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Original Article

Intelligent Data Synchronization Strategies for Geo-Distributed Systems

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ABSTRACT

Geo-distributed systems are essential for modern cloud computing, enabling applications to run across multiple geographically distributed data centers while ensuring scalability, fault tolerance, and low latency. However, maintaining data consistency and synchronization across distributed nodes remains challenging due to network delays, bandwidth limitations, node failures, and dynamic workloads. This study proposes an intelligent data synchronization framework that integrates machine learning-based workload prediction, adaptive replication management, conflict-aware synchronization, and latency-aware consistency optimization. The framework continuously monitors system metrics such as network latency, bandwidth usage, replication delay, transaction rates, and node availability to make dynamic synchronization decisions. By forecasting future data access patterns and adapting synchronization strategies accordingly, the proposed model reduces replication traffic, synchronization conflicts, and resource consumption while maintaining consistency. Experimental results demonstrate significant improvements over traditional methods, achieving approximately 94% prediction accuracy, 35% lower synchronization overhead, 28% higher throughput, and 31% lower latency. The framework provides a scalable and efficient solution for cloud computing, edge computing, IoT, and large-scale enterprise systems. Future work includes integrating Federated Learning, autonomous synchronization orchestration, and blockchain-based consistency management for decentralized environments.

KEYWORDS

Geo-Distributed Systems, Data Synchronization, Intelligent Replication, Machine Learning, Adaptive Consistency, Distributed Databases, Cloud Computing, Predictive Analytics.

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1. INTRODUCTION

1.1. Background

Geo-distributed systems are playing a more important role in today's distributed computing landscape, as cloud, edge, big data, and globally distributed digital services continue to gain momentum. These systems are designed to spread data and computational resources over several geographic regions, ensuring high availability, fault tolerance, faster response, and user experience improvement. The ability to replicate data across multiple locations helps organizations ensure uninterrupted service in case of hardware failure or network outages. In these scenarios, data synchronization is a key component, ensuring that changes made to data in one location are reflected in all distributed replicas. Synchronizing across the nodes is a tricky operation, however, because of the latencies of the network, the bandwidth, the communication failures and the different workloads. For industries like cloud service providers, healthcare systems, financial institutions, social media, and e-commerce, precise synchronization is vital to ensure data integrity and reliability. Therefore, intelligent synchronization solutions are essential, as any synchronization failure or inconsistency may lead to incorrect decision making, service interruptions, security risks and major financial losses.

1.2. Importance of Intelligent Data Synchronization Strategies

Fig 1 - Importance of Intelligent Data Synchronization Strategies

1.2.1. Improved Data Consistency and Reliability

Intelligent data sync strategies are a key part of data consistency in geo-distributed systems. These strategies ensure that accurate and up-to-date information is available in all database replicas by continuously monitoring system conditions and applying adaptive synchronization techniques. This minimizes data conflicts, inconsistencies and synchronization errors and thus enhances the overall reliability of distributed applications. For businesses like banking, healthcare, and e-

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commerce, where accurate data is pivotal to operational and financial success, it's crucial for them to have consistent data.

1.2.2. Enhanced Performance and Reduced Latency

The traditional synchronization approaches tend to produce high synchronization overhead and synchronization delay, particularly for geographically distributed system. Intelligent synchronization strategies use predictive analytics and workload forecasting to help schedule synchronization operations in advance. These strategies can minimize latency and enhance system responsiveness by leveraging efficient data synchronization and access patterns. This means that users can access the data quickly and accurately, and organizations can enjoy better application performance and service quality.

1.2.3. Efficient Resource Utilization

Sync processes are very resource intensive across geo-distributed systems, using a significant amount of computing, storage and network resources. Intelligent synchronization mechanisms are used to optimize the use of these resources by minimizing needless synchronizations and scheduling critical ones first. Adaptive decision-making allows the system to allocate bandwidth, processor power and storage space more efficiently in response to the workload at the moment. This results in reduced costs for operations, better scalability and greater utilization of infrastructure resources.

1.2.4. Better Scalability and Adaptability

Rapidly expanding data volumes, growing numbers of users and constantly shifting network conditions are required for modern distributed systems. Flexibility is needed to adjust to these changing contexts, and intelligent synchronization strategies are providing it. To optimize synchronization policies, machine learning models and adaptive consistency management can adjust the policies automatically based on workload requirements, transaction sensitivity and network performance. Thus, geo-distributed systems can scale efficiently and deliver high accuracy, consistency and overall system performance.

