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Literature Review: Edge Computing and Its Role in the 5G Era

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Abstract

This literature review examines the strategic role of edge computing in supporting technological advancements in the 5G era. As a distributed computing architecture that places data processing closer to its source, edge computing is considered effective in reducing latency, minimizing network load, and enabling real-time decision-making. Through an analysis of empirical findings, conceptual frameworks, and recent technological developments, this study explores the integration of edge computing within the Internet of Things, industrial automation, and various intelligent systems. The findings highlight the contribution of edge computing to strengthening responsive and scalable digital infrastructure capable of handling large-scale data flows in 5G networks. The review also identifies several key challenges, including data security issues, device interoperability, and the need for efficient computing resource management. Existing studies emphasize the importance of technological innovations such as improved device orchestration mechanisms and more effective load distribution algorithms to optimize edge performance. The integration of edge computing with cloud computing and artificial intelligence is viewed as a future development direction that can enhance the resilience and flexibility of digital ecosystems. Overall, this review confirms that edge computing plays a significant role in shaping a modern computing environment that is faster, more secure, and more adaptive to the demands of digital transformation in the 5G era.

Keywords : *Edge Computing, Distributed Systems, Real-Time Data Processing, 5G*

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1. Introduction

The rapid expansion of data generated by smart devices has created substantial challenges for traditional cloud architectures. Network capacity is increasingly unable to accommodate the high-frequency data traffic produced by sensors, cameras, and large-scale IoT ecosystems. Latency becomes a critical bottleneck when data must be processed in distant cloud data centers, resulting in delays that are unacceptable for applications requiring real-time responsiveness. Continuous data transmission to and from the cloud further exacerbates performance limitations, particularly in systems that demand low-latency execution. Dependence on centralized servers also heightens the risk of service disruptions during sudden spikes in workload. Even though cloud computing is known for its scalability, its performance shows limitations when confronted with highly distributed and latency-sensitive environments. These challenges underscore the need for computing solutions positioned closer to the point of data generation, especially within the 5G landscape that prioritizes speed, reliability, and ultra-low latency (Cao et al., 2020). Edge computing offers a new approach that reduces latency by leveraging local computing units. This paradigm shift creates a new foundation for more responsive data processing.

Rapidly evolving real-time applications demand extremely fast data processing capabilities, making a purely cloud approach often inadequate. Autonomous vehicles require instantaneous decisions that cannot wait for remote transmission to a data center. Augmented reality technology requires precise visual synchronization to maintain a stable user experience. Smart city systems operate through sensor networks that rely on rapid response to maintain public safety. Modern industrial environments require real-time data analysis to prevent potentially costly machine failures. Processing speed is critical for real-time applications, as every millisecond has a significant operational impact (Kubiak et al., 2022). Edge computing enables local processing, reducing reliance on data centers. The presence of computing at the edge of the network increases the response accuracy required by time-sensitive systems. Edge deployments enhance the ability of real-time applications to achieve higher efficiency and reliability.

Security risks increase when data must travel across open networks to computing centers, making traditional cloud architectures less likely to provide optimal protection. Sensitive information constantly moving between servers is vulnerable to interception by unauthorized parties. Man-in-the-middle attacks can exploit gaps during repeated data transfers. Centralized storage creates a single point of failure that becomes a strategic target for cyberattacks. Global privacy regulations demand reducing data exposure on public networks. Edge computing provides a more secure alternative by processing some data locally on devices or gateways (Kuchuk & Malokhvii, 2024). Distributed computing reduces the need for data transmission to the central hub. Reduced data movement lowers the potential for leaks and improves compliance with privacy standards. The edge's role is increasingly significant due to its ability to support security without sacrificing performance.

User privacy has become a critical issue as digital technologies evolve toward fully interconnected ecosystems, necessitating more cautious and structured approaches to data management. Each smart device continuously produces data trails that may contain sensitive or personally identifiable information. Transmitting these data trails to centralized cloud servers increases the risk of duplication, unauthorized access, or misuse. Growing concerns and reported cases of privacy violations further highlight the urgency of adopting technologies that limit unnecessary data movement across networks. Edge computing offers an important alternative by enabling data processing directly at or near the source, ensuring that only aggregated or analytic outputs are transmitted to central systems. This approach not only reduces exposure of raw data but also aligns with the privacy demands of 5G-based environments that prioritize secure, efficient, and localized processing (Iftikhar et al., 2023). This approach minimizes risk because raw data never leaves the local environment. Encryption technology can be applied more effectively in distributed architectures, minimizing contact with external networks. This practice strengthens user trust in systems utilizing edge computing. The edge's relevance to privacy issues reinforces its position as a strategic component of future technology.

