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Reducing Network Congestion in SAN Environments through Dedicated FC-Based Backup Architecture

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Abstract: A Storage Area Network (SAN) is a dedicated high-speed network architecture designed to facilitate block-level storage access for servers. By interconnecting storage devices, such as disk arrays, with servers, SAN enables efficient and rapid data retrieval. SAN differs from traditional NAS, which operates at the file level, by providing block-level access to storage. This enables greater performance, scalability, and flexibility—especially for applications that process large volumes of data. Due to its centralized storage management capabilities and reliability, SAN is widely deployed in enterprise environments, especially for disaster recovery and large-scale data processing. This study introduces an improved SAN backup technique aimed at optimizing CPU utilization and reducing link load. This study evaluates an enhanced SAN backup framework using the OPNET 14.5 simulation tool. A dedicated Fibre Channel (FC)-based architecture was modeled and tested against a conventional Ethernet-linked SAN. Simulation results show a 37% improvement in FTP response time (from 0.022s to 0.014s) and a 4% throughput increase (from 137 to 142 bytes/sec). These findings support the system's effectiveness in reducing congestion and enhancing backup operations in enterprise-like conditions.

Keywords: Big Data; Network-Attached Storage (NAS); Network Storage; Performance; Storage Area Network (SAN)

1 INTRODUCTION

Computing fundamentally depends on data, which serves as the essential resource underlying all computational processes. Data is stored on storage media and accessed by platforms operating on servers. In many cases, data represents a unique and valuable organizational asset, continuously generated and collected in real-time. Data has become central to business operations and is now considered a major driver of enterprise success. Consequently, effective data management and security measures are crucial to safeguarding sensitive information and maintaining system reliability. This highlights the necessity of implementing robust enterprise data protection strategies to mitigate potential risks and enhance overall operational efficiency [1-3].

To address this challenge, network storage offers a centralized, accessible solution for managing critical data generated by digital systems. By enabling centralized data storage, network storage systems enhance data organization, accessibility, and reliability, ensuring seamless access to essential business information. Organizations now deploy critical applications—like CRM, BI, ERP, and SCM—that treat data as a vital strategic asset across multiple industries. The integration of these applications necessitates scalable and high-performance storage solutions to accommodate growing data volumes and ensure seamless data retrieval. Furthermore, as businesses continue to digitize operations, network storage plays a vital role in supporting data-driven decision-making and enhancing overall operational efficiency. Consequently, investing in robust network storage infrastructures is essential for organizations aiming to maintain competitiveness and achieve long-term success [4-6].

While existing SAN architectures offer scalability and performance, their efficiency degrades during backup operations due to shared network congestion. This study addresses the gap by proposing a Fibre Channel-based backup path to isolate data flows. The main contribution lies in the architectural redesign and simulated performance evaluation, highlighting latency reduction and improved network stability [7-10].

To meet these demands, various network storage technologies have been developed, including Network-Attached Storage (NAS), Direct-Attached Storage (DAS), and Storage Area Networks (SAN). These technologies differ in performance, scalability, and data handling, enabling tailored storage architectures for various business needs. The adoption of these advanced storage solutions has enabled enterprises to optimize data handling processes while reducing latency and enhancing accessibility. As digital transformation accelerates, advanced storage management techniques are essential to ensure high availability and data durability [11].

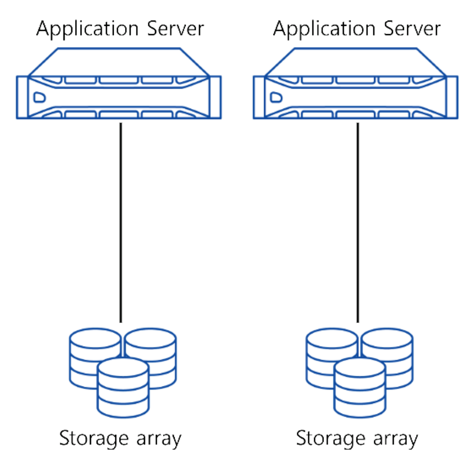

Figure 1 Architecture of DAS

The DAS approach involves utilizing internal server storage for each individual computer, as illustrated in Fig. 1. However, this method presents certain limitations, such as increased storage management complexity and the lack of data accessibility in the event of a server failure. Because DAS is linked to individual servers, failures can restrict access to stored data—posing risks for systems requiring continuous availability. To address these issues, Network-Attached Storage (NAS) technology has been introduced as a more efficient alternative.

