WITECH: Jurnal Teknologi Rekayasa Komputer dan Jaringan
Vol. 2 (No. 1), 2026: 1-14
https://journal.uwais.ac.id/index.php/witech/article/view/36

The Evolution of Distributed Systems: A *Systematic Literature Review* from *Centralized Computing* to *Cloud*, *Edge*, and *Fog* Paradigms

Evolusi Sistem Terdistribusi: Tinjauan Literatur Sistematis dari Komputasi Terpusat hingga Paradigma Cloud, Edge, dan Fog

Nur Fitriyah Ramadhani[1], Rahmaniar[2]
[1]Universitas Negeri Makassar, Indonesia; Email: 230209500005@student.unm.ac.id
[2] Universitas Negeri Makassar, Makassar, Indonesia; Email: rahmaniarzahraqueen@unm.ac.id

Article History
Received: 2026-03-03
Revised: 2026-03-31
Accepted: 2026-03-31
Published: 2026-04-03

Keywords:
Distributed Systems, System Evolution, *Cloud Computing*, Literature Review

Corresponding author:
rahmaniarzahraqueen@unm.ac.id

Paper type:
Research paper

POLITEKNIK WAHDAH ISLAMIYAH MAKASSAR
Program Studi Teknologi Rekayasa Komputer dan Jaringan, Politeknik Wahdah Islamiyah Makassar, Indonesia

Abstract
Distributed systems form a fundamental foundation for many modern digital services, including Cloud Computing, the Internet of Things (IoT), and data-driven intelligent applications. Their development originated from Centralized Computing models based on mainframe systems and gradually evolved into distributed architectures as networking technologies and hardware capabilities advanced. This study aims to examine the evolution of distributed systems and identify emerging trends and challenges using a Systematic Literature Review (SLR) approach based on selected textbooks and scientific publications. The results indicate that distributed systems have progressed toward modern architectures integrating Cloud, Edge, and Fog Computing within a distributed Computing Continuum. However, several challenges remain significant, including data consistency, heterogeneous resource management, security, and scalability in large-scale distributed infrastructures.

Abstrak
Sistem terdistribusi merupakan fondasi utama berbagai layanan digital modern seperti Cloud Computing, Internet of Things (IoT), dan aplikasi cerdas berbasis data. Perkembangannya berawal dari model komputasi terpusat berbasis Mainframe yang kemudian berevolusi menuju arsitektur terdistribusi seiring kemajuan teknologi jaringan dan perangkat keras. Penelitian ini bertujuan untuk mengkaji evolusi sistem terdistribusi serta mengidentifikasi tren dan tantangan yang muncul melalui pendekatan Systematic Literature Review (SLR) terhadap buku teks dan artikel ilmiah yang relevan. Hasil kajian menunjukkan bahwa sistem terdistribusi berkembang menuju arsitektur modern yang mengintegrasikan Cloud, Edge, dan Fog Computing dalam suatu Distributed Computing Continuum. Meskipun demikian, berbagai tantangan masih tetap menjadi perhatian, terutama terkait konsistensi data, pengelolaan sumber daya heterogen, keamanan, serta skalabilitas sistem.

Cite this article:
Nur Fitriyah Ramadhani, Rahmaniar. (2026). The Evolution of Distributed Systems: A Systematic Literature Review from Centralized Computing to Cloud, Edge, and Fog Paradigms. *WITECH: Jurnal Teknologi Rekayasa Komputer dan Jaringan, 2*(1), 1-14. https://journal.uwais.ac.id/index.php/witech/article/view/36.

Vol. 2 (No.1), 2026: 1-14
https://journal.uwais.ac.id/index.php/amanah/article/view/36

1. Introduction

The advancement of modern information technology is highly dependent on distributed systems, which serve as the foundation for various digital services, including internet-based services, cloud computing, the Internet of Things (IoT), and data-driven intelligent applications. Alongside parallel systems, distributed systems enable multiple computers or nodes to operate concurrently in processing data. This approach is essential for meeting the demands of large-scale computation, system scalability, and efficient resource utilization, particularly in modern applications such as big data analytics and artificial intelligence (Dai et al., 2025).

Historically, the development of distributed systems originated from the centralized computing model, which dominated modern computing from approximately 1945 to the mid-1980s. In this model, mainframe-based systems served multiple users through a single central computer. Due to limitations in network technology, computers operated independently, making it difficult to share resources effectively. The advancement of microprocessors, the reduction in hardware costs, and improvements in networking technologies later enabled computers to interconnect through message exchange, leading to the emergence of distributed systems. With the growth of the internet, these systems became more widely adopted and evolved into internet-based distributed systems that support global data and service exchange (Steen & Tanenbaum, 2017).

As application complexity and data volume increased—particularly in the fields of artificial intelligence and big data analytics—centralized systems became insufficient to meet modern computational demands. This condition drove the development of more flexible and scalable computing architectures. In this context, cloud computing emerged as a dominant paradigm based on the concept of computing as a utility, providing elastic computing resources through service models such as Infrastructure as a Service (IaaS), Platform as a Service (PaaS), and Software as a Service (SaaS). Through large-scale data centers, cloud computing is capable of supporting a wide range of modern applications with high levels of scalability and availability (Dai et al., 2025; De Donno et al., 2019).

