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Survey Based on Edge Structured File Systems in Edge Computing

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Abstract: Edge Structured File systems (ESFs) are distributed file systems designed to provide efficient and reliable storage solutions in edge computing environments. By employing distributed and decentralized designs, these file systems address specific challenges such as limited resources, inconsistent connectivity, and fluctuating network conditions, resulting in quicker access times, reduced latency, and enhanced resilience. ESFs adapt to dynamic edge settings through flexible data placement tactics, network congestion detection and resolution, and seamless integration with cloud-based storage systems. These techniques enable data portability and, when necessary, the outsourcing of computation-intensive operations to the cloud. Overall, edge-computing ecosystems rely on ESFs to deliver optimal performance, resilience, and data availability. The article discusses several studies on edge-structured file systems, highlighting their features and limitations of previous works. Furthermore, it identifies requirements and discusses research challenges in edge computing, laying the groundwork for future advancements in this rapidly evolving field. By providing insights into the state-of-the-art technologies, features, and limitations of ESFs, as well as their broader implications for edge computing, this article aims to offer valuable guidance to researchers, practitioners, and stakeholders interested in harnessing the full potential of edge computing technologies.

Keywords: cloud computing; decentralized designs; distributed file systems; edge computing; edge devices; edge environment; edge structured file system; stakeholders

1 INTRODUCTION

Performing computation at the edge, which refers to a local resource, is the foundation of the idea of edge computing. In edge computing, the nearby resource might be a computer or network resource that is situated among the client & the cloud data centers. A few of the choices provided by Edge Computing are described in [1] and [2]. Essentially, Edge Computing, Cloudlet Computing, and Fog Computing all operate under the same concepts.

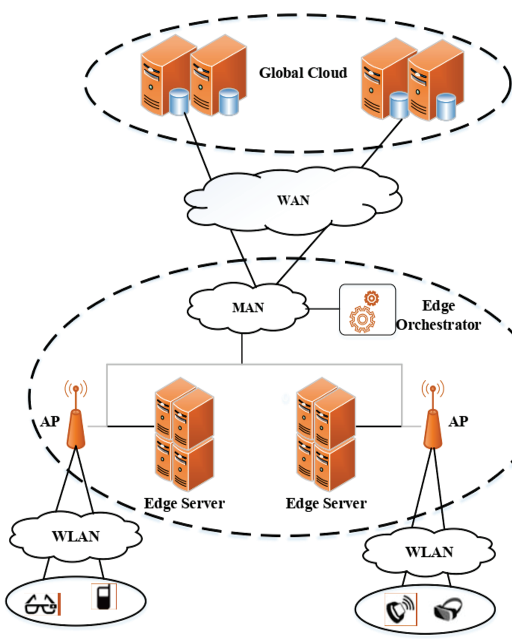

Figure 1 General Edge Computing architecture

Mobile Cloud Computing (MCC) [3, 4], Fog Computing [5], and other computing methods are all included in edge computing. To acquire a service from a nearby server located in the user's geographic area is the common purpose of several computer technologies. Overall, time-sensitive applications or situations where cloud connectivity is unavailable clearly benefit from this approach. Implementing a program or a portion of an application on the edge brings considerable benefits to mobile devices as well. To begin with, by utilizing an edge server, mobile devices may accomplish complicated processes while utilizing less battery power. Since clients do not face WAN (wide area network) delay in Edge Computing, it also has less transmission latency than cloud computing. Activities can be sent to the global cloud by mobile gadgets in two-tier architectures using the WAN connection provided by the corresponding access point. Since only the two-tier with Edge Offload (EO) model allows work performed on the initial layer to be offloaded to any edge server located in different buildings, the two-tier with EO design offers a substantial advantage. It is intended for the edge servers and orchestrators to be connected to an identical network. A general Edge Computing design is shown in Fig. 1.