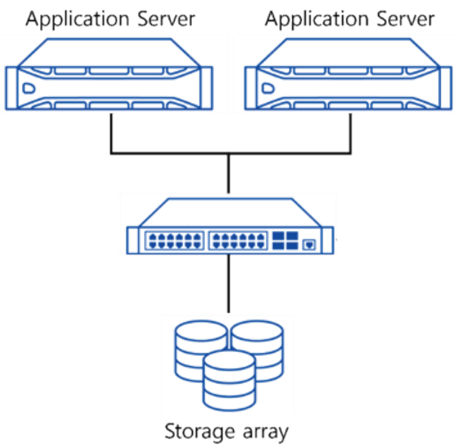

Figure 2 Architecture of NAS

NAS functions as a dedicated data storage solution that connects directly to a network, as depicted in Fig. 2. NAS assigns each device a unique address, enabling centralized or direct access without relying on a specific server, unlike DAS. This architecture enhances data accessibility, improves fault tolerance, and simplifies storage management for organizations handling large volumes of information. Additionally, NAS systems support multiple users simultaneously, enabling seamless data sharing across different devices and departments. With the rise of cloud adoption and remote work, integrating NAS with cloud storage is essential for ensuring redundancy, security, and scalability [12-13].

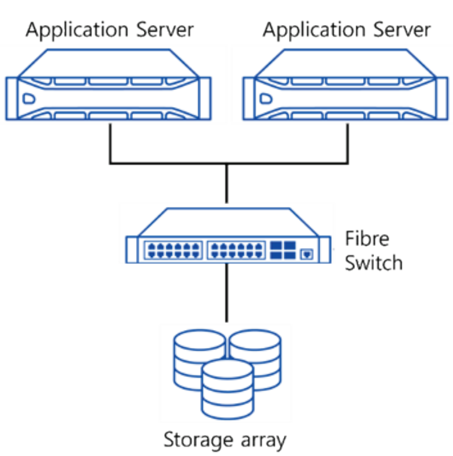

Figure 3 Architecture of SAN

A Storage Area Network (SAN) enhances the efficiency and flexibility of data distribution by providing high-speed, dedicated access to storage resources. Unlike a traditional Local Area Network (LAN), which allows users and applications to retrieve data from a central storage system, SAN significantly accelerates data transfer rates, ensuring optimal performance for data-intensive applications. As shown in Fig. 3, a SAN enables multiple computers to exchange large files simultaneously at speeds comparable to directly attached disk storage, without burdening the local network infrastructure.

By offloading storage-related traffic from conventional LANs, SAN improves overall network efficiency, reducing latency and congestion. This architecture is particularly beneficial for enterprise environments that require high availability, redundancy, and scalability in their storage solutions. Additionally, SAN facilitates seamless disaster recovery and backup processes by enabling remote replication of critical data, ensuring business continuity in case of failures. Furthermore, as modern enterprises continue to generate and process massive volumes of information, the integration of SAN with advanced storage management techniques, such as virtualization and cloud-based storage, has become essential for optimizing performance and ensuring long-term data sustainability.

Several researchers have conducted simulations to analyze the performance and advancements of Storage Area Networks (SANs). Various studies have utilized specialized simulation tools to model the functionality of Fibre Channel (FC) switches, establish input, and output connections between storage and server devices. These tools enable a detailed evaluation of data transmission efficiency and network reliability in diverse SAN configurations. One study introduced an advanced simulation framework capable of replicating multiple FC devices within a two-phase network structure, extending the capabilities of previous research. This approach allows for a more comprehensive analysis of SAN scalability and performance under varying workloads.

Additionally, a simulation system known as SANSim was developed to model the behavior of SAN environments, particularly focusing on the arbitrated loop mechanism in FC devices. By incorporating detailed network components, SANSim provides valuable insights into data flow, congestion management, and system optimization strategies. These simulation tools play a crucial role in enhancing SAN design, allowing researchers and engineers to identify potential bottlenecks and improve overall network efficiency.

2 RELATED WORKS

The primary objective of a Storage Area Network (SAN) is to facilitate efficient data transfer between computing systems and storage devices. The communication framework within a SAN consists of a physical infrastructure, computing nodes, and a management layer that orchestrates these connections to ensure secure and reliable data transmission. This layered architecture not only enhances data accessibility but also optimizes resource allocation by enabling centralized storage management. SANs are predominantly built on Fibre Channel (FC) technology, which offers high-speed data transfer rates, making them well-suited for enterprise environments that require low-latency and high-bandwidth storage solutions [14. 15].

