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A BIBLIOMETRIC ANALYSIS: AI-DRIVEN DATA PLACEMENT OPTIMIZATION IN CLOUD REPLICATION ENVIRONMENTS

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Abstract:

Data placement strategy using artificial intelligence (AI) in cloud replication environments has garnered significant attention in recent years. Several studies have examined this area, aiming to enhance data replication techniques by integrating AI algorithms. There is still a minimum number of studies that have discovered the trending of the existing literature that reveals cloud replication leveraging artificial intelligence techniques in the current body of knowledge. This study explores this field's significance and relevance through a bibliometric analysis, particularly its integration with artificial intelligence (AI) techniques. The study highlights key trends and developments, highlighting the collaborative potential between cloud replication and AI technologies. The outcome of this study contributes to practitioners and researchers in evaluating and identifying potential areas for future exploration in AI-driven data placement optimization in cloud replication environments.

Keywords:

Artificial Intelligence, Bibliometric, Cloud Computing, Data Placement, Replication Strategies.

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Introduction

The advent of cloud computing has profoundly transformed data storage and management approaches. One of the substantial cloud computing services is data replication, which demands creating and maintaining multiple copies of data across geographically distributed locations. This practice is essential for ensuring high data availability and reliability, as it mitigates the risk of data loss and business disruptions (Elango et al., 2021; Kuraj et al., 2022).

Static and dynamic replication are two (2) well-known conventional replication methods used in cloud replication environments. Static replication is about pre-determined techniques that decide the replica copies distributions among nodes before replication. Static replication is less effective in adjusting to diverse data access patterns and multiple workloads. Dynamic replication adapts the replication scheme based on data and system conditions (Aldailamy et al., 2024; Fazlina et al., 2021). Both approaches aim to improve data availability and reduce access latency by placing replicas based on specific conditions.

In the research area of data replication strategies, several strategies have been explored to optimize the placement of replica copies in cloud environments. Consistency-based replication is one of the strategies focused on maintaining data consistency across replica copies. Techniques like primary-copy replication and multi-version concurrency control (MVCC) are commonly used in consistency-based replication (Noraziah et al., 2021). This approach ensures that all replicas placed in different storage nodes and data items are updated consistently to provide users with the most recent and accurate data.

Load-balancing replication strategies aim to distribute replica copies across available resources evenly. As proposed by the researcher (Li et al., 2020), the replica load balancing strategy guarantees that the workload and access requests across replicas are allocated relatively to prevent resource bottlenecks and ensure efficient utilization of cloud resources. Storage capacities, network bandwidth, and data access patterns are considered when intelligently routing requests to the appropriate replica locations. Content-aware replication can improve data locality and reduce communication overhead (Zhou et al., 2020). Content-aware replication strategies leverage the characteristics and content of data items to optimize replica placement. These approaches analyze the data attributes, access patterns, and dependencies to identify and group related data items for efficient replication.

A study by (Bouhouch et al., 2023) introduced a novel data placement strategy complemented by a dynamic data replication management technique. The primary objective was to mitigate the cost of data transfers across data centers. The research predominantly addressed the expenditures associated with storage and network utilization, overlooking the potential optimization through storage consumptions. Similarly, in pursuing cost-effectiveness and latency reduction in spatial crowd-sourcing, researchers (Wang et al., 2023) introduced a strategy to identify optimal data placement within a multi-cloud environment, leveraging the interval pricing technique. Notably, the study primarily concentrated on mitigating storage and network utilization expenses without considering the potential benefits of incorporating other cost-saving measures, such as storage optimization.

Despite adopting dynamic and various optimization approaches in research endeavors, limitations persist, primarily stemming from the absence of advanced intelligence techniques. Artificial intelligence (AI) is one of the emerging technologies that advanced significantly,

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enabling more accurate and timely predictions in many research areas. This emerging technology empowers numerous algorithms to train the data and enable an analysis to determine decision-making. Nowadays, numerous cloud platforms utilize AI techniques to provide better services to customers.

Similarly, some researchers developed strategies in the cloud replication domain by leveraging AI techniques. Further, such research areas are being refined to improve their predictive accuracy and promise performance enhancement in cloud replication. Even in the past years, several studies have introduced innovative AI algorithms for data placement. However, their evaluations frequently relied on synthetic or constrained datasets, which may not fully capture the complexity and variability of real-world cloud environments (Ibrahim et al., 2016; Mansouri, Javidi, et al., 2020; Mansouri & Javidi, 2018). This raises concerns regarding the scalability and applicability of the proposed approaches in practical settings.

