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Optimized Data Deduplication Strategy with Distributed Bloom Filters for Efficient Routing and Load Balancing in Clustered Environments

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Abstract:- This research paper delves into the realm of data routing strategies enhanced by a distributed Bloom Filter. The utilization of data deduplication technology effectively curbs data storage requirements and optimizes resource utilization. While the potential of single-node storage and computation is limited, the cluster data deduplication approach offers significant advantages. However, it introduces fresh challenges related to diminishing deduplication rates and maintaining equilibrium among storage nodes.

To address these concerns, the study introduces a novel data routing strategy grounded in distributed Bloom Filter principles. The strategy capitalizes on the concept of a "Super chunk" as the fundamental data routing unit, bolstering overall system throughput. Following Broder's theorem, a selection process identifies the k smallest fingerprints, shaping Super chunk features sent to storage nodes. By employing Bloom Filter comparisons, the optimal routing node is determined, taking into account node storage capacity and memory maintenance.

The research progresses to the design and implementation of system prototypes. Rigorous experimentation yields precise parameters for various routing strategies, subsequently subjected to testing. The results affirm the viability of the proposed strategies, both theoretically and empirically. Notably, our approach outperforms alternative routing methods, showcasing a 3% enhancement in deduplication rates. Furthermore, it slashes communication query overhead by over 36% while bolstering the load balancing aspects of the storage system.

Keywords:- *Data Routing, Load Balancing, Clustered Deduplication, Distributed bloom filters, Super chunk, Deduplication rate, Communication overhead, Storage system, Cloud computing, System throughput.*

I. INTRODUCTION

In today's landscape, data holds unparalleled significance for both enterprises and individuals alike. However, the sheer exponential expansion of data has introduced formidable challenges in its management. As data volumes surge to unprecedented scales—reaching the levels of petabytes (PB) and even exabytes (EB) within enterprise data management centers—the associated costs of data administration become notably inflated. This intensifies the urgency to enhance the efficiency of data backup storage. Evidently, research endeavors have increasingly converged on this demand.

A survey of the contemporary data milieu reveals an astonishing reality: approximately 75% of the global data corpus is marked by redundancy. This phenomenon becomes even more pronounced in the realm of backup data and file systems, where redundant data reaches a staggering 90%. In this context, recent strides in deduplication technology stand out as a pivotal solution to the quagmire of duplicated data. By virtue of its robust data compression capabilities, deduplication has emerged as a potent strategy for modern storage systems burdened by voluminous data loads.

Yet, the scalability of deduplication has been constrained by the computational and storage limitations intrinsic to individual nodes. To surmount these constraints, the paradigm of Cloud Deduplication (CD) harnesses the collective power of clustered systems, capitalizing on their expansive storage capacity and parallel processing capabilities. This orchestrated integration enables the application of deduplication across large-scale distributed storage systems. Within the landscape of CD, a crucial pivot emerges in the form of data routing strategy—a mechanism that orchestrates the distribution of data to each storage node while effectuating data deduplication at these nodes. An alternate approach involves performing data deduplication prior to transmitting data to storage nodes. Each approach boasts its own merits and demerits. However, for maintaining system parallelism and mitigating system overhead, current cluster deduplication frameworks predominantly favor the former, where data deduplication is executed post data routing.

Implementing an effective routing strategy necessitates the maintenance of fingerprint indexes for data blocks within the memory of storage nodes. Typically, data blocks are sized at 4KB, while the fingerprint dimensions for each data block hover around 40B. This juxtaposition results in a notable ratio: the size of the block fingerprint versus the overall data volume approximates 1:100. However, the practical constraints of storage node memory capacity and associated costs loom large. Storing this colossal array of fingerprint indexes within storage node memory proves implausible, thereby mandating their storage on disk. Consequently, the fingerprint indexes required for deduplication are selectively loaded into memory solely during deduplication procedures.

In essence, the monumental surge in data's significance has been met with equally remarkable challenges. The pursuit of efficient data storage solutions has led to the ascension of deduplication technology. However, the intricate interplay of computational limits, storage capacities, and the dynamics of data routing strategies underscores the multifaceted nature of this pursuit. This research embarks on a journey to bridge these gaps, propelling data routing strategies grounded in the tenets of distributed Bloom Filter theory, thus ushering in a novel era of data management efficiency and distributed storage optimization.

II. LITERATURE SURVEY

The paper title “Research on multi-feature data routing strategy in deduplication” By Q. He, G. Bian, B. Shao, and W. Zhang [1], This study delves into the realm of deduplication, a powerful data reduction technique in storage systems. Highlighting its capacity to unearth and eliminate redundant data, diminish storage requirements, enhance resource utilization, and curtail costs, the research underscores its significance. Acknowledging the limitations of single-feature similarity calculations, particularly for similar files, the authors propose a multi-feature data routing strategy (DRMF). This strategy hinges on cluster features, entailing routing communication, file similarity computation, and target node determination. Through routing communication, routing servers, and storage nodes, mutual information exchange is facilitated. Storage nodes evaluate file similarities and subsequently steer routing based on routing server inputs. The routing server, factoring in similarity outcomes and node load, selects the route's target node. The study culminates in a system prototype, parameter experimentation, and simulation, revealing that DRMF enhances deduplication rates and minimizes data skew, outperforming single-feature alternatives like MCS.

