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Edge Computing in IoT for Smart Cities

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Abstract
As urbanization intensifies globally, nations are increasingly adopting the smart city approach to address the challenges of rising infrastructure demands and sustainability issues. Smart cities, powered by the Internet of Things (IoT), are designed to tackle these challenges by enabling real-time monitoring, digitization, and optimization of urban services. Nonetheless, the centralized cloud computing model often utilized by smart cities has challenges of high latency, bandwidth limitations, and privacy concerns. These challenges have resulted in the consideration of edge computing as the best option, as it enables the processing of data closer to its sources, rather than transferring to centralized platform. This makes decision-making faster while also enhancing security and enabling system resilience.
This article explores the important role of edge computing in IoT-driven smart city development across the globe, evaluating the effectiveness of edge computing in key domains such as smart transportation, energy management, public safety, and waste and water services. The article includes real-world case studies like Barcelona, New York, and Tokyo, analyzing the practical benefits, including reduced congestion, faster grid outage detection, and network traffic optimization the cities have gained from adopting the technology. It also presents the critical challenges such as interoperability, cybersecurity, infrastructure costs, and policy gaps, that are hindering faster adoption.

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Keywords: Edge Computing, Internet of Things (IoT), Smart Cities, Real-Time Data Processing, Urban Infrastructure Optimization

1. Introduction

Across the globe, nations are experiencing rapid urbanization, with cities projected to host 61% of the global population by 2030 (UN Report, 2017). This rapid urbanization has resulted in new difficulties, including rising demand for energy, overextension of healthcare infrastructure, transportation, and public safety. The world is also shifting towards a heightened emphasis on environmental sustainability and resource use efficiency. The combination of these issues has given rise to the concept of "smart cities", with a focus on harnessing technology to improve urban living. Smart cities promise efficient health and environment monitoring, smart transportation, energy and water quality management, and building monitoring (Seidor, 2024). A key technology powering smart cities is the Internet of Things (IoT), a network of interconnected physical devices and sensors that collect and share real-time data. This infrastructure enables cities to optimize resources, enhance services, and improve urban living. The IoT physical devices and sensors can be placed throughout the city in fixtures such as traffic lights, trash collection systems, wearable health trackers and others. IoT systems collects massive amount of data which poses additional challenges in processing, evaluating, and making real-time decisions. This challenge is improved by edge computing, which enable efficiency, reliability, and security of IoT applications by enabling data processing and data storage near the network's edge.
Edge computing is a decentralized model to computing that processes data closer to its source such as local servers, sensors, and

camera rather than sending it to distant cloud servers (Ilenia Ficili *et al*., 2025). When integrated with IoT, edge computing becomes a cornerstone of smart city development, enabling unprecedented connectivity, real-time decision-making, and operational efficiency. Edge computing decreases latency, which enables real-time decision making by processing massive amount of IOT data close to the source of creation at the network's edge. This dynamic synergy between Edge Computing and IoT is critical in smart cities as there is a need for split-second responses to enhance traffic flow, to address public safety, and overall city performance. Edge computing serves as a distributed hub for real-time data processing, alleviating the strain on centralized data centers. This results in leaner, more resilient systems with reduced latency and enhanced scalability. This interaction is crucial for also enhancing agility and responsiveness needed in smart cities, to enable data-driven insights and decisions quickly. Additionally, the integration of edge computing and IoT enables speed-up deployment of machine learning modes at the edge, enabling devices to make intelligent decisions in real-time.

Against the backdrop of emerging smart cities and enormous potential of edge computing and Internet of Things (IoT) to addressing key changing such as raising demand for energy, overextension of healthcare infrastructure, transportation, and public safety that accompany the smart cities, there is a need to conduct research on edge computing and IoT on smart cities. The research will analyze and highlight the solutions offered by edge computing and IoT, the use cases, and the challenges, so as to inform scalable, data-driven strategies. The key specific objectives are:

1. Evaluate the Effectiveness of Edge Computing in Enabling Real-Time IoT Applications in Smart Cities
2. Analyze the Role of Edge Computing in Reducing Network Load, Enhancing Data Privacy, and Ensuring Service Continuity.
3. Examine Use Cases and Sector-Specific Applications of Edge Computing Across Smart City Domains
4. Identify Challenges and Policy Considerations Related to the Adoption of Edge Computing in Smart Cities.