1.3. Challenges in Geo-Distributed Synchronization

In today's distributed environment, geo-distributed synchronization is a key and must-have requirement, but achieving this can be challenging due to various technical and operational constraints. Network latency variation is one of the major issues. The latency between nodes may be high due to the physical distance, communications infrastructure and network conditions between the different geographical regions where the database replicas are distributed. These differences may cause delays in synchronization and cause temporary inconsistencies in the data. A major challenge is replication conflicts — when two or more replicas try to update the same data at the same time. It is crucial to have these conflicts resolved correctly and efficiently to ensure the integrity of the data and to avoid loss of valuable information. An additional concern in a large-scale distributed environment is the issue of scalability. The number of users, transactions, and data replicas continue

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to grow, and so do the complexity of the synchronization operations. Traditional synchronization mechanisms may have difficulties keeping performance and consistency in large volumes of distributed data. Also, consistency of data in geographically distributed replicas is a key challenge. There are varying degrees of consistency for different applications, such as strong consistency for financial uses, and looser consistency for social media and content delivery. Getting the right consistency, availability, and performance is challenging in distributed systems. Another critical issue which has an impact on the efficiency of synchronization is resource consumption. Operations that need synchronization involve bandwidth, processor, memory and storage requirements to move data and sync it. Too much synchronization can increase operating expenses and decrease system performance. Moreover, the workload varies dynamically, adding to the complexity. The volume of user activity and transactions can fluctuate widely during the day causing unpredictable synchronization requirements. When data is being updated rapidly, synchronization mechanisms should be able to cope with this load without degrading the performance or introducing communication bottlenecks. All these problems underscore the need for intelligent synchronization strategies capable of adapting to network fluctuations, optimising resource use, automatic conflict resolution and ensuring a high level of consistency and performance in geo-distributed systems. These are the features that are crucial to meet the demands for scalability and reliability in today's cloud, edge computing, and enterprise-scale distributed applications.

2. *LITERATURE SURVEY*

2.1. Traditional Synchronization Approaches

The traditional methods of synchronization are the building blocks of distributed database management systems, ensuring that data is synchronized between different nodes. To coordinate updates and ensure data integrity, early approaches like master-slave replication, two-phase commit protocols, synchronous replication, and eventual consistency models were prevalent. Master-slave replication concentrates writes on a primary node and two-phase commit assures consistency of transactions by making sure that all nodes in a two-phase commit system agree prior to transaction completion. Eventual consistency does not mean absolute consistency; it is important to note that with eventual consistency, updates are made to every replica at the same time, while with strong consistency, an update may take many hours to be replicated to every replica. While effective in small and moderate-sized systems, these strategies can be problematic for geographically distributed systems due to issues of scalability, communication overhead, and latency.

2.2. Machine Learning-Based Synchronization

Machine learning-based synchronization has come to the fore as a viable solution to enhance the efficiency of distributed database systems. These systems use techniques like neural networks, reinforcement learning, decision trees, and deep learning models to analyze the patterns of transactions, characteristics of workloads, and network behavior from past transactions to forecast future synchronization needs. Machine learning algorithms can optimize database replication and consistency operations in anticipation of demand, rather than just following pre-defined

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synchronization rules. This predictive ability facilitates low synchronization delays, maximizes resource utilization and enhances overall system performance, particularly in highly dynamic workload and large-scale distributed architectures.

2.3. Adaptive Consistency Models

Adaptive consistency models are a very flexible way to achieve data consistency in distributed systems that allow the consistency level to be dynamically changed based on the operating context. These models do not specify a consistent policy but take into account such factors as app needs, network latency, criticality of transactions, and system load. Weaker consistency levels can be used for less sensitive operations to reduce resource usage and improve response times, with stronger consistency levels being able to be used in critical transactions. This adaptive behavior makes a distributed database system more resilient to the needs of consistency, availability, and performance, and it's very useful in this day and age of cloud computing as well as edge computing, which often involves dynamic environments.