“Boafft: Distributed deduplication for big data storage in the cloud.” By S. Luo, G. Zhang, C. Wu, S. U. Khan, and K. Li. [2], As the data volume burgeons in data centers, cloud storage systems grapple with challenges concerning storage capacity and efficient data movement. This project introduces Boafft, a distributed deduplication-enabled cloud storage system. Boafft employs multiple data servers to parallelize data deduplication, maintaining substantial deduplication ratios. Key strengths include an effective data routing algorithm grounded in data similarity, minimizing network overhead by swiftly pinpointing storage locations. In-memory similarity indexing within each data server accelerates local deduplication by reducing random disk I/O. Boafft also constructs hot fingerprint caches based on access frequency, elevating deduplication ratios. Comparative analysis against EMC's stateful routing algorithm highlights Boafft's superior deduplication ratios and balanced storage usage. Given the surge of enterprise data centers grappling with petabytes to exabytes, the technique of data deduplication emerges as a pivotal approach to enhance storage resource utilization and reduce costs.

“Data deduplication technology for cloud storage” by Q. He, G. Bian, B. Shao, and W. Zhang [3] In the realm of burgeoning data creation and storage, challenges emerge concerning both data retention and access speed. Despite data duplications within storage, swift access remains paramount. Cloud storage solutions alleviate this issue by granting easy data accessibility along with efficient memory reutilization. This approach enhances storage efficacy while facilitating data backup and restoration in the event of crashes, thereby averting data inconsistencies. Deduplication tactics encompass logical pointers and hash functions, managed by a deduplication manager that employs pointers to replace duplicate data, regardless of the load. Security and data consistency are central considerations. This chapter delves into data deduplication within cloud computing, elucidating how the cloud effectively tackles data duplication challenges, ultimately optimizing data management.

“EaD: A collision-free and high-performance deduplication scheme for flash storage systems” by S. Wu, J. Zhou, W. Zhu, H. Jiang, Z. Huang, Z. Shen, and B. Mao [4] Inline deduplication is favored for curtailing write traffic and enhancing flash-based storage efficiency, yet it introduces computing and memory overhead due to cryptographic hash generation. With advanced technologies like 3D XPoint and Z-NAND amplifying overheads, a solution is required. This study proposes "EaD," an ECC-assisted deduplication method. EaD leverages ECC values as data chunk fingerprints, circumventing costly cryptographic hash calculations and memory overhead. By comparing ECC-based chunk similarities in memory, redundant data removal is efficiently executed. EaD notably slashes I/O latency by 1.92× and 1.86× on average and trims memory usage by 35.0% and 21.9%, outperforming existing SHA- and sampling-based deduplication methods. As flash-based devices are pivotal for storage performance, deduplication plays a crucial role in mitigating write traffic and enhancing efficiency, especially in modern computer systems where storage demand and energy efficiency are paramount.

“Reducing garbage collection overhead in SSD based on workload prediction” by: P. Yang, N. Xue, Y. Zhang, Y. Zhou, L. Sun, W. Chen, Z. Chen, W. Xia, J. Li, and K. Kwon [5] Garbage collection (GC) holds significance in Solid-State Drives (SSDs), freeing up NAND blocks for new data. However, data movement during GC impacts SSD performance and lifespan. This project introduces a strategy to optimize GC by categorizing data into different blocks based on predicted "temperature" of use. Utilizing a neural network (LSTM) enhances temperature prediction accuracy. K-Means clustering groups similar "future temperature" data in the same blocks. Improved performance and reduced write amplification factor (WAF) are observed across applications. The most substantial enhancement is seen in a 43.5% reduction in WAF and up to 79.3% decrease in 99.99% write latency, signifying the effectiveness of this approach in enhancing SSD efficiency and longevity.

"Ultra-low latency SSDs' impact on overall energy efficiency" by B. Harris and N. Altiparmak [6] Recent technological strides have ushered in an era of Ultra-Low Latency (ULL) SSDs, effectively bridging the performance chasm between primary and secondary storage devices. However, their power consumption attributes remain a mystery, and ULL SSDs' impact on system components is anticipated to heavily influence overall energy efficiency. In this study, we delve into this domain using an Optane SSD as a real ULL storage device, a power meter, and a spectrum of IO workload behaviors. By offering critical insights into idle vs. active and read vs. write behaviors, energy proportionality, system software influence, and overall energy efficiency, this research marks the first comprehensive exploration of a ULL SSD's influence on a system's power consumption. This pioneering investigation holds promise for shaping future energy-efficient designs. The storage landscape has witnessed a slew of innovations, including widespread adoption of the NVMe interface for next-gen storage devices and advancements like multi-queue request handling (blk-mq) in the Linux block IO layer. Novel IO scheduling algorithms tailored for blk-mq and emerging storage technologies like Intel's Optane SSDs, Samsung's Z-SSD, and Toshiba's XLFlash, based on 3D XPoint and SLC 3D NAND technologies, have paved the way for ULL SSDs, characterized by sub-10 µs data access latency. This study elucidates how ULL SSDs revolutionize storage performance by narrowing the divide between primary and secondary storage devices. By meticulously analyzing ULL SSD behaviors and their implications for system-wide energy efficiency, this research marks a critical step toward harnessing the full potential of ULL SSDs and fostering energy-conscious design practices in the field of storage technology.

