large vehicles, thus also reducing the total number of vehicles parked in a specific area. The relationship can be demonstrated mathematically by the constant of proportionality, which is as follows:

$$Size\ of\ Object = k * Space\ Occupied\ by\ Object \qquad Eq\ (2)$$

k is a constant, and it remains constant as long as the vehicle's size and space occupied by it remain the same. The proposed algorithm is depicted in Figure 4.

## V. SIMULATION & PERFORMANCE ANALYSIS

This section investigates the simulation study and analyzes the proposed algorithm's performance. The algorithm is compared with two other algorithms, FCFS and SJF. The algorithm is simulated using the iFogSim simulator, a Java-based simulator used to build fog-based scenarios for interconnected objects. [22]. Table. I, below represents the different parameters used in our simulation setup.

TABLE I. PARAMETERSRAMETERS CONSIDERED DURING THE SIMULATION STUDY

| S.No | Parameters Name | Values |
|---|---|---|
| 1 | Area of Parking | 30 * 30 $m^2$ |
| 2 | Parking Slots | 20 |
| 3 | Nature of Parking area | Urban/crowded |
| 4 | Number of normal vehicles | 20 |
| 5 | Number of heavy vehicles | 10 |

### A. Degree of Traffic Congestion:

Traffic congestion refers to the condition of roadways when traffic flow stops and becomes a standstill. The congestion in one place creates traffic problems on all connected roadways. [23]If more slots are available, people will occupy them. Otherwise, they will occupy roadsides and other no-parking zones. After a thorough examination, the study found that in crowded areas, small vehicles are allowed to enter the parking area, and heavy roads are directed outside the area in other parking zones. Similarly, if using the same parameters, heavy vehicles enter the area, the degree of congestion increases.

A visual representation of comparative analysis between small vehicles and heavy vehicles within highly populated areas is shown in Figure. 4. It also estimates overall congestion, providing useful insights into traffic movement and vehicle distribution in the given environment. The graph indicates small vehicles enter crowded areas with less traffic congestion than heavy vehicles. Resultant as smaller vehicles produce less traffic congestion in congested areas.

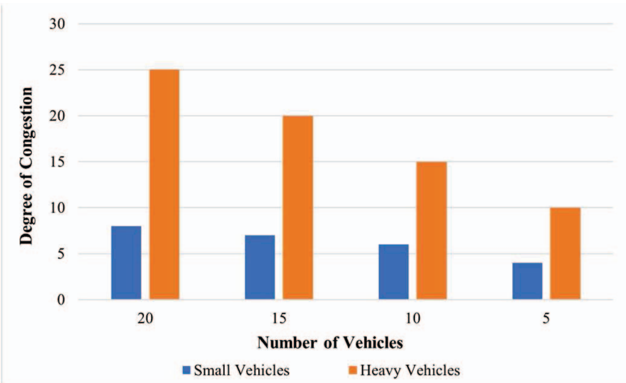


Fig. 4. Comparison between congestion degree and vehicle type

*B. Throughput:*

Throughput refers to the total amount of output generated by a parking system. It is directly proportional to the number of vehicles occupying spaces in the parking area and shows how many vehicles are directed to their specific locations. Figure. 5 depicts a graphical representation of throughput using a priority vehicle scheduler. The algorithm increases throughput by increasing the number of vehicles occupying parking areas. Furthermore, it increases revenue collection of parking areas, thus benefiting owners.