An edge structure file system (ESFs) is a form of file system developed for edge computing, in which information is processed closer to the source rather than being sent to a centralized server. ESFs distinguishes itself from typical file systems by designing it for low power, resource-constrained devices encountered in edge computing environments. To reduce the quantity of storage and processing power necessary, ESFs often employs improved information structures and algorithms. Furthermore, to increase performance and security in edge computing environments, ESFs frequently adds technologies such as data compression and encryption. Overall, the purpose of a ESFs is to create a lightweight, efficient, and secure file system capable of meeting the particular requirements of edge computing settings [6]. Edge-structured storage systems cater to edge computing demands by organizing data at the edge, enabling efficient storage, retrieval, and evaluation. These systems integrate edge-optimized approaches like distributed file systems, data replication, caching, metadata management, and data placement schemes for efficient resource utilization. Fig. 2 shows the overview of edge structured file systems.

High-speed connections are used in the edge computing surroundings to connect neighboring edge servers in an area [7], creating an edge server network that doubles as an edge storage system (ESS) [8, 9, 10]. The single-point failure along with bottleneck issues with the edge-cloud structure are addressed by ESS [11]. Studies are working toward different optimization goals by caching data replicas on edge servers, including minimum data retrieval latency [12], maximum cache hit ratio [13, 14], maximum caching advantages [15, 16], and maximum caching capacity [17, 18], have recently been drawn to new issues raised by ESS.