III. METHODOLOGY

In contrast, cloud storage stands as a pivotal cloud computing service, focusing on data storage and its efficient management. The integration of deduplication technology within cloud storage systems, coupled with the leveraging of node-based computational and storage capabilities, holds the promise of enhancing the overall performance of such storage infrastructures. Nonetheless, steering deduplication toward cloud storage introduces the intricate challenge of overseeing a multitude of storage nodes within the cloud ecosystem. This endeavor must ensure equitable distribution of node workloads while safeguarding the integrity of the deduplication process against significant degradation.

The data routing strategy emerges as a central protagonist in this narrative, orchestrating the seamless transfer of data from clients to designated storage nodes. A pivotal aspiration is to maximize the concentration of duplicate data within the same node. However, over time, this approach can engender an imbalance wherein certain nodes amass an excessive volume of system data, while others remain underutilized. Consequently, striking a harmonious equilibrium between these two dimensions becomes the crux of the matter when devising effective data routing policies.

The scope of this project encompasses the formulation of a data routing strategy that leverages the principles of data similarity along with pertinent factors like storage node capacity. Through this approach, a harmonious equilibrium is achieved, effectively managing the trade-off between redundancy rate and load distribution. The primary objective is to circumvent any substantial decline in the redundancy rate, all the while ensuring a judicious dispersion of data across the storage nodes, thereby upholding a balanced and efficient system configuration.

A. Problem Statement:

Nevertheless, an excessive volume of disk accesses can precipitate the emergence of disk bottleneck issues, consequently dampening overall system throughput. Furthermore, within the context of cluster deduplication systems, the prevalent practice primarily involves conducting deduplication operations using solely the data resident within each respective node. This practice, though, poses a twofold challenge: it not only contributes to a decline in the overall deduplication rate across the entire system but also culminates in the accumulation of a disproportionately large share of duplicate data being routed to a select few nodes, thereby inducing an undesirable state of load imbalance.

Hence, the predicaments confronted by cloud deduplication are threefold: the efficacious performance of data queries, the preservation of deduplication rates, and the pursuit of equitable load distribution. Against the backdrop of the advancing cloud computing landscape, cloud computing services have evolved to centralize the deployment and management of data resources, in turn, optimizing the comprehensive resource utilization. To address these challenges, the proposed solution involves the integration of a load balancing-oriented routing strategy within the overarching deduplication system framework, thereby orchestrating a synchronized increase in the storage capacity across all storage nodes

B. Existing System:

- Nonetheless, an excess of disk accesses has the potential to instigate bottlenecks within the disk subsystem, thereby exerting a detrimental impact on the overall efficiency of the system's data processing flow.
- Simultaneously, it's notable that in the operational landscape of cluster deduplication systems, the prevailing practice primarily confines deduplication processes to the data contained within each individual node. Unfortunately, this approach precipitates a

confluence of challenges. It not only engenders a decline in the overall deduplication rate across the entire system but also precipitates an unbalanced distribution of duplicate data, disproportionately routed to a select subset of nodes.

- In light of these complexities, the predominant challenges intrinsic to cloud deduplication coalesce into a triad: the optimization of query performance, the preservation of deduplication efficiency, and the facilitation of equitable load distribution across the system's nodes.

C. Existing System Disadvantages:

- It is difficult for the node memory to maintain such a huge hash table, Less Efficient and Security.
- If we exist efficient and security.

D. Proposed System:

This study presents a novel data routing strategy rooted in the principles of distributed Bloom Filter technology

- The fundamental data routing unit is designated as the "Superchunk," a pivotal element augmenting the system's throughput. Drawing from Broder's theorem, this approach entails the selection of k minimally-sized fingerprints to serve as Superchunk attributes. These attributes are subsequently dispatched to the storage node. Leveraging Bloom Filter matching, the optimal routing node is identified, considering the node's Bloom Filter and storage capacity. These parameters are actively maintained within the memory of the storage node.
- Furthermore, the endeavor includes the design and realization of system prototypes. The methodology involves conducting a series of experiments to ascertain the specific parameters applicable to diverse routing strategies. Subsequently, these refined routing strategies, conceived within the framework of this project, are subjected to rigorous testing and evaluation.

