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Original Article

The Sentient Parking Grid: AI-Driven Self-Organizing Spaces for Dynamic Urban Mobility

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Abstract *- This paper presents the Sentient Parking Grid, an innovative AI-driven system designed to optimize urban parking through self-organizing spaces. Leveraging swarm intelligence, the system enables dynamic coordination among autonomous vehicles and infrastructure to maximize space utilization. Predictive space morphing anticipates demand fluctuations, allowing real-time adaptive reconfiguration of parking layouts. The integration of adaptive infrastructure supports seamless interaction between vehicles and environment, enhancing efficiency and user experience. This approach addresses urban mobility challenges by reducing congestion and improving facility management. Simulation results demonstrate significant improvements in space efficiency and operational flexibility. The Sentient Parking Grid exemplifies a transformative step toward smart cities with responsive, intelligent urban systems.*

Keywords *- Sentient Parking Grid, Swarm Intelligence, Predictive Space Morphing, Adaptive Infrastructure, Urban Mobility, Facility Management, Dynamic Parking Systems*

1. Introduction

1.1. Background and Motivation

Urban parking management faces increasing challenges due to rapid urbanization and growing vehicle numbers, resulting in congestion, inefficient space utilization, and user inconvenience. Traditional static parking infrastructures lack the flexibility to adapt to fluctuating demand patterns and dynamic urban mobility needs. Motivated by these challenges, the Sentient Parking Grid proposes an AI-driven solution that leverages advanced technologies to create self-organizing parking spaces. [1] This system aims to optimize space usage and enhance operational efficiency by enabling real-time adaptation to changing conditions. The integration of swarm intelligence facilitates coordinated behavior among autonomous vehicles and infrastructure elements, while predictive space morphing anticipates demand shifts for proactive reconfiguration. Adaptive infrastructure further supports seamless interaction between vehicles and their environment, promoting a responsive urban ecosystem. Together, these innovations address critical facility management issues and contribute to smarter, more sustainable urban mobility. This background sets the stage for exploring how AI can revolutionize parking systems to meet future urban demands effectively. [2].

1.2. Challenges in Urban Parking Management

Urban parking management faces significant challenges stemming from increasing vehicle density and limited space within rapidly growing cities. These challenges include congestion, inefficient utilization of parking areas, and difficulty accommodating fluctuating demand throughout the day. Traditional parking infrastructures are typically static and unable to dynamically adjust to real-time changes, leading to underutilized spaces during off-peak periods and overcrowding during peak times. Additionally, lack of coordination between vehicles and infrastructure contributes to user frustration and operational inefficiencies. Addressing these issues requires innovative solutions that enable flexibility, adaptability, and intelligent coordination. The Sentient Parking Grid targets these challenges by employing AI-driven technologies such as swarm intelligence and predictive space morphing to optimize space allocation dynamically. Adaptive infrastructure further enhances system responsiveness by facilitating seamless interaction between vehicles and their environment. Collectively, these approaches aim to transform urban parking management into a more efficient, user-friendly, and sustainable system. [3]

1.3. Objectives and Scope

The objectives of the Sentient Parking Grid are to develop an AI-driven system that dynamically optimizes urban parking spaces through real-time adaptation and intelligent coordination. The system aims to enhance space utilization, reduce congestion, and improve user experience by integrating swarm intelligence for autonomous vehicle coordination and predictive space morphing to anticipate demand fluctuations. Additionally, it seeks to implement adaptive infrastructure that facilitates seamless interaction between vehicles and the environment, enabling flexible and scalable facility management. [4] The contributions include a novel approach to urban parking that moves beyond static designs, offering a self-organizing, responsive solution that addresses the complexities of modern urban mobility. By combining advanced AI models with innovative hardware and software components, the Sentient Parking Grid demonstrates significant improvements in operational efficiency and space management. This work lays the foundation for smarter, more sustainable cities by transforming parking systems into dynamic, intelligent networks capable of evolving with changing urban demands. [2]