2. Problem statement

The emergence of Smart cities as the solution for rapid urbanization and the consideration of IoT-enabled infrastructure as the enabler of the smart cities has introduced significant opportunities, but also serious technical and operational challenges. IoT sensors, devices, and systems collect massive volumes of data across urban landscapes, this makes centralized cloud computing systems untenable as they cannot efficiently analysis the data to support real-time decisions to enable functions such as real-time traffic management. To run efficiently, smart cities require low latency, high reliability, real-time responsiveness, and robust data privacy which cloud-based architectures struggle to meet. These limitations pose real risks to essential services, from traffic management and emergency response to environmental monitoring and healthcare delivery.

Edge computing possesses significant potential to overcoming these challenges by processing data closer to where it is generated. By shifting computation and analytics to the network's edge, smart city systems can react faster, reduce dependency on bandwidth-intensive cloud operations, and enhance overall system resilience. Nonetheless, in spite of the growing interest, there is a lack of structured understanding of how edge computing, in tandem with IoT, is transforming urban systems in practice, highlighting the need of research in the field.

With the interconnectedness of the smart cities, there are also issues of interoperability, infrastructure investment needs, cybersecurity risks, and limited technical expertise. Hence, there is a need to have clear insights into effectiveness, risks, and sector-specific applications of these technologies. This research article aims to bridge that gap by analyzing how edge computing enhances IoT performance in smart cities, assessing its impact, highlighting practical use cases, and identifying key challenges to guide informed, scalable deployment.

3. Effectiveness of Edge Computing in Smart Cities

3.1. Real-time Data Processing

By handling data near the sources of collection, Edge computing enhances real-time data processing in smart cities. According to Quantum Zeitgeist (2024), edge computing reduces latency by up to 90% compared to cloud-based systems. By lowering latency while dealing with massive amount of data, edge computing facilitates immediate responses to critical events, including traffic congestion, accidents, and energy management (Patnaik, 2024). The localized approach enabled by the technique further boosts efficiency, which eases bandwidth demands on city networks. Hence, while integrated effectively with IoT, edge computing empowers smart cities to deliver real-time as well as reliable public services while also upholding the necessary data privacy and operational resilience within the ever-interconnected urban environment (Ali, Y and Nawaz, 2024).

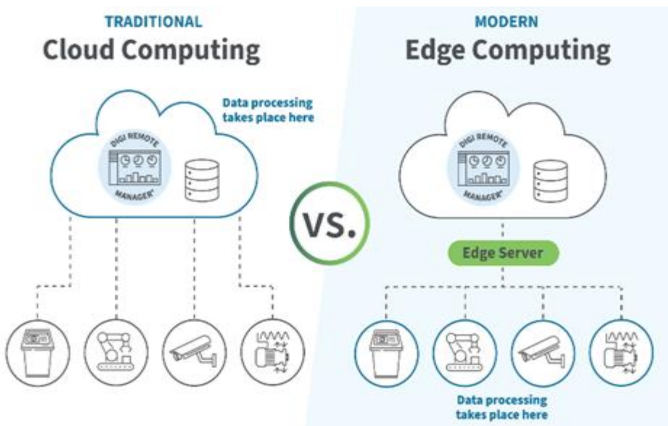

Fig 1: Cloud-based systems vs Edge computing

3.2. Reduced Network Load and Cost

Edge computing is also effective in reducing network load and cost. This is because it massively reduces the volume of data sent to centralized cloud servers by processing it locally, which cuts down on bandwidth usage and associated costs (Gkonis *et al*., 2023). In instance, within the Chicago's Array of Things project, only critical data summaries as opposed to raw streams are transmitted to the cloud, which reduces the network traffic by 60% (Catlett *et al*., 2022). This decentralized approach lowers infrastructure strain and improves system scalability as these smart cities grow. Moreover, a report by Gartner. (2022) indicated implementing edge computing reduces bandwidth costs by an average of 30-40%. Therefore, for smart utilities and surveillance systems, local data filtering minimizes cloud dependency, making operations more sustainable and cost-efficient over time.