E. Technique or Algorithm Used:

Distributed Bloom Filter-Centric Data Routing Strategy:

This section delves into the formulation of an innovative data routing strategy, firmly anchored in the principles of a distributed Bloom Filter framework. This strategy unveils an expedited route for data routing queries, leveraging the prowess of Bloom Filters and a select subset of superblock representative fingerprint IDs.

In stark contrast to EMC's stateful routing approach, this newly devised strategy capitalizes on Bloom Filters to govern the management of superblock representative fingerprint IDs within the storage node's memory. This circumvents the necessity of accommodating the complete array of fingerprint indexes within the node's memory space. Instead, solely a few superblocks representative fingerprint IDs are transmitted during this process.

Through the query process, this approach institutes the querying of a limited number of routing nodes. This endeavor is twofold: it aims to establish global load balancing through the aggregation of local load balancing efforts. As a result, the strategy epitomizes an innovative methodology that optimizes data routing by harnessing the efficiency of distributed Bloom Filters, fostering streamlined querying, and realizing dynamic load distribution across the network.

A. Super Block Similarity:

Within the realm of cluster data deduplication, the utilization of super blocks as routing units is a common practice, aimed at optimizing system throughput. An imperative challenge in this context involves determining the destination nodes for these superblocks before data transmission. This necessitates the identification of the storage node harboring the highest concentration of duplicate data within the superblock. To circumvent the communication overhead, the approach of sending data blocks for one-by-one comparison across all storage nodes is impractical. Common methodologies, like MD5 or SHA-1, compute data block fingerprints, transmitting this fingerprint data to the storage node, and subsequently employing a similarity algorithm to ascertain data resemblance.

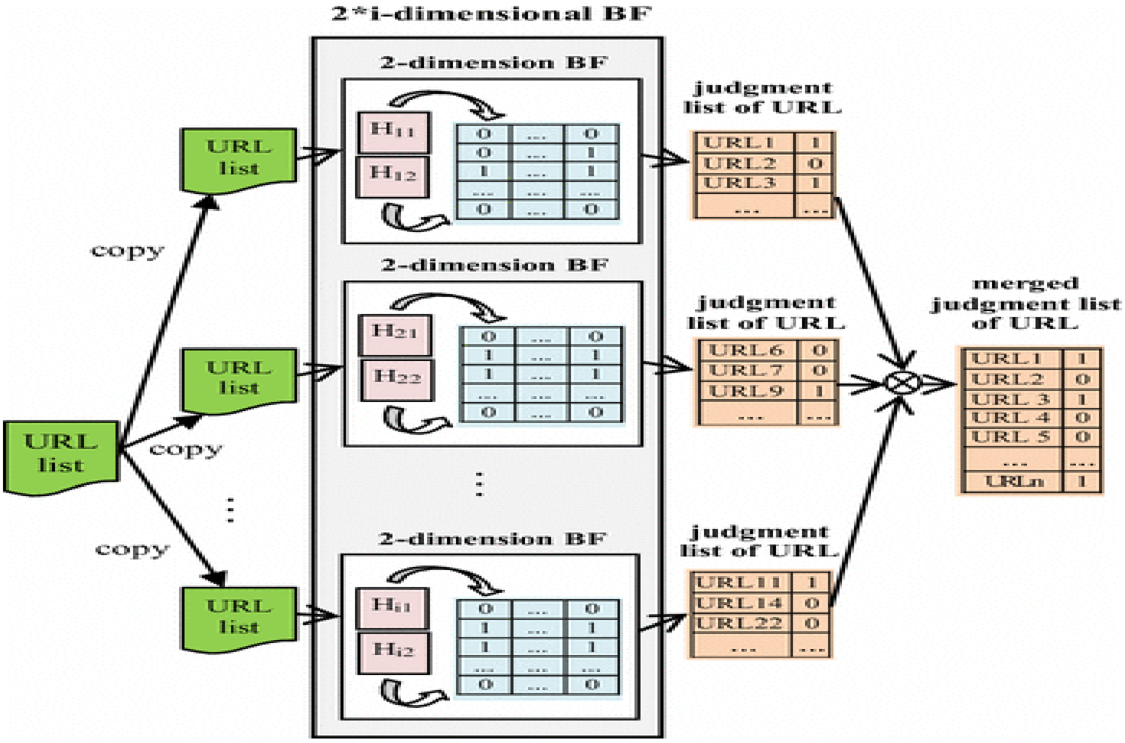

Fig. 1: The Distributed multi-dimensional bloom filter based on hash function

This project innovatively adopts Bloom Filters to assess the similarity of superblock data. The application of Bloom Filters capitalizes on the advantageous blend of heightened efficiency and minimal storage consumption. Moreover, this strategy minimizes the susceptibility of misjudgments influencing data assessments. Furthermore, maintaining load equilibrium within a cluster storage system necessitates not only directing maximum duplicate data to a specific storage node but also factoring in the storage node's capacity and overall load for comprehensive routing node selection.

