Scalability in Blockchain using Node Sharding and Directed Acyclic Graphs.

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This research reviews ten pivotal papers exploring **Directed Acyclic Graphs** (DAGs) and **node sharding** techniques to enhance blockchain scalability for the **Industrial Internet of Things (IIoT)** and **6G networks**. The aim is to address the limitations of traditional blockchain architectures, such as low throughput and high latency, which are incompatible with the demands of high-volume, real-time data processing in IIoT and 6G applications.

The research investigates how DAGs and sharding have been adapted and optimized for resource-constrained devices and massive network scales in future telecommunications and industrial systems. The integration of these technologies reduces transaction confirmation times and supports decentralization, securing IIoT and 6G ecosystems against various security threats. The findings will outline current capabilities, identify technology gaps, and propose future research directions for robust, efficient, and scalable blockchain frameworks, fostering innovation in industrial automation and smart infrastructure.

- **Industrial Internet of Things (IIOT)**: In the Industrial Internet of Things (IIoT), a vast array of devices generates substantial incoming traffic that needs efficient processing. Scalability is crucial in IIoT to manage the large number of devices and the immense data they produce. Additionally, the interconnected nature of these systems raises significant security concerns, necessitating robust mechanisms to safeguard sensitive industrial data and ensure reliable operations across various sectors.
- **6G Network**: In the context of 6G, the next generation of cellular networks aims to support even higher data rates and lower latency than its predecessors. This advancement will enable applications such as autonomous driving, immersive augmented reality, and more comprehensive smart city infrastructures. However, the complexity and scale of 6G demand advanced scalability solutions to handle the increased data traffic and device connectivity efficiently. Security also becomes paramount in 6G, as the network's expansive reach and the critical nature of its applications involve substantial privacy and safety risks.

Beyond 6G and IIoT, blockchain's scalability could also transform sectors like supply chain management, financial services, edge computing, healthcare, and governance by providing a secure, transparent, and decentralized infrastructure for data sharing and transaction processing.

INTRODUCTION

Addressing Blockchain Scalability Challenges

- **Emerging Challenges:** Scalability and efficiency issues facing current blockchain technologies.
- **Proposed Solutions:** Sharding and Directed Acyclic Graphs (DAGs) as potential remedies.
- **Study Focus:** Reviewing recent advancements in scalability through sharding and DAGs.

- **Growing Need:** Demand for scalable blockchain solutions in various fields, including finance and IoT.
- **Promise of Sharding and DAG:** Potential to revolutionize scalability, reducing latency and increasing throughput.
- **Identified Gaps:** Existing research gaps like security vulnerabilities and consistency issues, highlighting ongoing research opportunities.

Figure: Flow of research for enhancing scalability in blockchain

- **Objectives**:
  - To enhance the scalability of blockchain systems to handle a much larger volume of transactions per second.
  - To effectively apply sharding—a well-known database scaling technique—to blockchain technology
- **Methodology**:
  - Enhancing Byzantine consensus protocols to boost individual shard throughput.
  - Using trusted hardware (Intel SGX) for high-performance consensus and secure shard formation.
- **Limitations:**
  - **Dependence on trusted hardware:** The reliance on Intel SGX raises concerns about the general applicability in environments where such hardware might not be available or reliable.
  - **Complexity in protocol coordination:** Managing the distributed transactions across shards is complex and could be prone to errors or inefficiencies under different operational scenarios or attacks.
- **Results:**
  - Achieved over 3,000 transactions per second in realistic settings on Google Cloud Platform, significantly outperforming state-of-the-art solutions.
  - Maintained high transaction throughput in multi-region setups with hundreds to thousands of nodes.

- **Architecture of the Proposed Framework**
  - **Shard formation protocol:** Utilizes a trusted random beacon for secure node assignment to shards.
  - **Consensus protocol optimization:** Utilizes trusted execution environments to enhance consensus protocol efficiency and security.