Thus, it emphasizes the need for exploration into Artificial Intelligence (AI)-based solutions, driven by the recognition that such methodologies hold the potential to overcome existing constraints and enhance the efficacy of dynamic systems. Further, AI approaches encompass a broader range of techniques to replicate or augment human-like intelligence in cloud replication environments. The prominent strength of this study is the recognition of the potential benefits and trends of leveraging AI for data placement strategies. The scope of this study is illustrated in a graphical abstract as in Figure 1.

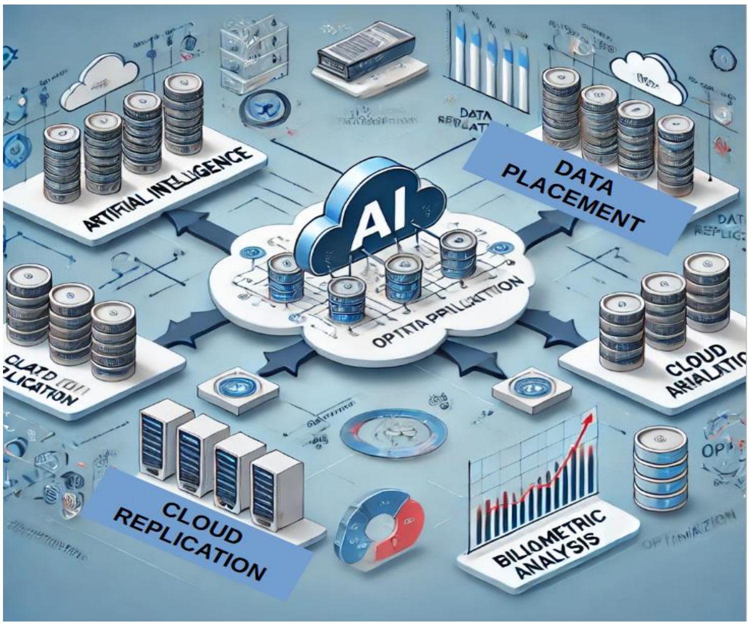

Figure 1. Graphical Abstract

This paper is organized as follows. Section 2. Related studies enlighten existing works and highlight the AI techniques leveraged in similar research works. Section 3-Method and Material details the methodology used throughout this study. Section 3 is Results and Discussions, which elaborates on key contributions presenting the bibliometric analysis and discussions. Section 4 is a Conclusion and Future Works, concluding the study contributions and potential areas for practitioners and researchers to explore.

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Related Works

The utilization of AI techniques, such as machine learning and data mining, offers promising opportunities to optimize data replication in cloud environments (Nannai John & Mirnalinee, 2020). Researchers have successfully demonstrated improved performance, scalability, and cost-effectiveness by employing AI-based data placement strategies (Awad et al., 2021b). The following subsection will discuss related research works that leverage AI techniques in replication strategies in cloud environments.

Machine Learning

Machine learning techniques have increasingly drawn interest for their role in enhancing data placement strategies within cloud replication environments (Han et al., 2021). These methods cover multiple algorithms, including reinforcement, supervised, and unsupervised learning. Supervised learning techniques such as decision trees and neural networks improve replica allocation and predict data access patterns. In contrast, unsupervised learning techniques, such as clustering and association rule mining, are applied to discern data relationships and categorize related data items, facilitating more effective replication processes. Moreover, reinforcement learning approaches have been proposed to dynamically adjust data placement strategies in response to real-time feedback and system performance metrics (Ahmed et al., 2023). Researcher (Awad et al., 2021b) embarked on a similar research area by utilizing machine learning technologies in replication. The research team has been working on observing users' access patterns in cloud replication environments and enhancing the replica placement performance.

Hybrid techniques aim to leverage the strengths of different strategies to achieve better data placement outcomes. Researchers have also explored hybrid approaches that combine multiple machine learning techniques or combine machine learning with traditional data placement strategies (Xie et al., 2020). For example, a hybrid approach could involve using unsupervised learning to group related data items and then applying a static or dynamic replication strategy to determine the replica placement based on the identified groups. It's important to observe that the choice of machine learning technique depends on the specific goals and requirements of the data placement problem. Researchers continue exploring and developing novel machine-learning techniques and hybrid approaches to enhance data placement strategies in cloud environments.