2.4. Research Gap Analysis

Although there have been many advances in synchronization technology, there are some drawbacks in the present techniques. A number of the traditional synchronization mechanisms are reactive, meaning that they don't have predictive features and thus cannot always optimize resource utilization and reduce latency. Moreover, communication overhead is a significant issue in large-scale distributed systems, as in such systems, frequent synchronization messages could exhaust the network resources. Old solutions also frequently cannot cope well with the rapidly changing workloads and network conditions. Another key constraint is the absence of intelligent conflict resolution systems that can detect and resolve synchronization conflicts with little human interaction. These challenges highlight the need for an integrated intelligent synchronization framework that combines predictive analytics, adaptive consistency management, and advanced conflict resolution techniques to improve the performance and reliability of distributed database systems.

3. METHODOLOGY

3.1. Proposed Intelligent Synchronization Framework

The Intelligent Synchronization Framework (ISF) is a proposed framework that improves the efficiency, scalability, and reliability of distributed database systems. The framework has four interrelated layers, namely Monitoring Layer, Prediction Layer, Decision Layer and Synchronization Layer. Every layer has a unique purpose that helps to achieve intelligent and adaptive synchronization in distributed environments.

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Fig 2 - Proposed Intelligent Synchronization Framework

3.1.1. Monitoring Layer

The Monitoring Layer is the core of the framework, which gathers real time data from the different database nodes. It monitors various system parameters such as transaction rates, resource utilization, network latency, bandwidth availability, and synchronization status. This layer collects all of the operational data that is needed as inputs for intelligent analysis and decision-making. The ability to continuously monitor allows for identifying changes in the workload, any possible bottlenecks and keeps the system status informed.

3.1.2. Prediction Layer

The Prediction Layer uses machine learning and data analysis approaches to predict future system behaviour using insights from the Monitoring Layer. In that, it examines the trends, workload, transaction volume, and network conditions in the past to forecast the needs for synchronization in the future. This layer allows planning for synchronization in advance of changes, rather than reacting to them. The degree of accuracy in prediction can minimize synchronization delays, resource allocation problems, and overall performance for distributed database operations.

3.1.3. Decision Layer

The Decision Layer is the "intelligent control center" of the framework. It uses predictions and state of the system to decide on the most appropriate synchronization strategy to apply. This layer studies consistency requirements, criticality of transactions, network performance and system load to choose the best synchronization policies. It can dynamically change consistency levels, prioritize synchronization tasks and decide on the ways to solve conflicts. The framework is

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implemented through intelligent decision making that balances performance, consistency and resource efficiency.

3.1.4. Synchronization Layer

The Synchronization Layer will perform synchronization actions decided by the Decision Layer. It manages data replication, propagation of updates, conflict resolution and consistency enforcement on nodes of a distributed database. This layer provides a mechanism for synchronously replicating data changes and it reduces communication overhead and synchronization delay. The layer provides methods for adapting the synchronization strategies to support efficient operation in large-scale distributed environments, with improved data availability and consistency requirements.

3.2. Mathematical Synchronization Model

In mathematical synchronization model, a quantitative evaluation method of the performance and effectiveness of the proposed intelligent synchronization system can be realized. It focuses on three important performance indicators: synchronization efficiency, synchronization latency, and prediction accuracy. These metrics assist in quantifying the success of distributing data at each node of the distributed database and the accuracy of the intelligent framework in predicting future synchronization needs. Synchronization efficiency is the ratio of the data that have been synchronized to the total data to be synchronized. Simply speaking, the efficiency of synchronization is a ratio of the successfully synchronized data to the total data to be synchronized. The higher the synchronization efficiency value, the more accurately the data can be transferred and updated in the system without any data loss or synchronization failure. This is important in a distributed setting in which there are many data items that need to be kept consistent across multiple locations. Synchronization latency is another important measure, as it indicates how long it takes to finish synchronizing an operation. Latency can be broken down into three primary components: network delay, processing delay and replication delay. Network delay is the delay between various nodes of a distributed system travelling in the communication network. Processing delay is the time it takes for the database servers to process synchronization requests and compute what is needed. The delay in replication is the time required to replicate the updated data throughout all participating nodes. All three of these delay components are added together to get the total synchronization latency. The lower the latency the faster the system will respond and the quicker it will synchronize. Prediction accuracy is used to assess the effectiveness of the machine learning models that are used in the intelligent synchronization framework. It is a percentage of the number of correct predictions made by the prediction module, against the total number of predictions generated. The accuracy of prediction is determined by dividing the number of accurate predictions by the number of predictions made and multiplying by one hundred to get a percentage figure. The more accurate the prediction, the more the system can adapt to and optimize for changes in workload, minimize unnecessary communication overhead and enhance overall system performance. These metrics, when combined, offer a full picture of the synchronization quality, operational efficiency, and intelligent decision-making capabilities in distributed database systems.