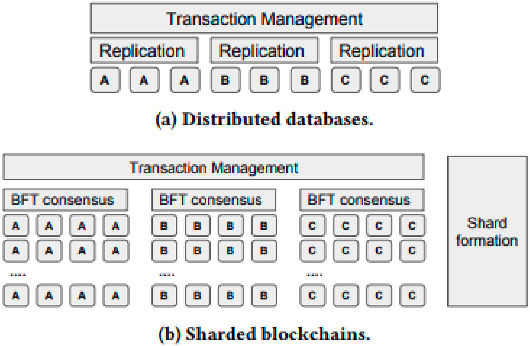

Figure: Sharding protocols in traditional databases vs. blockchains.[1]

Ostraka: Secure Blockchain Scaling by Node Sharding (2020) [2]

- **Objectives:**
  - Presenting a scalable blockchain architecture to improve transaction processing efficiency and security.
  - Introducing Ostraka architecture with node sharding.
  - Demonstrating security analysis proving comparable security to traditional systems.
  - Showcasing performance evaluation showcasing linear scalability.
- **Methodology:**
  - Node sharding to distribute transaction processing across node shards.
  - Transaction distribution mechanism using hashing with unique node-specific "salt."
  - Block validation with coordinated validation across node shards.
- **Limitations:**
  - Resource intensity demanding more computational resources per node.
  - Complexity in implementation due to the distributed nature of the architecture.
- **Results:**
  - Scaling performance achieving up to 400k transactions per second.
  - Security analysis proving comparable security to traditional systems.

Ostraka: Secure Blockchain Scaling by Node Sharding (2020) [2]

- **Architecture:**
  - Node-Shards (NSs) handling specific parts of transaction processing.
  - Coordinator managing NS operation and facilitating communication.
  - Distributed block validation allowing parallel validation, reducing block processing time.

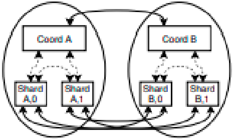

Figure: Two connected Ostraka nodes, with intra-node connections. [2]

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Scaling Blockchain via Layered Sharding(2022)[3]

- **Objectives:**
  - **Efficient Handling of Cross-Shard Transactions**: Develop a method to manage transactions that span multiple shards more effectively without the need to break them into smaller sub-transactions.
  - **Utilize Advanced Nodes**: Allow nodes with higher capabilities to participate in multiple shards, leveraging their capacity to enhance overall network performance.
- **Methodology:**
  - **Layered Sharding Approach**: Implement a hierarchical structure where some nodes operate in multiple shards, which can handle both internal and cross-shard transactions.
  - **Cooperative Cross-Shard Consensus**: Develop a consensus mechanism that enables efficient and secure validation and execution of cross-shard transactions in a single round of consensus.
- **Limitations:**
  - Assumption of a certain distribution and capacity of nodes may not always be practical.
  - Reliance on the capability of nodes in bridging shards, failure or compromise of which could affect the system.
  - Ensuring consistent security across all shards, particularly with nodes participating in multiple shards, is complex and requires robust safeguards against potential breaches or failures.
- **Results:**
  - Improved transaction throughput by up to 3.2 times compared to existing sharding techniques.
  - Achieving around 3821 transactions per second for 20 shards.

- **Architecture:**
  - Combination of intra-shard and inter-shard operations.
  - Nodes in bridging shards (b-shards) handling transactions across multiple individual shards (i-shards).
  - Reduced need for multiple consensus rounds for cross-shard transactions.

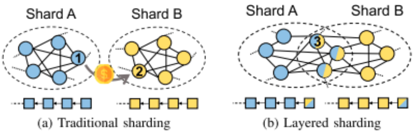


Figure: Illustration for different blockchain sharding systems [3]

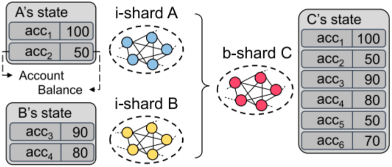


Figure: Illustration for a layered sharding for i-shard A, B and b-shard C.[3]

TxChain: Scaling Sharded Decentralized Ledger via Chained Transaction Sequences. (2022) [4]

