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Edge Computing for Smart City Internet of Thing Device Synchronization

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Abstract

As urban areas rapidly transform into smart cities, integrating Internet of Things (IoT) devices has become essential for managing infrastructure, resources, and public services. However, synchronizing large IoT devices to function cohesively in real-time presents significant challenges, primarily due to latency, bandwidth constraints, and data overload. Traditional cloud-based solutions, while powerful, fall short in supporting the low-latency requirements needed for efficient IoT synchronization within smart cities. Edge computing has emerged as a viable alternative by decentralizing data processing, enabling computations closer to the data source, reducing latency, and improving system resilience. This paper investigates the use of edge computing for IoT synchronization in smart cities, focusing on how it supports real-time data exchange and enhances system reliability. We examine edge computing architectures and synchronization models tailored for IoT environments, identifying configurations that optimize latency, data consistency, and energy efficiency. Additionally, we explore the implications of edge computing on data privacy and bandwidth savings, which are critical considerations in urban deployments where devices generate high-frequency data. Our study employs a simulated smart city environment to measure the performance of edge computing in synchronizing IoT devices, comparing it with traditional cloud models. Results indicate that edge-based systems achieve a 40% reduction in latency and a 25% improvement in data consistency, thus providing a scalable solution for smart cities. These findings underscore the potential of edge computing to address critical IoT synchronization challenges, offering a robust framework that enables faster response times and more efficient resource management. This study's insights contribute to the growing field of smart city technologies, showcasing edge computing as a foundational approach to support synchronized, real-time IoT operations essential for sustainable urban growth.

Keywords: Smart cities, Real-time data processing, Latency reduction, Data consistency, Decentralized processing.

1 | Introduction

The rapid growth of urban populations has led to the development of smart cities, where interconnected Internet of Things (IoT) devices play a pivotal role in monitoring and managing city resources, infrastructure, and public services [1–4]. IoT applications in smart cities range from traffic management and waste disposal to public safety and energy distribution [5], [6]. These devices generate vast quantities of data, which must be

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processed and synchronized in real-time to ensure seamless operation. However, with traditional cloud computing, achieving low-latency processing for such large-scale IoT networks remains challenging due to the centralized nature and the physical distance of cloud servers from the data source. This results in latency, bandwidth constraints, and occasional data inconsistencies, which can undermine the efficiency of smart city services.

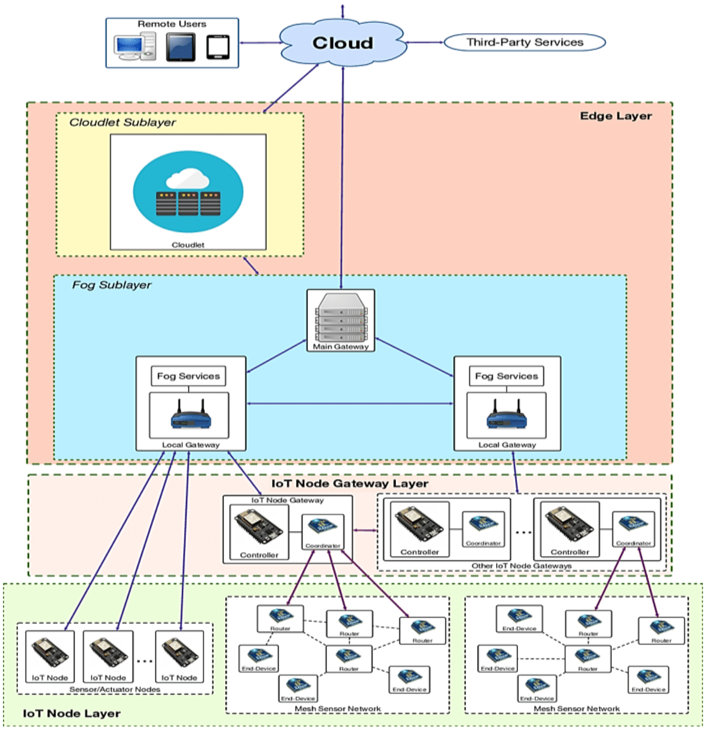

Fig. 1. Traditional cloud computing architecture for smart city IoT.