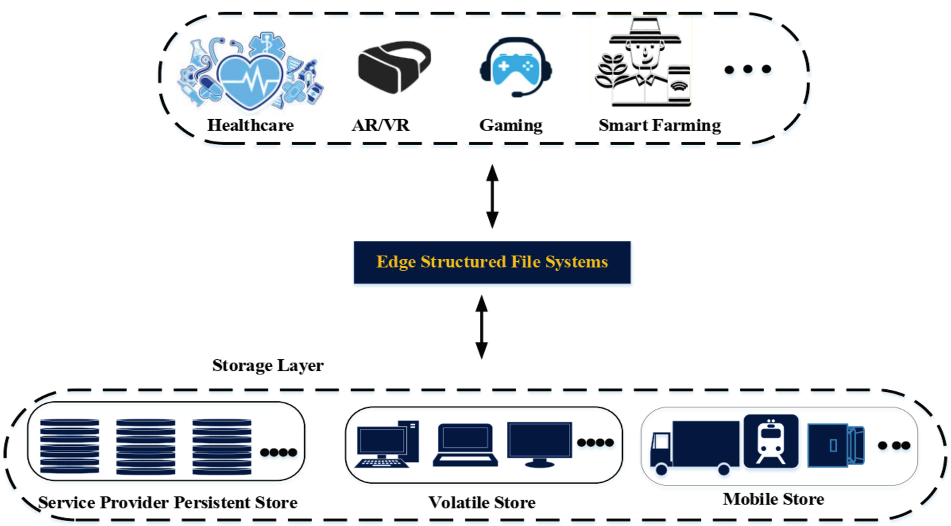

Figure 2 Overview of Edge Structured File Systems

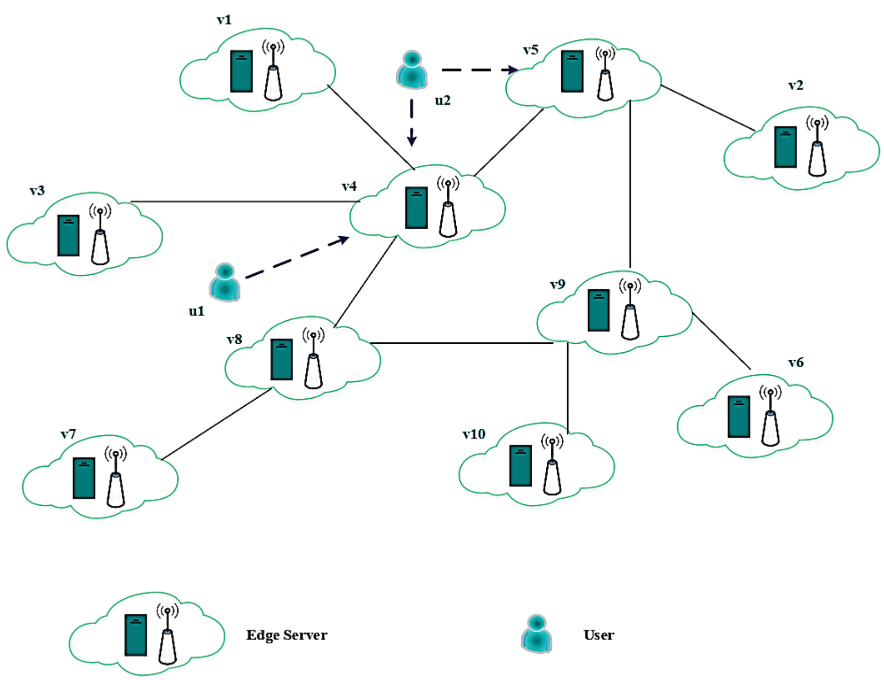

Figure 3 Example of edge storage system

Fig. 3 depicts an ESS made up of 10 networked edge servers that serve users in a specified region collectively. A basic replica-based distribution method for every of the 10 edge servers. The edge servers that protect consumers in the edge computing architecture are accessible to the consumer. Based on specific studies, the client's distance from the edge server affects data rate but not latency. As an outcome, this research considers the latencies among clients and edge servers.

This study aims to evaluate various edge-enabled storage solutions by examining cloudlet-based architectures, decentralized storage systems, and software-based edge computing platforms. It also investigates the integration of network resources into offloading decisions and the impact of network conditions on edge computing outcomes. The study also assesses the feasibility and effectiveness of utilizing existing distributed database platforms for edge infrastructure, focusing on attributes like data mobility, scalability, and accessibility. The analysis provides insights into designing edge storage solutions that meet diverse edge computing scenarios, considering factors like energy efficiency and reliability. These studies provide a comprehensive understanding of challenges and opportunities in edge storage. The objective and contribution of this survey paper is as follows:

- The research aims to tackle offloading decisions in edge computing frameworks, focusing on cloudlet-based architectures with a centralized multi-tiered tree structure, by developing a formulation considering computing and network resources' impact on edge computing outcomes.
- The study explores edge storage, focusing on adapting distributed database platforms, using S3 file systems in fog environments, and proposing efficient frameworks. The research also discusses decentralized data storage solutions on different edge nodes with unique operating systems and file systems.
- The research explores the integration of block-chain technology with edge storage to improve security and data integrity.

The organization of this article is as listed below: The survey study's concept is described in Section 2, and the contents of the current research papers are covered in Section 3. A summary of this study and its future prospects are given in Section 4, and the paper is wrapped up in Section 5.

2 THE STRUCTURE OF THIS SYSTEMATIC LITERATURE REVIEW'S PROCEDURE

This part describes the approach used to conduct a comprehensive of the literature for edge structured file systems. It sheds insight on several areas of the review process, including details on preferred article databases, the research method or conceptual structure, criteria for adding or omitting research papers, and the distribution of articles utilized in the research.

2.1 Search Strategy

Six digital libraries—IEEExplorer, ACMDigital Library, Science Direct, Web of Science, SCOPUS, and Google Scholar—were used to find the relevant research. The most widely utilized and well-liked digital libraries for edge-structured file systems. In order to find pertinent research based on study topics like "Edge computing," "cloud computing," "Edge environment," and "edge devices," a specific database is searched using a search query string. For the research, related terms and alternatives to important words such as ‘distributed file systems’, ‘edge server’, ‘computing environments’ are evaluated. The numerous ways for achieving the objectives are also given.

2.2 Research Questions

The research questions are essential in selecting the search strategy, data extraction, and analysis in the context of a systematic literature review. The following have been chosen as the research questions for this investigation:

RQ1. Which type of edge structured file systems used in the existing literature paper?

RQ2. What are the various techniques used?

RQ3. What are the various future suggestive techniques used for edge computing?

2.3 Criteria for Article Selection Process

The inclusion and exclusion standards have been established after thorough consideration of the quality of literature already in existence. With the help of an expert advisor, the writers reviewed the publications and decided which ones to include and exclude. The following standards evaluated the papers.

Inclusion Criteria: Depending on routing protocol categorization, we issued the papers between 2014 and 2022, and they were completely searchable.

Exclusion Criteria: Papers that fail to satisfy the aforementioned inclusion requirements.

2.4 Quality Assessment

The articles acquired and reviewed by qualified professionals connected to reputable journals and conferences. No specific quality requirements were required.

2.5 Data Extraction

The qualities have been identified from existing literature and published literature reviews. The characteristics taken into account in the extraction are as follows:

- Publication year
- Methods discussed
- Edge structured file systems.