2. Swarm Intelligence in Parking Systems

2.1. Principles of Swarm Intelligence

Swarm intelligence is a decentralized, collective behavior observed in natural systems, where simple agents interact locally to produce complex global outcomes. In the context of parking systems, it involves autonomous vehicles and infrastructure elements coordinating their actions through distributed algorithms without centralized control. This principle enables the system to adapt dynamically to changing conditions by leveraging local information and interactions among agents. Key features include robustness, scalability, and flexibility, allowing the parking grid to self-organize efficiently. By mimicking natural swarm behaviors, the system achieves optimized space utilization and improved traffic flow. The emergent coordination reduces conflicts and enhances operational efficiency, supporting real-time decision-making. Swarm intelligence thus forms the foundation for intelligent vehicle coordination and adaptive management within the Sentient Parking Grid, driving its ability to respond proactively to urban mobility demands. [4], [5]

2.2. Application to Vehicle Coordination

Swarm intelligence facilitates coordinated behavior among autonomous vehicles by enabling decentralized decision-making based on local interactions. In the Sentient Parking Grid, vehicles communicate and collaborate using distributed algorithms that mimic natural swarm dynamics, allowing them to self-organize efficiently within the parking environment. This coordination optimizes vehicle movement, reduces conflicts, and enhances space allocation by dynamically adjusting to real-time conditions. The system supports continuous information exchange between vehicles and infrastructure, promoting adaptive responses to fluctuating demand and traffic patterns. By leveraging swarm intelligence, the parking grid achieves scalable and robust vehicle coordination without reliance on centralized control. [6] This approach improves operational efficiency, streamlines parking processes, and contributes to a seamless user experience. Ultimately, the application of swarm intelligence to vehicle coordination is a key enabler for the Sentient Parking Grid’s dynamic and intelligent management of urban parking spaces.

2.3. Benefits for Space Optimization

Swarm intelligence significantly enhances space optimization in the Sentient Parking Grid by enabling decentralized, adaptive coordination among autonomous vehicles and infrastructure. This collective behavior allows the system to dynamically allocate parking spaces based on real-time local interactions, minimizing idle or wasted areas. The emergent, self-organizing patterns reduce conflicts and congestion, enabling more efficient use of limited urban parking resources. [7] Scalability and robustness inherent in swarm intelligence ensure that the system can handle varying vehicle densities and demand fluctuations without centralized control. By continuously adapting to environmental changes, the system maximizes throughput and optimizes spatial layouts. This leads to improved operational flexibility and responsiveness, directly addressing inefficiencies common in traditional static parking systems. Consequently, swarm intelligence drives a more sustainable and user-friendly parking environment by balancing demand and supply dynamically and intelligently. [8] Same depicted in Fig. 1.

Fig 1: Unveiling Swarm Intelligence in Parking Systems.

3. Predictive Space Morphing

3.1. Demand Forecasting Techniques

Demand forecasting techniques in the Sentient Parking Grid utilize advanced AI models to predict fluctuations in parking demand with high accuracy. These techniques analyze historical data, real-time inputs, and contextual factors such as time of day, events, and traffic patterns to generate short- and long-term forecasts. By anticipating demand shifts, the system enables proactive adjustments to parking space allocation, reducing congestion and underutilization. Machine learning algorithms continuously refine predictions by incorporating new data, enhancing responsiveness to evolving urban mobility trends. Integration with sensor networks and communication technologies ensures timely and precise data collection for forecasting models. This predictive capability forms the basis for real-time space morphing, allowing the parking grid to dynamically reconfigure layouts before demand peaks occur. Overall, demand forecasting is critical for enabling the Sentient Parking Grid's adaptive, efficient, and user-centric management of urban parking resources. [9], [10]

3.2. Real-Time Space Reconfiguration

Real-time space reconfiguration in the Sentient Parking Grid enables dynamic adjustment of parking layouts based on immediate demand and environmental changes. Utilizing AI-driven algorithms, the system continuously monitors sensor data and vehicle interactions to reorganize available spaces efficiently. This adaptive process allows the parking infrastructure to morph responsively, optimizing space allocation and minimizing idle areas during fluctuating usage periods.[4] By integrating predictive demand forecasts, real-time reconfiguration anticipates upcoming changes and proactively adapts the parking grid to maintain optimal throughput. Communication between vehicles and infrastructure supports seamless transitions and coordinated movements, reducing congestion and enhancing user experience. This capability ensures the system remains flexible and scalable, addressing the complexities of urban mobility in real time. Ultimately, real-time space reconfiguration is essential for maintaining the Sentient Parking Grid's responsiveness and operational efficiency in dynamic urban environments. [2], [11]

