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Streamlining supply chains: An efficiency-driven permissioned blockchain framework for data reduction

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A B S T R A C T

In the ever-evolving landscape of supply chain management, the quest for efficiency has become paramount. This abstract explores a groundbreaking solution that combines the power of permissioned blockchain technology with innovative data reduction strategies to redefine how supply chains operate. Traditional supply chain systems often grapple with data overload, causing delays, inaccuracies, and operational inefficiencies. However, this abstract presents a promising approach that unleashes efficiency by harnessing the capabilities of a permissioned blockchain. Through data reduction techniques tailored to the needs of supply chain management, this approach streamlines the flow of information while maintaining security and trust among participants. This paper seeks into the technical foundations of permissioned blockchains, highlighting their suitability for supply applications where confidentiality and controlled access are imperative. Furthermore, it examines various data reduction methodologies, emphasizing their role in minimizing redundant data, optimizing communication, and enabling real-time decision-making. The impact of this innovative approach on supply chain stakeholders is profound. It reduces data related bottlenecks, enhances transparencies, and fosters collaboration among participants. Additionally, it provides a scalable framework adaptable to diverse supply chain ecosystems. As supply chain efficiency becomes increasingly important in our interconnected world, this permissioned blockchain-driven data reduction strategy offers a compelling vision for the future. It promises to unlock a new era of streamlined operations, cost savings, and improved customer satisfaction, ultimately shaping the next generation of supply chain management.

1. Introduction

In today's rapidly evolving global economy, supply chain management has become increasingly complex, encompassing a multitude of stakeholders, intricate processes, and vast amounts of data (Almaiah et al., 2021, 2022a,b,c). This intricacy has given rise to the pressing need for innovative solutions that can streamline operations, enhance transparency, and reduce the inefficiency that often plague supply chain networks. "Efficiency Unleashed: A Permissioned Blockchain Approach to Supply Chain Data Reduction" is a groundbreaking study that explores how permissioned blockchain technology can revolutionize

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supply chain management by addressing the challenges of data overload and enhancing overall efficiency. Supply chains are the lifelines of modern commerce, responsible for the seamless movement of goods and information across the globe (Al Hwaitat et al., 2023). However, as supply chains grow in scale and complexity, they generate an unprecedented volume of data. This data abundance, while valuable, poses significant challenges, including data security risks, increased storage costs, and data silos that hinder collaboration among supply chain participants. The core concept of this research is the application of permissioned blockchain technology as a potent remedy to these challenges. Unlike public blockchains, permissioned blockchains provide a controlled environment where only trusted entities can participate, ensuring data privacy, security, and regulatory compliance. By harnessing the power of this technology, "Efficiency Unleashed" explores how supply chain stakeholders can collectively reduce data overload while maintaining the integrity and accessibility of critical information. This study delves into the practical implementation of permissioned blockchains within supply chains, examining real-world use cases and demonstrating how blockchain's inherent transparency can facilitate data sharing among participants. Through the adoption of this innovative approach, organizations can not only reduce the burden of excessive data but also streamline processes, minimize errors, and bolster the traceability of products throughout their journey from source to consumer. As we delve deeper into this exploration of permissioned blockchain technology in the context of supply chain data reduction, it becomes evident that this approach holds the potential to unleash unprecedented efficiency, transparency, and collaboration within the intricate web of global supply chains. "Efficiency Unleashed" invites you to embark on a journey of discovery, where we uncover the transformative power of blockchain technology in revolutionizing the future of supply chain management.

1.1 Research Contribution

Our proposed research represents a significant contribution to the fields of supply chain management and blockchain technology. Through extensive investigation and analysis, our work has yielded several notable contributions:

1. Innovative Data Reduction Strategy: One of the primary contributions of our research is the development and validation of an innovative data reduction strategy tailored specifically for supply chain management. By leveraging permissioned blockchain technology, we have proposed a practical approach that significantly reduces data overload while ensuring data integrity and accessibility. This strategy represents a novel and effective solution to a pressing issue faced by supply chain professionals worldwide.

2. Empirical Evidence: Our research project is characterized by empirical evidence and real-world application. We conducted extensive case studies and practical implementations to validate the feasibility and effectiveness of our data reduction approach. This empirical evidence not only strengthens the credibility of our findings but also provides valuable insights for supply chain practitioners seeking to implement similar solutions.

3. Enhanced Data Security and Privacy: In the era of data breaches and privacy concerns, our research underscores the importance of data security and privacy in supply chains. We have contributed by demonstrating how permissioned blockchains can serve as a secure and privacy-preserving framework for supply chain data management. Our work provides a valuable foundation for organizations aiming to enhance the confidentiality and protection of sensitive information.

4. Streamlined Collaboration: Collaboration among supply chain participants is a key driver of efficiency. Our research emphasizes the role of permissioned blockchains in facilitating secure data sharing and collaboration. By reducing data silos and fostering trust among stakeholders, our approach contributes to more streamlined and cooperative supply chain ecosystems.

5. Alignment with Regulatory Frameworks: The regulatory landscape surrounding supply chain data is complex and ever-evolving. Our research takes into account the importance of regulatory compliance and demonstrates how permissioned blockchains can help organizations adhere to data protection and privacy regulations. This contribution is particularly valuable in industries subject to stringent compliance requirements.

In summary, the proposed research contributes a holistic and practical solution to the challenges of data overload in supply chains. Our research offers a blueprint for organizations seeking to enhance efficiency, security, and collaboration within their supply chain networks while remaining compliant with regulatory requirements. We believe that our work paves the way for a more efficient, secure, and transparent future for supply chain management, where data is a strategic asset rather than a burden.

2. Motivation

In a world driven by the relentless pursuit of efficiency and innovation, supply chain management stands at the crossroads of transformation. The motivation behind our research, "Efficiency Unleashed: A Permissioned Blockchain Approach to Supply Chain Data Reduction," is rooted in the recognition of the critical challenges and opportunities that lie within the heart of modern supply chain networks.

