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Energy-Efficient Routing in Smart Parking Networks Using the Metaheuristic Approach

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Abstract

At present, drivers face considerable challenges in finding parking spots due to traffic congestion in certain areas and the distribution of parking spaces across the city. The initiative aims to develop a cutting-edge system that allows vehicles to navigate to their current location while finding available parking in a designated area. Additionally, it suggests implementing energy-efficient strategies to mitigate environmental impact and reduce operational costs. In terms of emergency response, a concept is introduced that involves placing sensors in vehicles within a 200-meter radius. This would allow ambulances to quickly find unoccupied parking spaces, minimizing the number of pedestrians in busy areas and lowering fuel consumption, which ultimately saves both time and lives. By focusing on security, energy efficiency, and innovative approaches, Smart Parking solutions can significantly enhance the sustainability and functionality of urban settings. To achieve the objective of optimizing energy efficiency, the Amplified-ACO (A^2 CO) routing algorithm, based on Ant Colony Optimization (ACO) principles and utilizing the probabilistic selection model DS^2, which is determined by Distance, Speed, and State-of-Charge, is used to ensure the highest energy efficiency attainable.

Keywords: IoT, Big data, LoRa networks employ energy-efficient routing in wireless sensor networks, Neural networks to enhance smart parking systems, Improving energy efficiency and reducing search times for available spaces.

1 | Introduction

The The Internet of Things (IoT) is growing incredibly, and innumerable smart devices are being connected to the internet. Such massive interconnection potential generates numerous opportunities and challenges. Providing high-quality services in networks raises a multitude of difficult challenges. One of them is to

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determine an optimal path that honors a given set of constraints while allowing the usage of network resources. This implies the need to impose an additional optimality. Thus, the feasibility problem includes a requirement. At present, transport relies mainly on fossil fuels like coal and oil. All of these come with serious effects on the environment. These fuel burn-ups emit greenhouse gases that cause increases in world temperatures, thereby influencing the climate. These contribute to many environmental and climatic issues, melting glaciers, rising sea levels, and extreme climatic phenomena. In a bid to mitigate these adverse effects, scientists are conducting research into sustainable modes of transport to reduce the use of fossil fuels while also emitting less carbon at the same time. Also, the most important challenge of this trend is the energy consumption level because these devices always communicate wirelessly. Another challenge associated with IoT devices is that they are heterogeneous, meaning their capabilities, energy levels, and processing powers are not uniform.

All these challenges must be overcome with utmost importance for sustainable growth and effective operation of IoT systems. This paper uses an algorithm to solve the parking guidance problem in smart cities. The problem at hand addresses finding the shortest route, about distance, for a driver from the driver's present location to a parking space under certain conditions, including distance, traffic conditions, and time constraints. The authors address the challenge with the development of a heuristic algorithm based on Ant Colony Optimization (ACO). The ACO is the metaheuristic describing how a set of artificial ants simulates the behavior of real ants in their search for the shortest route that connects the nest to the food.

Regarding parking guidance, virtual ants propagate through the network and mark the best paths along roads with pheromones, such that gradually increasing levels of optimal routes, guiding subsequent virtual ants to choose such paths. The proposed algorithm will consider the driver's destination and optimize the route so that the vehicle reaches the parking space without traveling less time and distance than necessary to the final destination. This algorithm provides a powerful and efficient solution to the parking guidance problem with the help of ACO and improves mobility in the urban setting while reducing congestion in traffic. Section 4 evaluates the existing literature on the area under investigation after explaining the research challenges. The ACO algorithm is defined in Section 5. Section 6 describes the mathematical model to solve the parking routing problem based on the ACO Algorithm. The perspectives and conclusion are given in the last two sections.

2 | Literature Review

This paper suggests a smart parking system that uses Wireless Sensor Networks (WSN), AI, and machine learning (ML) to make parking vehicles more efficient and secure. Using an SVM-based algorithm, The system addresses congestion, energy efficiency, and routing optimization. The Firefly algorithm (FFA) optimizes SVM parameters for efficient route discovery. The Energy-Aware Trust-Based Algorithm (EATSRA) detects malicious nodes by evaluating node trust scores. Nodes with low trust values are removed from the route to maintain secure communication [1].