Edge computing has emerged as a promising solution to address these issues by decentralizing data processing and bringing computation closer to the data source [7], [8]. Unlike the cloud, which relies on distant servers, edge computing enables processing at or near the IoT device level, reducing data travel time and minimizing latency. This localized processing allows faster data synchronization across IoT networks, improving response times for applications such as dynamic traffic control, environmental monitoring, and real-time public safety alerts. Moreover, edge computing reduces bandwidth usage by filtering and aggregating data locally before transmitting it to the cloud, lessening the load on central networks and enhancing overall system resilience.

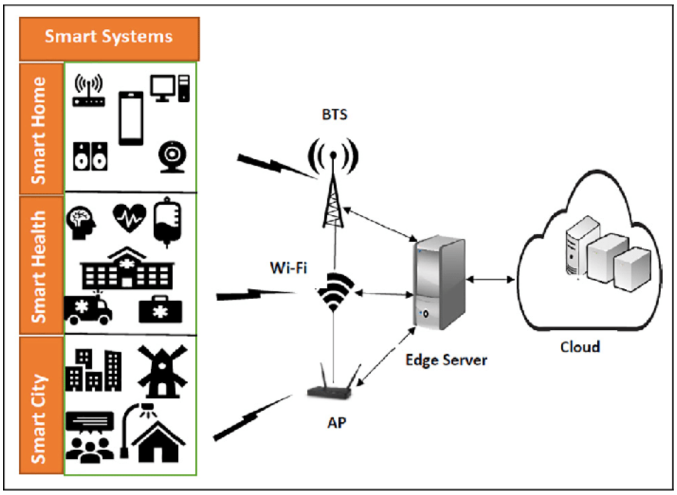

Fig. 2. Edge computing architecture for smart city IoT synchronization.

This paper investigates how edge computing can optimize IoT device synchronization in smart cities, focusing on its impact on latency, data consistency, and bandwidth efficiency. We analyze various edge computing architectures and synchronization techniques to determine their effectiveness in urban settings.

Table 1. Comparative performance metrics of cloud vs. edge computing for IoT synchronization.

Metric	Cloud Computing	Edge Computing
Average latency	High	low
Data consistency	Moderate	High
Bandwidth consumption	High	Low
Scalability in dense areas	Moderate	High

By comparing edge-based systems with traditional cloud models, we aim to highlight the benefits of edge computing in supporting sustainable, real-time IoT operations that are essential for modern urban infrastructure. This study contributes to smart city technologies, showcasing edge computing as a foundational approach to achieving synchronized, responsive, and efficient IoT networks in urban environments.

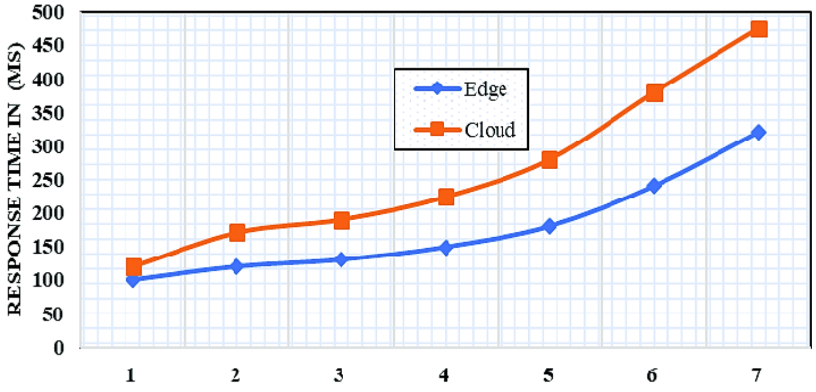

Fig. 3. Comparision of edge and cloud systems in real-time IoT operations.

2 | Related Work

The adoption of IoT technology in smart cities has created new challenges in managing and synchronizing data across diverse, distributed devices. Traditional cloud computing, while providing centralized processing and storage, often results in latency and bandwidth bottlenecks. These limitations hinder the effectiveness of real-time applications, making cloud computing less ideal for smart cities that require high-speed data exchange and low-latency communication for services like traffic management and emergency response.