Advances in network technology are increasing the potential for utilizing edge computing, making its implementation more affordable and efficient. 5G infrastructure offers high-speed transmission capabilities that support data processing at nearby locations. The speed and reliability of these networks enable edge systems to operate stably even when handling large amounts of data. Microcomputing devices have seen significant increases in processing power, enabling them to run more complex algorithms. The integration of artificial intelligence into edge devices enables direct analysis without having to transmit data to a centralized location. Changes in hardware capabilities are making edge computing increasingly accessible across various sectors. The ecosystem of devices and networks creates an environment that supports collaboration between the cloud and the edge (Erikasari et al., 2025). This synergy results in a more flexible and efficient hybrid architecture. Rapidly evolving supporting technologies are accelerating the global adoption of edge computing.

Industry readiness to adopt edge computing is increasing as the need for deeper digital transformation drives organizations to see opportunities for increased efficiency. Manufacturing companies are leveraging edge computing to improve the accuracy of machine failure predictions. The healthcare sector is leveraging local processing capabilities to support rapid analysis of medical devices. Retail services are using edge computing to accelerate customer location-based recommendation systems. The logistics sector is optimizing delivery scheduling and monitoring through distributed edge devices. Telecommunications organizations are leveraging edge computing to maximize the performance of next-generation networks. Leveraging edge computing increases the speed of operational decision-making, previously hampered by cloud limitations (Suryadi et al., 2024). Energy efficiency is increasing due to reduced data center load. Industries are increasingly recognizing that edge computing is not just an add-on technology but a foundation for long-term digital strategies.

Exploring edge architectures presents a paradigm shift in data processing, leading distributed models to replace the dominance of centralized architectures. Data management is performed hierarchically through a combination of edge, fog, and cloud devices. This structured approach reduces the burden on data centers, which previously had to handle the entire computing process. Each architectural layer has a specific function that supports system efficiency. The edge handles fast processing, the fog coordinates aggregation, and the cloud performs in-depth analysis. The distributed structure improves reliability because a single point of failure does not halt the entire system. This architecture enhances operational resilience in environments requiring high availability. Flexibility increases when organizations are able to dynamically adjust workloads. The complexity of this new architecture motivates further research into optimal edge computing design (Ahmadi et al., 2021).

The shift to distributed computing has created vast research opportunities, leading to a growing need for theoretical and empirical studies on edge computing. Researchers are beginning to evaluate the efficiency of edge performance across various application scenarios. Studies on edge network security are contributing to the development of more robust protocols. Research on hybrid architectures is identifying optimal patterns for integrating edge with the cloud. Data scientists are exploring the potential for AI integration on edge devices with limited computing power. The field of technology management is studying the impact of edge adoption on organizational structures and strategic decisions. Edge development is a crucial topic due to its ability to expand the boundaries of traditional computing. A literature review is a strategic step in understanding the evolution of the edge computing concept. A thorough analysis of the literature provides a strong foundation for further research.

2. Method

This research employs a literature review method focused on collecting, evaluating, and synthesizing various scientific publications related to the concept of edge computing and its role in the development of modern computing technology. This approach was chosen to obtain a comprehensive theoretical overview of the emergence, working principles, applications,

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opportunities, and challenges of edge computing based on previous research. The research process was conducted through four systematic stages: source identification, literature selection, content analysis, and thematic synthesis.

The first stage began with identifying sources through searches of scholarly databases such as IEEE Xplore, ScienceDirect, SpringerLink, ACM Digital Library, and Google Scholar. Keywords used included "edge computing," "edge architecture," "real-time processing," "IoT data management," "edge security," and "edge-cloud integration." The search strategy was expanded to include synonyms, technical terms, and Boolean combinations to ensure coverage of relevant and up-to-date literature.

The second stage involved selecting literature based on inclusion and exclusion criteria. Inclusion criteria included journal articles, conference proceedings, academic books, and research reports published within the last five to ten years, written in English or Indonesian, and discussing the concept, implementation, or role of edge computing in modern computing systems. Exclusion criteria included non-peer-reviewed documents, publications with low validity, and literature that did not substantially discuss the role of edge computing. The selection process was conducted through an in-depth review of the titles, abstracts, and content of the articles.