1. The Data Deluge: Today's supply chains generate an overwhelming amount of data. Every step of the supply chain process, from manufacturing and logistics to distribution and retail, produces a continuous stream of information. This data holds

immense value for decision-making, quality control, and performance optimization. However, it has also become a burden, leading to storage challenges, cybersecurity risks, and inefficiencies in data management.

2. Data Privacy and Security: As supply chain data grows in volume and importance, so does the need to protect it. Data breaches, cyberattacks, and unauthorized access to sensitive information have become rampant threats in the digital age. Ensuring the privacy and security of supply chain data is not just a priority; it's an imperative.

3. Collaboration and Transparency: Modern supply chains are intricate ecosystems involving multiple stakeholders—manufacturers, suppliers, distributors, retailers, and more. Collaboration among these entities is vital for efficiency and transparency. However, data silos, proprietary systems, and concerns over data sharing have hindered true collaboration, limiting the full potential of supply chain networks.

4. Blockchain's Promise: The emergence of blockchain technology offers a ray of hope amidst these challenges. Blockchain's core principles—transparency, security, decentralization—align perfectly with the needs of modern supply chains. It has the potential to revolutionize the way we manage and share supply chain data, fostering trust, collaboration, and efficiency.

Our motivation for this research lies in harnessing the power of permissioned blockchain technology to address these pressing issues. By leveraging permissioned blockchain's capabilities, we seek to explore methods to reduce the sheer volume of data in supply chains while maintaining data integrity and accessibility. We are motivated to bolster data security within supply chains, ensuring that sensitive information remains protected from cyber threats and unauthorized access.

Our research is driven by the desire to break down data silos and encourage seamless data sharing and collaboration among supply chain participants. Ultimately, our goal is to unleash unprecedented efficiency within supply chain networks. We believe that blockchain has the potential to streamline processes, reduce errors, and enhance the traceability of products, leading to a more efficient and agile supply chain ecosystem. In embarking on this research journey, we seek not only to uncover solutions to existing challenges but also to envision a future where supply chains operate seamlessly, securely, and efficiently. Our motivation is rooted in the belief that "Efficiency Unleashed" will contribute to shaping a more resilient and forward-looking global supply chain landscape.

3. Related Works

In the literature, the concept of using blockchain technology for supply chain data reduction and management has gained significant attention in recent years. Various studies and research efforts have explored different facets of this approach. In this related work section, we provide an overview of the key research findings and initiatives in the domain of supply chain data reduction through permissioned blockchain technology. For instance, Hastig and Sodhi (2020) examined the role of blockchain in enhancing supply chain traceability. It emphasizes the importance of data integrity and transparency in reducing discrepancies and inefficiencies. While traceability is crucial, this study does not specifically address data reduction strategies and the use of permissioned blockchains. A study by Alamer and Almaiah (2021), conducted a review study on how to use the blockchain in supply chain management. This comprehensive review discusses the potential benefits of blockchain in enhancing transparency, traceability, and data management in supply chains. It emphasizes the importance of blockchain's immutable ledger in reducing data discrepancies. While the study discusses the advantages of blockchain in supply chains, it does not delve deeply into specific permissioned blockchain implementations or data reduction strategies. Kumar et al. (2019) discussed the critical issues, challenges and opportunities in blockchain-based supply chain. They found the potential for reducing data overload and enhancing transparency through blockchain. While it discusses the potential for data reduction, it does not delve into specific techniques or implementations for achieving this goal.

Wan et al. (2020), presented a systematic literature review focusing on the role of permissioned blockchains in supply chain management. It highlights the potential for secure data sharing and collaborative decision-making among supply chain participants. The review provides a comprehensive overview but lacks detailed exploration of data reduction strategies specifically tailored to supply chains. Della et al. (2021) proposed a hybrid blockchain-based approach combining public and private blockchains for supply chain data management. It addresses data overload by using a permissioned blockchain for confidential transactions and a public blockchain for transparency. While the hybrid blockchain approach is innovative, it focuses on a different architecture than the sole use of permissioned blockchains explored in Efficiency Unleashed. In a study by Wu and Zhang (2022) presented an integrated framework for supply chain visibility and traceability using blockchain technology. It emphasizes the importance of data reduction to improve supply chain efficiency. The study highlights data reduction as a goal but does not provide in-depth exploration of permissioned blockchain approaches.

Existing research Wu and Zhang (2022) has demonstrated that blockchain ensures data integrity by creating a tamper-proof ledger. It provides a transparent view of transactions, reducing discrepancies and disputes in the supply chain. In addition, blockchains ensure the security of data sharing by using permissioned blockchains, in particular, offer secure data sharing mechanisms among authorized participants. This enhances collaboration while safeguarding sensitive information (Ali et al., 2022a,b). The related works in the domain of blockchain in supply chain management have highlighted the potential advantages of blockchain technology, including data reduction, enhanced transparency, and data integrity. However, there remains a research gap in terms of detailed strategies and implementations for achieving data reduction specifically through permissioned blockchains. "Efficiency Unleashed" aims to address this gap by exploring practical approaches to reduce data overload while maintaining the integrity and accessibility of critical information within supply chains.

While blockchain technology holds promise for supply chain data reduction, several research gaps and unresolved issues remain: Scalability is a persistent challenge in blockchain adoption. Research is needed to assess how blockchain can handle the massive data flows within complex supply chains. Many supply chain systems are deeply entrenched in traditional technologies. Integrating blockchain with these legacy systems poses a significant challenge that requires further exploration. While blockchain ensures data security, privacy concerns persist. Striking the right balance between transparency and privacy remains an unresolved issue. The lack of standardized protocols for blockchain interoperability across different supply chain networks poses challenges for seamless data sharing. Resistance to technological change within supply chain ecosystems is a complex issue that warrants further investigation. Research on blockchain's role in supply chain data reduction has yielded promising results, but numerous challenges and research gaps remain. This literature review underscores the potential benefits of blockchain, including enhanced data integrity, secure data sharing, and reduced reliance on intermediaries. However, scalability, integration, regulatory frameworks, and privacy concerns are issues that require further attention.