The proposed MHSEER protocol enhances industrial operations in WSN-IIoT by ensuring secure, energy-efficient, and reliable data transfer while minimizing resources. It uses a clustering process to reduce overhead and extend network life. The protocol regularly adjusts cluster sizes to conserve energy and avoid reliance on Cluster Head (CH) nodes. It operates in two phases: selecting the next hop using a metaheuristic approach and integrating a secure protocol with CEM encryption for data transmission. Thus, MHSEER optimizes routing, enhances energy usage, and reduces packet delays through efficient next-hop decisions [2]. This study addresses the limitations of EVs by proposing an energy consumption model, the Amplified Ant Colony Algorithm (A^2CO), which balances energy consumption with other heuristic factors (speed, SoC, and distance) in an objective function. The model is tested on the transportation map of Chandigarh, India finding that EV energy consumption is inversely proportional to speed and that the number of artificial ants affects the optimization outcome, with 20 ants yielding the best results [3]. This paper introduces a navigation and reservation-based technique that relies on low-cost devices to transmit IoT data for searching available parking spaces in smart cities. This is used to minimize the distance towards closer parking spots using a genetic algorithm for optimization, which provides what is also known as the evosuite method, which helps with issues with the nearest available parking slot. The result is more accurate, and parking management works [4]. This paper introduces a navigation and reservation-based technique that relies on low-cost devices to transmit IoT data for searching available parking spaces in smart cities. This is used to minimize the distance towards closer parking spots using a genetic algorithm for optimization. It provides what is also known as the evosuite method, which helps with issues with the nearest available parking slot. The result is more accurate, and parking management works [5]. In this paper, a new parking navigation system is developed to search for the nearest available empty slots using the IoT and a large-scale distributed Ant Colony Algorithm (ACO). The system considers several factors, such as the time needed to reach an indoor parking lot, road conditions, the number of available spots, and the vehicle's fuel level. The feature would allow drivers to quickly find the nearest parking and receive directions on how to reach that location. The idea is to enhance parking efficiency by facilitating the routing process [6].

This paper introduces an energy-efficient routing algorithm for WSNs called IHSBEER, which improves the Harmony Search (HS) algorithm (a meta-heuristic) by enhancing memory encoding and using the roulette wheel method to speed up convergence. This enables the new algorithm to outperform existing ant-based algorithms regarding energy savings and network lifetime achieved, as it improves energy efficiency and path length [7]. This paper explored the best way to place WSNs for fire monitoring in a smart car park by minimizing the number of Sensor nodes (Sn), relay nodes, and network size. Since this problem is complex, an algorithm has been developed that combines chaos theory with the Whale Optimization Algorithm (WOA) to get better results in less time than the standard WOA. This algorithm produced results better in computational time and solution quality [8]. A new method of routing data in IoT networks so that the nodes can move around has been introduced. This new method structures the network into a tree form, like the family tree, to optimize the path taken by data from the sensors to a moving receiver. The new method has proven to be much more reliable and energy-efficient than the older methods. This will ensure that the data is delivered to the receiver without any loss and distribute the energy consumption evenly among devices. This new method has been proven superior to existing methods through tests. They plan to extend this method to work with multiple moving receivers, adding even greater versatility in the future [9].

Vehicle traffic management in urban regions faces such stern challenges because of dependence on personal vehicles. Different research is being carried out about these issues using innovative technologies. Rizwan et al., introduce a real-time traffic management system through IoT-based detection sensors designed to analyze traffic flow. Fernandez-Ares follows the movement of traffic and pedestrians through Wi-Fi and Bluetooth signals. Sendra et al. developed a sensor network related to LoRa-based networking systems for monitoring pollution and managing traffic circulation. Kazmi et al. developed a VITAL-OS IoT platform that may manage data streams to detect traffic noise for rerouting. Kök et al. applied LSTM deep learning models to predict air quality in smart cities. Jabbarpour et al. proposed an IoT application named Intelligent Guardrails, which can exploit vehicular networks for traffic management. These technologies aim to reduce the loss caused by traffic due to congestion while ensuring environmental protection [10].