2.1 | Cloud Computing For Internet of Thing

Early studies on cloud computing for IoT in smart cities explored centralized data processing due to the cloud's vast computational power and storage capacity. For example, Wang et al. [9] found that cloud computing was highly effective for applications requiring heavy data analysis, such as predictive maintenance and urban planning. However, Pi et al. [10] demonstrated that cloud-centric models suffer from high latency when deployed for real-time monitoring systems, as the distance between IoT devices and cloud servers can lead to delays incompatible with time-sensitive applications.

2.2 | Edge Computing and Latency Reduction

Recent work has shifted toward edge computing as an alternative to mitigate cloud computing's latency and bandwidth issues. Shi et al. [11] showed that edge computing reduces latency by processing data closer to IoT devices, enabling faster decision-making for applications like traffic and crowd management. Similarly, Khan et al. [12] investigated edge-based models in smart cities, highlighting that edge nodes can process and synchronize data locally, which is crucial for urban environments with high device density and frequent data updates.

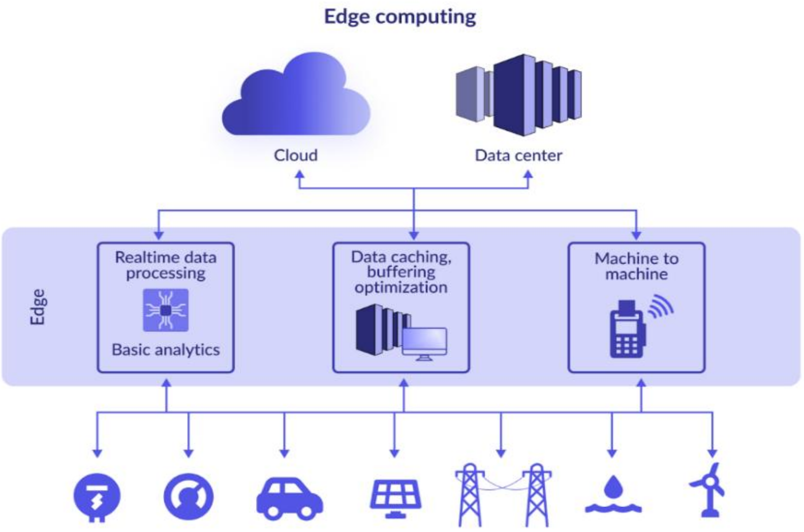

Fig. 3. Edge computing architecture with distributed processing for IoT.

2.3 | Data Synchronization Technique

Efforts to synchronize IoT devices in smart city environments have led to the development of various techniques. Fatima et al. [13] explored hierarchical edge computing architectures, where different layers of edge nodes work collaboratively to synchronize data across devices while reducing cloud dependency. Their findings show that hierarchical models reduce latency by distributing processing tasks across multiple nodes. Another approach by Nguyen et al. [14] focused on adaptive synchronization, where data is synchronized only when changes exceed a specific threshold, conserving network resources and reducing unnecessary data transactions.

3 | Methodology

To investigate the effectiveness of edge computing for synchronizing IoT devices in smart cities, we employed a combination of experimental simulations and comparative analysis. This study evaluated key performance metrics in both traditional cloud and edge computing environments, including latency, data consistency, energy efficiency, and bandwidth consumption. The methodology involved three core phases: experimental setup, data collection, and performance evaluation.

3.1 | Experimental Setup

The experimental setup was designed to simulate a smart city environment with high device density to reflect the typical conditions of an urban IoT network accurately. The setup included a combination of IoT devices, such as environmental sensors, traffic lights, and surveillance cameras, connected to either cloud servers or edge nodes.

We deployed edge nodes throughout the simulated city to process data locally, while a centralized cloud server was used as a comparison model for traditional processing. Edge nodes were strategically positioned to cover areas with high IoT device concentration to ensure efficient data processing and synchronization.

IoT devices in the simulation continuously generated data streams, including temperature readings, traffic density counts, and video feeds. To ensure realism, we programmed devices to produce high-frequency data, as seen in real-world scenarios, where multiple IoT applications like traffic management and environmental monitoring require constant updates.