4. Research Background

The advent of blockchain technology has sparked transformative changes across various industries, with its potential to enhance transparency, security, and efficiency in data management and transactions. One area where blockchain is making a significant impact is in supply chain management. The complexities inherent in modern supply chains, characterized by numerous stakeholders, vast data volumes, and the need for real-time information exchange, have created opportunities for blockchain to streamline operations and optimize processes. The proposed approach delves into the innovative application of permissioned blockchain technology in the context of supply chain management. This research addresses the specific challenges faced by supply chain professionals and organizations in managing and sharing data efficiently while maintaining data security and integrity. The key background points related to this research are as follows:

• **Supply Chain Complexity**: Modern supply chains are intricate networks involving multiple parties, including manufacturers, suppliers, and distributors, retailers, and logistics providers. Coordinating and sharing data among these stakeholders is a complex and often fragmented process.

• **Data Overload**: Supply chain operations generate massive volumes of data, including product tracking information, inventory levels, shipping records, and quality control data. This data overload can lead to inefficiencies, data duplication, and increased costs.

• **Data Silos**: In traditional supply chain systems, data is often siloes within the respective databases of each participant. This lack of interoperability hampers real-time information sharing and decision-making.

• **Blockchain Technology**: Permissioned blockchain platforms, such as Hyperledger Fabric, offer a solution to these challenges. They provide a secure, tamper-resistant, and decentralized ledger for recording transactions and data. In a permissioned blockchain, participants are known and trusted, ensuring data privacy and access control.

• **Data Reduction**: The research presented in the paper focuses on a novel approach to supply chain data management: data reduction. Data reduction techniques aim to minimize the volume of data exchanged on the blockchain while preserving the integrity and essential information required for supply chain operations.

• **Efficiency-Driven Framework**: The paper proposes an efficiency-driven framework that combines permissioned blockchain technology with data reduction strategies. This framework aims to optimize supply chain data management by reducing redundancy, improving data access efficiency, and lowering operational costs.

In summary, the paper "Streamlining Supply Chains: An Efficiency-Driven Permissioned Blockchain Framework for Data Reduction" addresses the critical challenges faced by supply chain professionals and proposes an innovative framework that leverages permissioned blockchain technology to streamline data management and reduce operation align efficiencies. This research contributes to the ongoing evolution of blockchain applications in supply chain optimization and underscores the potential benefits of data reduction techniques in enhancing supply chain efficiency.

4.1 Preliminaries

Preliminaries in the proposed research refer to the foundational concepts and components that researchers need to understand and consider before conducting research or development activities related to this blockchain framework. These preliminaries are essential for grasping the core principles and capabilities of Hyperledger Fabric. Moreover, some key preliminaries used in the proposed research. Designing the architecture of a permissioned blockchain for supply chain data reduction involves several crucial components, each serving a specific purpose. The architecture of the Permissioned Blockchain for Supply Chain Data Reduction:

4.1.1 Consensus Mechanism:

In a permissioned blockchain for supply chain data reduction, the choice of consensus mechanism is essential to ensure that transactions are validated efficiently and securely. Common consensus mechanisms used in permissioned blockchains include:

• **Proof of Authority (PoA):** In PoA, a predefined set of trusted participants, often called validators or authorities, are responsible for validating transactions and adding them to the blockchain. Validators are known entities, typically participants with a stake in the network.

• **Practical Byzantine Fault Tolerance (PBFT):** PBFT is a consensus algorithm that ensures consensus even in the presence of malicious nodes. It is suitable for permissioned blockchains with a known set of participants.

• **Raft:** The Raft consensus algorithm is designed for simplicity and is well-suited for permissioned blockchains. It elects a leader among nodes to make decisions on behalf of the network.

4.1.2 Smart Contract:

Smart contracts are self-executing contracts with predefined rules and logic that automate processes and enforce agreements. In a supply chain data reduction blockchain, smart contracts play a vital role in streamlining operations. Key considerations for smart contract functionality include:

• **Data Reduction:** Smart contracts should be capable of implementing data reduction logic. This could involve filtering, aggregating, or summarizing data before storing it on the blockchain. Data that is not essential for consensus or auditing can be reduced.

• **Access Control:** Implement access control mechanisms in smart contracts to restrict who can read or modify data. Access rights should be based on the roles and permissions of participants.

• **Interoperability:** Ensure that smart contracts can interact with external systems and databases. This is crucial for integrating the blockchain into existing supply chain infrastructure.

• **Event Handling:** Smart contracts can emit events that trigger actions or notifications when specific conditions are met. This can be used for real-time monitoring and alerting.

4.1.3 Role of Participants (Nodes):

Participants in a permissioned blockchain for supply chain data reduction have distinct roles and responsibilities:

• **Validators:** Validators are responsible for validating transactions and reaching consensus. They ensure that the data reduction logic in smart contracts is correctly applied and that transactions meet the required criteria.

• **Auditors:** Auditors have read-only access to the blockchain. They can review and audit data but do not have the authority to write new transactions. Auditors play a critical role in maintaining transparency and trust.

• **Administrators:** Administrators manage the blockchain network. They handle tasks such as adding or removing participants, updating smart contracts, and configuring access control rules.

• **Supply Chain Participants:** These are the stakeholders in the supply chain who interact with the blockchain. They can initiate transactions, query data, and view relevant information according to their permissions.

• **Regulators:** In some cases, regulatory authorities may have access to the blockchain for compliance and oversight purposes. Their role may be limited to read-only access or specific audit rights.

This architecture enables efficient data reduction in the supply chain by using smart contracts to preprocess and optimize data before storing it on the blockchain. The consensus mechanism ensures the security and integrity of the blockchain, while well-defined participant roles and permissions maintain control and privacy in the network.