Despite offering high scalability, cloud computing’s reliance on centralized data centers introduces limitations in meeting low-latency requirements and bandwidth efficiency, especially with the increasing adoption of IoT devices. This condition has led to the emergence of edge computing, which brings computation closer to the data source through approaches such as Mobile Cloud Computing (MCC), Cloudlet Computing, and Mobile Edge Computing (MEC), enabling real-time data processing. Furthermore, fog computing has evolved as an intermediate layer between cloud and IoT devices, distributing computational resources progressively from the core to the network edge. The integration of these layers forms the concept of the distributed computing continuum, which connects cloud, fog, edge, and end devices into a unified and integrated computing ecosystem (Filho et al., 2022; Lindsay et al., 2021; Shukla et al., 2023).

In addition to the evolution of computing paradigms, distributed systems also face various architectural challenges, including the management of heterogeneous resources, communication and synchronization mechanisms among nodes, and system interoperability. These challenges become increasingly complex with the emergence of new trends in parallel and distributed systems, such as heterogeneous computing, serverless computing, cloud-native architectures, and distributed AI systems.

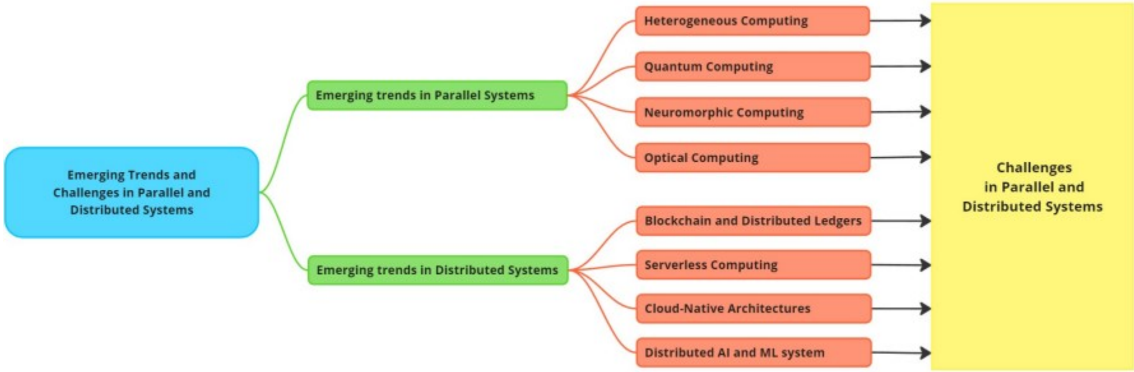

Figure 1. Emerging Trends and Challenges in Parallel and Distributed Systems (Dai et al., 2025)

Although various paradigms such as cloud, edge, and fog computing have been extensively studied, existing research remains fragmented and has yet to provide a comprehensive view of the evolution, trends, and challenges of distributed systems (Dai et al., 2025; De Donno et al., 2019; Singh Chowhan, 2019). Therefore, this study adopts a Systematic Literature Review (SLR) approach to comprehensively map the evolution of distributed systems and identify existing research gaps.

2. Literature Review

2.1 Definition and Characteristics of Distributed Systems

A distributed system is defined as a system composed of a collection of autonomous computers that are interconnected through a network and collaborate to achieve a common goal, such that it appears to users as a single unified system (Fahmi Ajismanto et al., 2023; Steen & Tanenbaum, 2017). Each computer operates with its own control, yet resources such as data, storage, and computational services can be shared collectively.

The concept of distributed systems emerged as a response to the limitations of centralized computing systems, which were unable to support large-scale and collaborative computational requirements. With the advancement of networking technologies and the increasing demand for scalability and service availability, distributed systems have become the foundation of various modern computing paradigms, including cloud computing, edge computing, and fog computing.

Key characteristics of distributed systems include the use of multiple nodes operating independently, communication among nodes through a network, and the ability to share resources efficiently. In addition, distributed systems are designed to support scalability, fault tolerance, and high service availability.

2.2 Historical Development of Distributed Systems

The development of distributed systems is closely linked to the evolution of computer and networking technologies. In the early stages of computing, systems were dominated by mainframe computers that served multiple users through simple terminals. This model was inherently centralized, as all computational processes were executed on a single central machine (Steen & Tanenbaum, 2017)

Advancements in networking technologies, particularly the introduction of packet switching and the growth of the internet, enabled geographically dispersed computers to communicate with one another. The development of ARPANET and the TCP/IP protocol suite paved the way for the establishment of a global network, which eventually evolved into the modern internet.

WITECH: Jurnal Teknologi Rekayasa Komputer dan Jaringan
Vol. 2 (No.1), 2026: 1-14
https://journal.uwais.ac.id/index.php/amanah/article/view/36

As hardware capabilities improved and the cost of computing decreased, new approaches were developed to distribute computational processes across multiple machines. These advancements led to the emergence of various distributed computing paradigms, which have continued to evolve alongside progress in computer and network technologies.

2.3 Evolution of Distributed Computing Paradigms

The development of distributed systems can be understood through the evolution of various computing paradigms that have emerged alongside advancements in computer and network technologies.

2.3.1 Centralized Computing

In the early stages of computing, systems were dominated by centralized computing, which relied on a single central computer to process all data and execute applications. This model was typically based on mainframe systems that served multiple users through simple terminals within a limited environment (Steen & Tanenbaum, 2017). Although this approach simplified system management, its dependence on a single computing center resulted in limitations in terms of scalability and service availability.