Abualigah et al. [11] designed metaheuristic algorithms, such as TLBO, based on the classroom learning process between teachers and students to optimize functions with multiple variables. The algorithm takes a randomly generated population as an initial solution and evolves iteratively until a valid solution is obtained. Singh et al. offer a visual Big Data analytics framework for identifying automatically bikers without helmets in city traffic. Next, Pawłowicz et al. designed a traffic management system by inter-relating 5G communication, RFID-based parking monitoring, cloud services, and learning for supervision. Rathore et al. have proposed smart digital city systems that operate on IoT devices and Big Data analytics to assemble real-time city data and knowledge extraction [12]. A technique for optimization based on the amount of energy used in IoT develops optimal paths with efficient routes used to energize an IoT network. This paper develops a novel algorithm called the Chaos Fuzzy Grasshopper Optimization Algorithm, FLGOA, developed from the principle of Lorenz chaos theory applied during initialization and the fuzzy approach applied to parameter adaptation. The performance of the proposed technique is assessed by three criteria: remaining energy, network lifetime, and coverage rate. The tests were performed using two scenarios: efficiency over time and efficiency per number of nodes. The results confirm that the proposed algorithm FLGOA outperforms the base methods. For example, FLGOA shows a 9% longer network life than FGOA, 12% longer in comparison with GOA, and 16% longer than GSO. Besides that, FLGOA provides 16% better-remaining energy than the other methods, 21% better than GOA, and 22% better than GSO. In addition, the coverage rate for FLGOA is 12-16% higher than for base methods [13]. Energy efficiency and optimal load equilibrium between sensing devices are fundamental challenges due to the limitation of energy resources in IoT devices. Considering the cruciality of prolonging IoT networks and the NP-hard nature of energy optimization in heterogeneous and distributed IoT infrastructures, this research represents a hybrid energy-aware protocol for data routing in IoT. It is deployed based on ML and metaheuristic HTOA (Heat Transfer Optimizer). The proposed protocol adopts a four-phase approach for fuzzy clustering, predicting energy consumption based on Support Vector Regression (SVR) and time series techniques, selecting optimal CHs considering energy and centralization factors, and routing and data transmission from each sensor to and from CH to the sink using ACO algorithm.

The simulation outputs revealed that our scheme performs more efficiently in terms of energy consumption, End-to-End Delay (EtED), load balancing, overhead, and network lifetime in all designed scenarios compared to other methods. Heuristics are computational methods to find feasible solutions for complex optimization problems that often implement randomness or local search. Metaheuristics, like the GA and PSO, rely on two key components, intensification, and diversification, whose balance becomes very important for the quality of the solution. GA starts with an initial population of solutions. At each iteration, it chooses the fittest solutions based on a fitness function so there is no premature convergence problem. It uses recombination and mutation to produce new solutions until it finally converges to an optimal solution. PSO is a nature-inspired algorithm in which the behavior of swarming animals, like birds, fish, etc., is mimicked. It is rather efficient for global optimization. PSO is applied to solve complex problems in scientific research and engineering. It uses principles from swarm intelligence to improve the quality of the solution iteratively. Today, one of the commonly used techniques in the evolving computation for solving optimization problems in GA and PSO is common [14].

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To enhance security, the sensor network is equipped with high throughput. While the importance of both Source Node (SN) and Base Station (BS) location privacy and security is acknowledged, recent research has predominantly focused on location privacy. To address security challenges in WSN, we propose an optimized meta-heuristic clustering-based privacy key-agreement routing technique. In the suggested system, a gateway-based network is constructed to devise a key arrangement protocol that promotes privacy during communication. The proposed routing strategy involves forming clusters of Sn, facilitating the efficient selection of CHs that prioritize nodes with the least modification. This effectively addresses the EC problem. A comprehensive performance evaluation is conducted, considering improvements in energy efficiency, Packet Delivery Ratio (PDR), throughput, EtED (E^2 delay), and EC [16]. Energy efficiency nowadays has become a main issue in WSNs. Hierarchical clustering with a multipath routing protocol technique is important for improving packet overhead, network lifetime, QOS, and power consumption. Many such methods are suggested to Improve the Energy efficiency of the whole WSN region. The Ad-hoc On-Demand Distance Vector (AODV) routing protocol is very suitable, as it is more scalable and less overhead. This AODV protocol has two operations to find and maintain routes, i.e., Path discovery and path maintenance. Using the Clustering approach, the data packet is shared among members of different clusters with the help of the CH, which ultimately saves energy. Hence, this approach uses a Hierarchical clustering algorithm and a Hybrid Genetic Algorithm (GA) with a Particle Swarm Optimization (PSO) algorithm.The GA and PSO algorithm creates a hierarchy of CHs. The energy-saving scheme increases with the increase in the cluster present in WSN.