3.3. Integration with Parking Infrastructure

Integration with parking infrastructure in the Sentient Parking Grid ensures seamless coordination between predictive space morphing capabilities and the physical environment. This integration leverages sensor networks, communication technologies, and modular hardware to enable real-time data exchange between vehicles and infrastructure components. By embedding adaptive elements such as movable barriers, dynamic signage, and responsive lighting, the system can physically reconfigure parking layouts in response to AI-driven forecasts. The infrastructure's connectivity supports continuous monitoring and feedback loops, allowing the system to adjust spatial configurations proactively and maintain optimal utilization. This tight coupling of software intelligence with physical assets enhances operational flexibility and scalability, accommodating varying urban contexts and demand patterns. Furthermore, integration facilitates interoperability with existing urban mobility frameworks, ensuring smooth adoption and incremental upgrades. Overall, this synergy between predictive algorithms and adaptive infrastructure is critical for realizing a responsive, efficient, and user-centric parking ecosystem within the Sentient Parking Grid. [12], [13]

4. Adaptive Infrastructure Design

4.1. Sensor and Communication Technologies

Sensor and communication technologies form the backbone of the adaptive infrastructure in the Sentient Parking Grid, enabling real-time data collection and seamless interaction between vehicles and the environment. The system employs a network of advanced sensors, including proximity detectors, cameras, and environmental monitors, to continuously gather detailed information on vehicle positions, occupancy, and surrounding conditions. Communication technologies, such as vehicle-to-infrastructure (V2I) and vehicle-to-vehicle (V2V) protocols facilitate instantaneous data exchange and coordinated decision-making across the parking grid. This interconnected framework supports dynamic adjustments in parking layouts and operational parameters, enhancing responsiveness to fluctuating demand. The integration of wireless communication standards ensures scalability and interoperability within diverse urban settings. Together, these technologies enable the infrastructure to sense, communicate, and adapt autonomously, forming a critical component of the Sentient Parking Grid is intelligent, self-organizing system. [9], [14]

4.2. Infrastructure-Vehicle Interaction

Infrastructure-vehicle interaction in the Sentient Parking Grid is facilitated through continuous, bidirectional communication enabled by advanced sensor networks and communication protocols such as vehicle-to-infrastructure (V2I) and vehicle-to-vehicle (V2V). This interaction allows vehicles and parking infrastructure to exchange real-time information about space availability, vehicle positions, and environmental conditions, supporting coordinated decision-making. Adaptive infrastructure components, including dynamic signage and movable barriers, respond to vehicle inputs and AI-driven commands to optimize parking flow and layout. [15] The seamless integration ensures that vehicles can navigate efficiently, receive guidance, and adjust behavior based on infrastructure signals, enhancing user experience and operational efficiency. This interaction also supports safety by enabling proactive responses to potential conflicts or congestion. Scalability and flexibility are maintained as the system adapts to varying urban contexts and demand patterns. Overall, infrastructure-vehicle interaction forms a critical link that enables the Sentient Parking Grid's intelligent, responsive, and self-organizing urban mobility ecosystem. [16]

4.3. Scalability and Flexibility Considerations

Scalability and flexibility considerations in the Sentient Parking Grid are essential to accommodate varying urban densities and evolving mobility demands. The system's modular design allows incremental expansion and integration with diverse urban environments without compromising performance. Flexible infrastructure components, such as movable barriers and adaptive signage, support reconfiguration to suit different spatial constraints and usage patterns. The underlying AI algorithms scale efficiently with increasing numbers of vehicles and infrastructure elements, maintaining robust coordination and responsiveness. Wireless communication protocols ensure interoperability across heterogeneous devices and facilitate seamless updates or upgrades. This adaptability enables the Sentient Parking Grid to respond effectively to fluctuating demand, technological advancements, and policy changes. By prioritizing scalability and flexibility, the system ensures long-term viability and relevance within dynamic urban contexts. These considerations reinforce the grid's capacity to provide sustained, intelligent facility management in smart cities. [17], [18] Same depicted in Fig. 2.