2.3.2 Client–Server Architecture

With the advancement of networking technologies, the client–server architecture emerged, separating the roles of service providers (servers) and service users (clients). In this model, client-side applications send service requests to servers over a network using specific communication protocols. The server then processes the requests and returns responses to the clients. This mechanism established the client–server model as one of the earliest forms of distributed computing based on request–response communication (Nyabuto, 2024).

The client–server architecture enables workload distribution between clients and servers while supporting centralized data management on the server side. This model further evolved into various architectural forms, such as two-tier and three-tier architectures, and became the foundation for many modern networked applications, including web services and distributed database systems (Hamid et al., 2020).

2.3.3 Cluster and Grid Computing

In the subsequent stage, cluster computing and grid computing were developed to enhance computational capabilities by combining multiple computers operating in parallel. Cluster computing connects a group of computers within a single network location, allowing them to function as a unified system (Single System Image) to improve performance and system availability. This approach is widely used in high-performance computing (HPC) environments to handle scientific computations and applications requiring substantial computational power (Etawi, 2018).

In contrast, grid computing enables the utilization of computational resources from geographically distributed locations via the internet. Unlike clusters, which are typically confined to a single physical location, grid computing emphasizes the concept of resource sharing, allowing users to access distributed computational resources without needing to know their physical location or underlying infrastructure. This approach is widely applied in scientific research, big data analysis, and other large-scale computational applications (Etawi, 2018).

2.3.4 *Cloud Computing*

The advancement of virtualization technologies led to the emergence of the cloud computing paradigm, which provides computing resources as services over the internet. In this model, users can access resources such as servers, storage, and applications without directly owning or managing physical infrastructure. Cloud computing offers high flexibility and scalability, as resources can be dynamically adjusted based on demand, and supports a pay-as-you-go model that reduces initial investment and infrastructure maintenance costs (Andriulo et al., 2024).

Cloud services are generally delivered through several service models, including Infrastructure as a Service (IaaS), Platform as a Service (PaaS), and Software as a Service (SaaS).

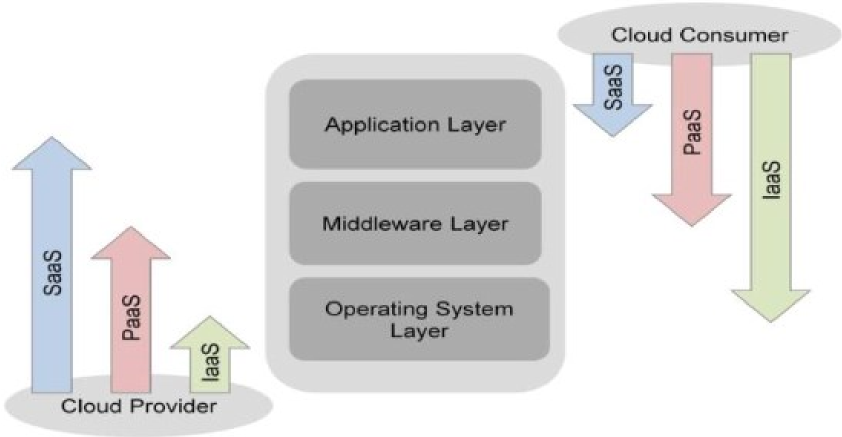

Figure 2. Cloud Computing service models (IaaS, PaaS, SaaS) (Liu et al., 2011).

With its large computational capacity and elastic storage capabilities, cloud computing is widely used for processing and analyzing data at scale, including data generated by Internet of Things (IoT) devices (De Donno et al., 2019).

2.3.5 Edge Computing

Despite offering significant computational capacity and scalability, the centralized nature of cloud computing introduces several limitations, such as increased latency, high bandwidth consumption, and heavy processing loads when handling massive amounts of data from distributed devices. These challenges are particularly critical in applications that require real-time processing, such as IoT systems that continuously generate data from various devices and sensors (J. Li et al., 2022).

To address these limitations, the edge computing paradigm emerged, shifting part of the computational processes closer to the data source or end users. One implementation is Mobile Edge Computing (MEC), where computing servers are deployed at the network edge, such as base stations or micro data centers. This allows latency-sensitive applications to be processed more quickly and efficiently. This approach enables local data processing, reduces network load, and improves system responsiveness in large-scale IoT applications (Luo et al., 2025; Shukla et al., 2023).

2.3.6 Fog Computing

As an extension of edge computing, fog computing introduces an additional computational layer positioned between cloud data centers and edge devices. This paradigm leverages computational resources closer to end devices, such as routers, gateways, or other network nodes, to process part of the data locally before transmitting it to the cloud. This approach enables a gradual distribution of data processing from the core to the network edge, thereby reducing latency and improving the efficiency of managing widely distributed IoT devices (Filho et al., 2022).