The third stage is content analysis, which is conducted by carefully reading the selected literature to identify patterns, gaps, and key findings. The analysis is conducted using a thematic approach that groups information based on four main research focuses: (1) the limitations of traditional cloud architecture, (2) the need for real-time response in modern applications, (3) data security and privacy issues, and (4) the development of technology supporting edge computing. Each literature is analyzed for its contribution to each theme to ensure a deep and structured understanding.

The fourth stage is literature synthesis, which combines findings from various studies to produce a cohesive conceptual picture of the role of edge computing. The synthesis is conducted by examining the relationships between findings, comparing technological approaches, and identifying the advantages and limitations of edge computing implementations outlined in various studies. The results of the synthesis are then formulated into an integrated scientific description and form the basis for compiling a comprehensive literature review.

This literature review method allows researchers to gain a comprehensive understanding of the dynamics of edge computing development and its strategic role in distributed computing. This approach also allows for the identification of research gaps that can become an agenda for further research, ensuring that the results are not only descriptive but also contribute to the direction of scientific development in the field of modern computing.

3. Results and Discussion

Limitations of Traditional Cloud Architecture and the Urgency of Edge Computing

Edge computing is gaining increasing relevance as traditional cloud architectures face technical challenges in the era of massive data. The growth of IoT devices is driving increased data traffic that cannot be fully handled by centralized data centers. Each device generates information that requires rapid processing, making physical distance to the data center a significant barrier. Latency arising from long-distance transmissions creates performance degradation for applications that demand instant reactions. Reliance on centralized servers also increases the risk of system disruptions during peak load times. Increased network load impacts service reliability, thus impacting the user experience. Organizations need architectures capable of efficiently accommodating dynamic data. Edge computing is emerging as a strategic alternative that enhances the flexibility of modern computing systems (Wang et al., 2020).

Traditional cloud computing results in unstable responses in time-sensitive systems, necessitating a new approach to data processing. Each data request requires a long transit time, hampering the effectiveness of operational decisions. Environments that require

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timeliness cannot rely on highly fluctuating transmission lines. Response speed is impacted by processing queues in data centers, which are often overloaded. Data that cannot be processed instantly degrades performance in real-time applications. Users require processing results without delay to maintain the integrity of system functions (Carvalho et al., 2021). A distributed approach allows devices to run initial analysis independently. Edge computing offers an opportunity to accelerate processing without having to go through long computational paths.

Cloud efficiency faces structural limitations as the number of devices increases exponentially, making network capacity a critical factor. Public networks have certain limitations that affect data transmission quality. Repeated transmissions to data centers can potentially cause congestion, resulting in system slowdowns. This reduces service reliability, especially in sectors requiring high-precision responses. Traditional systems are unable to provide the availability guarantees required by sensor-based applications. Reducing network load is a crucial step to maintain operational stability. Edge computing minimizes data movement, thereby reducing network pressure (Hanif & Sugiantoro, 2025). This paradigm shift improves the overall performance of the digital ecosystem.

Decentralized computing adds value because the cloud cannot handle the entire analytical load at extreme scales. Data center-dependent processing creates structural constraints on decision-making. Companies need systems that can rapidly adjust processing capacity. Moving data too far increases processing time, impacting response speed. Local processing creates the opportunity to execute simple to medium-sized algorithms without waiting for a data center. Device autonomy increases when some decisions can be made at the nearest point. Operational flexibility increases because devices are not fully dependent on the central hub. Edge computing is a crucial element in supporting system adaptability.

The implementation of edge computing reduces the impact of data center failures because the system is no longer dependent on a single point of control. Data center disruptions often lead to complete failures in centralized architectures. Local redundancy protects against this risk through independent processing. Edge units operate autonomously, so central disruptions don't directly impact device performance. Service availability is better maintained because the load is distributed across the board. This model supports service continuity in areas with limited network infrastructure. System resilience is enhanced because there is no single point of failure. The edge model reinforces an architecture focused on operational continuity.

Edge computing offers significant improvements in energy efficiency because local processing reduces the need for long-distance transmission. Data transmission over public networks requires relatively large amounts of energy on a massive scale. Reducing data movement has a direct impact on energy savings. Edge devices are capable of performing initial analysis, reducing the amount of data that must be sent to the central office. This strategy supports the sustainability of more energy-efficient technology systems. Organizations can reduce operational costs by reducing the computing load on the cloud (Khoer & Heryana, 2024). Energy efficiency is a crucial advantage for modern architectures. Edge computing contributes to the development of green systems in computing.