3.3. Improved Reliability and Resilience

Edge computing is also effective in enhancing the reliability of smart city systems by enabling continuous operation even with limited connectivity with centralized cloud servers (Haseeb *et al*., 2024). In critical smart city infrastructure, including traffic control, public safety systems, and environmental monitoring, edge devices can function autonomously during outages (when there is no connectivity with centralized cloud servers), reducing the risk of service failure. According to a report by McKinsey, the predictive maintenance, enabled by edge computing, reduces machine downtime by 30-50% (Psico-smart, 2023). This resilience is especially vital during emergencies, such as natural disasters, where centralized networks may be compromised but localized systems must remain operational to protect lives and property by ensuring systems continue to run.

4. Role of Edge Computing in Smart City Functions

4.1 Smart Transportation

Smart transportation systems require high level responsiveness based on real-time data for traffic flow optimization, congestion prediction, and safety. Edge computing plays a critical role in enabling instant processing of data from vehicle-to-everything (V2X) communications, traffic cameras, and road sensors, allowing dynamic adjustments to traffic lights and rerouting strategies (Ali and Nawaz, 2024). By minimizing latency, edge computing systems are able to address congestion, improve emergency vehicle navigation while also enhancing pedestrian safety (Naseem and Ashrafuzzaman, 2024). For instance, In Tokyo's advanced smart transport network, localized edge controllers dynamically adjust traffic signal timing in real-time based on immediate traffic conditions. This ensures smooth traffic flow even during disruptions in cloud connectivity (Marshall, 2025). Such responsiveness is crucial in urban environments, where even milliseconds can make a significant difference in preventing accidents or reducing delays.

4.2 Energy Management and Smart Grids

Decentralized energy management is central to sustainable smart cities (Mishra and Singh, 2023). Utilizing Edge computing enables the smart cities to have real-time monitoring capabilities and to also control distributed energy resources, including solar panels, smart meters, and battery storage systems (Pandiyan *et al*., 2023). Edge computing also facilitates the efficient analysis of energy usage patterns at the edge. This supports smart grid ability to detect anomalies, balance load, and respond to outages faster than centralized computing systems (Minh *et al*., 2022). Moreover, edge-based grid systems are able identify and isolate energy errors and faults within seconds, mitigating the risks of blackouts and enabling easy redirections and also localized systems are no bond. Furthermore, the localized intelligence boosts energy infrastructure resilience while also supporting demand response programs, which additionally contributes to carbon footprint reduction by optimizing energy use.

4.3 Public Safety and Surveillance

Public safety enabled by surveillance is a major component of most smart cities, as urban dwellers seek the freedom to explore their cities even as population raises (Kashef *et al*., 2021). To promote safety, the cities use vast networks of surveillance cameras, emergency sensors, and incident reporting tools. By having lower latency and being more cost-effective, Edge computing empowers these public safety systems to analyze video feeds and sensor data in real-time, enabling faster and easier crime detection, anomaly recognition, and enabling efficient event response (Troisi and Visvizi, 2022). AI-powered edge devices are able to flag suspicious behavior or detect crowd surges, triggering alerts without waiting for centralized analysis, this massively improves police and emergency services' situational awareness and enables proactive interventions. These systems also enhance privacy by minimizing the transmission of sensitive footage across networks, given they enable local data processing

4.4 Waste and Water Management

Water management is also critical component of smart cities. Efficient waste and water management depends on timely data from bins, pipelines, and treatment systems (Naqash *et al*., 2023). Edge computing integrated with IoT sensors can detect fill levels, leaks, contamination, or pressure fluctuations and trigger immediate corrective actions. This integration enables city services to optimize collection routes, prevent water loss, and respond to sanitation issues without delay. Edge analytics have improved solid waste collection efficiency by over 20% through real-time bin monitoring (Addas and Naseer, 2024). By automating routine operations and minimizing resource waste, edge computing supports cleaner, more sustainable urban environments.