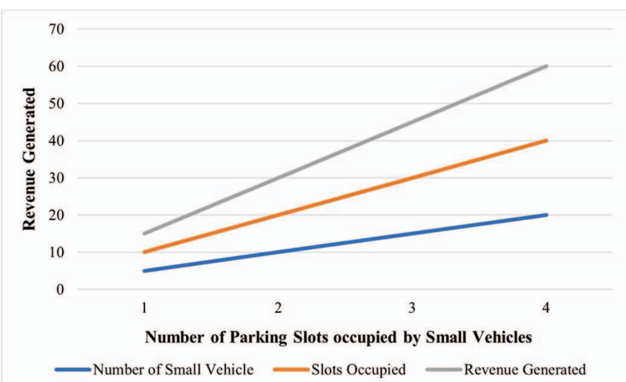


Fig. 5. Occupation of slots and revenue generation by small vehicles

Similarly, Figure. 6, depicts revenue generation with the occupancy of parking slots, primarily by heavy vehicles. This Figure provides insights into how heavy vehicles use parking spots and the revenue earned from their parking activities, leading to a thorough understanding of the parking dynamics from the perspective of heavy vehicles in the area.

*C. Degree of Environmental pollution:*

Environmental pollution refers to the degradation of air quality and the generation of toxic gases [24]. The environmental pollution increases with road congestion. If congestion is high, pollution will be high. This is because toxic

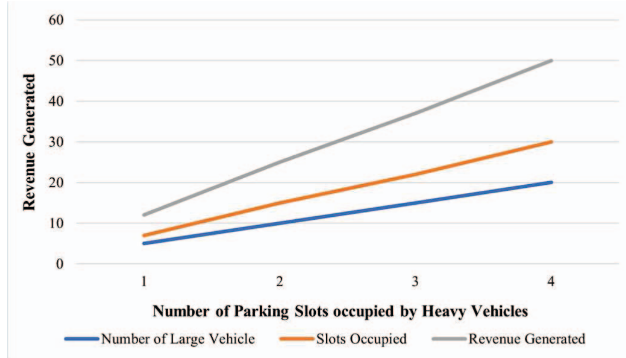


Fig. 6. Occupation of slots and revenue generation by heavy vehicles

gases generated by vehicles harm the air quality. Figure. 7, shows the relationship between the degree of congestion and the degree of environmental pollution.

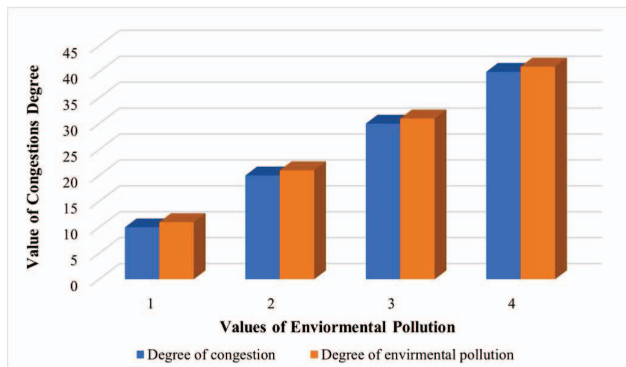


Fig. 7. Comparison of the degree of congestion and environmental pollution

The compared protocols demonstrate different effects on the overall traffic paradigm. Suppose space consumption is compared to the number of vehicles. If the number of vehicles increases, space consumption decreases as more vehicles require space. More space is needed without designated areas for different vehicle types. The analysis shows heavy and non-essential vehicles are parked away from important areas. The available space in the proposed protocol is high, as shown in Figure 8.

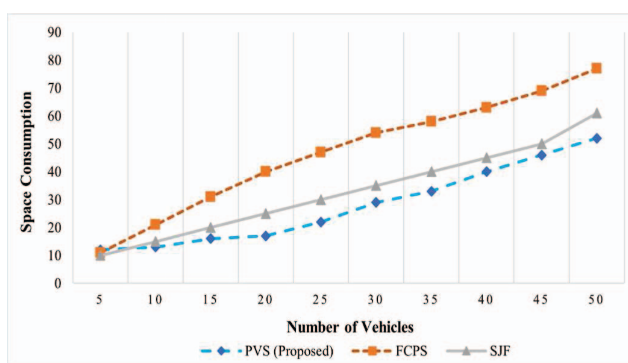


Fig. 8. Comparative Analysis of different protocols in terms of space consumption