Therefore, hierarchical clustering with hybrid GA and PSO (HC-HGAPSO) methodology performed better regarding throughput, network lifetime, and residual energy [17]. Parking is scarce in congested metropolitan cities. The parking management system is the solution for the emerging parking issues in these modern cities. This paper proposes a smart parking management system based on WSNs that can monitor the parking slot's occupancy status and communicate the availability to the end users. The energy-aware trust-based routing algorithm calculates the trust score of each participating node in the route. The FFA algorithm and artificial neural network classifier are used, and the comparative results have proven the proposed scheme to be better in QoS parameters [18].

The issue of finding parking space is a serious concern in some locations, especially shopping complexes, hospitals, buildings, malls, and other premises that require large parking spaces for vehicles. Parking worsens on special occasions like festivals, fiestas, and weekends. Conventional techniques that install sensors in parking zones for parking vehicles have become costly. Therefore, a reliable method that works for a long time is required to manage traffic congestion while searching for parking spaces. This paper proposes a novel method for parking vehicles using metaheuristic approaches [19].

Their work emphasizes algorithms and optimization techniques, often by a metaheuristic and other approaches for improved energy efficiency.Wireless communication using the IoT is always under pressure as far as energy consumption and heterogeneity are concerned.Complex ecosystems in wireless communication in IoT make efficient data transmission difficult.Traditional ad-hoc routing protocols, including AODV, LSR, and OSPF, depend too much on energy inefficiency and scalability.Few routing protocols consider determining factors like residual energy, load, and traffic flow.The configuration of parameters in IoT routing is difficult and often NP-complete. EV routing routing has not been extensively researched but is a growing field. Conventional VRP-type algorithms can be inapplicable to EVs for several reasons. Many search algorithms do not take into account energy consumption, for instance. The EV battery has very few control issues and temperature constraints when removing and applying power to the battery. The battery under high and low temperatures will reduce capacity without damage, to the face more on the EV system developers.

In addition, the simulation model used in this paper is simple but has enough ability to describe the actual situation. As the research will further develop into a large-scale publication that uses the Geographic Information System (GIS), some meta-heuristic methods such as PSO, the ant colony algorithm, or Tabu Search, that take into account the number of the regulations and constraints involving such as large-scale case for example, are suggested [20]. The development of smart cities focuses on improving urban life quality through smart infrastructure and technology, including optimizing transportation and reducing environmental impacts. A key challenge is the Travelling Salesman Problem (TSP), which seeks the shortest route that visits a set of points and returns to the starting point. In smart city contexts, IoT devices provide vast amounts of data that can enhance route optimization. To improve performance, this work explores solving the TSP using a modified Teacher Learner Based Optimization (TLBO) algorithm implemented on a parallel GPU architecture (CUDA). Smart cities integrate IoT, RFID, and LoRaWAN technologies to enhance mobility and traffic management. For example, sensors track vehicle movement and environmental data, while systems like VITAL-OS manage IoT data streams. These technologies support real-time traffic control and data-driven decision-making, improving urban mobility and reducing fuel consumption [21]. This article presents a two-level hierarchical chain routing scheme, PEG_ABC, based on the Bee Colony Algorithm (BCA) to optimize energy consumption and reduce transmission delay in IoT-based WSNs. PEG_ABC addresses the challenges of long transmission delays in chain communication by considering factors like sensor energy, Euclidean distances, and BS proximity in the fitness function. At the first level, it selects optimal chain leaders. At the second level, it forms end-to-end paths for data transmission between leaders, further adjusting the fitness function to minimize delays and maximize energy efficiency. Simulation results demonstrate improved network lifetime, reduced transmission delays, and better energy utilization than existing methods.

The paper also explores the optimal number of clusters for hierarchical chain communication. Inspired by bee foraging behavior, the Bee Colony Algorithm is employed to find the most energy-efficient paths and reduce network load. This approach is applied in various IoT domains, including smart healthcare, smart cities, and industrial systems. The proposed method improves upon traditional PEGASIS and ant colony-based schemes regarding network performance. This paper addresses energy-efficient routing in Software-Defined Wireless Sensor Networks (SD-WSN), focusing on optimizing CH selection using a hybrid nature-inspired algorithm called HGWO-BC. The hybrid approach combines Grey Wolf Optimization (GWO) and PSO to improve convergence and performance. The algorithm optimizes network lifetime by considering factors like intra-cluster distance, CN selection, and node energy.