- **Objective:**
  - Utilize sharded ledger for scalable, secure, parallel blockchain transaction processing.
- **Proposed Methodology:**
  - TxChain: Merkle Patricia tree for account leaf nodes with chained transaction sequences (TxSEQs).
  - Transactions processed instantly within shards, broadcasted for synchronization.
  - Validators verify transactions, maintain network consistency via Transaction Sequence Conversion (TSC) algorithm.
- **Conclusion:**
  - TxChain achieves significant throughput gains through parallel processing across shards.
  - Benefit diminishes with more shards due to ledger replica overhead.
  - Offers promising scalability and secure consensus mechanism.
- **Limitation:**
  - **Storage bottleneck:** TxChain maintains full ledger copies on each shard, limiting storage scalability.
  - **Cross-shard complexity:** The paper lacks details on how TxChain handles cross-shard interactions, potentially impacting performance.

TxChain: Scaling Sharded Decentralized Ledger via Chained Transaction Sequences. (2022) [4]

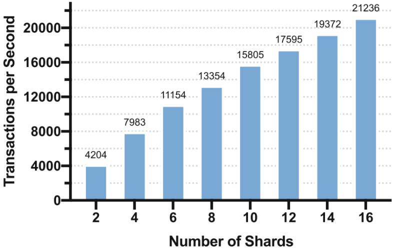


Figure: Throughput Scalability (Throughput vs Number of shards)[4]

- **Results:** TxChain demonstrates throughput improvement with increasing shards with doubling the shards leading to a 1.59-1.89x throughput increase. This benefit lessens with more shards due to each shard holding the full ledger and TxChain's dependency analysis overhead.

Benzene: Scaling Blockchain With Cooperation-Based Sharding (2022) [5]

- **Objective:**
  - Improve transaction throughput while maintaining fixed fault tolerance, even with increasing shards.
- **Methodology Proposed:**
  - Unique double-chain architecture decouples transaction recording from consensus execution.
  - Allows cross-shard cooperation without interfering in transaction processing within shards.
  - Each shard maintains proposer chain for recording transactions and vote chain for cross-shard consensus.
  - Cross-shard verification facilitated by Trusted Execution Environments (TEEs) providing validation proofs, minimizing individual node overhead.
- **Architecture:**
  - Double-Chain Architecture: Each shard maintains separate proposer and vote blockchains, as shown in Shard 1, Shard 2, and Shard N.
  - Cross-Shard Verification: Nodes with TEEs verify proposer blocks from other shards and provide validation proofs, depicted by the dotted blue arrows between shards.
  - Cross-Shard Voting Consensus: Miners vote on proposer blocks from all shards based on TEE proofs, shown by the solid red arrows between shards to confirm the most voted block.

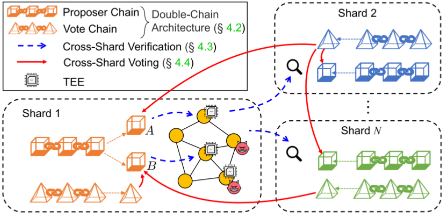


Figure: Architecture of Benzene [5]

Conclusion:

- Architecture achieves high throughput through cross-shard cooperation, double-chain design, and voting consensus with TEE verification.

Limitation:

- Security risks due to reliance on TEEs like rollback attacks, jeopardizing system integrity.
- The increment of throughput starts to stop at around 400 shards, therefore leading to a maximal number of blocks that can be verified per second.

Benzene: Scaling Blockchain With Cooperation-Based Sharding (2022) [5]

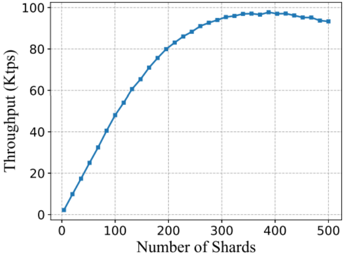


Figure: Throughput evaluated by simulations. [5]

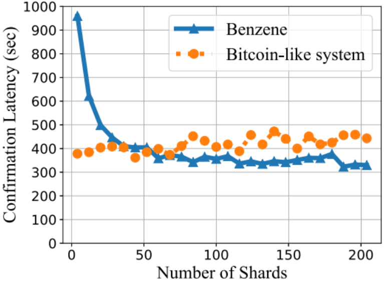


Figure: Confirmation latency in simulations [5]

- **Result:**
  1. Linear throughput scalability, achieving 32,370 TPS with 50 shards, outperforming traditional systems like Bitcoin as can be seen from Fig 8 and Fig 9.
  2. Fixed fault tolerance of 1/4, independent of the number of shards.
  3. Cross-shard communication for TEE and voting data (87KB with 50 shards) is negligible compared to block size (1MB).