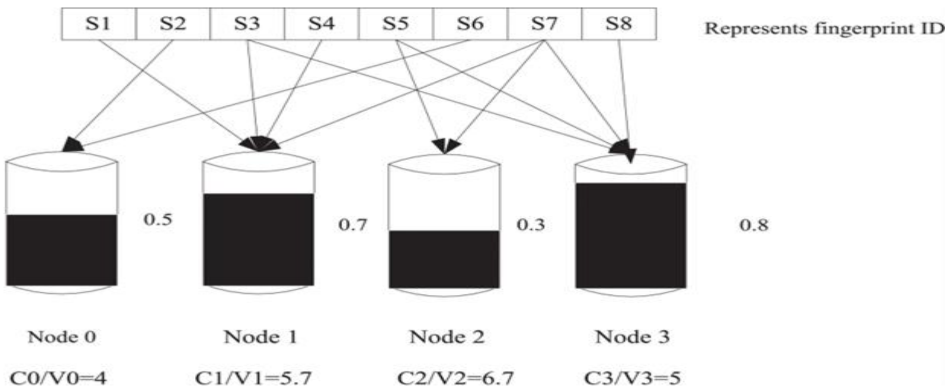

Fig. 2: K- representative fingerprint's

In Figure 2, let's consider k representative fingerprint IDs numbering 8, within a cluster deduplication system featuring 4 storage nodes. The figure illustrates the distribution of representative fingerprint IDs and storage capacities across the nodes. Node0 accommodates 2 out of the 8 representative fingerprint IDs, bearing a storage capacity of 0.5. Node1 houses 4 fingerprints, Node2 has 2, and Node3 hosts 4. Although initial intuition might direct the superblock towards Node1 or Node3, the figure's depiction highlights the substantial data already amassed in these nodes. Prolonged data influx could potentially exhaust the storage capacity of these nodes.

To address this, the article proposes a selection methodology employing the ratio Ci/Vi, where Ci represents the count of stored data block fingerprints in storage node i, and vi signifies the storage node's data block capacity. Computationally, this ratio identifies the optimal routing node. The article accentuates that the actual application doesn't prioritize deduplication rates initially but pivots towards load balance once a certain number of data blocks populate the system.

By integrating load balancing into the overall deduplication framework, the storage capacities of all nodes are concurrently augmented. Consequently, the disproportionate storage capacity disparities depicted in Figure 1 are preemptively averted. In practical scenarios, this balanced storage capacity aligns with the similarity matching of superblocks, negating the depicted disparities.

The paper presents alternative approaches to node selection: one based on a threshold and another leveraging the average storage capacity of the system. These approaches enhance the robustness of the routing strategy by considering diverse factors beyond the sole maximization of Ci/Vi. The presented strategies contribute to achieving better system outcomes, fostering an equilibrium among storage nodes and promoting efficient data routing.

F. E-R Diagram:

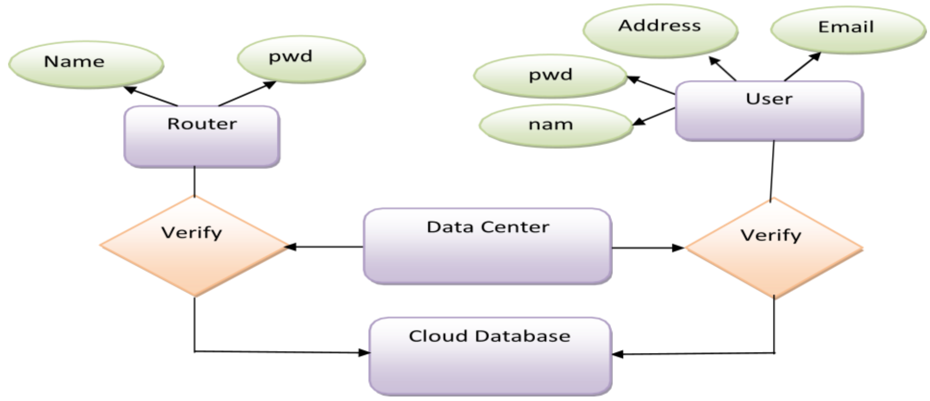

Fig. 3: E-R Diagram

G. System Architecture:

The proposed system architecture integrates distributed Bloom Filters into a clustered deduplication framework, aiming to enhance data routing and load balancing. At its core, the architecture utilizes the concept of a "superchunk" as the fundamental data routing unit, enhancing system throughput. Leveraging Broder's theorem, a subset of the smallest-sized fingerprints is selected as superchunk features, which are then transmitted to storage nodes. The optimal routing node is determined by matching these features against Bloom Filters stored in the memory of the storage node. This architecture addresses the challenges of deduplication rate reduction and storage node load imbalance. By distributing workload intelligently and utilizing efficient fingerprint management, the system achieves improved deduplication rates, reduced communication overhead, and enhanced load balance within the storage infrastructure.