Unlike traditional Direct-Attached Storage (DAS) systems, which create isolated storage silos, SANs provide a unified storage infrastructure that improves overall data availability and scalability. Furthermore, the integration of advanced security protocols within SAN architectures strengthens data protection mechanisms, reducing vulnerabilities associated with unauthorized access or potential data loss. By consolidating storage resources, SANs effectively eliminate the fragmentation of data islands that were common in older DAS-based systems. This consolidation not only enhances operational efficiency but also simplifies disaster recovery and backup processes, ensuring business continuity in the event of system failures. As data-intensive applications continue to grow, SAN technology remains a critical component of modern IT infrastructures, enabling organizations to manage and scale their storage environments efficiently.

Storage Area Networks (SANs) are designed to connect storage server devices in a clustered configuration, ensuring data availability and redundancy in the event of a primary storage failure. By distributing connections between servers and clients, SANs enhance data accessibility and reliability while reducing the risk of service disruptions. One of the key benefits of SAN technology is its ability to establish alternate data paths dynamically, enabling seamless failover mechanisms and minimizing downtime. This capability is particularly advantageous for high-performance computing (HPC) environments that require consistent data availability and low-latency access. Additionally, SANs incorporate advanced load-balancing techniques to optimize data traffic distribution, preventing network congestion and improving overall system efficiency. These features make SANs a vital component of modern IT infrastructures, providing organizations with scalable and resilient storage solutions tailored to support data-intensive applications.

The key advantages that make Storage Area Networks (SANs) essential include the efficient utilization of disk storage, minimizing wasted space while ensuring the availability of disaster recovery backups. This approach is particularly cost-effective, as it requires fewer servers compared to traditional storage methods. Additionally, SANs leverage high-speed Fibre Channel (FC) technology, capable of achieving data transfer rates of up to 200 Mbps, making them ideal for handling large-scale enterprise storage demands. Another significant benefit of SANs is their ability to support centralized storage management, allowing organizations to optimize storage allocation and enhance overall data accessibility. Furthermore, these networks are engineered for long-distance data transmission, with the capability to transfer information over distances of up to 100 km. This extended reach makes SANs particularly valuable for disaster recovery solutions, ensuring data redundancy across geographically distributed locations and enhancing business continuity strategies [16-18].

The Fibre Channel (FC) protocol utilizes the SCSI standard to facilitate high-bandwidth data transmission, supporting speeds of up to 1 GB per second. Recognized as a standard by the American National Standards Institute (ANSI) and the International Committee of Information Technology Standards, FC has become a critical component of modern high-speed storage networks. Originally developed for use in manufacturing environments, FC has since been widely adopted in enterprise data centers due to its reliability and efficiency in handling large-scale data transfers. The architecture of FC is composed of two primary components and is structured into seven distinct layers, each serving a specific function. One of its key advantages is its ability to provide lossless data transmission with low latency, making it particularly suitable for applications requiring high availability and real-time processing. Furthermore, FC technology is designed to support long-distance communication, enabling organizations to establish geographically distributed storage infrastructures for disaster recovery and business continuity.

3 PROPOSED METHOD

The proposed architecture introduces a backup-dedicated Fibre Channel (FC) path connecting backup servers and storage via an FC switch, bypassing traditional LAN congestion. We simulated this design using OPNET Modeler 14.5, configuring two scenarios: (1) a conventional SAN using Ethernet for all traffic, and (2) a proposed SAN with a separate FC backup path. Each network comprised three servers, one backup server, and two storage devices. FTP and HTTP applications were tested under concurrent load conditions for 60 minutes of simulated time. Metrics including FTP throughput and response time were collected using OPNET's Application Response Time (ART) and Traffic Sent/Received modules.

In traditional SAN environments, data streams travel across the LAN network to reach the backup server before being transferred to storage. However, the proposed design optimizes this process by using the FC network solely for the movement of backup data from the server to the storage device. This targeted approach not only reduces latency but also enhances data security by restricting access to backup data within the high-speed FC infrastructure. Additionally, the separation of backup traffic from regular LAN operations prevents potential bottlenecks, ensuring smooth and uninterrupted service for other network functions.

A key advantage of the proposed network design is its ability to deliver a higher response time compared to conventional SAN configurations. This improvement is particularly significant for high-performance computing environments and enterprise applications where rapid data recovery and low-latency access are essential. By optimizing data transfer pathways and reducing unnecessary network load, the proposed method enhances the overall efficiency of storage management while maintaining the integrity and availability of critical business data.