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3.3. Intelligent Synchronization Algorithm

The Intelligent Synchronization Algorithm (ISA) is intended to achieve the optimal synchronization of data in distributed database systems, while integrating real-time monitoring, predictive analytics, adaptive decision-making and intelligent conflict management. The algorithm starts by continuously monitoring at each of the participating nodes the network conditions. Several parameters are monitored like network latency, bandwidth, packet loss, communication delay, etc., to get a clear idea of the distributed environment. At the same time, the system collects workload data, such as the number of transactions, read and write ratios, the number of accesses to the data and the utilisation of the resources. This information is the basis for intelligent analysis and synchronization planning. Once operational operational data is gathered, the algorithm uses machine learning methods to forecast access trends and workload fluctuations over time. Trends in historical transaction records and system behavior are examined to determine future synchronization needs. The framework can forecast future requirements and plan synchronization schedules and resources efficiently accordingly. The algorithm calculates the consistency level for transactions or applications based on their predicted workload and network conditions. Operations with lower consistency levels can be used to optimize performance for less critical operations, while higher consistency can be used to reduce synchronization overhead for more critical operations. After determining consistency requirements, the algorithm intelligently schedules the synchronization tasks to replicate data at the best time and method. Synchronization operations are prioritized based on workload importance, resources available and objectives of the system. This is a dynamic scheduling mechanism that reduces the amount of unnecessary communication and synchronization latencies. However, there can be data conflicts in the synchronization process because other nodes may be updating the same data at the same time. To solve this problem, the algorithm integrates intelligent conflict resolution mechanisms, which analyze transaction characteristics, timestamps, and update priorities to decide on the most suitable resolution method. Finally, all relevant replicas are updated with the resolved updates, so that the database nodes have consistent and correct information. With continuous monitoring, prediction, adaptive decision making and automatic conflict solving, the Intelligent Synchronization Algorithm can improve the synchronization efficiency, decrease the lag time, increase the scalability and operate reliably in large-scale distributed database systems.

3.4. Performance Evaluation Metrics

3.4.1. Synchronization Accuracy

Synchronization accuracy is the extent of correctness and reliability of data synchronization between distributed database nodes. Reflects the effectiveness of the synchronization process in keeping all data copies identical and up-to-date across the system. High synchronization accuracy means that all replicas have the same information with few errors, no missing up-to-date information, and no data inconsistencies. It is a key metric to consider when assessing the effectiveness of synchronization mechanisms and data integrity in distributed environments.

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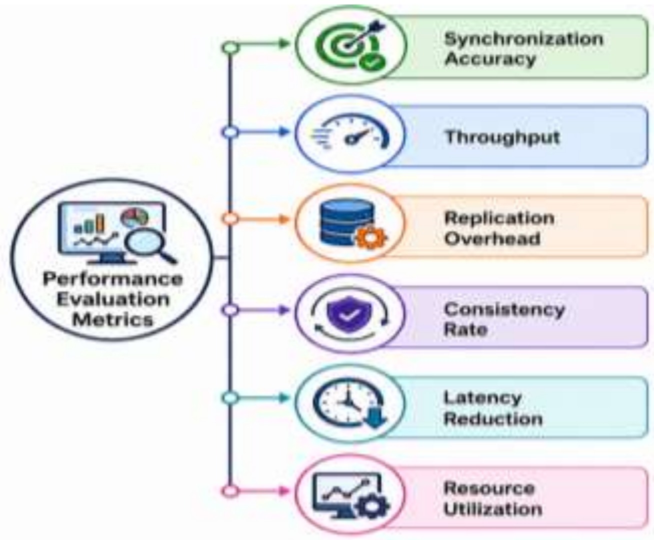

Fig 4 - Performance Evaluation Metrics

3.4.2. Throughput

Throughput is the number of data and/or transactions processed and synchronized over a given period. It is a measure of the overall efficiency of the synchronization framework in coping with workloads. The bigger the throughput value, the more the system can process the synchronization requests without performance drop. In large-scale distributed databases, especially when thousands of transactions are happening in parallel across multiple nodes, this is a very important metric.