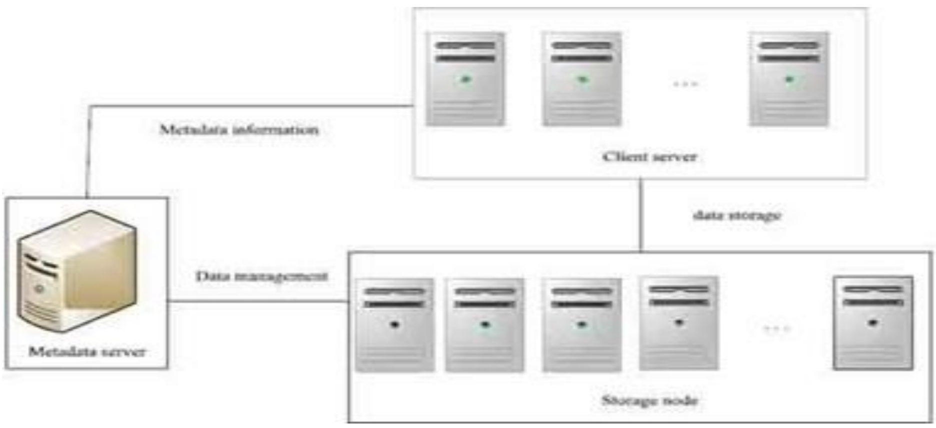

Fig. 4: System Architecture

H. Proposed System Advantages:

- The system throughput overhead caused by the broadcast data query method and the Bloom Filter with many fingerprints maintained within the query node greatly affect the system performance.
- More Efficient and more security.

The routing algorithm proposed within this segment aligns with the architecture of the cluster deduplication system. However, when orchestrating data routing processes, it becomes unfeasible to transmit the entirety of superblock data to the storage node for the purpose of query-driven routing node determination. If storage nodes were to rely on indexed tables for the storage of data block fingerprints, the constraints of memory capacity prohibit the accommodation of all fingerprint data.

An alternative strategy involves maintaining only a subset of representative fingerprint ID indices from the superblock in memory. While this approach curtails the memory space requirements, it inadvertently introduces a sequential query mode for the index table, leading to an escalation in the communication overhead experienced by the system.

To address these intricacies, the adoption of Bloom Filter technology emerges as a solution for managing fingerprint indexes within memory. This approach finds resonance in stateful routing policies, albeit at the cost of incurring a notable degree of system overhead.

To implement this project, we have designed following modules:

➢ *Interface Design for User Interaction:*
Within this module, the project's graphical user interface (GUI) is meticulously crafted. The central emphasis is on sculpting an intuitive and visually appealing interface for user interaction. A primary objective of this module revolves around the design of the login page, which incorporates elements of partial knowledge information. When users seek access to the application's functionalities, they are prompted to engage with the GUI. This interface essentially serves as the bridge connecting users and the media database. Notably, the login screen within the GUI provides an avenue for users to input their respective usernames and passwords. These credentials are subsequently cross-referenced with the database, facilitating the validation process. Successful authentication grants users the privilege to access the database and its associated resources.

➢ *Client-Server Interaction (CS):*
The pivotal role of this module lies in the effective processing of data streams. Within this algorithmic framework, the client-server interaction takes center stage. Upon receiving an incoming data stream, the client-server duo undertakes a sequence of vital operations. This includes the segmentation of data into data chunks, the computation of fingerprints for individual data blocks, and the orchestration of superblock assembly and routing.

Furthermore, as part of this process, the determination of the appropriate routing node for the data becomes imperative. In parallel, the metadata associated with the data is dispatched to the metadata server, a critical step designed to facilitate future data recovery procedures. The crux of the routing node determination lies in the selection of the k minimum block fingerprints. These fingerprints are dispatched to the designated storage node for query operations. This strategic choice avoids the necessity of forwarding complete data blocks to the storage node, thereby effectively curtailing the communication overhead experienced by the system.

➢ *Routing Mechanism (Router):*
This module stands as the second cornerstone of the project's architecture. The initial action involves the entry of the username and password, serving as a secure gateway into the web-based interface. Upon successful login, the system undertakes an intricate process, meticulously scrutinizing the data requests emanating from various users' clients. All incoming requests are duly acknowledged and processed. A pivotal capability of this module lies in its capacity to comprehensively display all files within the system, affording administrators and users the ability to peruse the system's contents. Moreover, the module operates as a vigilant overseer, promptly detecting and addressing any anomalies that may arise throughout the data processing journey.