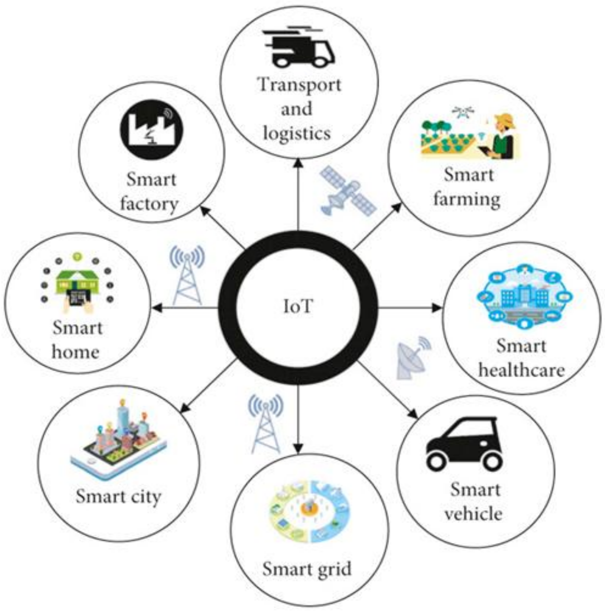

Fig 2: Role of Edge Computing in Smart City Functions

5. Application / Use Cases

5.1 Barcelona – Smart Traffic Optimization

Barcelona city is morphing into a Smart city, the city edge-enabled traffic sensors process several terabytes of data daily, enabling the city to analyze road conditions and traffic density in real-time (Asad and Martin, 2024). The system enables instant adjustments to traffic lights and signal coordination, leading to a massive reduction in congestion (Ferrer, 2017). The localized processing ensures faster response to changing traffic patterns and reduces reliance on centralized data centers, resulting in more adaptive and efficient transportation systems.

5.2 New York City – Smart Grid Fault Detection

New York City also has integrated edge computing into its smart grid infrastructure, enabling real-time monitoring and diagnostics of the electrical network (Geeks, 2025). This system enables efficient detection of power outages in under two seconds, vastly improving response times and reducing downtime and also promoting energy sustainability. The localized responsiveness facilitated by the edge computing enhances grid resilience and supports better energy management, particularly in high-demand urban settings (Mehmood *et al*., 2021)

5.3 Chicago – Data Efficiency with Array of Things

Chicago's Array of Things project is a pioneering urban initiative that utilizes edge computing to process environmental and infrastructure data directly at the source. By employing this technology, the project avoids the need to send all raw sensor data to the cloud, instead transmitting only critical summaries (Catlett *et al*., 2017). This approach has significantly reduced network traffic significantly. The reduction in data transmission significantly reduces the burden on cloud infrastructure and also cuts operational costs and enables faster analytics. These benefits are crucial for urban planning and maintenance, as they allow city planners and engineers to make more informed and timely decisions.

5.4 Tokyo – Resilient Smart Transportation

The integration of edge-enabled controllers in Tokyo's smart traffic systems is also a successful example of smart city (Kambala, 2024). Within the system, edge-enabled controllers manage signal timing independently from central servers. The localized control system in the city ensures that traffic flow continues uninterrupted even during network outages or cloud connectivity disruptions. This system enables Tokyo maintains high levels of transportation efficiency and reliability, especially during peak hours or emergencies.

6.0 Challenges of Edge Computing in IoT for Smart Cities

6.1 Scalability and Infrastructure Costs

The high upfront cost associated edge computing hardware and software is a major barrier to widespread adoption (George *et al*., 2023). The cost of deploying and maintaining multiple edge nodes across a city is expensive. As compared to centralized cloud infrastructure, edge computing needs a distributed network of processing units located near data sources, like traffic lights, utility meters, and surveillance systems. The Installation and maintenance needed for these localized nodes at scale are massively capital-intensive and logistically complex, this is especially the case in aging cities with aging infrastructure which often have limited technical capacity (Sharma *et al*., 2024).