- **Objective:**
  To improve blockchain's efficiency and scalability in the context of the Industrial Internet of Things (IIoT) by organizing blocks in a compacted DAG structure instead of a linear chain.
- **Methodology Proposed:**
  The proposed framework addresses resource limitations in Industrial IoT (IIoT) networks by dividing devices into miners, gateways, and nodes. Miners, similar to Bitcoin miners, maintain the ledger using custom CoDAG protocols for fast transaction processing. Gateways, with more resources than basic nodes, manage ledger sections, secure communication, and conduct transactions. Nodes submit data and payments through gateways. This division leverages device capabilities while CoDAG's fast consensus ensures efficient transaction handling in resource-constrained IIoT environments.
- **Limitation:**
  Potential instability under high transaction rates and needs further work for large data volumes (security & throughput).

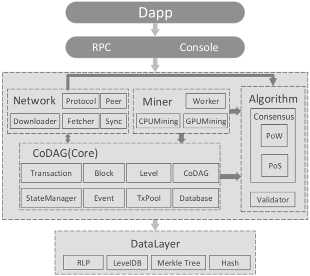


Figure: Implementation Framework with CoDag[6]

- **Architecture:**
  DApp Layer: Supports decentralized applications built on CoDAG.
  RPC/Console Layer: Communicate with the CoDAG system.

Chain Layer (Core):

1. Network Module: Synchronizes network information via peer-to-peer protocols.
2. CoDAG Module: Maintains the core data structure and algorithms.
3. Miner Module: Manages miners and adjusts mining difficulty.
4. Consensus Algorithm Module: Ensures agreement among nodes.

Miner Module: Secure the network by validating transactions and adding blocks.
Consensus Algorithm Module: Guarantees consistent ledger state via a custom, resource-friendly consensus algorithm designed for IIoT.
Data Layer: Stores transaction data using RLP encoding, LevelDB database, Merkle Trees, and hashing.

An Efficient and Compacted DAG-Based Blockchain Protocol for Industrial Internet of Things. (2020) [6]

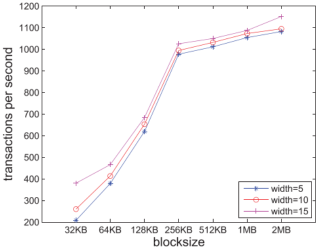


Figure: Relationship between throughput and blocksize[6]

Result: The CoDAG protocol achieved 1151 transactions per second (tps) when the block size was 2 MB and the width was 15, which is 164 times the throughput of Bitcoin and 77 times that of Ethereum. The paper examines security vulnerabilities and proposes ways to mitigate them.

Conclusion:
The proposed framework tackles scalability and efficiency limitations of traditional blockchains in IIoT.

TIPS: Transaction Inclusion Protocol With Signaling in DAG-Based Blockchain(2022) [7]

- **Objective**: To address the key challenges faced by DAG-based blockchain systems- the transaction inclusion collision and the resulting revenue and throughput dilemmas by proposing a novel Transaction Inclusion Protocol with Signaling (TIPS) to resolve these dilemmas.

- **Research Gaps Identified**:
  - **The revenue dilemma:** Miners are discouraged from including high-fee transactions due to the risk of transaction collision, which leads to a split of the reward.
  - **The throughput dilemma:** Increasing the block size to boost throughput leads to higher network propagation delay, which in turn increases transaction collisions and degrades the system throughput.

- **Components of the Architecture**:
  - **Bloom filter in the block header:** This compact data structure serves as a "signal" to quickly propagate information about the transactions included in the newly-mined block.
  - **Header-first block propagation:** TIPS decouples the propagation/verification processes of the block header and the block body, allowing the block header to be broadcast to the network quickly.
  - **Transaction inclusion game and strategy update:** Miners update their transaction inclusion strategies based on the received signal to avoid collision.

