Smart Parking System Using LoRa and Edge Computing: A Computing Continuum Approach

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1 Introduction

Rapid growth in urban populations has led to increased traffic congestion and a shortage of available parking spaces. Traditional parking management is often inefficient, contributing to unnecessary traffic and increased CO_2 emissions as drivers search for vacant spots [1, 2, 3]. Intelligent parking systems, which combine digital monitoring with real-time visibility, have emerged as a solution that can reduce search time, traffic, and environmental impact by improving parking space allocation.

Modern smart parking systems can benefit significantly from the computing continuum paradigm, which represents a seamless integration of computational resources spanning from IoT devices at the network edge to powerful cloud data centers. This distributed computing approach optimizes latency, performance, and resource utilization by strategically placing computational tasks across different layers of the infrastructure based on application requirements and resource constraints [4].

By combining low-power, long-range communication protocols such as LoRaWAN (Long Range Wide Area Network) with edge computing within a computing continuum framework, it is possible to build a cost-effective, real-time parking availability system. This approach allows quick decision making at the device and edge layers, reducing cloud dependency, latency, and network load [1].

2 Identified Problem

Traditional cloud-based smart parking systems are highly dependent on continuous communication between sensors and central servers. This leads to several limitations:

- **High bandwidth usage**: Constant communication increases operational costs, especially with a large number of sensors [1, 3].
- **Increased latency**: Centralized processing can introduce delays, making real-time decision-making less effective [1].
- **Energy consumption:** Frequent transmissions drain sensor batteries more quickly, thus increasing maintenance needs.
- **Over-reliance on cloud processing**: All computational tasks are performed centrally, creating bottlenecks and single points of failure [1, 3].

Furthermore, in dense urban areas, communication infrastructure may be unreliable or expensive to scale. There is also a lack of systems that can dynamically adapt to the local context (e.g., high-demand periods, sensor malfunctions, maintenance windows, or blocked spaces). These limitations suggest a need for decentralized logic and lightweight communication protocols.

3 Related Work

Several studies explore the use of LoRaWAN and edge computing in smart parking systems. Sarker et al. [1] propose a system that uses LoRa sensors and edge-cloud integration to improve energy efficiency and support dynamic pricing. Jabbar et al. [3] build a smart parking platform using LoRaWAN, designed for crowded cities, and focus on reliable communication and low power use.

Barriga et al. [2] design a cloud-based parking solution that incorporates Kubernetes for dynamic scaling, focusing on flexibility of deployment and improvements in latency through edge computing. Meanwhile, Santana et al. [5] study how LoRa signals behave in real urban environments, showing some limitations in signal range and quality.

These works show the benefits of using LoRa and edge computing in smart parking. However, challenges remain, such as making the system more adaptive to local conditions and reducing the amount of data sent over the network.

4 Proposed Solution

This project proposes a smart parking system that leverages the computing continuum, where computation is distributed across the device, edge, and cloud layers to optimize performance, latency, and scalability:

- **Device layer:** Parking sensors equipped with microcontrollers can perform basic data preprocessing (e.g., filtering noise or redundant signals) to reduce unnecessary transmissions.

- **Edge layer:** LoRaWAN gateways act as edge nodes that aggregate data, execute real-time analytics (e.g., occupancy detection, demand prediction), and perform dynamic decision-making such as local parking guidance or preliminary dynamic pricing.

- **Cloud layer:** The cloud can provide long-term data storage, city-wide analytics, global coordination, machine learning model training for demand prediction, and integration with user applications and external services such as payment systems and navigation applications.

The system uses **LoRaWAN** for energy-efficient, long-range communication between parking spot sensors and edge devices [1, 3], and the **MQTT (Message Queuing Telemetry Transport) protocol** for efficient messaging between edge nodes and cloud services. A **user interface** will allow drivers to view available parking spots and optionally book/pay for them in real time.

Additionally, the system will include a **continuum orchestration mechanism** responsible for dynamically allocating computational tasks across layers based on latency, bandwidth availability, and resource constraints, using predefined rules and simple conditions (policy-based orchestration). This ensures efficient resource usage and adaptability to varying traffic and network conditions without requiring complex AI-driven orchestration.

This layered computing continuum approach ensures that time-critical operations (such as updating parking availability) are handled locally, while resource-intensive tasks (such as city-wide traffic optimization) leverage cloud capabilities.

5 Specific Objectives

1. **Architecture design**: Develop a modular smart parking system architecture integrating LoRaWAN devices, edge nodes, and cloud services with clear task distribution across device, edge, and cloud layers .

2. **Simulate data processing:** Generate synthetic parking sensor data and evaluate how processing is distributed along the continuum.

3. **Develop and evaluate edge logic**: Implement algorithms for event filtering, aggregation, and decision making at the edge node to minimize unnecessary traffic to the cloud.

4. **Implement and evaluate orchestration strategies:** Develop simple orchestration logic that dynamically decides which tasks (e.g., analytics, filtering) are executed at device, edge, or cloud layers based on network conditions, system load, and latency requirements.

5. **Evaluate performance across layers:** Compare communication efficiency, latency, and energy consumption with and without edge and device-level preprocessing.

6. **Integrate cloud analytics and user applications:** Design a cloud-based dashboard and mobile/web interface for parking availability, reservation, and payment while ensuring efficient edge-cloud communication.

6 Conclusion

This project addresses real-world urban mobility challenges by combining IoT communication protocols (LoRa, MQTT) with a computing continuum approach. By distributing computation across the device, edge, and cloud layers, the system enhances responsiveness, scalability, and energy efficiency while reducing cloud dependency and network load [4].

The proposed architecture supports real-time decision making at the edge, long-term analytics in the cloud, and lightweight data processing at the device level. The simulation environment will allow thorough exploration of the continuum-based architectural decisions, protocol efficiency optimization, and dynamic resource allocation strategies without requiring physical hardware deployment. The results will contribute to the broader understanding of how computing continuum principles can be applied to smart city infrastructure, providing insights applicable to other IoT applications beyond parking management.

Future work will include real-world prototyping, integration of advanced analytics (e.g., AI-based demand prediction), and improved security for edge-cloud interactions.

References

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