6.2 Security and Privacy

Even though edge computing mitigates some data privacy risks by reducing transmission to centralized clouds, it poses new security vulnerabilities. By edge computing enabling processing of data at the edge, it expands the number of potential attack surfaces, especially in public, physically accessible environments. Edge devices often lack robust security protocols compared to centralized cloud computing platform; this makes them susceptible to cyber-attacks. Moreover, given the huge data processed at the edge, ensuring data integrity and user privacy is difficult, especially in sensitive applications like surveillance or health monitoring, requires strong encryption, authentication, and compliance with evolving data protection laws.

6.3 Interoperability

The diversity of IoT devices and platforms used in smart city ecosystems poses significant interoperability challenges. Edge computing requires seamless integration with a wide range of sensors, communication protocols, and data formats, often developed by different companies with proprietary standards. This lack of unified framework or standardized approach, risk the cities having vendor lock-in, fragmented systems, and increased complexity in data management. Addressing these issues will require industry-wide collaboration on interoperability standards and the adoption of open architectures to support cross-platform communication.

7. Conclusion

Edge computing is increasingly emerging as the keystone technology within the mushrooming smart cities trend. The technology is enabling decentralized, efficient, and responsive digital infrastructure for managing water, energy, traffic, and others. Edge computing achieves this by reducing latency, lowering network traffic, and ensuring continuous operation, even during periods where there is network disruptions, such as during natural disasters. As emphasized through real-world applications in transportation, energy, surveillance, and sanitation, the integration of edge computing with IoT enhances urban service delivery and citizen experiences. Nonetheless, realizing the full potential of this synergy requires addressing several challenges, including high deployment costs, a lack of standardized frameworks, and cybersecurity vulnerabilities. To overcome these barriers, key stakeholders, including policymakers, urban planners, and technology providers must collaborate to create clear regulatory guidelines, invest in edge infrastructure, and promote public-private partnerships.