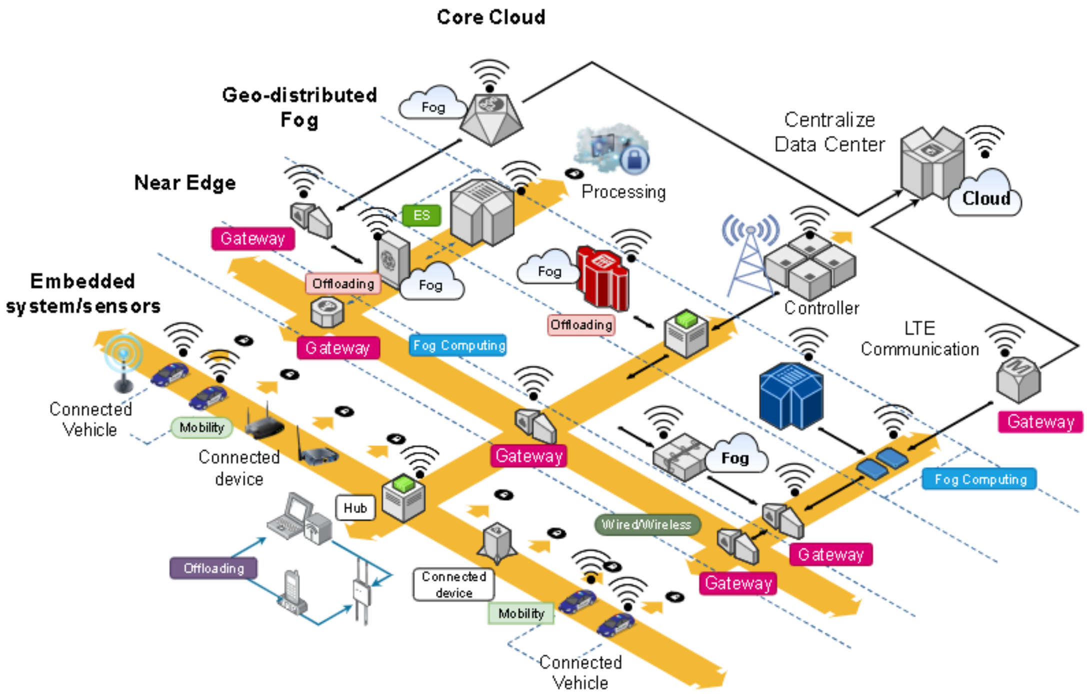

Figure 3. Fog Computing architecture that connects Edge devices, Fog nodes, and the Cloud (Hazra et al., 2023; Srirama, 2024)

Furthermore, fog computing is designed to address the limitations of cloud-centric architectures in IoT systems, which can result in high network loads when all processing is performed in centralized data centers. With its hierarchical and distributed architecture, data processing can be performed progressively from edge devices to fog nodes and finally to the cloud. This mechanism enables faster system responses and supports various real-time IoT applications, such as smart cities, smart healthcare, and intelligent transportation systems (Hazra et al., 2023; Srirama, 2024). Based on the evolution of these computing paradigms, distributed systems have evolved toward increasingly complex and integrated architectures.

2.4 Trends and Challenges in Distributed Systems

The evolution of distributed systems indicates that computing paradigms continue to diversify, with ongoing shifts between centralized and decentralized approaches. Cloud computing offers high scalability and resource availability; however, it faces limitations in terms of network latency and bandwidth efficiency. To address these challenges, edge and fog computing paradigms have emerged, relocating portions of computational processes closer to the data source.

Looking ahead, distributed systems are expected to become increasingly complex with the emergence of trends such as heterogeneous computing, distributed artificial intelligence, serverless computing, and cloud-native architectures. In addition, the concept of the computing continuum is gaining traction, integrating multiple computing layers—including cloud, fog, edge, and end devices—into a unified and interconnected ecosystem.

This approach has the potential to enhance the performance of data-intensive applications, such as machine learning and big data analytics. However, it also introduces several challenges, including system interoperability, service orchestration, management of heterogeneous resources, and communication and synchronization mechanisms among nodes (Dai et al., 2025; De Donno et al., 2019; Kimovski et al., 2024).

3. Research Method

3.1 Research Design

This study employs the Systematic Literature Review (SLR) method as the research design to systematically examine the evolution of distributed systems based on relevant scientific literature. The SLR approach is chosen because it provides a structured and rigorous process for literature searching, selection, and analysis, thereby minimizing bias and enabling a more accurate identification of patterns, trends, and research gaps (Torres-Carrion et al., 2018).

The reviewed literature encompasses fundamental concepts of distributed systems, architectural elements, and the evolution of computing paradigms, ranging from centralized systems to cloud computing, the Internet of Things (IoT), edge computing, and fog computing. The research process is conducted through stages of planning, literature collection, and analysis, in which the findings are categorized and synthesized to address the research questions related to the evolution, trends, challenges, and research opportunities in distributed systems, while also providing a solid foundation for future studies.

3.2 Research Question

Tabel 1. Research Question

	Research Question	**Goal**
RQ1	How has the evolution of distributed systems progressed from centralized computing models to modern parallel and distributed architectures, including Cloud Computing, the Internet of Things (IoT), Edge Computing, and Fog Computing, based on a review of the scientific literature?	To identify and explain the stages in the evolution of distributed systems, from centralized computing models to modern parallel and distributed architectures such as Cloud Computing, the Internet of Things (IoT), Edge Computing, and Fog Computing, based on a review of the scientific literature.
RQ2	What are the main trends, architectural and operational challenges, and research gaps identified in the literature regarding the evolution of distributed systems?	To identify the main trends, architectural and operational challenges, as well as research gaps reported in the literature on the evolution of distributed systems, as a basis for determining future research directions and opportunities.