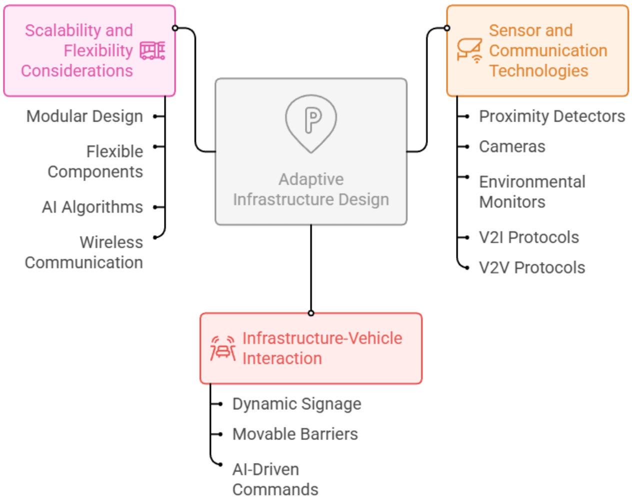

Fig 2: Adaptive Infrastructure Design in Sentient Parking Grid

5. System Architecture and Implementation

5.1. AI Models and Algorithms

The AI models and algorithms underpinning the Sentient Parking Grid are designed to enable dynamic, real-time optimization of urban parking spaces through intelligent coordination and adaptation. These models incorporate machine learning techniques for demand forecasting, enabling the system to anticipate fluctuations and proactively adjust space allocation. Swarm intelligence algorithms facilitate decentralized decision-making among autonomous vehicles and infrastructure elements, promoting self-organization without centralized control.[19], [20] Reinforcement learning and predictive analytics further enhance the system's ability to respond to evolving urban mobility patterns by continuously refining strategies based on feedback. The integration of these AI components supports real-time space morphing and adaptive infrastructure control, ensuring efficient utilization and operational flexibility. Advanced optimization algorithms handle complex spatial layouts and vehicle routing, minimizing conflicts and maximizing throughput. Collectively, these AI models form a robust framework that drives the Sentient Parking Grid's intelligent, scalable, and responsive management of dynamic urban parking environments.[4], [19]

5.2. Hardware and Software Components

The hardware and software components of the Sentient Parking Grid comprise an integrated ecosystem designed to support dynamic, AI-driven parking management. Hardware includes sensor arrays (proximity sensors, cameras, environmental monitors), communication devices supporting V2I and V2V protocols, and modular infrastructure elements such as movable barriers and dynamic signage. These components enable continuous data acquisition and real-time interaction between vehicles and infrastructure. On the software side, the system employs AI-driven platforms incorporating machine learning, swarm intelligence algorithms, reinforcement learning, and predictive analytics to process sensor data and execute adaptive control strategies. Middleware facilitates seamless communication and coordination across distributed agents, while optimization modules handle spatial layout adjustments and vehicle routing. The software architecture supports scalability and robustness, ensuring efficient operation under varying demand and urban conditions. Together, these hardware and software elements form a cohesive framework that enables the Sentient Parking Grid to achieve responsive, self-organizing, and efficient urban parking management. [4], [9]

5.3. Simulation Environment and Setup

The simulation environment and setup for the Sentient Parking Grid involve a comprehensive framework designed to evaluate the system's performance under realistic urban conditions. The environment integrates detailed models of autonomous vehicles, adaptive infrastructure components, and sensor networks to replicate dynamic interactions within the parking grid. Simulations utilize AI-driven algorithms for swarm intelligence, predictive space morphing, and adaptive control to test real-time space optimization and vehicle coordination. [19] Key parameters such as vehicle density, demand fluctuations, and environmental variables are systematically varied to assess scalability and robustness. The setup includes modular software platforms that enable iterative testing and refinement of AI models and infrastructure responses. Performance metrics focus on space utilization, operational efficiency, congestion reduction, and user experience. This simulation framework provides critical insights into the system's effectiveness and guides further development toward practical deployment. It ensures that the Sentient Parking Grid can adapt flexibly and maintain optimal function in complex, real-world urban mobility scenarios. [8]