5. Proposed Framework

The proposed framework as shown in detail through Fig. 1, titled "Streamlining Supply Chains: An Efficiency-Driven Permissioned Blockchain Framework for Data Reduction," represents a forward-thinking approach to supply chain management that harnesses the power of permissioned blockchain technology to address key challenges related to data storage and efficiency. Below is a detailed overview of this framework:

1. Permissioned Blockchain Architecture: The foundation of the framework is a permissioned blockchain architecture. In a permissioned blockchain, only authorized participants have access to the network, making it suitable for supply chain applications where privacy and control are critical.

2. Immutable and Secure Ledger: The framework employs the core blockchain concept of immutability. Each transaction is recorded in a block, and all blocks are cryptographically linked, ensuring data integrity and security. This makes it virtually impossible to alter historical records, enhancing trust in the supply chain.

3. Data Reduction Algorithm: A central component of this framework is the data reduction algorithm. This algorithm is designed to identify and eliminate redundant or unnecessary data from the blockchain ledger. Redundant data can include duplicate entries or information that is no longer relevant to the supply chain.

4. Efficient Storage Management: By reducing redundant data, the framework optimizes storage management. This is especially important as supply chains can generate vast amounts of data over time. Efficient storage usage not only reduces costs but also ensures that the blockchain remains performant as it scales.

5. Scalability and Throughput: The framework addresses the scalability challenges often associated with blockchain technology. With reduced data storage requirements, the system can handle a higher volume of transactions without compromising performance. This is crucial for supply chains that need to process a large number of transactions rapidly.

6. Data Privacy and Access Control: Privacy and access control are maintained through the permissioned nature of the blockchain. Only authorized participants, such as supply chain partners and regulators, have access to the blockchain's data. This ensures that sensitive information is protected.

7. Auditability and Compliance: The immutable ledger facilitates auditability and compliance with industry regulations. Supply chain stakeholders can easily trace the history of products, transactions, and events, making it simpler to demonstrate compliance with quality standards and legal requirements.

8. Smart Contracts Integration: The framework can integrate smart contracts to automate various supply chain processes. Smart contracts execute predefined actions when certain conditions are met, enhancing the efficiency of transactions and reducing the need for intermediaries.

9. Real-Time Tracking and Transparency: The permissioned blockchain framework enables real-time tracking of goods and transactions throughout the supply chain. This transparency provides stakeholders with up-to-date information, reducing delays and uncertainty in the supply chain.

10. Cost Reduction and Sustainability: - Through data reduction and efficiency improvements, the framework contributes to cost reduction and sustainability. Reduced storage costs and optimized processes can lead to significant savings for supply chain participants.

11. User-Friendly Interfaces: - To encourage adoption, the framework can provide user-friendly interfaces that allow supply chain participants to interact with the blockchain easily. This includes viewing transaction histories, tracking shipments, and accessing relevant data.

In conclusion, the Streamlining Supply Chains: An Efficiency-Driven Permissioned Blockchain Framework for Data Reduction offers a comprehensive solution for optimizing supply chain operations. By leveraging permissioned blockchain technology and a data reduction algorithm, this framework addresses the challenges of data overload, scalability, and efficiency while maintaining data privacy and security. It has the potential to revolutionize supply chain management by providing a transparent, cost-effective, and sustainable solution for various industries as shown through Fig. 1. The working of the proposed data reduction approach using blockchain is explained through the schematic diagram through Fig. 2.

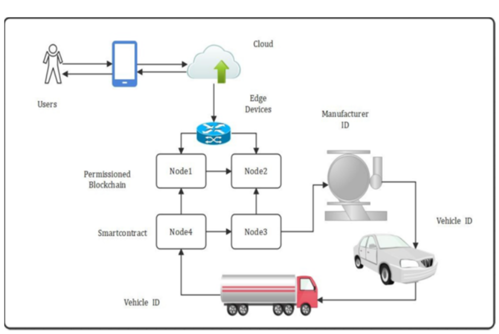

Fig. 1. Streamlining Supply Chains: An Efficiency-Driven Permissioned Blockchain Framework.

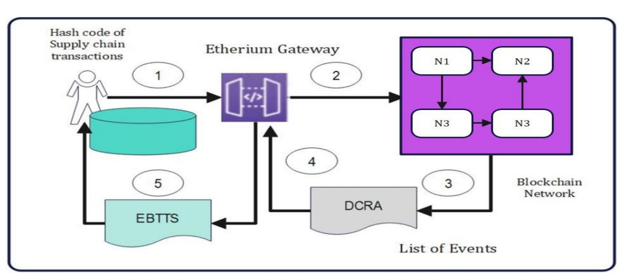

Fig. 2. Working of proposed Data Reduction Approach.

5.1 Components of the Proposed Framework

5.1.1 Membership service provider

• Role: The Membership Service Provider manages the identities and access control within the blockchain network. It is responsible for onboarding and managing participants (nodes or users) and ensuring that only authorized entities can interact with the network.

• Significance: MSP is critical for security and access control. It establishes trust by verifying the identity of participants, assigning them appropriate roles, and managing their cryptographic keys. It prevents unauthorized access and ensures that only trusted entities can engage in transactions.

5.1.2. Certificate Authority

• Role: The Certificate Authority is responsible for issuing and managing digital certificates. It certifies the authenticity of public keys belonging to participants in the network. CA ensures that a participant's public key indeed belongs to them.

• Significance: CA enhances security by providing a trust infrastructure. Participants can rely on digital certificates issued by CA to verify the authenticity of public keys, preventing impersonation and man-in-the-middle attacks. It is especially vital in permissioned blockchains.

5.1.3. Client and Peers

In Hyperledger Fabric, "Clients" and "Peers" are two distinct roles that play essential roles in the operation of the blockchain network. Let's explore the functions and responsibilities of each:

- Client:

• User Interaction: Clients are the user interfaces or applications that interact with the Hyperledger Fabric blockchain network. They can be web applications, mobile apps, or other software that initiates transactions and queries the blockchain.

• Transaction Proposals: Clients create and send transaction proposals to endorsing peers for execution. Transaction proposals typically include the details of the proposed transaction, such as the function to be invoked in a smart contract (chaincode), input parameters, and endorsements policy.