Genetic-AI

Genetic algorithms are an emerging AI-based method used in many recent research fields to address data placement problems in cloud replication environments. These algorithms use a population-based search approach inspired by natural evolution. Genetic algorithms can evolve and optimize replica placement solutions over multiple generations by encoding the data placement problem as a genetic representation, such as chromosomes and genes. Fitness functions based on performance metrics are used to evaluate and guide the evolutionary process (Yin et al., 2018). This genetic-AI-based replication helps find the pattern to optimize the replica placement in cloud replication. The other researcher proposed a genetic algorithm-based data replica placement strategy for scientific applications in clouds that reduced data transmissions and had better performance than random placement strategies (Cui et al., 2018).

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Metaheuristic-AI

Machine Metaheuristic approaches are known as AI-based algorithms. This approach was deployed to address the energy optimization issue in the cloud replication environment via integrating Particle Swarm Optimization (PSO) and Tabu Search (TS) algorithm (Ebadi & Jafari Navimipour, 2018). HPSOTS can determine the number of replicas before replication activities are triggered in a cloud environment. Tabu Search (TS) is adapted to search space, ensuring replicas are not placed in the same local data centers. The researchers succeeded in decreasing energy consumption and cost. Unfortunately, data availability is relatively low due to the static number of replicas fixed in the strategy. Thus, any decisive data might not have sufficient copies, affecting poor availability and high wait time for file downloads.

Data replica placement strategies broadly employ metaheuristic AI-based techniques, which can reduce data access costs and improve quality of service (QoS) in a cloud replication environment. Researchers (Ebadi & Jafari Navimipour, 2018) proposed an energy-aware method for data replication in cloud environments that used a hybrid AI-metaheuristic algorithm to get high-quality solutions and outperformed other algorithms in terms of consumed energy and cost. Another researcher proposed a novel data replica placement strategy for the coordinated processing of data-intensive IoT workflows in a collaborative edge and cloud computing environment that outperformed traditional algorithms (Shao et al., 2019). Data replica placement can be modeled as a 0–1 integer programming problem to consider the overall data reliance, data reliability, and user participation. Then, to handle this model, the IT algorithm, a subtype of intelligent swarm optimization, is presented in this research paper. While maintaining data accuracy and sharing across user groups, the strategies can significantly lower the overall cost of data access. However, respective researchers proposed data placement method only considers the workflow execution in a single region, which is inadequate for the heterogeneous scientific collaboration environments in practice.

Similarly, researcher (Awad et al., 2021a) proposed an intelligence algorithm integrating an AI-based approach for dynamic data replication in a cloud environment. The researcher developed Multi-Objective Particle Swarm Optimization (MO-PSO) to select a replica depending on the most requested frequencies, and the Ant Colony Optimization (MO-ACO) algorithm was also used in this study to retrieve the best replica placement decision. The study successfully accelerated the response time and enhanced network usage efficiency. Yet, the drawbacks overlooked by the researcher are that the bio-based algorithms caused process time overheads and high replication frequencies. Despite the trade-offs, the study underscores betterments in data replication with higher data availability.

Besides, an Artificial Bee Colony algorithm for data replication optimization in cloud environments was proposed by another research group (Salem et al., n.d.). The researchers suggested that AI techniques used in the study helped optimize data placement and reduce latency, yet risks and challenges associated with its use, such as data privacy concerns and the need for specialized hardware and software.

Deep Learning

Deep learning has been increasingly utilized for data placement in cloud replication environments, as demonstrated in the study by (Liu et al., 2023), where Markov decision processes were formulated, and deep reinforcement learning was leveraged for decision-making. However, it's essential to recognize that in Online Social Networks (OSNs), the

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engagement rate holds significant importance in predicting future access to data objects, adding complexity to formulating and evaluating data placement strategies.

Data Mining

Data mining involves discovering large dataset patterns, relationships, anomalies, and other valuable insights. Data mining is another widely emerging discipline that goes hand in hand with cloud replication. Research by (Mansouri, Mohammad Hasani Zade, et al., 2020) is one of the studies that contributed to this discipline by developing a data mining-based algorithm to bring data files close to consumers. The technique enhances accuracy in finding the best location to store replica copies for users to retrieve quickly.
The discussion emphasized an important insight, which is to note that these strategies are not mutually exclusive, and there can be overlaps and combinations among them. Researchers continue to explore novel data replication strategies that combine the strengths of AI techniques to improve data availability, performance, and resource utilization in replica placement within cloud replication environments.