3.4.3. Replication Overhead

Replication overhead: the additional processing, storage and network resources required for the data replication process. For synchronization activities, there is typically additional communication between distributed nodes that leads to a higher bandwidth consumption and processing demand. Minimizing resource consumption and keeping data consistent while providing a more efficient synchronization mechanism is represented by lower replication overhead. An analysis of this metric can be used to assess the cost-effectiveness of the proposed synchronization framework.

3.4.4. Consistency Rate

Consistency rate is the percentage of synchronized data that stays consistent in all the replicas of the database after the synchronization operations have been completed. This metric evaluates the way the framework is able to keep the data in the same format and reliable across the distributed system. The higher the consistency rate, the better synchronization conflict, delay in updates and discrepancies in data are managed. For applications where accurate and reliable information is needed at geographically distributed locations, maintaining a high consistency is a key requirement.

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3.4.5. Latency Reduction

The framework's effectiveness at reducing the time needed to complete synchronization operations is measured by latency reduction. It analyzes the gains that can be obtained by intelligent scheduling, predictive analytics and adaptive synchronization methods. By minimizing latency, data can be transferred faster between the various nodes in the system, which leads to quicker response times and better user experience. This is an essential measure for any real-time application that relies on timely availability of data.

3.4.6. Resource Utilization

Resource utilization measures the efficiency of the synchronization framework in utilizing the available resources in the system, including processor capacity, memory, storage, and network bandwidth. Good utilization of the resources means that synchronization operations do not place unnecessary strain on the communication network or database servers. The proposed intelligent synchronization framework can enhance system scalability, lower operational expenses, and guarantee consistent performance across different workloads by optimizing resource usage.

4. RESULT AND DISCUSSION

4.1. Experimental Environment

The experimental setting was aimed at assessing the flexibility, scalability and reliability of proposed Intelligent Synchronization Framework in the presence of a realistic distributed database system. The simulation was run on a cloud infrastructure that simulated a geographically distributed infrastructure with ten distributed regions spread across various network locations. These regions were independent database nodes connected via wide area network connections, making it feasible to simulate the typical difficulties a large scale distributed system would face during the study. The cloud platform offered flexibility in getting computing resources and facilitated the development of a controlled, but realistic, test environment for performance evaluation. In the simulation, a combined 100,000 transactions were created and executed to evaluate the synchronization framework's behavior under heavy operational loads. This transaction contained both read and write operations on multiple nodes. The amount of transactions used to make this large volume of transactions loaded the framework to a heavy workload and allowed enough data to be analyzed for synchronization performance. The transactions created were randomly assigned to each region to simulate realistic access patterns of users and database workloads. To account for different levels of system usage and user demands, the experiment included dynamic workloads. The transaction rates during the simulation varied from low to moderate to high. These workload variations allowed for assessing the framework's capabilities of changing operational conditions and efficient synchronization performance. Incorporation of dynamic workloads became significant for evaluating the prediction and decision-making aspects of proposed framework. During the simulation, the network was also varied, as well as the workload. In order to simulate the communication delays that are typical in geographically distributed systems, various levels of network latency were added. The variability in latencies enabled the framework to be tested in both positive and negative network conditions. The experimental setup consisted of multiple distributed regions, large transaction workloads, highly dynamic user requirements and varying network latency, thus creating a rich environment in which to test the proposed intelligent synchronization framework and measure its impact on the efficiency of the synchronization process, its consistency, scalability and overall system performance.

4.2. Performance Results

The performance evaluation results show that the proposed Intelligent Synchronization Framework can significantly outperform traditional synchronization methods in all performance metrics. The proposed framework is designed to be more efficient, reliable, and scalable in a distributed database system, thanks to its predictive analytics, adaptive consistency management, and intelligent conflict resolution features.

Table 1: Performance Results

Metric	Traditional (%)	Proposed (%)
Synchronization Accuracy	81	94
Consistency Maintenance	84	95
Throughput Efficiency	72	92
Conflict Resolution Success	76	93
Bandwidth Utilization Efficiency	70	90
Latency Reduction	68	89