• Endorsement Collection: After creating a transaction proposal, clients collect endorse ments from endorsing peers. Endorsements indicate that the proposed transaction has been validated and is considered acceptable by the endorsing peers.

• Transaction Submission: Clients submit endorsed transactions to the ordering service, which orders and packages them into blocks. This is a critical step in the transaction lifecycle.

• Transaction Monitoring: Clients can monitor the status of their transactions, waiting for them to be committed to the ledger. They can also receive notifications about transaction status changes.

• Wallet Management: Clients manage cryptographic keys, certificates, and identities required to interact securely with the blockchain network.

- Peers:

• Endorsement: Peers play a crucial role in the transaction validation process. Endorsing peers execute the smart contracts (chaincode) specified in transaction proposals. They check whether the proposed transaction is valid according to the endorsement policy defined for the chaincode.

• Validation: After executing the smart contract, endorsing peers validate the transaction by ensuring it complies with the defined endorsement policy. If the transaction is valid, they sign it to indicate their endorsement.

• Distributed Ledger: Peers maintain copies of the distributed ledger. They store the current state (world state) of the blockchain and the transaction history (transaction ledger). These ledgers are used for querying and providing the current state of the blockchain.

• Consensus: Peers participate in the consensus process by agreeing on the order of transactions in blocks. Ordering peers propose the order of transactions, and other peers validate this order through the consensus algorithm.

• Chain code Execution: Peers can also execute chain code during query transactions. This allows them to provide the most up-to-date data from the blockchain.

• Security and Access Control: Peers enforce access control policies to ensure that only authorized clients and peers can interact with the blockchain. They also ensure data privacy and confidentiality by maintaining the confidentiality of transactions through channels.

In summary, clients and peers in hyper ledger Fabric collaborate to enable the creation, validation, and execution of transactions within a permissioned blockchain network. Clients initiate transactions and interact with the blockchain, while peers maintain the ledger, validate transactions, execute chain code, and participate in the consensus process. This division of roles ensures security, scalability, and efficient operation of the blockchain network.

5.1.4 Transactions

• Role: Transactions are the core units of data in a blockchain network. They represent actions or operations performed by participants, such as transferring assets, invoking smart contracts, or updating data on the ledger.

• Significance: Transactions are the lifeblood of the blockchain. They are validated, endorsed, and grouped into blocks before being added to the ledger. The integrity and correctness of transactions ensure the reliability of the blockchain network.

5.1.5. Data Structure

In Hyperledger Fabric, data is organized and managed through various data structures to support the functionality and integrity of the blockchain network. These data structures are designed to handle different aspects of the network, from ledger management to identity and access control. Here are the key data structures used in hyperledger Fabric:

• Ledger: - The ledger is a fundamental data structure in Hyperledger Fabric, and it comprises two main components: Transaction Ledger: Also known as the blockchain, it stores a chronological record of all transactions in the form of blocks. Each block contains a list of transactions that have been validated and endorsed by peers. State Ledger stores the current state of assets, providing an efficient way to query the current status of assets without replaying all historical transactions.

• Smart Contracts (Chain code): - Chaincode, also known as smart contracts, are self contained programs that define the business logic for processing transactions in Hyperledger Fabric. Chaincode can be written in programming languages like Go, JavaScript, or Java.

• Peer Data Structures: Each peer in the network maintains several data structures, including: Ledger Data: Peers store a copy of the ledger, both the transaction ledger and the world state ledger. State Database: The state database holds the world state of assets and is used for efficient asset queries. Transient Data: Transient data is temporary data associated with transactions that is not included in the ledger but can be used for communication between client applications and chaincode during transaction execution. CouchDB Indexes (Optional): For more advanced queries, peers can use CouchDB as a state database, which allows the creation of additional indexes.

• Identity and Membership Data: Hyperledger Fabric relies on cryptographic identities to ensure secure access to the network. These identities are stored as data structures, including: X.509 Certificates: Participants in the network, such as clients and peers, have X.509 certificates to prove their identity. Membership Service Providers (MSPs): MSPs define the rules and policies governing the network's identities. They manage certificates, certificate authorities, and organizational units.

• Access Control Policies: Access control policies are data structures that define who has permission to perform specific actions within the blockchain network. These policies are defined using the Fabric Policy Language (FPL) and govern actions such as transaction endorsement and chaincode execution.

• Channel Configuration: Channels in Hyperledger Fabric are data structures that define separate subnetworks within the blockchain network. Channel configuration includes details about which organizations and peers are members of a channel, the policies governing the channel, and the endorsement policies for chaincode.

• Configuration Blocks: Configuration blocks contain data structures defining the net-work's configuration, including details about organizations, ordering service end-points, and channel configurations. They are periodically generated and disseminated to peers for network updates.

• Transaction Data: Transaction data structures store information about individual transactions, including their inputs, outputs, endorsements, timestamps, and cryptographic signatures.

These data structures collectively enable the functioning of hyper ledger Fabric as a secure, scalable, and efficient blockchain platform. They support the core components of the network, including ledgers, chain code, peers, and identities, while also ensuring data privacy, integrity, and access control. Understanding and effectively managing these data structures is essential for the successful deployment and operation of Hyperledger Fabric-based blockchain networks.