3 LITERATURE SURVEY

Routaib et al. [19] recommend a cloudlet-based framework with a centralized multi-tiered tree architecture. It might be challenging to choose where to offload in a situation like this since an edge-computing framework may consist of numerous edge servers. Previously, only computing resources were included while framing the offloading issue. Yet since network resources may utilize local edge computational units, the formulation must account for both kinds of resources.

Betzler et al. [20] discovered that network resources have a substantial impact on outcomes in edge circumstances. For example, Chen et al.'s [21] optimization of offloading choices in a multi-tier scenario where mobile clients offload faraway cloud and compute access points. The researchers employ a heuristic approach that considers both resource and interaction assessments.

Saguna et al. [22] introduced Sagunas Open-RAN, a software-based Edge Computing solution, in 2016. It is a platform that enables third-party Multi-access Edge Computing (MEC) applications via virtualized environments. DNS caching, retail-targeted video marketing, safe cities, and smart security were among the application cases for the project.

The majority of study is being done on edge storage via utilizing existing distributed database platforms and adapting it to the edge infrastructure. The utilization of an S3 file system in a fog environment is the main focus of the writers Confais et al. [23]. The following list of attributes of an edge storage framework: Data should be moved or copied from one location to another, matching client locations, and should be accessible in splitting circumstances and network confinement. It should also have high scalability to handle a large number of sites, customers, and products.

Table 1 Papers with their specifications

Authors and Reference no	Technique Used	Storage Systems	Limitations/ Future work	Published Journal
Routaib et al. [19]	Centralized multi-tiered tree architecture	Cloudlet-based storage systems	Further studies will concentrate on simulating various applications and assessing workload migration between clouds or cloudlets.	International Conference on Intelligent Systems: Theories and Applications, IEEE
Betzler et al. [20]	wireless SDN-based architecture	Heuristic approach for optimizing offloading choices in a multi-tier scenario.	Experiments on real constrained devices demonstrate successful implementation and execution of these policies.	European conference on networks and communications, IEEE
Chen et al. [21]	Heuristic approach considering both resource and interaction assessments	Multi-tier storage systems	In future, Integrate edge computing in mobile cloud architecture to optimize offloading, resource allocation, and energy efficiency by utilizing network resources near mobile devices.	International Conference on Acoustics, Speech and Signal Processing, IEEE
Saguna et al. [22]	Software-based Edge Computing solution enabling third-party MEC applications via virtualized environments	Edge computing storage systems	Explore optimal edge-server placement strategies considering user density, mobility patterns, and network traffic demands. Develop algorithms for optimal deployment locations and explore mobility management techniques for seamless connectivity.	White paper
Confais et al. [23]	Adaptation of existing distributed database platforms to edge infrastructure	S3 file systems	RozoFS reduces local reading times by 34%, but more realistic edge-Fog networking issues remain.	Transactions on Large-Scale Data-and Knowledge-Centered Systems XXXIII
Gheorghe et al. [24]	Wireless communication for file transfer, shared data with continuous Cloud backup	Distributed and decentralized storage applications	Performance is improved overwall, and experimental evaluation covers proposed attack scenarios.	Designing privacy enhancing technologies: international workshop on design issues in anonymity and unobservability Berkeley, Springer Berlin Heidelberg.
Freenet et al. [25]	Epidemic method for building decentralized storage networks	Decentralized storage systems	Address the challenge of data availability and redundancy in a distributed system. Explore replication strategies, data erasure coding, and redundancy schemes to ensure high availability of data while maintaining anonymity. Investigate mechanisms to incentivize users to contribute storage resources and maintain data replication.	Resource Management for Big Data Platforms. Springer
Wilkinson et al. [26]	Block-chain system for recording item positions, periodic integrity and availability checks	Block-chain storage systems	Develop strategies to ensure fault tolerance and resilience in the Storj network. Investigate techniques for data replication, redundancy, and erasure coding to protect against data loss and ensure high availability.	
Cohn et al. [27]	Integration of edge storage with decentralized block-chain technologies	Decentralized block-chain storage systems	Improve the scalability and performance of ADEPT systems. Develop resource allocation and energy management strategies for ADEPT systems.	Patent and trademark office
Shreshth et al. [28]	Prototype system called APEX, pre-optimized weights for low adapting time	APEX file system	The research may be expanded to include secured file-systems, wear leveling optimization, and new non-volatile memories like RRAMs for power-efficient edge devices.	International Conference on Cloud Computing Technology and Science IEEE
Jin et al. [29]	EC-EDP-O solution using integer programming and EC-EDP-V solution for addressing processing complexity	EC based storage systems and distributed storage systems	Research on reliability of data and storage expenses in EC-based edge storage will be made possible by experimental findings that show effective, cost-efficient methods.	IEEE Transactions on Services Computing
Sonbol et al. [30]	EdgeKV decentralized storage system with data replication and location-transparent architecture	Decentralized storage systems	EdgeKV can be employed with alternative replication mechanisms in the future to give weaker types of consistency for faster response times.	Journal of Parallel and Distributed Computing, Elsevier publication