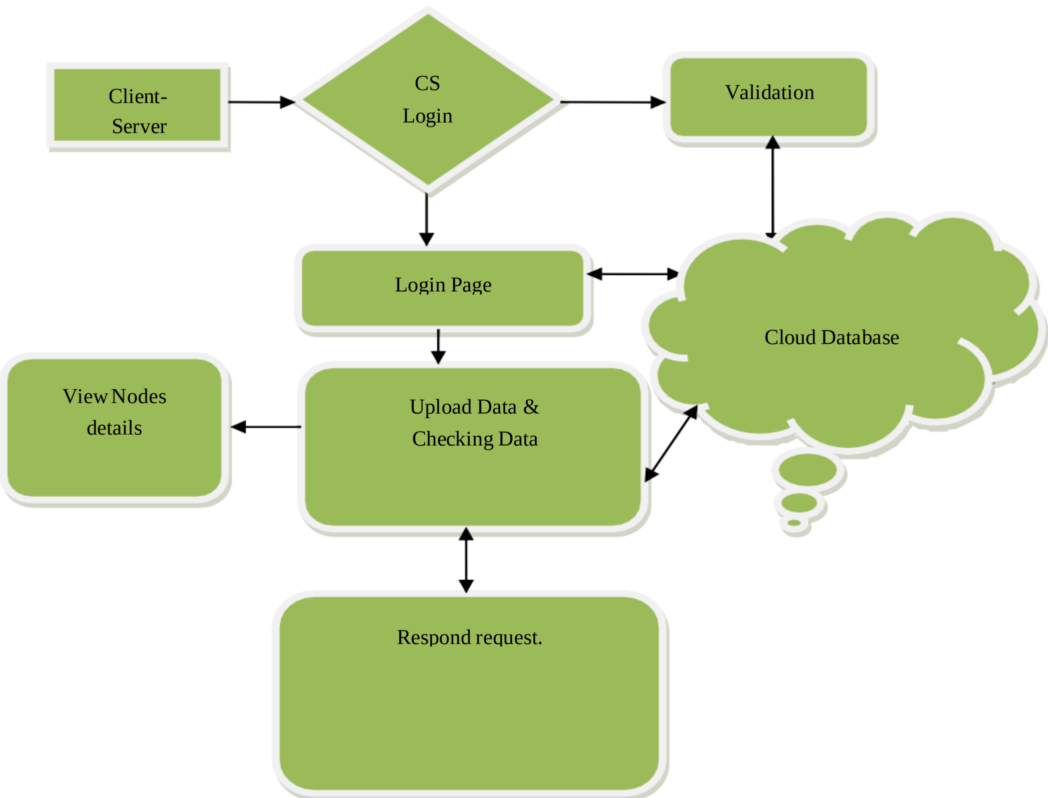

Fig. 5: Client-Server Interaction (CS)

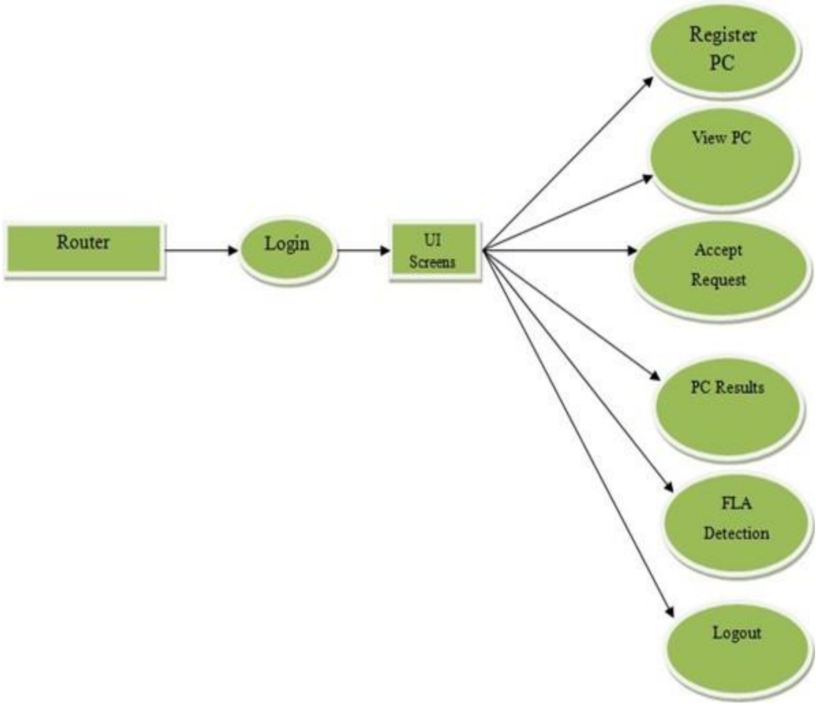

Fig. 6: Routing Mechanism (Router)

➢ *User Interface (PC):*

Within this context, the user engagement commences with a preliminary registration process, enabling users to establish their unique identities. Following registration, users gain access to the web-based interface through a secure login process. The system generates personalized credentials in the form of usernames and passwords, derived from the user-provided details. These credentials serve as the key to unlock the web interface, affording users the opportunity to delve into its functionalities. Once logged in, users possess the capacity to comprehensively survey the available data resources. Moreover, the interface facilitates the seamless storage of user-generated data within the system, contributing to the repository's expansion.