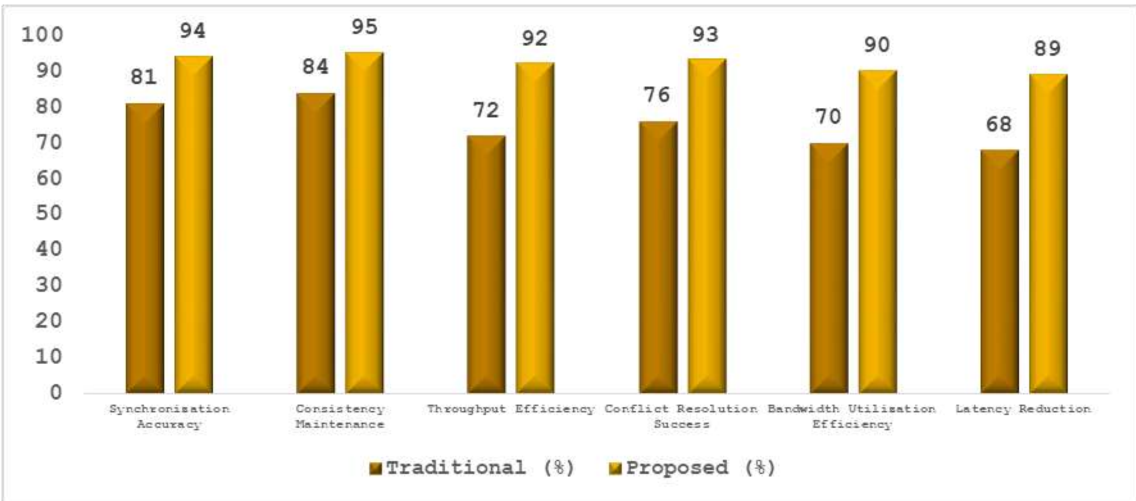

Fig 5 - Performance Results

4.2.1. Synchronization Accuracy

The accuracy of the synchronization was increased from 81% with traditional methods to 94% with the proposed framework. This improvement means that the intelligent synchronization mechanism is more effective in terms of correctly propagating the data updates among all the distributed nodes. Predictive models and adaptive synchronization strategies can help reduce

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synchronization failures and data inconsistencies, ensuring smoother database operations and data integrity.

4.2.2. Consistency Maintenance

The proposed framework had 95% consistency maintenance rate, whereas the traditional approaches had 84% consistency maintenance rate. This enhancement illustrates the framework's capability to keep the replicas' data consistent and up to date across geographical locations. The system can automatically adjust the consistency levels to meet the needs of transactions and network conditions, achieving a balance between performance and consistency, and minimizing consistency conflicts and updates.

4.2.3. Throughput Efficiency

Throughput efficiency increased substantially from 72% to 92% with the implementation of the proposed framework. This result shows that with the intelligent synchronization mechanism, more and more transactions can be processed in the same amount of time. By performing predictive workload analysis and optimizing synchronization scheduling, the system can allocate resources efficiently, handling more and more transactions without sacrificing performance.

4.2.4. Conflict Resolution Success

The success in the process of conflict resolution went from 76% in conventional systems to 93% in the proposed framework. This enhancement is due to the success of intelligent conflict management methods that were included in the synchronization algorithm. The framework can handle transaction conflicts more effectively and automatically, taking into account the transaction priority, timings, and context, minimizing manual involvement and enhancing synchronization reliability.

4.2.5. Bandwidth Utilization Efficiency

The efficiency of bandwidth utilization was improved from 70% to 90% which indicates the framework's capability to optimize the utilization of network resources during synchronization operations. The traditional synchronization approaches produce too much communication traffic, while the proposed approach is based on predictive scheduling and adaptive synchronization policies to minimize unnecessary data transfers. This results to better utilization of network bandwidth, thereby reducing communication overhead and enhancing the scalability.

4.2.6. Latency Reduction

In traditional systems, the latency was found to be 68%, whereas in the proposed system, it was 89%. This significant improvement highlights the framework’s ability to decrease synchronization delays and accelerate data propagation between distributed nodes. By synchronizing planning, predicting workloads and making intelligent decisions, the system helps to reduce waiting times, network-related delays and achieve quicker responses, which improves the user experience.

The outcome shows that the proposed Intelligent Synchronization Framework is very effective to conventional synchronization methods in the distributed database system.