A distributed, decentralized data storage solution was suggested by Gheorghe et al. [24] that will operate on a variety of edge nodes, every having a unique operating system, design, and file system. The edge nodes will use a wireless communication environment to transfer files from multiple sensors and host sharded data with continuous Cloud backup.

Freenet [25] presents an epidemic method for building decentralized storage networks that support data publication, replication, and retrieval. Without a centralized index or broadcast searches, the files regularly copied into nodes near users and discarded from nodes with low interest. Freenet allows customers to share spare disc space in a cooperative distributed network. In terms of safety, the platform ensures anonymity for the consumers who enter information and for customers who retrieve data.

Requests for an item that exists locally cannot be forwarded to the Cloud in the Edge context. Thus, Wilkinson et al. [26] employed the block-chain system to record the item positions. Because the block-chain saves all transactions that are duplicated on every node, network clients might utilize it to locate every item kept on the edge. The approach presents a challenging method built around a periodic check of a file's integrity and availability.

In Autonomous Decentralised Peer-to-Peer Telemetry (ADEPT) by Cohn et al. [27], proposed IBM and Samsung Electronics provide a proof of concept combining edge storage with decentralized Block-chain technologies. Three open-source protocols serve as the foundation of ADEPT: BitTorrent for distributed sharing of files, Telehash for message-based interactions, and Ethereum for device coordination. Ethereum-based behaviors include authentication with proximity-based norms of interaction, for instance.

Shreshth et al. [28] propose a lightweight, adaptable, portable, and efficient file allocation mechanism that is adaptable, reliable, and independent of storage design, as well as a set of pre-optimized weights that call for only a small change of hyper-parameters based on utilization resulting in low adapting time for new circumstances. In addition, they develop a prototype system of files called APEX and show how it may be used to maliciously overwrite or delete video surveillance records in real life.

Cloud computing may now store information on network edge servers, opening up new options and difficulties. Traditional replica-based edge storage techniques might be expensive. Thus, in order to ascertain the most efficient method for positioning coded data blocks, Hai Jin et al. [29] investigate the application of erasure codes for low-cost storage of data at the edge. The researchers propose an ideal solution called EC-EDP-O that utilizes integer programming and additional approximation approach named EC-EDP-V to address the high processing complexity of large-scale situations.

According to the diverse and dispersed nature of the edge along with its limited resources, it is challenging to create an efficient edge-enabled storage platform. Several distributed applications are frequently meant for the cloud. EdgeKV is a decentralized storage system designed for the network edge that Sonbol et al. [30] propose. Through data replication with solid consistency guarantees, EdgeKV offers speedy and trustworthy storage. EdgeKV's location-transparent and interface-based architecture enable it to expand with a variety of edge node platforms. At last, they look at how employing edge resources with EdgeKV instead of centralized cloud results in better energy efficiency.

Various studies explore different aspects of Edge Computing, particularly focusing on the challenges and solutions related to edge storage and decentralized systems. One study proposes a cloudlet-based structure with a centralized multi-tiered tree design, highlighting the importance of considering both computing and network resources in offloading decisions. Other research investigates the impact of network resources on edge computing outcomes and presents software-based solutions for Edge Computing, such as Saguna's Open-RAN platform. Additionally, there's a focus on edge storage solutions, including the adaptation of existing distributed database platforms, the use of decentralized storage applications, and epidemic methods for building decentralized storage networks. These solutions aim to address issues like data locality, scalability, and data accessibility in partitioning situations.