TIPS: Transaction Inclusion Protocol With Signaling in DAG-Based Blockchain(2022) [7]

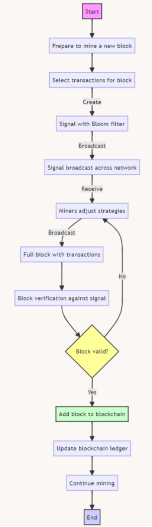
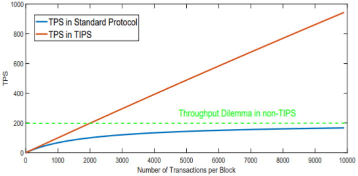


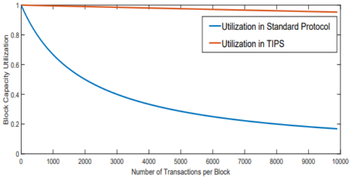
Figure: Workflow of TIPS

- **Proposed Methodology:**
  - Miners first create a "signal" containing a Bloom filter that indicates which transactions are included in a new block. This signal is quickly broadcast across the network.
  - Upon receiving the signal, other miners adjust their transaction inclusion strategies to avoid collisions by excluding transactions indicated in the signal.
  - After the signal, the complete block including all transaction details and proof of work is broadcast. Other miners verify the block against the Bloom filter in the signal. If validated, the block is added to the blockchain, extending the chain and updating the network's ledger.
- **Contributions:**
  - TIPS can effectively resolve DAG-based blockchain systems' revenue and throughput dilemmas.

TIPS: Transaction Inclusion Protocol With Signaling in DAG-Based Blockchain(2022) [7]



(a) TPS in TIPS and Standard Protocol



(b) Utilization in TIPS and Standard Protocol

Figure: Comparing results of TIPS with standard protocol [7]

- **Results:**
  - TIPS can achieve a block capacity utilization of around 90%.
  - TIPS can provide a system throughput (TPS) that is up to 5 times higher than the standard protocol.
- **Limitations**
  - The analysis assumes homogeneous miners and transaction fees.
  - The paper does not consider the potential computational and communication overhead introduced by the Bloom filter-based signaling mechanism.
  - Bloom filters do not focus on preventing false positives.

Understanding Characteristics and System Implications of DAG-Based Blockchain in IoT Environments(2022) [8]

- **Objective**:The paper focuses on IOTA, a DAG-based blockchain for IoT environments. The study identifies gaps in traditional block-based blockchain systems like Bitcoin and Ethereum, which suffer from low transactions per second, significant computation demands, and high costs—factors unsuitable for IoT scenarios. DAG-based blockchains promise higher throughput and lower latency, but lack comprehensive evaluations especially in realistic IoT settings.
- **Proposed Methodology**: The authors have developed a private IOTA network with 35 Intel NUCs, where one NUC acts as a coordinator, others as full nodes, and some as clients. They have implemented three key components as part of their benchmark tools: Automatic transaction initiator, Real-time status monitor, Double-spending attacker.
- **Limitation:** Increased network synchronization overhead with more full nodes.
  The DAG's validation and tip-selection processes follow complex and computationally intensive algorithms.
  The reliance on Coordinator node creates a point of centralization and a single point of failure.

Understanding Characteristics and System Implications of DAG-Based Blockchain in IoT Environments(2022) [8]

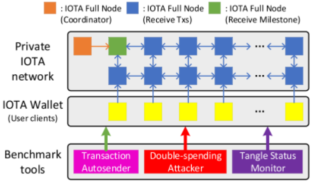


Figure: Private IOTA System Architecture [8]

- **Architecture:**
  The Tangle: An innovative DLTspecifically designed for IoT environment. The Tangle is a graph where each transaction is its own node.
  Coordinator NUC: Responsible for sending milestones to the IOTA network.
  Full nodes: Run the IOTA reference implementation (IRI) service to receive and handle transactions.