Based on the discussions, Table 1 summarizes the prominent contributions of existing studies in levering AI techniques into data placement within cloud environments.

Table 1. AI Techniques in Replication Srtategies

AI-Techniques	Contributions		
	Data Access Pattern	**Placement Decision**	**Performance Optimization**
Machine Learning	/	/	/
Genetic-AI	/		/
Metaheuristic-AI		/	/
Deep Learning	/	/	
Data Mining		/	/

Method and Material

This study mainly seeks the existing literature to investigate the coverage of multiple related topics, the research trends, and the relevant studies field that have been published. The methodology implied in obtaining the source papers in this study mainly follows the guidelines suggested by (Sofian et al., 2022). The guidelines for this study follow the essential steps of searching for relevant papers, screening the papers, keywording the abstracts, extracting the data, and finally, analysing the trends.

Definition of Research Scope –The primary goal of this study is to obtain the trending of the existing literature that reveals cloud replication leveraging artificial intelligence techniques in the current body of knowledge.

Search for Primary Studies (All Papers) –Primary research was conducted using keyword search terms on scientific databases or through relevant journal articles or conference proceedings.

Screening of Papers for Inclusion and Exclusion (Relevant Papers) –Studies irrelevant to addressing the study contexts were eliminated using inclusion and exclusion criteria, as in Table 2. As shown in Figure 2, 131 articles were initially selected for bibliometric analysis, spanning 2017 to the middle of July 2024. These articles were sourced from the Scopus database. The keywords used " (("Data Placement" OR "Replication Strategy") AND ("AI Techniques") AND ("Cloud")) are explicitly specified to obtain relevant articles on the practice of AI techniques for data placement strategies in cloud replication environments. Later, 40 articles were eliminated from the analysis due to their being irrelevant to this study, such as the lack of employment of AI in the cloud replica placement strategies. Finally, 91 articles most relevant to this study were used for bibliometric analysis. These principles were employed in all the studies retrieved during the different phases of the study selection procedure

Data Extraction and Tool for Studies –After the classification scheme, this study used the relevant articles to discuss the bibliometric analysis. The tool used to run the analysis is the Biblioshiny, which uses RStudio as a platform.

Data Sources – Scopus online databases were primary data sources for potentially related studies. Other data sources were not considered to impede the overlapping of source results.

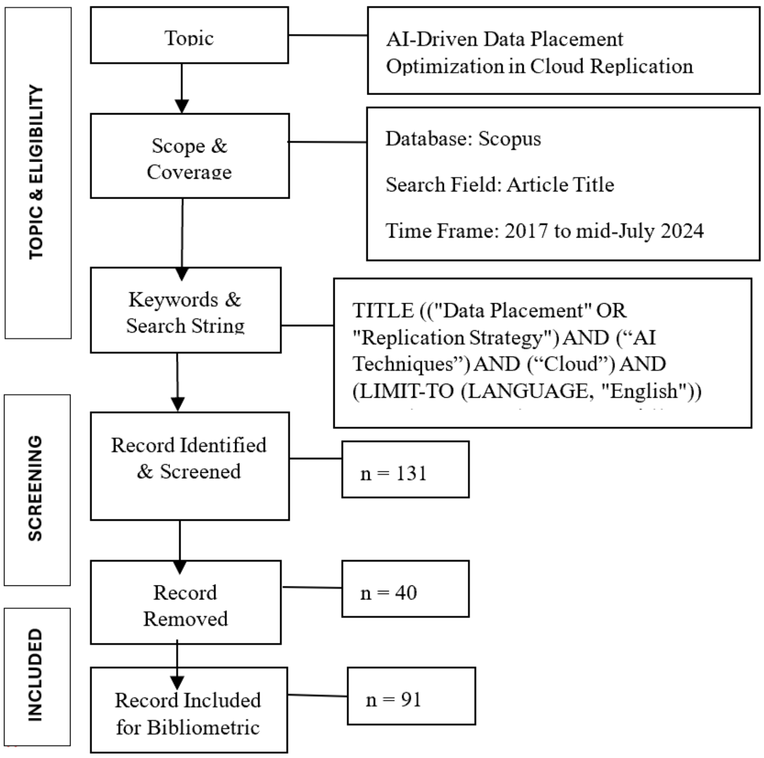

Figure 2. Article Search Strategy Flow Diagram

Results and Discussion: Bibliometric Analysis

Abundant studies cohesively developed numerous strategies to place replicas in the replication storage. At this point, scholars usually innovate a novel strategy to decide how to replicate the desired data, how many replicas are needed, and where to place the replicas using AI techniques. This bibliometric analysis represents how many researchers embarked on this

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similar research area focused explicitly on trends and yearly contributions in cloud replication environments.