Furthermore, some studies explore the integration of edge storage with block-chain technologies for enhanced data integrity and availability. Proposed systems like ADEPT combine edge storage with decentralized block-chain technologies for telemetry applications. Moreover, researchers propose novel file allocation systems optimized for post-deletion recovery and efficient utilization of resources. They also investigate the application of erasure codes for cost-effective data storage at the edge. Finally, there's a proposal for EdgeKV, a decentralized storage system designed for the network edge, offering quick and reliable storage with strong consistency guarantees and increased energy efficiency compared to centralized cloud solutions.

4 METHODS AND EXPERIMENTAL SETUP DETAILS

4.1 Optimization of Edge Offloading and Resource Considerations

The framework aims to use a cloudlet-based, centralized multi-tiered tree architecture, following Routaib et al.'s [19] recommendations. It also considers computing and network resources, considering edge server challenges. A heuristic approach is used to optimize offloading choices based on resource and interaction assessments, inspired by Chen et al.'s work [21].

4.2 Development and Optimization of Edge Storage Frameworks

The study explores the use of existing distributed database platforms for edge storage, focusing on their adaptation to edge infrastructure. It also evaluates the use of an S3 file system in a fog environment, focusing on data movement, scalability, and accessibility [23]. The study also explores the implementation of a distributed, decentralized data storage solution, considering various edge nodes with diverse operating systems and file systems [24]. Finally, it explores Freenet's epidemic method for building decentralized storage networks, ensuring anonymity and safety for users.

4.3 Integration of Block-chain with Edge Storage

The study aims to implement Wilkinson et al.'s [26] block-chain system for item position recording, enabling periodic file integrity and availability checks. It also evaluates IBM and Samsung Electronics' proof of concept in ADEPT [27], combining edge storage with decentralized block-chain technologies using BitTorrent, Telehash, and Ethereum protocols.

4.4 Lightweight and Adaptable File Allocation Mechanism

The proposed mechanism aims to implement Shreshth et al.'s lightweight, adaptable, and efficient file allocation mechanism [28], while the APEX prototype system will be developed and evaluated, showcasing its usage and potential vulnerabilities in real-life scenarios.

4.5 Low-Cost Storage with Erasure Codes and Energy Efficiency with EdgeKV

The study explores the use of erasure codes for low-cost edge storage using Hai Jin et al.'s methodology [29]. It also investigates the implementation of EdgeKV, a decentralized storage system for network edge, and evaluates its performance in terms of data replication, consistency guarantees, and energy efficiency compared to centralized cloud storage [30]. The study also assesses the energy efficiency implications of EdgeKV with edge resources.

4.6 Experimental Setup Details

Aspect	Details
Focus Area	Edge Offloading, Edge Storage, Block-chain Integration
Methodologies	Evaluate heuristic approaches for offloading decisions, implement distributed storage solutions, and integrate block-chain with edge technologies.
Instruments	Edge servers, network simulation tools, block-chain platforms.
Materials	Cloudlet-based frameworks, Open-RAN, distributed database platforms, Freenet, block-chain systems.
Procedures	Offloading optimization, storage framework implementation, block-chain integration.
Measurements	Performance metrics for offloading decisions, scalability, anonymity, and safety measures for storage solutions.
Variables	Computing resources, network resources, file systems, block-chain transactions.
Challenges Addressed	Efficient offloading, decentralized storage, security, and integrity in edge environments.

5 DISCUSSION AND FUTURE STUDIES

The literature presents a comprehensive overview of diverse approaches and challenges in edge computing, particularly focusing on offloading decisions, edge storage, and the integration of block-chain technologies. Notably, the recommendations for a cloudlet-based framework, network-aware offloading optimization, and the introduction of Sagunas Open-RAN demonstrate the evolving strategies to address the complexities of edge computing environments. The emphasis on edge storage solutions, such as the S3 file system, decentralized data storage, and the application of erasure codes, highlights the ongoing efforts to optimize data management at the edge. Block--chain integration, as seen in Wilkinson et al.'s and ADEPT, addresses issues related to item position tracking and file integrity. Shreshth et al.'s [28] proposed file allocation mechanism, APEX, while showcasing adaptability, also raises concerns about security vulnerabilities. Furthermore, EdgeKV's decentralized storage system provides insights into efficient and energy-effective storage at the network edge. Future work should focus on refining security measures for decentralized storage, addressing potential vulnerabilities in lightweight file allocation mechanisms, and exploring the broader implications of edge computing, especially concerning the integration of emerging technologies like block-chain. Additionally, efforts should be directed towards standardization and interoperability to foster a more seamless integration of diverse edge computing solutions.