3.3 Study Collection

The literature collection in this study was conducted to address the research questions related to the evolution of distributed systems, as well as their trends, challenges, and research gaps. The reviewed literature includes academic textbooks, journal articles, and survey papers relevant to the topic of distributed systems. These sources were utilized to obtain a comprehensive understanding of the development of concepts and technologies in distributed systems.

Textbooks were used as a conceptual foundation to understand the definitions, principles, and fundamental elements of distributed systems. The primary reference employed is the work of Tanenbaum and Van Steen, which is widely recognized in the field of distributed systems. In addition, several Indonesian-language textbooks were used as supporting references to strengthen the understanding of basic concepts.

Journal articles and scientific surveys were used to trace the development of distributed systems from centralized computing models to modern computing paradigms. The scope of the review includes various technologies such as Cloud Computing, the Internet of Things (IoT), Edge Computing, and Fog Computing. These studies contribute to identifying development trends as well as emerging research issues in the field of distributed systems.

The literature was collected from several academic databases, including IEEE Xplore, ScienceDirect, SpringerLink, and Google Scholar. The search process was conducted using keywords such as "distributed systems evolution," "Cloud Computing architecture," "Edge Computing," "Fog Computing," and "distributed computing continuum." The collected literature was then systematically selected based on its relevance to the research questions and the credibility of the sources before being analyzed qualitatively.

3.4 Data Analysis Technique

The data analysis in this study was conducted using a descriptive qualitative approach with a narrative synthesis method, which is commonly applied in Systematic Literature Reviews (SLR). This approach aims to systematically integrate and interpret findings from various studies in order to obtain a comprehensive understanding of the evolution of distributed systems. A literature review is not only used to summarize previous research but also serves as a foundation for knowledge development and the identification of future research directions (Snyder, 2019).

The selected literature was analyzed by categorizing and comparing findings based on key themes aligned with the research questions, such as the stages of distributed system evolution, shifts in computing paradigms (Cloud, IoT, Edge, and Fog), as well as emerging trends and challenges. Through this synthesis process, the study is able to identify patterns of development and research gaps more accurately, enabling the findings to provide clear and relevant contributions to the field of distributed systems.

4. Results and Discussion

4.1 Result

The findings of the literature review indicate that the evolution of distributed systems has occurred progressively and has been influenced by increasing computational demands, advancements in networking technologies, and the growing complexity of applications. In the early stages, distributed systems were primarily understood as a collection of computers operating in parallel, with key challenges centered on synchronization and event ordering. Lamport (1978) emphasized that distributed systems do not possess a global clock, thereby requiring logical time mechanisms (Logical Clocks) to maintain process ordering (Lamport, 1978). This concept serves as a fundamental theoretical foundation for subsequent developments in distributed systems.

As computer networks and the internet evolved, research focus shifted from basic coordination issues to the design of larger and more open system architectures. Models such as client–server, peer-to-peer, and cluster computing were introduced to improve resource utilization and scalability. Lindsay et al. (2021) demonstrate that during this phase, distributed systems transitioned from centralized models toward increasingly decentralized architectures. This evolution is dynamic, with the degree of centralization and decentralization adapting to system requirements such as performance, latency, and efficiency (Lindsay et al., 2021).

In the context of modern enterprise systems, the evolution of distributed systems has also occurred at the application architecture level. Ishaq et al. (2025) identify a transformation from monolithic systems to microservices and cloud-native architectures. At this stage, distributed systems are not only used for resource sharing but also to enhance flexibility, scalability, and system resilience (Ahmeth Maulana Ishaq et al., 2025). This shift is driven by business demands that require rapid adaptation to dynamic workloads and continuously changing environments.

Cloud computing subsequently emerged as a dominant paradigm by providing centralized yet elastic computational resources through large-scale data centers. While effective for large-scale data processing and enterprise applications, several studies indicate that cloud computing has limitations in supporting latency-sensitive and real-time applications, particularly in Internet of Things (IoT) environments (Filho et al., 2022; Lindsay et al., 2021). These limitations have encouraged the development of computing approaches that are closer to the data source.

In response to the limitations of cloud computing, more decentralized paradigms have emerged, one of which is fog computing. Fog computing was introduced to bridge the gap between cloud infrastructure and end devices by providing computational resources at intermediate nodes. Since its introduction by Cisco in 2012 and further development through the OpenFog Consortium, fog computing has evolved into a layered model that enables continuity of computation from the cloud to IoT devices. The National Institute of Standards and Technology (NIST) later defined fog computing as part of a distributed system architecture designed to support latency-sensitive and context-aware applications (Kirsanova et al., 2021).