Simulations were performed using OPNET Modeler 14.5 with two network topologies: (1) a traditional SAN using shared Ethernet for all traffic and (2) the proposed SAN architecture with a dedicated FC path for backup. Each setup included three client nodes, one backup server, and two storage nodes, interconnected via Ethernet and FC switches, respectively. FTP and HTTP traffic generators were configured with fixed packet sizes (1024 bytes) and transmission intervals (0.01s), and each simulation ran for 60 virtual minutes. All results were averaged over five runs to account for variability, but no hardware fault simulation was included in this stage. Fig. 4 shows a proposed improved SAN system.

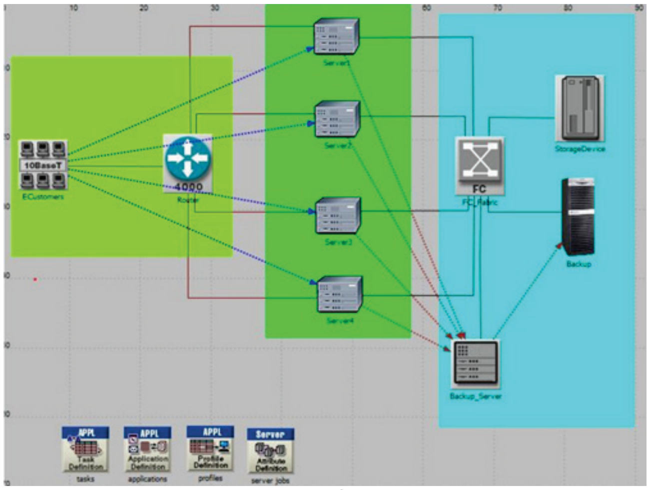

Figure 4 Proposed SAN architecture

Furthermore, the implementation of the proposed method provides an effective solution for organizations seeking to enhance data protection and disaster recovery strategies. By integrating a dedicated backup server and optimizing the use of FC switches, enterprises can achieve more efficient storage management while reducing dependency on Ethernet-based backups. This approach also facilitates scalability, allowing businesses to expand their storage infrastructure without compromising performance or network stability.

In conclusion, the proposed backup strategy introduces a more effective and flexible method for managing data backups within SAN environments. By leveraging the high-speed capabilities of FC technology and minimizing LAN network congestion, the new design significantly improves response times, data transfer efficiency, and overall system reliability. As organizations continue to generate and store vast amounts of data, adopting advanced backup solutions such as the one proposed in this study will be essential for maintaining high availability, security, and performance in modern data centers.

4 RESULT

Fig. 5 illustrates the comparison of FTP traffic received between the traditional SAN network and the proposed network architecture. The proposed architecture achieved a throughput increase of approximately 4%, from 137 to 142 bytes/sec. While the absolute value may seem modest, the isolated FC backup channel reduces contention on the main data path, offering stability and predictability under concurrent access. These improvements are meaningful in high-availability environments where consistent performance is critical. One of the primary factors contributing to this improvement is the optimized data flow, which reduces congestion and enhances bandwidth utilization. Additionally, the proposed network design effectively separates backup traffic from general network operations, ensuring minimal interference and improved performance for real-time data transfers. This higher throughput is particularly beneficial for applications requiring consistent and rapid data exchange, such as enterprise storage systems and cloud computing environments. The observed performance gains highlight the advantages of the proposed system in optimizing network resource allocation while maintaining high-speed data accessibility.