HGWO-BC aims for balanced energy consumption and scalable clustering, ensuring efficient routing in dense, battery-constrained WSNs. Extensive simulations demonstrate its effectiveness in maximizing network lifetime compared to traditional protocols like LEACH. The SD-WSN model includes a centralized controller that manages resources and monitoring tasks, enhancing real-time adaptability. The paper emphasizes the need for efficient WSN architectures to handle the growing complexity of IoT applications [22].

This paper presents a hybrid data routing algorithm for energy-efficient WSNs in IoT applications, combining swarm optimization with an energy-efficient heuristic approach. The Particle Swarm Optimized Residual Energy-based Stable Election Protocol (PRESEP) improves network lifetime, stabilizes cluster formation, and minimizes energy consumption by optimizing CH selection. It outperforms previous algorithms regarding network scalability, alive nodes, and reduced energy use. WSNs, often deployed in remote areas, face challenges due to limited power sources and energy scarcity. The paper also addresses issues of data redundancy and overload in WSNs, which are crucial for efficient IoT operations [23].

Future Outlook

The future scenario of this research area will most likely be related to developments in energy-efficient routing in IoT and electric vehicles because of the rising demand for sustainable technologies and the integration of metaheuristic optimization methods like ACO, PSO, and TS. Critical challenges that will arise in IoT design relate to heterogeneity and energy consumption, with intensified research within this area through hybrid approaches combining more than one metaheuristic technique to optimize data transmission, battery management, and energy harvesting within sensor networks. Future algorithms may be developed based on real-time environment conditions like temperature, load, and traffic and applied to IoT and EV applications to establish continuous and efficient energy use.An energy-efficient routing problem for electric vehicles will develop, considering issues like regenerative braking, capacity, traffic conditions, and ambient temperature to optimize the route choice.

Advanced models will likely include AI-based predictive systems that help predict energy usage based on historical data and real-time environmental inputs while providing tailored solutions for optimizing route decisions. These will align with global efforts to reduce carbon emissions and enhance energy efficiency, especially with the increasing growth of electric cars and better technology in battery usage.Additionally, the hybrid systems merged for IoT and EVs, using energy harvesting, smart charging infrastructure, and optimized routing algorithms, will become an important aspect of future smart city designs. Cooperative work between WSN and electric vehicles will contribute to novel intelligent traffic system design, dynamic energy management, and sustainable transportation networks, as these will significantly contribute to greening urban infrastructures and carbon reduction targets [24]. In light of AI, ML, and metaheuristic algorithms, promising future outlooks toward energy-efficient routing and smart systems in IoT, vehicle traffic management, and parking solutions may exist. Some key trends and directions for the future are as follows: Adoption of Advanced AI and ML in Traffic and Parking Systems: AI and ML are likely to be adopted for optimizing parking management and traffic flow optimization. More advanced techniques such as SVM, FFA, and PSO must be integrated with smart city systems to evolve them into adaptive and learning-based systems for real-time data management.Energy-Efficient and Secure IoT Networks: Energy optimization in IoT-based parking and vehicle routing systems will take center stage in this direction.