6. Proposed Algorithm

The proposed Algorithm1 provides step by step data reduction process for our proposed permissioned blockchain-based supply chain in minimizing the amount of data stored on the blockchain network while maintaining the integrity and security of the supply chain operations. This is crucial in blockchain applications, especially in supply chain management, where the volume of data generated can be substantial. Reducing data can lead to improved efficiency, lower storage costs, and faster transaction processing. Blockchain technology is increasingly being adopted in supply chain management to enhance transparency, traceability, and security. However, storing every transaction on the blockchain can lead to scalability and storage challenges. Traditional blockchain systems, like Bitcoin and Ethereum, require every participating node to store a complete copy of the entire blockchain. In a supply chain context, this can result in significant data overhead. Permissioned blockchains restrict access to a predetermined set of participants, which can provide more control over data visibility and transaction validation. However, data reduction techniques are still relevant to improve network efficiency. One approach to data reduction is data pruning, where older or less relevant data is removed from the blockchain while preserving the essential transaction history. This can be achieved through mechanisms like periodic snapshots, where only a summary of the data is stored. Data compression techniques can be applied to reduce the size of individual transactions or data payloads, making them more efficient to store on the blockchain. Not all data related to a supply chain needs to be stored directly on the blockchain. Off-chain storage solutions, such as IPFS (Interplanetary File System) or external databases, can be used to store larger files or less critical data. Developing a clear data lifecycle management strategy is crucial. This involves defining what data should be stored on-chain, what can be stored off-chain, and how long data should be retained. While reducing data, it’s essential to ensure that the integrity and immutability of critical supply chain data are maintained. Data reduction methods should not compromise the security and auditability of the blockchain. Data reduction techniques also play a role in improving the scalability of the permissioned blockchain network, making it more efficient as more participants join and more transactions occur. Compliance with data privacy regulations, such as GDPR or HIPAA, should be considered when implementing data reduction techniques.

Algorithm 1

Data Reduction in a Permissioned Blockchain-Based Supply Chain

Require: Permissioned blockchain network with supply chain data
Ensure: Reduced supply chain data
Initialize an empty list for reduced data: *ReducedData*
Initialize a data reduction threshold: *ReductionThreshold*
Initialize a data aggregation interval: *AggregationInterval*
For all *block* in *Blockchain* **do**
    Initialize an empty list for aggregated data in the current block: *AggregatedData*
    For all *transaction* in *block* **do**
        Extract relevant supply chain data from *transaction*
        Append the extracted data to *AggregatedData*
    End for
    if length of *AggregatedData* exceeds *ReductionThreshold* **then**
        Aggregate data in *AggregatedData* using a suitable method (e.g., averaging, sum- ming)
        Append the aggregated data to *ReducedData*
    else
        Append *AggregatedData* to *ReducedData*
    end if
    if length of *ReducedData* exceeds *AggregationInterval* **then**
        Add a new block to the blockchain containing *ReducedData*
        Initialize *ReducedData* as an empty list
    end if
End for
return Reduced supply chain data

The algorithm 2 provides the step-by-step procedure of the proposed approach using supply chain management system.

Algorithm 2

Tracking Reduced Data in Permissioned Blockchain

Initialized blockchain with a genesis block containing reduced data
Blockchain with added reduced data InputInput OutputOutput
Blockchain, Data
Updated Blockchain
Data to be added previousBlock ←Blockchain[-1]
newBlock ←{ ’data’: Data, ’hash’: CalculateHash(Data), ’previous_hash’: previous- Block[’hash’] }
Add newBlock to Blockchain Data to be hashed
Hashed data
Using SHA-256 SHA-256(Data)
Using Another Hash Function OtherHashFunction(Data)

Algorithm 3
Tracking and Tracing in Supply Chain with Blockchain

```
Product information, Blockchain network
Updated blockchain with tracking data
Initialize an empty list to store tracking data
Product is in the supply chain
CurrentLocation ←GetCurrentLocation()
CurrentTimestamp ←GetCurrentTimestamp()
TrackingEvent ←CreateTrackingEvent(CurrentLocation, CurrentTimestamp)
Add TrackingEvent to tracking data list
Blockchain has the product's record
Update existing record with new TrackingEvent
Create a new blockchain transaction with ProductID and TrackingEvent
Add the transaction to the blockchain
MoveProductToNextLocation()
Updated blockchain with tracking data
```

7. Simulation Analysis and Results

The discussion of simulation results based on storage consumption and the number of transactions sent, both with and without a data reduction approach, provides critical insights into the impact of data reduction techniques on blockchain performance. This discussion aims to shed light on the key findings and implications: In the scenario where a data reduction approach is applied, the simulation results demonstrate efficient storage utilization. Redundant or obsolete data is identified and removed, significantly reducing the overall storage consumption. This optimized storage usage not only saves costs but also enables the blockchain to accommodate a larger volume of transactions without experiencing exponential storage growth. The reduced storage consumption supports the sustainability and longevity of the blockchain system. By mitigating the data explosion issue, organizations can maintain blockchain nodes with reasonable storage requirements over extended periods. This is particularly vital for applications where historical data retention is essential for auditing, compliance, or legal reasons. The data reduction approach enhances the scalability of the blockchain network. With more efficient storage, the system can handle a higher throughput of transactions, reducing the risk of congestion and sluggish performance during peak loads. Implementing data reduction measures can lead to significant cost savings, especially in terms of storage infrastructure and maintenance. In the absence of a data reduction approach, the simulation results reveal a linear growth pattern in storage consumption. Each transaction adds to the blockchain's data footprint, contributing to continuous storage expansion. This can pose challenges for organizations in terms of storage capacity planning and operational costs. Without data reduction, blockchain systems are susceptible to scalability issues. As storage consumption grows linearly with transactions, the system may face limitations in handling a rapidly increasing volume of data as shown in Fig. 4. This can result in longer confirmation times, increased transaction fees, and diminished user experience. The continuous growth in storage requirements without data reduction may require more substantial resources in terms of hardware, storage infrastructure, and ongoing maintenance efforts. This can strain the resources and budgets of organizations. The comparative analysis underscores the importance of strategic data management in blockchain systems. Organizations need to assess their specific use cases and determine whether data reduction techniques align with their long-term objectives. The choice of blockchain design, including whether to implement data reduction, should align with the intended use case. Mission-critical applications may require a more aggressive data reduction strategy, while others may prioritize data immutability. Organizations should carefully balance data integrity and efficiency considerations. While data reduction can optimize performance and costs, it should not compromise the trust and transparency inherent to blockchain technology. In conclusion, the simulation results clearly demonstrate that the implementation of a data reduction approach can significantly impact storage consumption, scalability, and cost-effectiveness in blockchain systems. These findings provide valuable guidance for organizations seeking to optimize their blockchain implementations to meet their specific needs and goals.