6. Performance Evaluation

6.1. Metrics for Space Utilization and Efficiency

Metrics for space utilization and efficiency in the Sentient Parking Grid focus on quantifying how effectively parking areas are allocated and managed under dynamic conditions. Key metrics include space occupancy rates, which measure the proportion of utilized parking spots relative to total available spaces, and turnover rates that assess how frequently spaces are vacated and reoccupied. Efficiency metrics evaluate the system's ability to minimize idle or wasted space, reduce vehicle search time, and optimize traffic flow within the parking grid. Additional performance indicators consider the responsiveness of space reconfiguration to fluctuating demand and the system's capacity to maintain smooth vehicle coordination without congestion. These metrics collectively capture operational flexibility, throughput maximization, and user convenience. By employing such comprehensive measures, the Sentient Parking Grid can assess improvements over traditional static systems and guide further optimization of AI-driven adaptive management strategies. This evaluation framework is fundamental for demonstrating the system's impact on urban mobility and facility management efficiency. [21], [22]

6.2. Simulation Results and Analysis

Simulation results and analysis for the Sentient Parking Grid demonstrate significant improvements in space utilization and operational flexibility compared to traditional static parking systems. The simulations, conducted within a detailed virtual urban environment, assess the system's performance under varying vehicle densities and demand fluctuations. Results indicate that the AI-driven swarm intelligence and predictive space morphing algorithms enable dynamic, real-time reconfiguration of parking layouts, effectively reducing idle space and congestion. Key performance indicators such as occupancy rates, turnover, and vehicle search times show marked enhancements, reflecting smoother traffic flow and optimized space allocation. [23] The system's adaptive infrastructure supports seamless coordination between vehicles and environment, contributing to improved user experience and operational efficiency. Comparative analysis highlights the Sentient Parking Grid's scalability and robustness in managing complex, fluctuating urban mobility demands. These findings validate the system's potential to transform urban parking management into a more responsive, sustainable, and intelligent process. The simulation framework also provides a platform for iterative refinement of AI models and infrastructure components, ensuring continuous performance optimization. Overall, the analysis confirms the Sentient Parking Grid as a viable solution for future smart city applications. [4], [16]

6.3. Comparative Assessment with Traditional Systems

The comparative assessment with traditional parking systems highlights the Sentient Parking Grid's superior adaptability, efficiency, and user experience. Unlike static infrastructures that suffer from fixed layouts and limited responsiveness, the Sentient Parking Grid dynamically reconfigures spaces in real time using AI-driven swarm intelligence and predictive space morphing. This enables higher space utilization rates, reduced congestion, and improved vehicle coordination without centralized control. Traditional systems often face underutilization during off-peak hours and overcrowding at peak times, issues effectively mitigated by the Sentient Parking Grid's adaptive infrastructure. The integration of sensor networks and communication technologies further enhances operational flexibility and scalability, which traditional designs lack.[24] Simulation results demonstrate marked improvements in throughput, turnover, and reduced vehicle search times compared to conventional approaches. Additionally, the Sentient Parking Grid supports a more sustainable urban environment by optimizing resource use and minimizing traffic-related emissions. This assessment confirms that the proposed system offers a transformative advancement over existing parking management solutions, positioning it as a foundational technology for future smart city developments. [25], [26]

7. Conclusion

The Sentient Parking Grid represents a significant advancement in urban parking management by integrating AI-driven swarm intelligence, predictive space morphing, and adaptive infrastructure to create a dynamic, self-organizing system. Through real-time coordination among autonomous vehicles and intelligent reconfiguration of parking layouts, the system effectively addresses challenges of congestion, inefficient space utilization, and fluctuating demand inherent in traditional static parking infrastructures. Simulation results validate its enhanced operational efficiency, scalability, and user experience, demonstrating marked improvements over conventional approaches. By seamlessly combining advanced AI models with modular hardware and robust communication technologies, the Sentient Parking Grid offers a transformative framework for smarter, more sustainable urban mobility and facility management, positioning itself as a foundational technology for future smart city ecosystems.