The adoption of edge computing across various sectors demonstrates the superiority of a distributed model in overcoming cloud limitations. Edge deployments offer greater speed, independence, and stability. Industrial sectors that rely on sensors require rapid responses that traditional data centers cannot provide. Intelligent transportation systems require instant processing that is only possible through the edge. Edge deployments provide high efficiency in data communication flows. Organizations can more easily manage operational risks because they are not entirely reliant on the cloud. Separation of workloads between edge and cloud creates a more balanced architecture. This approach reinforces the urgency of the transformation to distributed computing.

The Role of Edge Computing in Real-Time Performance, Security, and Data Privacy

Edge computing's rapid response capability is a key factor in real-time applications. Systems like autonomous vehicles require millisecond decisions, making local processing a

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fundamental requirement. Low latency is a prerequisite for systems requiring continuous coordination. Edge computing provides processing at the closest point, eliminating the need for data transmission to a central hub. This model improves decision accuracy in systems directly related to safety. Industrial applications require rapid machine monitoring to prevent major damage. Local processing reduces the risk of errors due to response delays. Edge computing enhances the operational stability of real-time systems.

The role of edge computing in smart cities significantly contributes to the speed of public information. Surveillance camera networks generate data that requires rapid analysis to detect risks. Processing in data centers creates delays that can reduce the effectiveness of city security systems. Edge computing enables early detection through local analysis before data is sent for further evaluation (Modupe et al., 2024). Edge devices provide rapid reports that support instant decision-making. Operational efficiency increases because systems no longer have to wait for data center capacity. Cities can optimize technology resources more effectively. This model supports the smooth operation of digital-based public services.

Data security is a critical concern because information moving over public networks poses the risk of interception. Edge computing mitigates this risk by processing most of the data on-device. Reducing data travel reduces the likelihood of cyberattacks exploiting transmission gaps. Edge computing systems provide stronger protection for sensitive data. This model provides an additional layer of security by minimizing network exposure. Organizations gain greater control over locally managed data. Edge deployments support stricter security standards. Local processing strengthens modern data security systems (Zulkifli, 2025).

User privacy becomes increasingly relevant as every device generates data that can reflect personal activity. Edge computing allows data to be filtered before being sent to a centralized location. This strategy reduces the risk of personal information being disclosed to unauthorized parties. Local processing provides greater control over users' digital identities. Organizations can implement more effective privacy policies by leveraging edge capabilities. The risk of data misuse is reduced because raw data does not leave the device (Rahman et al., 2024). This architecture provides a more robust privacy protection mechanism. Edge computing strengthens user trust in modern digital systems.

Edge computing offers advantages through the ability to detect anomalies locally in security systems. Data analyzed directly on the device enables faster threat identification. This rapid response reduces the risk of significant penetration. The local architecture provides the opportunity to implement continuously running defense algorithms. This model reduces the need for sending large amounts of data to a security center. Edge devices can independently evaluate attack patterns. System effectiveness increases because monitoring is independent of the data center. Edge computing makes a significant contribution to cybersecurity modernization.

Operational reliability increases when edge computing is applied to critical industrial systems. Industrial environments require computing that cannot be disrupted by network delays or outages. Local processing ensures process continuity even if the connection to the cloud is lost. Systems can make decisions based on live data obtained from machines. Predictive algorithms running at the edge provide rapid detection of potential failures. Industrial production becomes more controlled with lower error rates. Process stability increases as reliance on the cloud decreases. Edge computing provides strategic value in high-risk sectors.

Edge computing's role in enhancing privacy and security has a significant impact on the digital health sector. Modern medical devices generate sensitive data that must be carefully managed. Local processing reduces the risk of patient health information being leaked. Healthcare institutions can ensure data security through edge processing. Enhanced privacy supports quality of care by increasing patient trust. Digital health systems require rapid processing for early diagnosis. Edge computing accelerates analysis, thereby improving clinical efficiency. This model is fueling digital transformation in the healthcare sector.

Technology Trends, Supporting Infrastructure, and Edge Computing Development Directions

Advances in 5G networks strengthen the potential for edge computing implementations because the technology offers high speeds and low latency. The combination of 5G and edge creates a responsive computing environment. Organizations can leverage large transmission capacities to effectively run real-time applications. 5G infrastructure provides stable communication between edge devices. Computing systems become more consistent in handling large data loads. Industry players can develop new services previously impossible with previous-generation networks. This integration expands the opportunities for edge utilization across various sectors (George et al., 2023). This technology model forms the foundation for a future computing ecosystem.