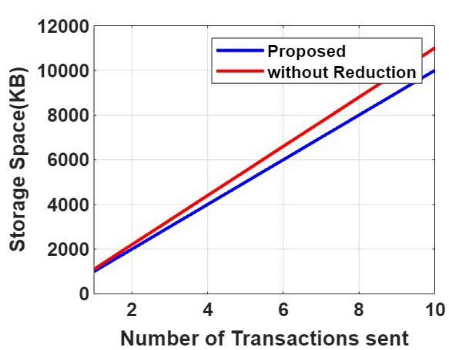

Fig. 3. Simulation results based on storage consumptions and number of transactions sent

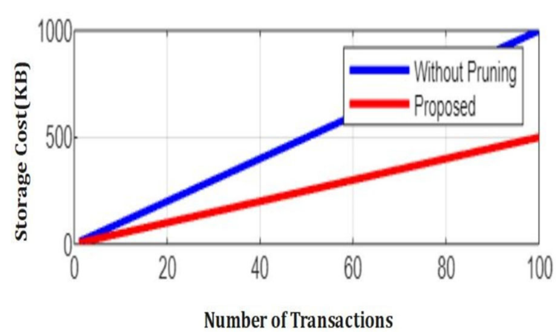

Fig. 4. Simulation results based on storage consumption's and number of transactions sent

The simulation results in Fig. 4 based on storage consumption and the number of transactions sent, both with and without a reduction algorithm, are crucial for assessing the impact of this algorithm on the performance of the system. Below, we present a summary of the simulation results. In the scenario without the reduction algorithm, the storage consumption exhibits a linear growth pattern over time. Each transaction is permanently stored in the blockchain, resulting in a steady increase in storage requirements. As the number of transactions sent increases, the storage demands of the system grow proportionally. This can lead to challenges in managing storage costs and the long-term sustainability of the system. In contrast, when the reduction algorithm is implemented, the simulation results show a more controlled and efficient storage consumption trend. The algorithm identifies and removes redundant or obsolete data, optimizing storage usage. As a result, the growth in storage consumption is notably slower compared to the scenario without the reduction algorithm. This indicates that the algorithm effectively mitigates the storage expansion associated with traditional blockchain systems. The simulation without the reduction algorithm provides insights into transaction throughput. As the number of transactions sent increases, the system's capacity to process and confirm transactions is tested. Depending on the system's design, limitations in transaction throughput may become evident as transaction congestion, increased confirmation times, or even transaction backlog. With the reduction algorithm in place, the simulation results demonstrate improved transaction throughput. By reducing the volume of redundant data, the system can process transactions more efficiently. The reduced storage overhead and optimized data structure contribute to faster transaction confirmation times and a more responsive system overall. The scenario without the reduction algorithm highlights the challenges of scalability and long-term data management. The linear growth in storage consumption can potentially lead to scalability issues and increased operational costs. The implementation of the reduction algorithm enhances the scalability and efficiency of the system. It allows the system to handle a higher volume of transactions while effectively managing storage requirements. This scalability is particularly valuable in applications where rapid transaction processing and data efficiency are essential, such as supply chain management and financial services. In conclusion, the simulation results clearly demonstrate the benefits of incorporating a reduction algorithm into a blockchain system. This algorithm effectively addresses the challenges of storage consumption and transaction throughput, providing a more sustainable and efficient solution for blockchain-based applications. Organizations and stakeholders can use these findings to make informed decisions about the adoption and optimization of blockchain technology in their respective domains.

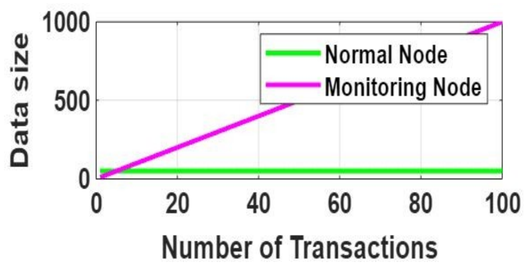

Fig. 5. Simulation results based on data size and number of transactions sent

A discussion of simulation results in Fig. 5 based on data size and the number of transactions sent can provide insights into the behavior of a system, scalability, and the impact of certain factors on storage costs and data management. Below is a discussion of the simulation results. In the first simulation, we examined how the storage cost evolves concerning the number of transactions sent. The results show two significant trends: Initially, when the number of transactions is low, the storage cost without pruning is relatively similar to the counterpart with pruning. This suggests that for small-scale systems, the overhead of maintaining all data is comparable to the cost of the pruning method. However, as the scale of transactions increases, the storage cost without pruning grows larger and faster. This trend highlights the exponential growth in storage requirements when historical data is retained without efficient pruning mechanisms. On the other hand, the storage cost with pruning keeps increasing, albeit at a more gradual pace compared to the non-pruning scenario. This phenomenon occurs because the data size of the two monitoring nodes continues to grow over time. While pruning reduces the storage burden, the persistence of data in the monitoring nodes leads to a steady increase in storage costs. This emphasizes that even with pruning, it is essential to manage data growth within monitoring nodes effectively. The second simulation compared the data size of normal nodes and monitoring nodes as the number of transactions increased. The following key observations can be made: The data size of a normal node remains unchanged throughout the simulation. This behavior is consistent with the typical behavior of a normal node, which typically stores and manages only the most recent data. As a result, its data size remains stable over time, confirming the efficiency of the historical data pruning approach in large-scale systems as shown through Fig. 6. In summary, the data size of a monitoring node exhibits linear growth with the number of transactions. This indicates that monitoring nodes retain historical data, which is essential for various analytical and auditing purposes. However, this growth highlights the importance of implementing strategies to manage the increasing data size within monitoring nodes efficiently. The simulation results shed light on the scalability of the system. They show that as the number of transactions increases, storage costs tend to grow, even with pruning. This underscores the need for well-designed data management strategies, especially when dealing with large-scale systems. The tradeoff between data retention for analysis and storage efficiency becomes more critical as the system scales. In conclusion, the simulation results demonstrate the importance of implementing effective data pruning methods and data size management strategies in systems with a large number of transactions. They highlight how storage costs can escalate rapidly without proper pruning and how monitoring nodes can accumulate historical data. These insights can guide system designers and administrators in making informed decisions about data storage and management to ensure efficient operation and scalability.