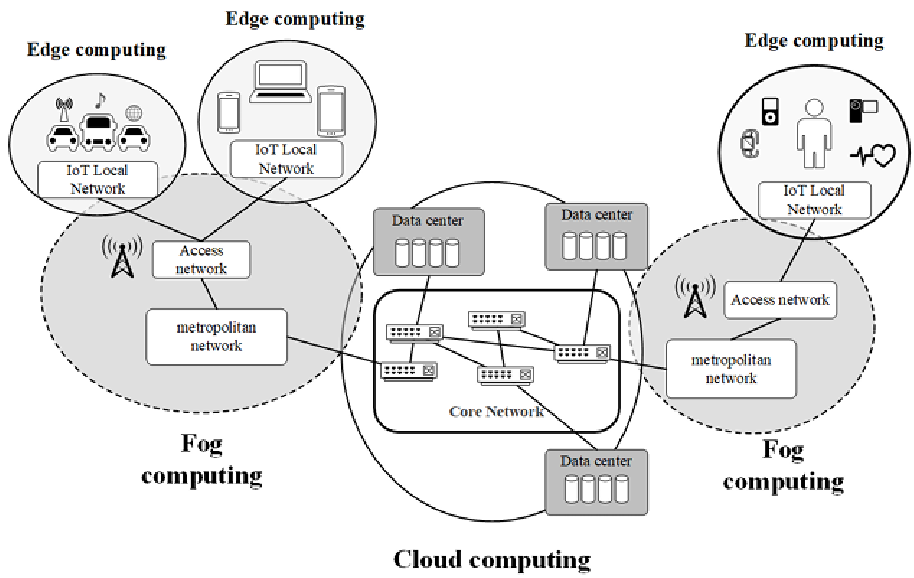

Figure 4. The relationship between Cloud Computing, Fog Computing, and Edge Computing in Distributed Systems (Kirsanova et al., 2021)

Vol. 2 (No.1), 2026: 1-14
https://journal.uwais.ac.id/index.php/amanah/article/view/36

In the context of the evolution of distributed systems, fog computing plays a crucial role by coordinating distributed resources from the core to the edge of the network. The literature indicates that fog computing forms a computing continuum that integrates cloud, core network, and edge in a unified manner. This approach enables distributed systems to support real-time and mission-critical applications such as smart cities and autonomous vehicles, while also introducing new challenges related to resource management, service orchestration, security, and scalability (Kirsanova et al., 2021; Shukla et al., 2023).

In recent developments, distributed systems have also become essential in supporting large-scale artificial intelligence. Shukla et al. (2023) demonstrate that edge intelligence is effective for real-time IoT applications, while Vatter et al. (2024) emphasize that training and inference of artificial intelligence models, such as Graph Neural Networks (GNNs), require distributed system architectures capable of handling high computational and data communication loads (Shukla et al., 2023; Vatter et al., 2024).

More recently, the concept of the distributed computing continuum has emerged as an approach that integrates multiple computing layers—from cloud to fog and edge—into a unified and interconnected ecosystem. This paradigm enables applications to be executed collaboratively across different infrastructure layers, allowing them to leverage the strengths of each computing environment (Dustdar et al., 2022).

Alongside this development, the concept of edge intelligence has evolved within the distributed computing continuum paradigm, representing a computing model that integrates resources from cloud, edge, and end devices in a continuous manner. This approach enables collaborative data processing and artificial intelligence across multiple layers of distributed systems to support real-time, low-latency applications. However, its implementation still faces challenges such as service orchestration, heterogeneous resource management, and adaptive system management mechanisms (Casamayor Pujol et al., 2023).

Overall, the synthesis of the literature indicates that the evolution of distributed systems has progressed from a focus on basic coordination to large-scale and enterprise architectures, and further toward layered systems based on cloud, edge, fog, and artificial intelligence. These paradigms do not replace one another but rather complement each other in forming a computing continuum that supports modern applications characterized by real-time processing, adaptability, and data-intensive workloads.

A summary of the comparative findings across studies addressing the evolution of distributed systems—from theoretical foundations to modern paradigms based on cloud, edge, fog, and artificial intelligence—is presented in Table 2 below.

Table 2. Summary of Findings on the Evolution of Distributed Systems from Selected Literature

No	Author/Year	Key Findings
1	Lamport (1978)	Establishes the theoretical foundation of distributed systems by introducing the concept of Logical Clocks, explaining that no global time exists and synchronization must be achieved through logical mechanisms.

2	Lindsay et al. (2021)	Demonstrates that the evolution of distributed systems is dynamic and adaptive, shifting between centralization and decentralization based on performance, latency, and efficiency requirements.
3	De Donno et al. (2019)	Explains the development of modern computing paradigms from Cloud to IoT, Edge, and Fog as a response to the limitations of centralized systems.
4	Ishaq et al. (2025)	Identifies the transformation of distributed systems in enterprise environments from monolithic architectures to microservices and cloud-native systems to enhance scalability and flexibility.
5	Filho et al. (2022)	Highlights the shift from cloud-centric approaches to Edge and Fog Computing to support real-time processing and reduce latency by bringing computation closer to the data source.
6	Kirsanova et al. (2022)	Emphasizes the role of Fog Computing as a layered architecture that forms the computing continuum from Cloud to IoT, while also addressing challenges related to orchestration, security, and scalability.
7	Shukla et al. (2023)	Demonstrates the effectiveness of edge intelligence in modern distributed systems, particularly for IoT applications requiring real-time responsiveness and local processing.
8	Vatter et al. (2024)	Explains that distributed systems are key to enabling large-scale artificial intelligence, especially for data- and computation-intensive AI model training and inference.
9	Dai et al. (2025)	Provides a comprehensive overview of trends, challenges, and the evolution of modern parallel and distributed systems, including Cloud, Edge, Fog, and distributed AI.
10	Casamayor Pujol et al. (2023)	Introduces the concepts of the distributed computing continuum and edge intelligence, which integrate Cloud, Edge, and end devices to support AI applications and real-time data processing in modern distributed systems.
11	Kimovski et al. (2024)	Shows that the computing continuum integrates heterogeneous computing architectures, including neuromorphic and quantum computing, which can enhance performance but also introduce interoperability challenges.