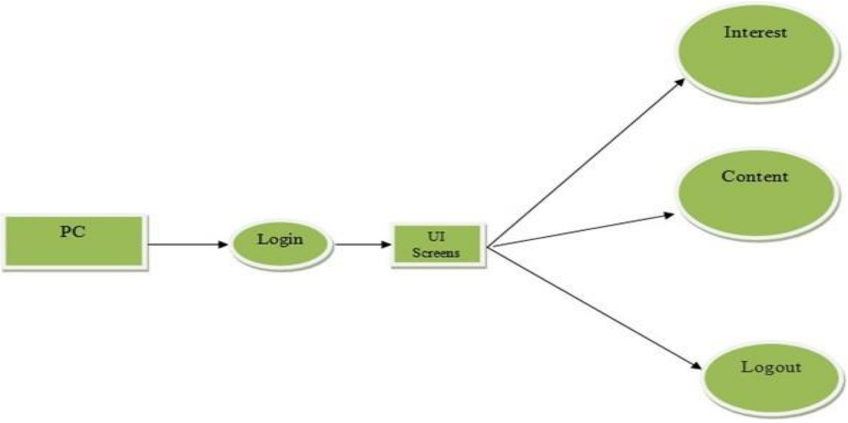

Fig. 7: User Interface (PC)

- Output Snapshots:

Fig. 8: Home Page

Fig. 9: User Registration

Fig. 10: System Manager Login

Fig. 11: Activate user

Fig. 12: View users

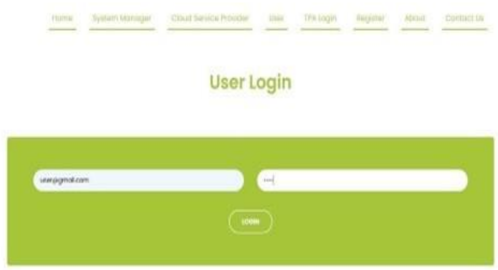

Fig. 13: User login

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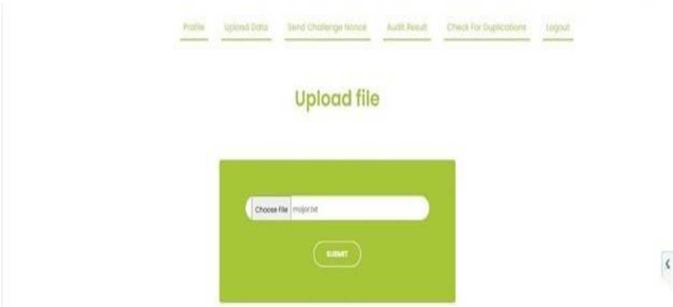

Fig. 14: Upload file to the cloud

Fig. 15: Cloud Service Provider Login

Fig. 16: Create Index for the uploaded file

Fig. 17: Send file for Audit

Fig. 18: Audit the file and send to TPA for publishing

Fig. 19: TPA Login

Fig. 20: Publish file

Fig. 21: Generating Hash code and Hash values after publishing the file

Fig. 22: Result, when we try to upload a wrong file

IV. CONCLUSION

The pursuit of streamlining communication overhead within clustered deduplication systems has led to the development of a novel data routing strategy, as proposed in this project. This strategy centers around the utilization of a distributed Bloom Filter framework, harnessing the superblock as the fundamental unit for data routing. Key to this strategy is the selection of k minimal block fingerprints from the superblock to serve as representative fingerprint IDs. These IDs guide the determination of p storage nodes, subsequently employing Bloom Filters to ascertain the occurrence count of these fingerprint IDs in the designated nodes. The ultimate routing node is then calculated by considering both the match count and the storage node's capacity.

This strategy offers a compelling solution that not only mitigates communication overhead but also improves the deduplication rate and fosters enhanced load balancing. As of now, research into cluster deduplication routing strategies primarily orbits around the twin focal points of deduplication rate and load distribution. While significant progress has been made in these areas, various challenges persist or have emerged as prominent avenues for further exploration. This underscores the evolving nature of the field and the ongoing potential for innovation in the domain of cluster deduplication routing strategies.

V. FUTURE ENHANCEMENT

The trajectory of future research should pivot towards the exploration and refinement of the following domains:

Dynamic Management of Storage Nodes: The evolution of the cluster deduplication system necessitates a more comprehensive understanding of how to seamlessly integrate the addition and removal of storage nodes. Instances where nodes cease to function or when the existing storage capacity proves insufficient for burgeoning data demand effective solutions. While current strategies like consistency hashing and erasure coding exhibit some efficacy, there exists ample room for improvement. Future research should delve into devising more efficient and robust mechanisms for transferring data to new storage nodes and recovering lost data.

Refining Representative Fingerprint ID Selection: The current practice predominantly relies on the Border theorem to select representative fingerprint IDs for superblocks. However, the consequential impact of this selection on the data routing strategy's efficiency for the data routing unit remains less pronounced. Future studies should critically examine the selection of optimal data routing units or representative fingerprint IDs. Through this exploration, the deduplication rate of the system can be significantly elevated, unlocking new dimensions of effectiveness and optimization.

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