Annual Scientific Production

Figure 3 presents a bibliometric analysis of the annual scientific production of the research area. The data from Scopus retrieved from 2017 until the middle of July 2024 causes the graph to decrease at the peak of the year 2024. 11 articles were published till mid-July 2024, and rendering to the graph pattern, the number of publications is presumed to exceed compared to previous years. The graph outline proves that it gradually increases over the years. Years 2017 to 2018: 100% increase (3 to 6 articles) 2018 to 2019: remain (6 articles in both years) 2019 to 2020: 100% increase (6 to 12 articles) 2020 to 2021: 16.67% increase (12 to 14 articles) 2021 to 2022: 7.14% increase (14 to 15 articles) 2022 to 2023: 60% increase (15 to 24 articles). The consistent presence and growth reveal substantial fluctuations in year-over-year growth rates, highlighting this research area's cruciality. AI is one of the emerging technologies globally, and every research project is leveraging and implementing this technique to ensure performance advancements, including in cloud replication environments.

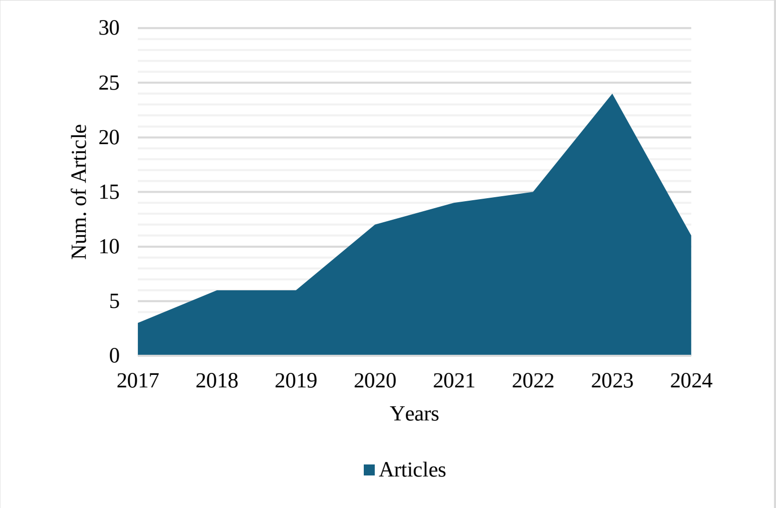

Figure 3. Annual Scientific Production

Source Production Over Time

Figure 4 describes the total number of source production occurrences from 2017 to mid-July 2024 across all publications. The distribution of these publications among the ten venues reveals distinct trends.

- Lecture Notes in Computer Science (LNCS): The number of papers published in LNCS has gradually increased, from 1 paper in 2017 to 7 in 2023 and 2024. This suggests that this series continues to be a popular venue for disseminating research on replication strategies findings in the field.
- Lecture Notes in Networks and Systems: Papers published in this venue first appeared in 2023, with 6 publications, and remained steady until mid-July 2024. This emergence points to a growing recognition of the relevance of network systems in cloud replication studies.
- IEEE Access: The number of articles published in IEEE Access has also risen, from 0 in the initial years to 5 up to mid-July 2024. This open-access journal has become an increasingly preferred outlet for researchers.

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- Future Generation Computer Systems (FGCS): Publications in FGCS have progressively increased, reaching 3 papers in mid-July 2024. This trend underscores the importance of forward-looking research in computational systems.
- ACM International Conference Proceeding Series: The presence of papers in this outlet has remained relatively stable, with a slight increase from 1 paper in 2019 to 2 from 2023 onwards.
- Journal of Network and Computer Applications (JNCA): The number of papers published in JNCA has shown modest growth, with 1 paper from 2021 to 2022 and 2 papers in both 2023 and 2024.
- Lecture Notes in Electrical Engineering (LNEE) and Lecture Notes on Data Engineering and Communications Technologies: Publications in these series have been minimal, with noticeable contributions only starting from 2022, indicating niche but growing interest.
- Procedia Computer Science and Proceedings of SPIE: Both venues have shown a consistent number of publications, with a slight increase observed until mid-July 2024, suggesting a perpetual interest in these proceedings.