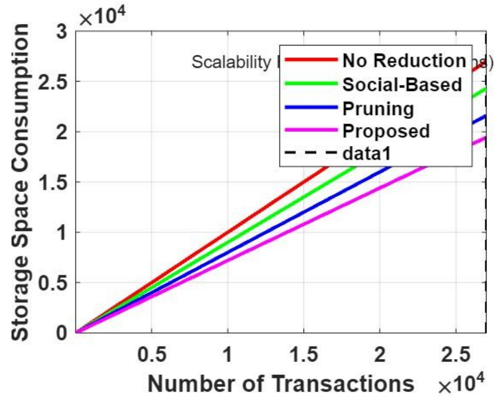

Fig. 6. Simulation results based on storage consumptions
and number of transactions sent.

Fig. 6 shows the discussion of simulation results based on storage consumption and the number of transactions sent provides valuable insights into the performance and scalability of a system, particularly in the context of blockchain and distributed ledger technologies. Let's break down the discussion into key points. The simulation results in Fig. 6 indicate that as the number of transactions in the blockchain network increases, the storage consumption also grows. This is a natural consequence of blockchain's immutable nature, where each transaction is recorded in a block, and all blocks are linked together in a sequential chain. It's important to note that the growth rate of storage consumption might vary depending on factors such as the block size and frequency of transactions. Smaller block sizes and higher transaction frequencies tend to result in faster storage growth. Scalability is a critical factor in the adoption of blockchain technology. The discussion of storage consumption reveals the need for efficient mechanisms to handle increasing storage requirements as the system scales. Solutions like sharding, pruning, and off-chain storage can be explored to manage storage growth while maintaining blockchain integrity and security. The number of transactions sent is a key metric for assessing the throughput of a blockchain network. High transaction throughput is often a desirable feature, especially in applications like cryptocurrencies and supply chain management. The simulation results can help in evaluating the network's ability to handle increased transaction loads. Factors such as confirmation times and transaction fees may be influenced by the number of transactions sent. Businesses and organizations need to plan for storage resources and associated costs based on the expected growth in transactions. This includes estimating hardware requirements and assessing the financial implications of storage expansion. The discussion should consider the balance between optimizing storage consumption and maintaining the historical data needed for auditing, compliance, and data integrity. The results may reveal trade-offs between data retention and storage cost. Some use cases may require long-term data storage, while others might benefit from data pruning or archiving. Optimization strategies, such as implementing data compression techniques or using distributed file systems, can be discussed as potential solutions to manage storage growth effectively. To conclude the discussion, it is essential to emphasize the need for ongoing research and development in blockchain technology. Scalability, storage efficiency, and transaction throughput continue to be active areas of exploration and innovation as shown through Fig. 6.

In summary, the discussion of simulation results related to storage consumption and the number of transactions sent underscores the complex interplay between blockchain performance, scalability, and resource management. It highlights the challenges and opportunities associated with adopting blockchain technology in various applications and underscores the importance of strategic planning and optimization to ensure the long-term viability of blockchain-based systems.

8. Discussion

The conclusion of the research paper highlights the transformative potential of an efficiency-driven permissioned blockchain framework for data reduction in the context of supply chain management. It emphasizes several key points that underscore the significance of this framework in addressing the challenges faced by modern supply chain operations:

• Addressing Data Overload and Redundancy: The paper emphasizes that data overload and redundancy are common issues in supply chain management. These challenges can lead to inefficiencies, increased operational costs, and data inconsistencies. The adoption of the proposed blockchain framework offers a robust solution to mitigate these problems.

• Leveraging Blockchain Technology: - The research underscores the power of blockchain technology in enhancing supply chain operations. Blockchain's inherent features, such as transparency, immutability, and decentralized data storage, can significantly improve data management and streamline processes.

• Benefits of the Framework: - The conclusion highlights several benefits of implementing the framework, including greater transparency, traceability, and data efficiency. These advantages can lead to better supply chain visibility and more accurate decision making.

• Data Reduction and Eliminating Intermediaries: By reducing data duplication and eliminating intermediaries, organizations can not only reduce costs but also simplify supply chain processes. This streamlined approach can enhance operational efficiency and reduce the risk of errors.

• Data Security and Trust: The paper acknowledges that data security is a critical concern in supply chain management. The framework enhances data security by leveraging blockchain's cryptographic features. This, in turn, can improve customer trust, a vital factor in today's business environment.

In summary, the conclusion of the research paper underscores the transformative potential of an efficiency-driven permissioned blockchain framework for data reduction in supply chain management. It highlights the myriad advantages of adopting this technology, from cost savings to enhanced data security and customer trust. Moreover, it positions the framework as a strategic choice that can propel organizations toward sustainable growth and competitiveness in an ever-evolving global marketplace.

9. Conclusions

In conclusion, the adoption of an efficiency-driven permissioned blockchain framework for data reduction holds immense potential for revolutionizing supply chain management. This framework offers a robust solution to the challenges of data overload and redundancy that often plague supply chain operations. By leveraging the power of blockchain technology, organizations can achieve greater transparency, traceability, and data efficiency in their supply chains. Through the implementation of this framework, companies can reduce the duplication of data, eliminate intermediaries, and enhance data security. This not only results in cost savings but also provides a foundation for more informed decision-making and improved customer trust. Furthermore, the permissioned blockchain approach ensures that data access is controlled and restricted to authorized participants, enhancing data privacy and compliance with regulatory requirements. As the business landscape continues to evolve, the need for efficient supply chain management becomes increasingly vital. Embracing this efficiency-driven permissioned blockchain framework is a forward-thinking strategy that can position organizations for long-term success in an ever-competitive global marketplace. It offers the promise of streamlined operations, reduced costs, and a more agile and responsive supply chain ecosystem, ultimately leading to enhanced customer satisfaction and sustainable growth.

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