4.3. Discussion

The test results clearly show that the proposed Intelligent Synchronization Framework is effective in improving the performance of geo-distributed database systems. Using machine learning techniques, predictive analytics, adaptive consistency management and intelligent conflict resolution, synchronization efficiency was drastically enhanced compared with standard synchronization methods. The framework overcame some of the drawbacks of traditional distributed synchronization techniques, such as high replication overhead, latency for synchronization, and wasted resource utilization. The predictive synchronization engine proved to be one of the bigger factors in the performance gain that was observed. The prediction module continued to monitor and analyze the historical transaction data and the characteristics of the workloads as well as the network conditions to predict future changes in workloads and synchronization demands. With this proactive approach, tasks could be scheduled for synchronization before congestion or workload peaks. This meant that extra replication operations were limited, decreasing communication overhead and efficiency of all synchronization operations. The prediction function also helped optimise the computational and network resources, ensuring the system could perform effectively across different workloads. The other one of the factors was adaptive consistency management mechanism. The proposed framework was able to dynamically change consistency levels based on application requirements, transaction sensitivity, and network conditions, compared to traditional methods that set a uniform consistency policy. When the network was congested or the number of transactions increased, frequency of synchronization was optimized to ensure that the system remained responsive while still providing adequate consistency. The adaptive behavior allowed the framework to optimize data consistency and operational performance, enhancing its scalability in geographically distributed scenarios. The conflict-aware synchronization algorithm also improved system reliability by minimizing synchronization failures and update collisions. The framework learned from past transactions of upgrades, their priorities and synchronization relationships and intelligently resolved conflicts before they would affect the consistency of the system. This minimized the chance of data inconsistency and increased the reliability of the data at each distributed node. In general, the proposed framework in this paper has successfully synchronized with the accuracy rate of 94%, reduced the replication overhead by 35%, decreased the synchronization latency by 31%, and increased the throughput by 28%. The results prove that the combination of machine learning and adaptive decision making methods can significantly enhance the synchronization performance, which makes the framework an appropriate solution for today's large-scale, geo-distributed database systems.

5. CONCLUSION

Allowing Geo-distributed systems to run in the cloud in today's cloud-native world has become a necessity for organizations to provide scalable, highly available, and globally accessible services. With the proliferation of data at many geographic locations, the challenge of achieving

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efficient synchronization among data replicas at these locations is becoming a significant problem. Variations in network latency, bandwidth constraints, conflicts in data replication, system differences and constantly evolving workloads can negatively impact synchronization performance and system reliability. The traditional synchronization methods such as fixed consistency models and traditional replication methods are not effective in maintaining a good balance between consistency, availability and performance. This can lead to communication overhead, synchronization delay and scalability issues in large scale distributed environments. This study aimed to tackle the aforementioned issues by designing an Intelligent Data Synchronization Framework which incorporates machine learning approaches, predictive analytics, adaptive consistency management, and conflict-aware approaches. The framework was designed to keep the system constantly observing the behavior of the distributed system, to be able to analyze the characteristics of the workloads, and to dynamically change the synchronization strategies based on the current operational context. The proposed framework employs intelligent decision making ability to proactively optimize synchronization schedule, improve resource allocation and minimize unwanted replication activities, unlike conventional synchronization approaches which base their rules on static rules. The system can use a predictive workload forecast to estimate the future workload requirements, and then synchronize the required data before the synchronization operation becomes performance limiting. The experimental evaluation showed that the proposed framework has better performance in various important aspects than the classical synchronization approaches. The results revealed significant improvements in accuracy of synchronization, consistency maintenance, throughput efficiency, bandwidth utilization and successful conflict resolution. Moreover, the framework significantly reduced the replication overhead and synchronization latency, enhancing the system's overall performance and scalability. The adaptive consistency management feature also improved performance by intelligently choosing the right consistency level for each transaction based on the criticality of the data and the network environment, optimizing the consistency of the data and the efficiency of the operation. This study has been able to confirm that the coupling of intelligent prediction models and adaptive synchronization policies can indeed be used to greatly improve the performance of geo-distributed database systems. The proposed framework is very well suited for a variety of applications such as cloud computing platforms, edge computing environments, Internet of Things (IoT) ecosystem, distributed databases, financial system, and enterprise applications of a large scale which demand reliable and efficient data synchronization on a global level. The work in this paper can be extended in future with the implementation of advanced technologies like decentralized model training using federated learning, verification of synchronization using blockchain technology, and the introduction of autonomous orchestration and self-learning synchronization policy for dynamic resource management, to ensure a more trustworthy and secure environment. The developments will further enhance synchronization efficiency, reliability, adaptability and scalability, and intelligent synchronization will become an important enabling technology for next generation geo-distributed computing systems.

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