## VI. Conclusion & Future Work

The increase in urban population and the influx of people from rural to urban areas has significantly increased the number of vehicles on roads. The increase is directly proportional to the level of environmental pollution and healthcare problems. If the number of vehicles increases, pollution will increase because of the emission of harmful gasses. The strength of these issues can be plummeted by adopting efficient algorithms for transport systems. One such area in transportation is smart parking. The efficient management of the vehicle parking system increases the smoothness of vehicle flow and restricts unauthorized vehicles' entry to cities. It also decreases traffic jams by redirecting jams, causing vehicles to far or neighbour vehicle parking. The system also assigns priorities to vehicles and gives preference to emergency vehicles or vehicles in dire need of parking at a specific location.

In the future, we will discuss security and privacy issues arising from smart parking systems. To decrease these issues, the federated learning concept will be adopted.


## Acknowledgment

The Zayed University Research Grant # R23082 supported this work.


## References


[1] S. Rafique, S. Gul, K. Jan, and G. M. Khan, "Optimized real-time parking management framework using deep learning," *Expert Syst. Appl.*, vol. 220, p. 119686, Jun. 2023.

[2] H. Zulfiqar, H. M. Ul Haque, F. Tariq, and R. M. Khan, "A survey on smart parking systems in urban cities," *Concurr. Comput. Pract. Exp.*, vol. 35, no. 15, p. e6511, Jul. 2023.

[3] M. Nikhar and S. Kamath, "IoT-Based E-Parking System for Multiplexes and Shopping Malls," *Lect. Notes Electr. Eng.*, vol. 977, pp. 81–89, 2023.

[4] M. Jemmali, L. K. B. Melhim, M. T. Alharbi, A. Bajahzar, and M. N. Omri, "Smart-parking management algorithms in smart city," *Sci. Reports 2022 121*, vol. 12, no. 1, pp. 1–15, Apr. 2022.

[5] H. Yang, R. Ke, Z. Cui, Y. Wang, and K. Murthy, "Toward a real-time Smart Parking Data Management and Prediction (SPDMP) system by attributes representation learning," *Int. J. Intell. Syst.*, vol. 37, no. 8, pp. 4437–4470, Aug. 2022.

[6] C. P. Lee, F. T. J. Leng, R. A. A. Habeeb, M. A. Amanullah, and M. H. ur Rehman, "Edge computing-enabled secure and energy-efficient smart parking: A review," *Microprocess. Microsyst.*, vol. 93, p. 104612, Sep. 2022.

[7] P. Gupta, R. R. Kaikini, D. K. Saini, and S. Rahman, "Cost-Aware Resource Optimization for Efficient Cloud Application in Smart Cities," *J. Sensors*, vol. 2022, 2022.

[8] M. Khalid, K. Wang, N. Aslam, Y. Cao, N. Ahmad, and M. K. Khan, "From smart parking towards autonomous valet parking: A survey, challenges and future Works," *J. Netw. Comput. Appl.*, vol. 175, p. 102935, Feb. 2021.

[9] J. M. Carrera García, J. Recas Piorno, and M. Guijarro Mata-García, "Expert system design for vacant parking space location using automatic learning and artificial vision," *Multimed. Tools Appl.*, vol. 81, no. 27, pp. 38661–38683, Nov. 2022.

[10] B. Ram and M. Pundir, "Vehicular Parkig System Using IoT With FCFS and Round Robin Scheduling Algorithms," Aug. 2023.

[11] N. A. Rosli, N. S. M. Hadis, S. Abdullah, M. N. Ibrahim, M. H. Abdullah, and I. S. Isa, "Development and Implementation of a Smart Parking Spot Allocation System Based on the User's Category and Priority using Verilog HDL," *J. Electron. Volt. Appl.*, vol. 3, no. 2, pp. 15–32, Dec. 2022.