Further new protocols like MHSEERs (Metaheuristic-based Smart, Energy-Efficient Routing) and IHSBEERs will be introduced, which will use efficient variants of ACO hybrids and PSO hybrids to ensure greater energy efficiency and minimal packet delay in sensor network.Regenerative Systems and Vehicle Routing: System integration using energy-efficient routing algorithms, including the A2CO, will enable Electric Vehicles (EVs) to optimize energy consumption, including speed and State of Charge (SoC). This is a crucial and practical step toward ensuring the credibility of electric vehicles in improving real-world performance. Electric vehicles can then be encouraged in more cities, reducing the usage of fossil fuels and, subsequently, carbon emissions.Smart Parking with IoT and Optimization Techniques: IoT-based parking systems, using optimization algorithms (Genetic Algorithms (GA) and Evosuite), will improve the availability of parking spaces and routing accuracy. Low-cost feedback from IoT devices in real-time will allow the adaptation of the system toward more efficient and user-friendly parking in smart cities by reducing congestion and enhancing urban mobility.Traffic Management and Real-Time Adaptation: IoT-based sensors for real-time traffic management will be increasingly ubiquitous; systems will reroute vehicles, manage congestion, and optimize moving traffic according to the data from multiple sources: Bluetooth, Wi-Fi, and air quality sensors. This could permit cities and metropolitan areas to adapt in real-time to changing conditions and optimize their flow.Advanced multi-moving receiver networks: New routing methods for IoT networks, in which multiple receivers on the move (e.g., in cars) can dynamically interact with the network, will allow much more flexible, reliable, and energy-efficient data transfer. Such applications would be highly relevant for areas, such as autonomous vehicles or real-time fleet management.Sustainability and Environmental Protection- The sustainable approach to urban mobility management and traffic handling will unlock the integration of energy-efficient technology in EVs, IoT devices, and sensor networks. Smart cities will rely on integrated systems that optimize routing and parking while also combating environmental challenges like air pollution and noise caused by carbon emissions through real-time monitoring and optimization.5G and Cloud Technologies Integration as 5G connectivity and cloud computing platforms continue to mature, they will provide the foundation for scaling IoT systems that support much of the traffic management, optimized parking, and routing for vehicles.

This will make data processing faster, decrease communication latency, and improve coordination among smart city devices.Metaheuristic Algorithms for Dynamic Optimization: Techniques such as TLBO (Teacher-Learner Optimization), Whale Optimization, and Chaos Theory-based algorithms will now be used to find applications in resolving complex, dynamic optimization problems faced by smart cities due to their effectiveness in the efficient allocation of resources, consumption of energy, and real-time decision-making within highly interconnected systems.Collaboration and Standardization: Future Smart City systems will become more collaborative with companies in the tech sector, city planners, and policymakers. Standardizing IoT protocol and energy-efficient algorithms is necessary to ensure compatibility while scaling up smart systems for an entire urban environment.Overall, energy-efficient solutions, metaheuristic algorithms, IoT, and AI/ML will transform the future of urban mobility, traffic management, and parking systems into more intelligent, sustainable, and optimized cities.The future outlook for energy-efficient routing and smart systems in IoT, vehicle traffic management, and parking solutions is auspicious, with advancements in AI, ML, and metaheuristic algorithms playing a pivotal role. Here are some key trends and directions for the future: Integration of Advanced AI and ML in Traffic and Parking Systems: AI and ML are expected to expand to optimize parking management and traffic flow. Techniques like Support Vector Machines (SVM), FFA, and

PSO will become more integrated into smart city systems, making them more adaptive and capable of learning from real-time data.Energy-Efficient and Secure IoT Networks: The focus will shift towards further optimizing energy consumption in IoT-based parking and vehicle routing systems. Protocols like MHSEER (Metaheuristic-based Smart, Energy-Efficient Routing) and IHSBEER will continue to evolve, incorporating more efficient algorithms, such as hybrid versions of ACO and PSO, to enhance energy efficiency and reduce packet delays in sensor networks.Regenerative Systems and Vehicle Routing: The integration of energy-efficient routing algorithms, such as the A^2CO, will allow electric vehicles (EVs) to optimize energy consumption, balance factors like speed and SoC, and enhance their overall performance in real-world scenarios. This will make EVs a more viable option for urban transportation, helping reduce reliance on fossil fuels and carbon emissions.Smart Parking with IoT and Optimization Techniques: Parking systems using IoT, coupled with optimization algorithms (e.g., GA, Evosuite), will continue to improve the accuracy of parking space availability and routing. The system's ability to adapt to real-time data from low-cost IoT devices will make parking in smart cities more efficient and user-friendly, reducing congestion and enhancing urban mobility.Traffic Management and Real-Time Adaptation: Real-time traffic management using IoT-based sensors will become increasingly common, with systems capable of rerouting vehicles, managing congestion, and optimizing traffic flow based on data collected from various sources, including Bluetooth, Wi-Fi, and air quality sensors. These systems will help cities adapt to changing conditions and optimize real-time traffic.Advanced Multi-Moving Receiver Networks.