Take home messages from this survey:

Consideration of Network Resources: It is important to consider both network and computational resources while creating edge computing frameworks, as noted by Routaib et al. [19] and Betzler et al. [20].

Diverse Applications of Edge Computing: Saguna et al. [22] showcased the variety and potential impact of edge computing by demonstrating a range of applications such as DNS caching, video marketing, safe cities, and smart security.

Focus on Edge Storage: Numerous academics are experimenting with distributed database platforms, proposing decentralized storage systems such as the S3 file system in fog environments, and investigating edge storage solutions (Confais et al. [23], Gheorghe et al. [24]).

Decentralized Approaches: With a focus on data privacy, redundancy, and integrity, Freenet and Wilkinson et al. support Block-chain-based solutions and decentralized storage networks.

Integration of Edge Storage with Block-chain: Block-chain technologies and edge storage can be integrated for improved security and decentralization, as shown by projects like Cohn et al.'s ADEPT [27].

Efficiency and Adaptability: The goal of Shreshth et al.'s [28] lightweight and flexible file allocation algorithms is to achieve dependability and efficiency in a variety of storage scenarios.

Optimization for Edge Storage: In order to overcome the difficulties brought on by scarce resources and sophisticated processing, Hai Jin et al. [29] investigate the use of erasure codes for inexpensive storage at the edge.

Edge-specific Storage Solutions: Sonbol et al.'s [30] EdgeKV decentralized storage system is designed with the network edge in mind, with a focus on energy efficiency, speed, and dependability.

6 CONCLUSION

In conclusion, this survey paper has thoroughly explored the current landscape of edge computing, with a particular focus on edge storage solutions. Through an exhaustive review of the literature, several key findings have emerged. Firstly, the study identifies various approaches to edge storage, ranging from cloudlet-based frameworks to decentralized storage systems like EdgeKV, addressing the challenges of managing data at the network edge. Secondly, the importance of considering both computational and network resources in offloading decisions has been underscored, as evidenced by optimization techniques proposed by several researchers. Additionally, the integration of Block-chain technology, exemplified by projects like ADEPT, holds promise for enhancing the security and efficiency of edge storage solutions. Lastly, the need for lightweight and adaptable file allocation mechanisms, coupled with the exploration of erasure codes for low-cost storage, underscores ongoing efforts to optimize edge storage platforms for diverse and resource-constrained environments. These key findings provide valuable insights into the current state of edge storage research and offer directions for future exploration in this rapidly evolving field. The take-home messages from this survey highlight the importance of considering various factors, such as architectural design, resource management strategies, and security measures, in the development and implementation of edge storage systems. Furthermore, the significance of the study lies in its contribution to a broader scientific consensus on edge storage by synthesizing diverse research findings and fostering a more comprehensive understanding of the topic. By offering practical implications for decision-making and guiding future research and innovation, this survey equips scholars and industry practitioners with the knowledge needed to address the challenges and opportunities in edge computing effectively. Overall, this collaborative endeavor aims to provide scholars and industry practitioners with a comprehensive understanding of current trends and challenges in edge computing, paving the way for informed advancements in this dynamic and rapidly evolving field. Moving forward, future research endeavors should prioritize strategies for seamlessly integrating edge and cloud resources to optimize storage, computation, and data management across distributed environments. It is imperative to further investigate novel approaches aimed at enhancing security and privacy in edge storage systems, particularly considering the unique challenges posed by decentralized and distributed architectures. Additionally, the development of edge-native storage solutions tailored to the specific requirements and constraints of edge computing environments is paramount, focusing on scalability, reliability, and energy efficiency. As a collaborative endeavor, this survey aims to equip scholars and industry practitioners with a comprehensive understanding of current trends and challenges in edge computing, paving the way for informed advancements in this dynamic and rapidly evolving field.

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