4.2 Discussion
This section discusses the research findings by directly relating them to the formulated research questions and evaluating the extent to which the results address the research objectives.

Discussion of RQ1: Evolution of Distributed Systems

Based on the literature review, the evolution of distributed systems has occurred progressively alongside advancements in computing and networking technologies. In the early stage, computing systems were centralized, where all processes were executed by a single central computer. The limitations of this model led to the emergence of parallel and distributed systems, enabling multiple computers to operate simultaneously through message exchange. The theoretical foundation of distributed systems was strengthened by Lamport (1978), who explained that there is no global time in distributed systems, thus requiring Logical Clocks to maintain the ordering of processes.

With the development of the internet, distributed systems evolved into more open and large-scale architectures, such as client–server, peer-to-peer, and cluster computing. Cloud computing subsequently became the dominant paradigm due to its ability to provide elastic computing resources. However, the increasing adoption of IoT and real-time applications has revealed limitations of cloud computing, particularly in terms of latency and network efficiency. This condition has driven the development of edge and fog computing, which bring computational processes closer to the data source and form a computing continuum from the cloud to IoT devices. The literature indicates that these paradigms are complementary rather than substitutive.

Discussion of RQ2: Trends, Challenges, and Research Gaps

The literature identifies key trends in distributed systems toward increasingly decentralized and heterogeneous architectures. The integration of cloud, edge, and fog computing has become a common approach to support modern applications requiring fast response times and large-scale data processing. At the application level, there is a shift from monolithic systems to microservices and cloud-native architectures, enabling more flexible service development and deployment. Furthermore, distributed systems are increasingly playing a crucial role in supporting artificial intelligence and edge intelligence, particularly for real-time, data-driven applications.

On the other hand, this evolution also introduces several challenges, including heterogeneous resource management, cross-layer service orchestration, communication and synchronization among nodes, as well as security and scalability issues. These challenges become more complex within the computing continuum environment, which integrates diverse computing architectures, including both classical and non-von Neumann architectures such as neuromorphic and quantum computing. While this approach has the potential to enhance the performance of data-intensive applications, architectural heterogeneity also introduces issues related to system interoperability and management (Kimovski et al., 2024). Therefore, further studies are still needed to provide a comprehensive understanding of the evolution of distributed systems and the integration of these computing paradigms.

5. Conclusion

ased on the results of this Systematic Literature Review, it can be concluded that the evolution of distributed systems has occurred progressively, starting from centralized computing models and advancing toward modern architectures based on Cloud Computing, the Internet of Things (IoT), Edge Computing, and Fog Computing. This evolution has been driven by advancements in computing and networking technologies, as well as increasing application demands for scalability, real-time responsiveness, and large-scale data processing.

The literature indicates that distributed systems evolve dynamically between centralized and decentralized approaches, where paradigms such as Cloud, Edge, and Fog Computing complement one another in forming a computing continuum. Despite the continuous evolution of system architectures, fundamental concepts such as synchronization, consistency, and coordination remain the core foundations. This review also reveals the existence of challenges and research gaps, particularly related to security, energy efficiency, service management, and the increasing complexity of system management. Therefore, further research is required to support the development of more efficient and sustainable distributed systems.

References

Ahmeth Maulana Ishaq, Isa Faqihuddin Hanif, Mohammad Rafli Nugroho, & Naufal Aditya Putra. (2025). *Evolusi dan Tantangan Sistem Enterprise Terdistribusi di Era Modern: Perspektif Teknologi dan Arsitektur Pasca-2020*. *8*(12).

Andriulo, F. C., Fiore, M., Mongiello, M., Traversa, E., & Zizzo, V. (2024). *Edge Computing* and *Cloud Computing* for Internet of Things: A Review. *Informatics*, *11*(4), 71. https://doi.org/10.3390/informatics11040071

Casamayor Pujol, V., Morichetta, A., Murturi, I., Kumar Donta, P., & Dustdar, S. (2023). Fundamental Research Challenges for Distributed *Computing Continuum* Systems. *Information*, *14*(3), 198. https://doi.org/10.3390/info14030198

Dai, F., Hossain, M. A., & Wang, Y. (2025). State of the Art in Parallel and Distributed Systems: Emerging Trends and Challenges. *Electronics*, *14*(4), 677. https://doi.org/10.3390/electronics14040677

De Donno, M., Tange, K., & Dragoni, N. (2019). Foundations and Evolution of Modern Computing Paradigms: *Cloud*, IoT, *Edge*, and *Fog*. *IEEE Access*, *7*, 150936–150948. https://doi.org/10.1109/ACCESS.2019.2947652

Etawi, N. A. A. (2018). A Comparison between *Cluster*, Grid, and *Cloud Computing*. *International Journal of Computer Applications*, *179*.