[12] M. Nazari-Heris, A. Loni, S. Asadi, and B. Mohammadi-ivatloo, "Toward social equity access and mobile charging stations for electric vehicles: A case study in Los Angeles," *Appl. Energy*, vol. 311, p. 118704, Apr. 2022.

[13] R. O. Ogundokun, E. I. Soladoye, E. O. Asani, O. Akande, O. J. Ishola, O. Akinwumi, C. O. Aremu, and A. N. Babatunde, "Towards the Development of a Smart Parking System for Highly Populated Cities," *2023 Int. Conf. Sci. Eng. Bus. Sustain. Dev. Goals, SEB-SDG 2023*, 2023.

[14] J. N. Njoku, G. O. Anyanwu, I. S. Igboanusi, C. I. Nwakanma, J. M. Lee, and D. S. Kim, "State-of-the-Art Object Detectors for Vehicle, Pedestrian, and Traffic Sign Detection for Smart Parking Systems," *Int. Conf. ICT Converg.*, vol. 2022–October, pp. 1585–1590, 2022.

[15] S. Kumara, N. H. Prasad, M. Monika, H. Tuli, S. Supreeth, and S. Rohith, "Smart Vehicle Parking System on Fog Computing for Effective Resource Management," *Int. Conf. Appl. Intell. Sustain. Comput. ICAISC 2023*, 2023.

[16] T. Nakazato, Y. Fujimaki, and T. Namerikawa, "Parking Lot Allocation Using Rematching and Dynamic Parking Fee Design," *IEEE Trans. Control Netw. Syst.*, vol. 9, no. 4, pp. 1692–1703, Dec. 2022.

[17] R. Aron and D. K. Aggarwal, "Resource scheduling of concurrency based applications in IoT based cloud environment," *J. Ambient Intell. Humaniz. Comput.*, vol. 14, no. 6, pp. 6817–6828, Jun. 2023.

[18] E. Al-Masri, A. Souri, H. Mohamed, W. Yang, J. Olmsted, and O. Kotevska, "Energy-efficient cooperative resource allocation and task scheduling for Internet of Things environments," *Internet of Things*, vol. 23, p. 100832, Oct. 2023.

[19] Y. Kong, J. Ou, L. Chen, F. Yang, and B. Yu, "The Environmental Impacts of Automated Vehicles on Parking: A Systematic Review," *Sustain. 2023, Vol. 15, Page 15033*, vol. 15, no. 20, p. 15033, Oct. 2023.

[20] A. Shahzad, A. Gherbi, and K. Zhang, "Enabling Fog–Blockchain Computing for Autonomous-Vehicle-Parking System: A Solution to Reinforce IoT–Cloud Platform for Future Smart Parking," *Sensors 2022, Vol. 22, Page 4849*, vol. 22, no. 13, p. 4849, Jun. 2022.

[21] Y.-C. Yu, "Smart Parking System Based on Edge-Cloud-Dew Computing Architecture," *Electron. 2023, Vol. 12, Page 2801*, vol. 12, no. 13, p. 2801, Jun. 2023.

[22] R. Paesani, G. Paolone, P. Di Felice, D. Iachetti, and M. Marinelli, "iFogSim Simulations on IoT Computational Alternatives," *Eng. Proc. 2023, Vol. 31, Page 44*, vol. 31, no. 1, p. 44, Dec. 2022.

[23] F. Rosero, N. Fonseca, Z. Mera, and J. M. López, "Assessing on-road emissions from urban buses in different traffic congestion scenarios by integrating real-world driving, traffic, and emissions data," *Sci. Total Environ.*, vol. 863, p. 161002, Mar. 2023.

[24] D. Wu, Y. Xie, and S. Lyu, "Disentangling the complex impacts of urban digital transformation and environmental pollution: Evidence from smart city pilots in China," *Sustain. Cities Soc.*, vol. 88, p. 104266, Jan. 2023.