Conflicts of Interest
The author declares that there is no conflict of interest concerning the publishing of this paper.

References

[1] M. Laaouafy, F. Lakrami, and O. Labouidya, "A smart parking system combining IoT and AI to address improper parking," IJITS, vol. 16, no. 2, pp. 39–50, June 2024, doi: 10.59035/zmry7124.

[2] A. Janowski, M. Hüsrevoğlu, and M. Renigier-Bilozor, "Sustainable Parking Space Management Using Machine Learning and Swarm Theory—The SPARK System," Applied Sciences, vol. 14, no. 24, p. 12076, Dec. 2024, doi: 10.3390/app142412076.

[3] D. H. De La Iglesia, G. Villarrubia, J. Bajo, and J. F. De Paz, "Multi-Sensor Information Fusion for Optimizing Electric Bicycle Routes Using a Swarm Intelligence Algorithm.," Sensors, vol. 17, no. 11, p. 2501, Oct. 2017, doi: 10.3390/s17112501.

[4] V. Knights, M. Prchkovska, and O. Petrovska, "Enhancing Smart Parking Management through Machine Learning and AI Integration in IoT Environments," Intechopen, 2024. doi: 10.5772/intechopen.1006490.

[5] R. Babu, N. Purandhar, R. Prathipa, T. Kanth, K. Tamilselvan, and P. Selvam, "Adaptive Computational Intelligence Algorithms for Efficient Resource Management in Smart Systems," IJCESEN, vol. 11, no. 1, Jan. 2025, doi: 10.22399/ijcesen.836.

[6] K. Kuru and W. Khan, "A Framework for the Synergistic Integration of Fully Autonomous Ground Vehicles With Smart City," IEEE Access, vol. 9, pp. 923–948, Dec. 2020, doi: 10.1109/access.2020.3046999.

[7] O. Vermesan et al., "Automotive Intelligence Embedded in Electric Connected Autonomous and Shared Vehicles Technology for Sustainable Green Mobility," Front. Future Transp., vol. 2, Aug. 2021, doi: 10.3389/ffutr.2021.688482.

[8] S. Vjii, N. Singh, R. Vij, M. Natha, and Q. Mohammad, "Artificial Intelligence Techniques to Optimize the Traffic in Urban Areas," Igi Global, 2024, pp. 85–100. doi: 10.4018/979-8-3693-4268-8.ch006.

[9] N. Cahyadi, L. A. Haq, P. Dorand, N. R. F. Rozi, and R. I. Maulana, "A Literature Review for Understanding the Development of Smart Parking Systems," j_ict, vol. 5, no. 1, pp. 46–56, Dec. 2023, doi: 10.52661/j_ict.v5i1.196.

[10] J. C. Provoost, A. Kamilaris, L. J. J. Wismans, S. J. Van Der Drift, and M. Van Keulen, "Predicting parking occupancy via machine learning in the web of things," Internet of Things, vol. 12, p. 100301, Sept. 2020, doi: 10.1016/j.iot.2020.100301.

[11] G. Leone et al., "An Intelligent Cooperative Visual Sensor Network for Urban Mobility.," Sensors, vol. 17, no. 11, p. 2588, Nov. 2017, doi: 10.3390/s17112588.

[12] L. Meng, J. C. Vasquez, J. M. Guerrero, and T. Dragicevic, "Dynamic consensus algorithm based distributed global efficiency optimization of a droop controlled DC microgrid," Institute Of Electrical Electronics Engineers, May 2014, pp. 1276–1283. doi: 10.1109/energycon.2014.6850587.

[13] P. Boccardo, Y. Yadav, and L. La Riccia, "Urban Echoes: Exploring the Dynamic Realities of Cities through Digital Twins," Land, vol. 13, no. 5, p. 635, May 2024, doi: 10.3390/land13050635.