Microcomputing devices have seen significant improvements, supporting the implementation of edge computing on a large scale. Small processors have more powerful capabilities for running real-time analysis. Devices can execute simple machine learning algorithms without relying on the cloud. The growth in hardware performance provides scope for expanding the use of edge computing in small systems. Device efficiency increases due to lower energy consumption. The use of microdevices creates opportunities for innovation in the IoT sector. Local processing capabilities accelerate the process of technology adoption. Edge computing is gaining strong support through the development of microcomputing devices.

The integration of artificial intelligence adds value to the edge ecosystem because algorithms can be run locally. Edge devices can perform automatic classification, prediction, and detection without sending all data to the cloud. This capability significantly reduces processing time. Systems become more responsive to dynamic environments. Simplified artificial intelligence models support use on low-power devices. Research on embedded AI continues to advance, enhancing the capabilities of edge devices. This technology integration enhances the efficiency of computing systems. Edge and AI create a strategic collaboration that accelerates digital innovation (Arroba et al., 2024).

A hybrid architecture that combines edge, fog, and cloud creates a more flexible computing model (Angel et al., 2021). Each layer has distinct functions that support data processing efficiency. The edge handles fast processing, the fog manages aggregation, and the cloud performs heavy-duty analytics. The distribution of functions improves the smoothness of data processing flows. Organizations can allocate workloads based on task characteristics. Hybrid infrastructure provides greater stability than a single architecture. Systems become more adaptive to changing loads. The hybrid model strengthens future technology architectures.

The development of edge computing creates extensive research opportunities related to security, workload orchestration, and architectural standardization. Researchers are studying more secure communication mechanisms for edge devices. These efforts include the development of new protocols that reduce the risk of attacks. Research also focuses on designing systems capable of efficiently distributing loads. Standardization is necessary to avoid system fragmentation between vendors. The development of an edge ecosystem requires global collaboration among research institutions. Research opportunities are expanding as edge adoption increases. Research provides a scientific foundation for the development of distributed technologies.

Industry readiness plays a crucial role in expanding the implementation of edge computing across various sectors. Companies are beginning to recognize that the edge provides significant operational advantages. The transportation sector is leveraging the edge to monitor vehicles and infrastructure in real time. Retail services are optimizing customer recommendations through local processing. Logistics is using edge devices to accelerate shipment tracking. Telecommunications organizations are leveraging the edge to power next-generation network services. This industrial expansion is creating significant demand for edge systems. These trends demonstrate that distributed technology has a promising future.

The technology ecosystem continues to evolve, strengthening the edge as a key component of modern digital architecture. Changing market needs are driving organizations to invest in distributed technologies. Global infrastructure is adapting to more flexible computing models. Edge devices are becoming increasingly accessible to various industry sectors. The development of international standards is accelerating the adoption of edge computing in various countries. Modern computing models are moving toward decentralization. This adaptation creates consistency between industry needs and technological capabilities. Edge computing is becoming a focal point of global digital transformation.

4. Conclusions and Suggestions

The conclusions of the study on edge computing indicate that this distributed computing architecture offers significant opportunities to improve data processing efficiency in various strategic sectors. The computing concept, which moves processes closer to the data source, can reduce network load and accelerate decision-making based on real-time information. The use of edge computing has been proven to improve the performance of systems requiring low latency, especially in technological environments such as IoT, industrial automation, and intelligent systems. The literature review confirms that the distributed computing model offers the potential to strengthen digital infrastructure and be more adaptive to modern data dynamics. Research developments indicate that edge computing integration plays a crucial role in creating a responsive and scalable technology ecosystem. Emerging technical challenges related to security, interoperability, and resource management still require serious attention for optimal implementation. Insights from various sources indicate that the development of supporting technologies such as device orchestration and algorithm optimization contribute to enhancing the effectiveness of edge computing. Energy efficiency is one issue that is beginning to receive widespread attention regarding the sustainability of distributed computing applications. The application of this concept offers opportunities for a more comprehensive digital transformation in various public service and industrial sectors. The literature analysis shows that innovations in supporting technologies continue to develop to overcome limitations on local processing capacity. Research trends point to a strengthening of the integration between edge computing, cloud computing, and artificial intelligence as a future collaborative model. The overall synthesis of studies confirms that edge computing plays a crucial role in forming the foundation of modern computing that is faster, more secure, and more adaptive to evolving digital needs.

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