Fahmi Ajismanto, Mahmud, Guntoro Barovih, Frits Gerit John Rupilele, Guntoro, D Tri Octafian, Yarza Apriza, M. Tirtana Siregar, Surya Afnarius, Erly Krisnanik, & Yuni Widiastiwi. (2023). *Sistem Terdistribusi*. Widina Bhakti Persada Bandung.

Filho, C. P., Marques, E., Chang, V., Dos Santos, L., Bernardini, F., Pires, P. F., Ochi, L., & Delicato, F. C. (2022). A *Systematic Literature Review* on Distributed Machine Learning in *Edge Computing*. *Sensors*, *22*(7), 2665. https://doi.org/10.3390/s22072665

Hamid, S. A., Abdulrahman, R. A., & Dr.Ruaa Ali Khamees. (2020). *What is Client-Server System: Architecture, Issues and Challenge of Client -Server System (Review)*. https://doi.org/10.5281/ZENODO.3673071

Hazra, A., Rana, P., Adhikari, M., & Amgoth, T. (2023). *Fog Computing* for next-generation Internet of Things: Fundamental, state-of-the-art and research challenges. *Computer Science Review*, *48*, 100549. https://doi.org/10.1016/j.cosrev.2023.100549

Kimovski, D., Saurabh, N., Jansen, M., Aral, A., Al-Dulaimy, A., Bondi, A. B., Galletta, A., Papadopoulos, A. V., Iosup, A., & Prodan, R. (2024). Beyond Von Neumann in the *Computing Continuum*: Architectures, Applications, and Future Directions. *IEEE Internet Computing*, *28*(3), 6–16. https://doi.org/10.1109/MIC.2023.3301010

Kirsanova, A. A., Radchenko, G. I., & Tchernykh, A. N. (2021). *Fog Computing state of the art: Concept and classification of platforms to support distributed computing systems* (arXiv:2106.11726). arXiv. https://doi.org/10.48550/arXiv.2106.11726

Lamport, L. (1978). *Time, clocks, and the ordering of events in a distributed system*. *21*(7).

Li, J., Gu, C., Xiang, Y., & Li, F. (2022). *Edge-Cloud Computing* Systems for Smart Grid: State-of-the-art, Architecture, and Applications. *Journal of Modern Power Systems and Clean Energy*, *10*(4), 805–817. https://doi.org/10.35833/MPCE.2021.000161

Lindsay, D., Gill, S. S., Smirnova, D., & Garraghan, P. (2021). The evolution of distributed computing systems: From fundamental to new frontiers. *Computing*, *103*(8), 1859–1878. https://doi.org/10.1007/s00607-020-00900-y

Liu, F., Tong, J., Mao, J., Bohn, R., Messina, J., Badger, L., & Leaf, D. (2011). *NIST Cloud Computing Reference Architecture* (Nos. 500–292). https://doi.org/https://doi.org/10.6028/NIST.SP.500-292

Luo, R., He, Q., Xu, M., Chen, F., Wu, S., Yang, J., Gao, Y., & Jin, H. (2025). *Edge* Data Deduplication Under Uncertainties: A Robust Optimization Approach. *IEEE Transactions on Parallel and Distributed Systems*, *36*(1), 84–95. https://doi.org/10.1109/TPDS.2024.3493959

Nyabuto, Mr. G. M. (2024). Architectural Review of Client-Server Models. *International Journal of Scientific Research and Engineering Trends*, *10*(1), 139–143. https://doi.org/10.61137/ijsret.vol.10.issue1.126

Shukla, S., Hassan, Mohd. F., Tran, D. C., Akbar, R., Paputungan, I. V., & Khan, M. K. (2023). Improving latency in Internet-of-Things and *Cloud Computing* for real-time data transmission: A *Systematic Literature Review* (SLR). *Cluster Computing*, *26*(5), 2657–2680. https://doi.org/10.1007/s10586-021-03279-3

Singh Chowhan, R. (2019). Evolution and Paradigm Shift in Distributed System Architecture. In P. Li (Ed.), *New Trends in Industrial Automation*. IntechOpen. https://doi.org/10.5772/intechopen.80644

Snyder, H. (2019). Literature review as a research methodology: An overview and guidelines. *Journal of Business Research*, *104*, 333–339. https://doi.org/10.1016/j.jbusres.2019.07.039

Srirama, S. N. (2024). A Decade of Research in *Fog Computing*: Relevance, Challenges, and Future Directions. *Software: Practice and Experience*, *54*(1), 3–23. https://doi.org/10.1002/spe.3243

Steen, M. van, & Tanenbaum, A. S. (2017). *Distributed systems* (Third edition, Version 3.01). Maarten van Steen.

Torres-Carrion, P. V., Gonzalez-Gonzalez, C. S., Aciar, S., & Rodriguez-Morales, G. (2018). Methodology for *Systematic Literature Review* applied to engineering and education. *2018 IEEE Global Engineering Education Conference (EDUCON)*, 1364–1373. https://doi.org/10.1109/EDUCON.2018.8363388

Vatter, J., Mayer, R., & Jacobsen, H.-A. (2024). The Evolution of Distributed Systems for Graph Neural Networks and Their Origin in Graph Processing and Deep Learning: A Survey. *ACM Computing Surveys*, *56*(1), 1–37. https://doi.org/10.1145/3597428