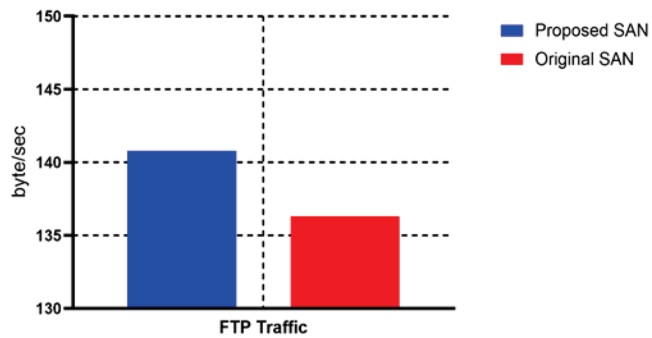

Figure 5 Results of FTP traffic

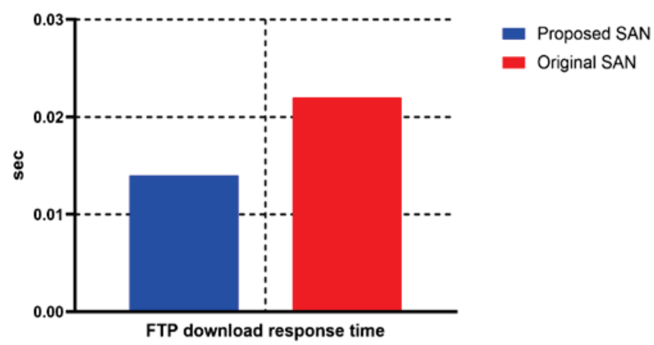

Figure 6 Results of FTP download time

Fig. 6 presents a comparison of FTP download response times between the traditional SAN network and the proposed network architecture. The results demonstrate that the proposed network achieves a lower response time, averaging approximately 0.014 seconds, compared to around 0.022 seconds in the conventional SAN network. This reduction in response time indicates the improved efficiency of the proposed system in handling data requests and minimizing latency. One of the primary reasons for this enhancement is the optimized data transmission pathways, which reduce network congestion and improve overall system responsiveness. Additionally, by dedicating Fibre Channel (FC) exclusively for backup data transfers, the proposed network minimizes interference with regular data traffic, allowing for faster and more stable download speeds. The reduced response time is particularly advantageous for high-performance computing environments, enterprise data centers, and cloud-based applications that rely on low-latency communication. These findings highlight the effectiveness of the proposed architecture in optimizing network performance while ensuring a seamless and efficient data transfer experience.

Fig. 7 illustrates the comparison of HTTP page response times between the traditional SAN network and the proposed network. The results indicate that the proposed network achieves a lower response time, averaging approximately 0.018 seconds, compared to around 0.04 seconds in the conventional SAN network. This reduction in response time highlights the enhanced efficiency of the proposed system in handling web-based requests and improving overall network performance. One of the key contributing factors to this improvement is the optimized traffic management approach, which reduces congestion and ensures a more efficient allocation of network resources. Additionally, the separation of backup traffic from regular network operations prevents bandwidth contention, allowing HTTP requests to be processed more quickly and reliably. The lower response time is particularly beneficial for applications that require fast and consistent access to web-based services, such as cloud computing platforms and enterprise web applications. These findings demonstrate the effectiveness of the proposed network architecture in enhancing HTTP performance while maintaining a stable and responsive communication environment.

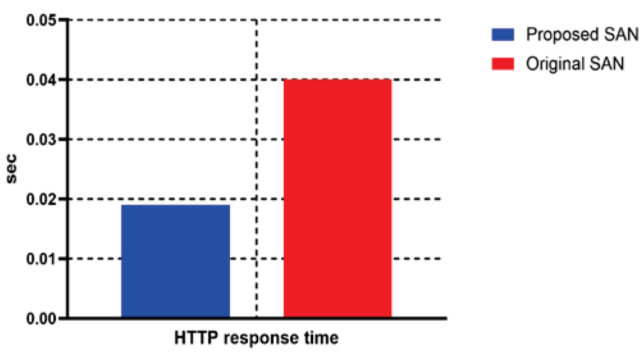

Figure 7 Results of HTTP response time

The results highlight the advantage of utilizing dedicated Fibre Channel links for backup operations in SAN environments. The proposed architecture demonstrates not only improved response times but also better bandwidth utilization. These benefits are especially relevant in industries such as finance, healthcare, and telecommunications, where data availability and integrity are critical. Nevertheless, limitations exist: simulations do not account for hardware failures or asynchronous backup behaviors. Further real-world testing and cost analysis are required before deployment at scale.

5 CONCLUSION

This study proposes an enhanced SAN architecture that improves backup performance through the integration of a dedicated Fibre Channel (FC) switch. By isolating backup traffic from general network operations, the proposed design minimizes congestion and ensures using bandwidth more efficiently. Simulations conducted using the OPNET 14.5 tool demonstrated a 37% reduction in FTP response time and a 4% increase in throughput compared to conventional SAN configurations. These improvements are primarily attributed to the optimized data transmission pathways enabled by FC-based routing. The system's architecture also facilitates better resource allocation and supports scalability, making it suitable for data-intensive enterprise environments. This work contributes a practical and cost-effective solution for enhancing SAN performance, especially in scenarios where low-latency, high-availability storage access is critical. Future research will focus on implementing the proposed design in real-world settings and evaluating its performance under heterogeneous workloads and larger network scales.

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