[14] J. A. Vera-Gómez, A. Quesada-Arencibia, C. R. García, R. Suárez Moreno, and F. Guerra Hernández, "An Intelligent Parking Management System for Urban Areas," Sensors, vol. 16, no. 6, p. 931, June 2016, doi: 10.3390/s16060931.

[15] P. Melnyk, S. Djahel, and F. Nait-Abdesselam, "Towards a Smart Parking Management System for Smart Cities," Institute Of Electrical Electronics Engineers, Oct. 2019, pp. 542–546. doi: 10.1109/isc246665.2019.9071740.

[16] N. Sakib, K. Yamada, S. Susilawati, M. A. S. Kamal, and A. S. M. Bakibillah, "Eco-Friendly Smart Car Parking Management System with Enhanced Sustainability," Sustainability, vol. 16, no. 10, p. 4145, May 2024, doi: 10.3390/su16104145.

[17] V. Demertzi, S. Demertzis, and K. Demertzis, "An Overview of Cyber Threats, Attacks and Countermeasures on the Primary Domains of Smart Cities," Applied Sciences, vol. 13, no. 2, p. 790, Jan. 2023, doi: 10.3390/app13020790.

[18] H. K. Channi and R. Kumar, "The Role of Smart Sensors in Smart City," Springer, 2021, pp. 27–48. doi: 10.1007/978-3-030-77214-7_2.

[19] K. Sundaramoorthy, A. R. Arunarani, A. Maheshwari, G. Sumathy, A. Singh, and S. Boopathi, "A Study on AI and Blockchain-Powered Smart Parking Models for Urban Mobility," Igi Global, 2023, pp. 223–250. doi: 10.4018/978-1-6684-9999-3.ch010.

[20] A. R. Singh, R. S. Kumar, K. R. Madhavi, F. Alsaif, M. Bajaj, and I. Zaitsev, "Optimizing demand response and load balancing in smart EV charging networks using AI integrated blockchain framework," Sci Rep, vol. 14, no. 1, Dec. 2024, doi: 10.1038/s41598-024-82257-2.

[21] Y. Yang, B. Yang, Z. Yuan, R. Meng, and Y. Wang, "Modelling and comparing two modes of sharing parking spots at residential area: Real-time and fixed-time allocation," IET Intelligent Trans Sys, vol. 18, no. 4, pp. 599–618, Feb. 2023, doi: 10.1049/itr2.12343.

[22] J. Miller, J. P. How, A. Hasfura, and S.-Y. Liu, "Dynamic arrival rate estimation for campus Mobility On Demand network graphs," Institute Of Electrical Electronics Engineers, Oct. 2016, pp. 2285–2292. doi: 10.1109/iros.2016.7759357.

[23] C. Rhodes, G. Morgan, G. Ushaw, W. Blewitt, and C. Sharp, "Smart Routing: A Novel Application of Collaborative Path-Finding to Smart Parking Systems," Institute Of Electrical Electronics Engineers, July 2014, pp. 119–126. doi: 10.1109/cbi.2014.22.

[24] J. C. Bedoya, C.-C. Liu, and Y. Wang, "Distribution System Resilience Under Asynchronous Information Using Deep Reinforcement Learning," IEEE Trans. Power Syst., vol. 36, no. 5, pp. 4235–4245, Sept. 2021, doi: 10.1109/tpwrs.2021.3056543.

[25] S. Priyadarshi, D. Bhardwaj, S. Kumar, H. Mohapatra, and S. Subudhi, "Analysis on Enhancing Urban Mobility With IoT-Integrated Parking Solutions," Igi Global, 2024, pp. 143–172. doi: 10.4018/979-8-3693-6695-0.ch006.

[26] F. Piccialli, F. Giampaolo, E. Prezioso, D. Crisci, and S. Cuomo, "Predictive Analytics for Smart Parking: A Deep Learning Approach in Forecasting of IoT Data," ACM Trans. Internet Technol., vol. 21, no. 3, pp. 1–21, June 2021, doi: 10.1145/3412842.