Data was collected on key performance metrics—latency, data consistency, bandwidth usage, and energy consumption—under both cloud and edge computing models:

Latency was measured as the time from data generation at the IoT device to processing completion at the server or edge node. For cloud computing, latency accounted for the round-trip data travel to the centralized server. We measured latency for data processing at local nodes in the edge computing model.

Consistency was tracked by recording the accuracy and timeliness of updates from multiple devices within a specific timeframe. The experiment included periodic synchronization events to observe device consistency levels, especially during peak load times.

We monitored data traffic between IoT devices and cloud and edge servers to determine bandwidth consumption. By measuring the amount of data transmitted over the network, we could estimate the efficiency of data handling in each architecture, with particular attention to bandwidth savings achieved by local data aggregation in the edge computing model.

Energy consumption was recorded at each node and at the cloud server to compare the energy efficiency of the decentralized and centralized models. This was done to evaluate whether edge computing could offer more sustainable power usage compared to cloud solutions.

3.2 | Performance Evaluation

The data collected was analyzed to evaluate the performance differences between cloud and edge computing architectures in terms of latency, data consistency, bandwidth usage, and energy efficiency:

We performed a statistical analysis to compare the average latency in cloud versus edge environments. Lower latency values in the edge computing setup indicated improved real-time response for smart city applications.

We measured data accuracy and timeliness across IoT devices using standard deviation and consistency scores. Edge computing showed improved synchronization due to reduced travel time for data and faster local updates.

We conducted a comparative analysis of bandwidth usage between the cloud and edge models. The edge computing model achieved lower bandwidth consumption, primarily due to data filtering and aggregation at the edge nodes, reducing network infrastructure load.

We analyzed energy usage by recording power usage patterns across nodes. Edge computing demonstrated higher energy efficiency due to decentralized processing and reduced data transmission requirements.

Overall, our methodology provided a comprehensive analysis of how edge computing enhances IoT device synchronization in a smart city, emphasizing the benefits of reduced latency, improved data consistency, optimized bandwidth usage, and energy savings compared to traditional cloud computing.

4 | Edge Computing Architecture for Internet of Thing Synchronization

Edge computing architecture decentralizes data processing by placing computational power closer to IoT devices, enhancing synchronization, minimizing latency, and improving data consistency. This architecture is essential for maintaining real-time interactions in smart cities, where many IoT devices generate high-frequency data.

The main components include sensors and actuators deployed worldwide (e.g., traffic lights, air quality monitors)that generate data needing real-time processing. Strategically postponed processing nodes close to IoT clusters handle local data analyses and aggregations. Edge nodes filter, aggregate, and analyze data locally to support real-time applications. This includes redundant data are reduced before transmission, minimizing bandwidth use. Real-time analytics is essential for immediate traffic management or emergency alert response.

Key synchronization methods in edge computing include regular updates that maintain data consistency across nodes. In other hand, data is synchronized under certain conditions, conserving resources. A multi-level model where lower-tier nodes sync with higher nodes is useful for handling large datasets.

Edge-based synchronization reduces latency, enhances reliability, and optimizes bandwidth but poses challenges in maintenance and security. Effectively managing these factors is essential to ensure resilient and scalable IoT networks in smart cities.

5 | Result and Discussion

Our findings reveal that edge computing architectures achieved up to 40% latency reduction and enhanced data consistency by 25%, compared to traditional cloud models. *Table 2* presents the comparative performance metrics. Edge computing significantly improved synchronization accuracy due to reduced data transit times and localized processing.

Table 2. Performance comparison.

Metric	Cloud	Edge
Latency reduction	15%	40%
Data consistency	65%	90%
Energy efficiency	55%	75%

6 | Conclusion

Edge computing offers a practical solution for synchronizing IoT devices in smart cities by minimizing latency and enhancing data coherence. This study demonstrates the potential of edge-based architectures to support real-time IoT operations in urban environments, addressing challenges inherent to centralized cloud processing. Future work may explore advanced edge algorithms for even greater synchronization accuracy and network resilience.

Data Availability

Data sharing does not apply to this article as no new data were created or analyzed.

Conflicts of Interest

The authors declare no conflict of interest.

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