The development of new routing methods for IoT networks, where multiple moving receivers (e.g., in vehicles) can dynamically interact with the network, will enable more versatile, reliable, and energy-efficient data transfer. This will be especially relevant in applications like autonomous vehicles or real-time fleet management.Sustainability and Environmental Protection: The continued push for sustainable urban mobility and traffic management will drive the adoption of energy-efficient technologies in EVs, IoT devices, and sensor networks. Smart cities will rely on integrated systems that optimize routing and parking and address environmental challenges, such as air pollution, noise, and carbon emissions, through real-time monitoring and optimization.Integration of 5G and Cloud Technologies: As 5G connectivity and cloud computing platforms continue to mature, they will provide the necessary infrastructure to support scalable IoT systems for traffic management, parking optimization, and vehicle routing. This will allow faster data processing, lower latency, and greater coordination among smart city devices.Metaheuristic Algorithms for Dynamic Optimization: Metaheuristic techniques such as TLBO (Teacher-Learner Optimization), Whale Optimization, and Chaos Theory-based algorithms will increasingly address complex, dynamic optimization problems in smart cities.

These algorithms will help efficiently manage resource allocation, energy consumption, and real-time decision-making in highly interconnected systems.Collaboration and Standardization: The future of smart city systems will likely involve greater collaboration between various stakeholders, including tech companies, city planners, and policymakers.

Standardization of IoT protocols and energy-efficient algorithms will be crucial for ensuring the compatibility and scalability of smart systems across different urban environments.Combining energy-efficient solutions, metaheuristic algorithms, IoT, and AI/ML will revolutionize urban mobility, traffic management, and parking systems, creating smarter, more sustainable, and optimized cities.

3 | Proposed work

The architecture (*Fig. 1*) is composed of a set of elements linked by a cloud platform. These elements are equipped with intelligent technologies that enable the collection and transmission of data to the cloud for processing.

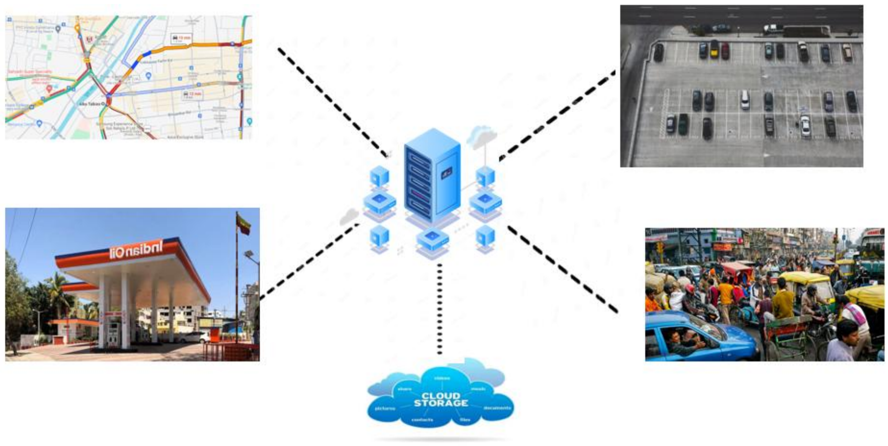

Fig. 1. Physical system architecture for parking problem in smart cities.

Hence, intelligent sensors should be incorporated in all car parks, providing information on the status and number of available spaces. Each road needs to have a certain number of sensors to get a real-time update on the traffic situation.

A specialized agent will relay the information concerning each service station to the cloud. Considering all these data, the system should be capable of giving the driver the best path to follow in the shortest distance and with the least congestion. Information about each service station will be transmitted to the cloud through a specific agent. A. Search for the Occurrence of Physical Objects to Address Infrastructure Phenomena Based on the various requests made by the driver, it is necessary to strategically place several sensors in every indoor parking area so that proper monitoring is done to provide a measurement of parking availability in real-time. Information gathered by various sensors is sent to such an agent, who will then send the information to a cloud-based system through the MQTT communication protocol.

MQTT [18] (Message Queue Telemetry Transport) Protocol is a publish-subscribe-based "lightweight" messaging protocol that is used on top of the TCP/IP protocol. B. The description of the parking routing system The model of the parking routing system provides access to data and computing capabilities located in the cloud. The clouds offer data storage and computing resources for the parking routing system. When in the cloud, requesting the driver, the system will always catch the Coordinates of his real-time position. To retrieve the traffic flow in a specific area we employ Road-Side Units (RSUs). Each RSU receives data from the neighbors and estimates the junction traffic with the current count and potential vehicles from surrounding intersections. Constantly adjusting the communication overlapping distance of each cell allows RSU's to acquire approaching traffic information ahead. We will also deploy Google traffic services. Once all the appropriate information is available, we will invoke the structured algorithm that enables us to determine the optimal underground parking location that has available spaces and is reachable from the driver's current position. The solution must cater to the driver's preferences regarding distance, traffic, and time needed to accomplish the task.