8. References

1. Addas A, Naseer. Waste management 2.0 leveraging internet of things for an efficient and eco-friendly smart city solution. PLoS One. 2024;19(7):e0307608. doi:10.1371/journal.pone.0307608.
2. Ali Y, Nawaz K. Edge-based IoT solutions for real-time traffic and speed management systems. 2024.
3. Ali Y, Nawaz K. Edge-based IoT solutions for real-time traffic and speed management systems. 2024.
4. Asad U, Martin Y. The role of edge computing in modern traffic management and speed detection. 2024. doi:10.13140/RG.2.2.23474.00961.
5. Catlett C, Beckman P, Ferrier N, Taylor V, Reed D. Hands-on computer science: the array of things experimental urban instrument. Computing in Science & Engineering. 2022;24(1):57-63. doi:10.1109/mcse.2021.3139405.
6. Catlett CE, Beckman PH, Sankaran R, Galvin KK. Array of things: a scientific research instrument in the public way. Proceedings of the 2nd International Workshop on Science of Smart City Operations and Platforms Engineering - SCOPE '17. 2017. doi:10.1145/3063386.3063771.
7. Ferrer J-R. Barcelona's smart city vision: an opportunity for transformation. Field Actions Science Reports. The journal of field actions. 2017;Special Issue 16:70-5. Available from: https://journals.openedition.org/factsreports/4367.
8. Gartner. Market guide for edge computing in industrial IoT. 2022.
9. Geeks. How IoT hardware development companies are enabling smart cities and urban innovation. 2025. Available from: https://vocal.media/geeks/how-io-t-hardware-development-companies-are-enabling-smart-cities-and-urban-innovation [Accessed 25 Apr 2025].
10. George AS, George AH, Baskar T. Edge computing and the future of cloud computing: a survey of industry perspectives and predictions. Partners Universal International Research Journal. 2023;2(2):19-44.
11. Gkonis P, Giannopoulos A, Trakadas P, Masip-Bruin X, D'Andria F. A survey on IoT-edge-cloud continuum systems: status, challenges, use cases, and open issues. Future Internet. 2023;15(12):383.
12. Haseeb K, Din IU, Almogren A, Ahmed I, Guizani M. Intelligent and secure edge-enabled computing model for sustainable cities using green internet of things. Sustainable Cities and Society. 2021;68:102779.
13. Ilenia Ficili, Giacobbe M, Tricomi G, Puliafito A. From sensors to data intelligence: leveraging IoT, cloud, and edge computing with AI. Sensors. 2025;25(6):1763. doi:10.3390/s25061763.
14. Kambala G. Edge computing for IoT-driven smart cities: challenges and opportunities in real-time data processing. 2024.
15. Kashef M, Visvizi A, Troisi O. Smart city as a smart service system: human-computer interaction and smart city surveillance systems. Computers in Human Behavior. 2021;124:106923.
16. Marshall DE. Tokyo: the world's largest and most advanced metropolis that never sleeps. Engineerine. 2025. Available from: https://engineerine.com/tokyo-the-worlds-largest-metropolis/.
17. Mehmood MY, Oad A, Abrar M, Munir HM, Hasan SF, Muqeet HA ul, Golilarz NA. Edge computing for IoT-enabled smart grid. Security and Communication Networks. 2021;2021:1-16. doi:10.1155/2021/5524025.
18. Minh QN, Nguyen VH, Quy VK, Ngoc LA, Chehri A, Jeon G. Edge computing for IoT-enabled smart grid: the future of energy. Energies. 2022;15(17):6140.
19. Mishra P, Singh G. Energy management systems in sustainable smart cities based on the internet of energy: a technical review. Energies. 2023;16(19):6903.
20. Naqash MT, Syed TA, Alqahtani SS, Siddiqui MS, Alzahrani A, Nauman M. A blockchain based framework for efficient water management and leakage detection in urban areas. Urban Science. 2023;7(4):99.
21. Naseem D, Ashrafuzzaman M. Decentralized traffic surveillance: leveraging edge computing for speed monitoring systems. 2024.
22. Pandiyan P, Saravanan S, Usha K, Kannadasan R, Alsharif MH, Kim MK. Technological advancements toward smart energy management in smart cities. Energy Reports. 2023;10:648-77.
23. Patnaik S. Cloud and edge computing integration in smart city IoT solutions. Smart Internet of Things. 2024;1(3):183-90.
24. Psico-smart. The impact of edge computing on realtime performance evaluation tools. Psico-smart.com. 2023. Available from: https://psico-smart.com/en/blogs/blog-the-impact-of-edge-computing-on-realtime-performance-evaluation-tools-171358.
25. Quantum Zeitgeist. Edge computing benefits: edge vs cloud computing. 2024. Available from: https://quantumzeitgeist.com/edge-computing-benefits-edge-vs-cloud-computing/ [Accessed 25 Apr 2025].
26. Seidor. Smart cities and IoT: how technology is transforming cities. Seidor.com. 2024. Available from: https://www.seidor.com/en-ke/blog/smart-cities-iot-technology-transforming-cities [Accessed 24 Apr 2025].
27. Sharma M, Tomar A, Hazra A. Edge computing for industry 5.0: fundamental, applications and research challenges. IEEE Internet of Things Journal. 2024.
28. Troisi O, Kashef M, Visvizi A. Managing safety and security in the smart city: Covid-19, emergencies and smart surveillance. In: Managing Smart Cities: Sustainability and Resilience Through Effective Management. Cham: Springer International Publishing; 2022. p. 73-88.
29. UN Report. UN report says world urban population of 3 billion today expected to reach 5 billion by 2030. United Nations: Information Service Vienna. 2017. Available from: https://unis.unvienna.org/unis/en/pressrels/2004/pop899.html.