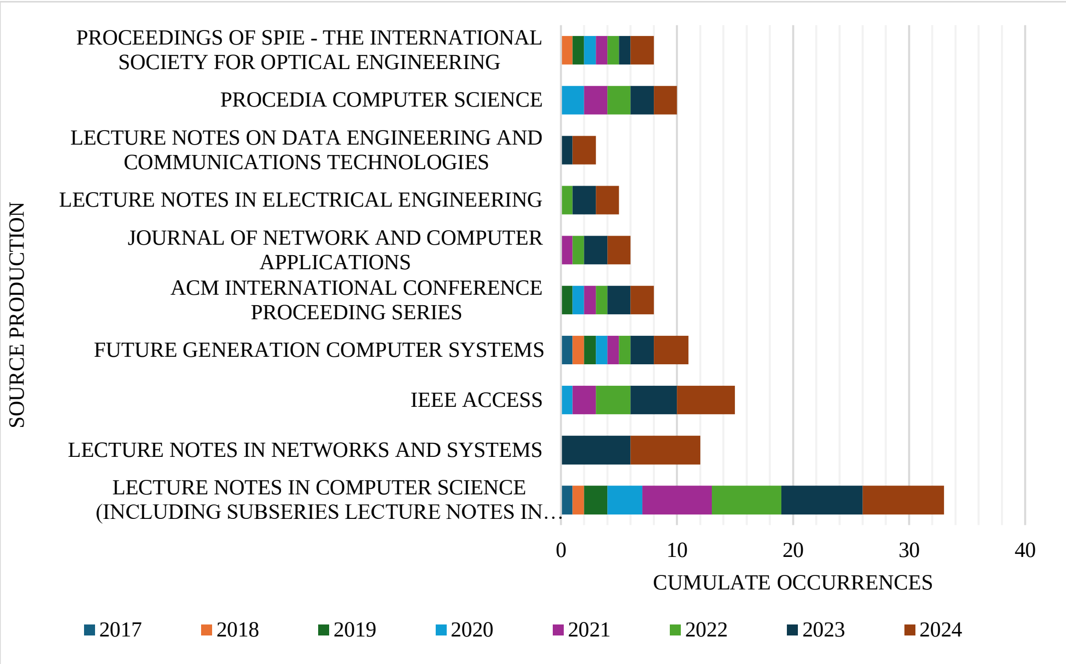

Figure 4. Source Production Over Time

The analysis reveals evolving research on AI techniques in data placement strategies for cloud replication environments. The diversity of publication outlets and the increasing number of publications highlight this research field's interdisciplinary nature and expanding scope. The consistent presence and growth in prominent venues like LNCS, IEEE Access, and FGCS emphasize the significance and relevance of the research. The observed trends also suggest the rising importance of network systems, electrical engineering, and data engineering in addressing the challenges of cloud replication.

Word Cloud

Word-cloud in Figure 5 illustrates the keywords revealing significant contributions, trends, and patterns of AI techniques usage in cloud replication strategies. The word cloud was generated

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using bibliometric analysis, and 91 related research topics were covered from 2017 till mid-July 2024. A keyword's highest usage is indicated by its size; as in Figure 5, the most prominent word size concerns artificial intelligence, which consists of deep learning, machine learning, ant colony optimization, and green computing. Minimum-used keywords include the environment of studies that are not limited to cloud, edge, green computing, internet of things, and virtual machines. The smaller the keyword implies, the less frequently it has been explored in this research field.

Figure 5. Word Cloud for Keywords

Conclusion And Future Recommendations

This bibliometric study has explored the trendy research and significance of AI-driven data placement optimization in cloud replication environments. As discussed in this study, numerous research works continuously explored and contributed to this collaborative research area. It discovers the potential of AI techniques to improve data placement decisions and enhance cloud replication performance. In conclusion, leveraging AI techniques in cloud replication strategies is essential to address foreseen limitations, including the demand for more security with multi-objective data placement optimization considerations.

Further research is needed to develop hybrid approaches that combine the strengths of traditional data placement strategies with AI techniques. Challenges include the scalability of proposed strategies or algorithms to handle large-scale cloud environments, the dynamic nature of data access patterns, and the need for privacy-preserving techniques when using sensitive data for training, which always persist. Hence, future research efforts should explore and focus on addressing multi-objective optimization techniques to strike advancements that contribute to efficiently improving replication performance in cloud environments.

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