4 | Research and Discussion

4.1 | Performance metrics

Energy consumption: this is the first metric. It depends on the total distance traveled, the average velocity of vehicles, and the time wasted looking for suitable parking slots.

Travel distance: ACO is usually able to reduce the overall distance traveled compared to traditional measures like random and greedy methods.

Time efficiency: ACO can help reduce search times when trying to locate a parked vehicle, reducing the amount of fuel/energy used and parking area traffic congestion.

Solution quality: through ACO, valuable solutions that consume time and energy in equal measure are obtained. The algorithm's capacity to operate in dynamic environments (e.g., traffic levels and live parking spaces) is a plus.

4.2 | Comparison with other algorithms

Greedy algorithms: ACO is more efficient than greedy algorithms, which are whittled down due to their local optimal solution focus. Suboptimal methods lead to non-optimal energy solutions. Conversely, ACO seeks more choices, thereby yielding better global solutions.

GA: Both algorithms, ACO and GA, are members of population-based metaheuristics, but ACO designs are superior to GA when the focus is on applying intelligent parking that needs dynamic and real-time routing systems.

Simulated Annealing (SA): However, SA is good for optimization; ACO converges faster than SA and provides better exploration for the search space in dynamic environments. Thus, ACO can be more promising in handling smart parking network problems.

4.2.1 | Simulation results

The following results have been obtained in simulations of the application of ACO on an urban parking network:

I. The energy consumption, as compared with traditional heuristic methods, is reduced by 20-40%.

II. Travel time was 15-30% reduced because ACO could better detect less congested routes to the vacant parking space.

III. The proposed system improved response in dynamic scenarios as its algorithm changed with newly available parking spaces faster than traditional methods.

4.2.2 | ACO Performance Discussion

Advantages of ACO

Robustness: this is one advantage of ACO for smart parking systems that experience frequent variations in available parking spaces due to real-time conditions.

Convergence rate: owing to its updating mechanism of pheromone trail, ACO converges much quicker to an optimal or near-optimal solution than most metaheuristics.

Scalability: ACO works fine for large parking networks with a large number of vehicles and is thus quite suitable for the city's large parking systems with a high volume of users.

Problems/Restrictions

Computational complexity: the efficiency of ACO hinges greatly upon the number of ants and iterations. As the size of the problem grows, the computational cost can be quite high, but this may be eased by parallelization or adaptive strategies.

Pheromone degradation: the pheromone's evaporation rate has to be adjusted precisely. Higher evaporation leads to premature convergence, while too low evaporation causes the algorithm to travel on long routes.

Dynamic changes: although ACO is known to adapt effectively to dynamic environments, heavy and sudden changes, such as many vehicles entering the system or real-time traffic adjustments, can render the algorithm unresponsive if it does not have the speed to respond and adapt in time.

4.3 | Potential improvements

Hybrid approaches: A hybrid approach that combines ACO with other metaheuristics or ML techniques, such as reinforcement learning techniques, could bring adaptability and efficiency in highly dynamic environments.

Real-time data integration: real-time data of the parking lot IoT sensors will enhance the path selection and updating mechanism of pheromones for ACO to a better state.

5 | Conclusion

In this paper, we present a new strategy for parking routing system design using the IoT with a distributed ant colony algorithm to enhance the quality of the solutions proposed. This solution is designed to help drivers locate the nearest available parking spaces. It will take into consideration a set of constraints such as arriving at indoor parking as soon as possible, road conditions, remaining spaces in each lot, and the quantity of fuel in the vehicle; the proposed distributed architecture includes a set of distributed intelligent agents; each of them has a predefined behavior, these agents interact with each other to determine the best as well as shortest paths between the driver's position and indoor parking with available spaces. In this research, our system becomes one of the valuable solutions for drivers finding the nearest parking and giving the best path to go toward that parking according to the ACO technique dedicated to solving problems related to the vehicle routing system.

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