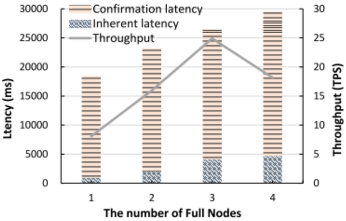


Figure: Latency and throughput with multiple nodes [8]

- **Results:**
  - The IOTA network can recover from an off-syncing attack, with a recovery speed of around 20 TPS.
  - The system throughput under scaled configurations peaked at approximately 25 TPS with three full nodes but slightly decreased when four full nodes were active.

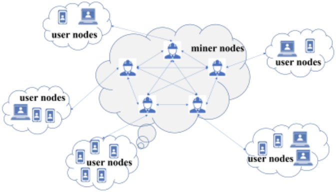
DAG-BLOCK: A Novel Architecture for Scaling Blockchain-Enabled Cryptocurrencies (2024) [9]

- **Objective**:The paper proposes a novel DAG-based architecture to enhance the scalability of blockchain systems used in cryptocurrency markets. Existing systems like Bitcoin struggle with low transactions per second and high latency due to the linear block validation process.

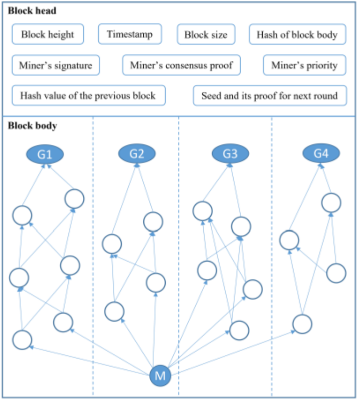
- **Proposed Methodology**:
  - **Transaction Submission:** User nodes submit transactions and miner nodes maintain local sub-DAGs.
  - **Random Leader Selection:** Potential leader miners are randomly selected to build blocks from sub-DAGs.
  - **Block Verification and Finalization:**Highest priority block is accepted and linked to the blockchain.
  - **Economic Incentives:** Transaction fees incentivize miners to scale user nodes and maintain stability.

- **Contributions:** Replacing the Merkel-tree-based transaction structure within the block by a DAG structure to retain the globally linear chain structure while limiting the size of the DAG.
  Proposing the concept of "open blocks".
  Proposing to segment the cryptocurrency ecosystems into niche markets.

DAG-BLOCK: A Novel Architecture for Scaling Blockchain-Enabled Cryptocurrencies (2024) [9]



(a) Network Market Architecture



(b) DAG Block Structure

Figure: System Architecture [9]

DAG-BLOCK: A Novel Architecture for Scaling Blockchain-Enabled Cryptocurrencies (2024) [9]

- **Components of Architecture:**
  Market Network Architecture: Utilizes a decentralized P2P network mixed with centralized components where each miner serves a specific subset of users, reducing the range of transactions each miner must manage.
  DAG-BLOCK Structure: Incorporates a DAG within each blockchain block, enhancing the ability to process multiple transactions simultaneously.
  Open Blocks: Allows user nodes to participate directly in the transaction verification process, reducing dependency on miners and decentralizing the control further.

- **Limitations:**
  - The division of the market into segments introduces complexity in managing and synchronizing these segments.
  - Increased user participation in the transaction verification process could introduce increased communication overhead and potential security vulnerabilities.
  - The system's efficiency heavily relies on the algorithmic selection of tips within DAGs.

- **Results:**
  - Reduces transaction confirmation time to a few seconds.
  - DAG-Block system can increase throughput to 50-100 TPS, compared to 7TPS of Bitcoin and 15-25 TPS of Ethereum.

Resource-Efficient DAG Blockchain with Sharding for 6G Networks (2021) [10]

- **Aim**: The main aim of this paper is to propose a resource-efficient DAG blockchain with sharding to enable secure and scalable resource sharing in 6G networks.
- **Methodology used**:
  - **Implement Sharding:** The blockchain network is segmented into multiple committees, each responsible for a disjoint subset of transactions. This structure supports concurrent processing and local recording, facilitating rapid and efficient handling of transactions.
  - **Utilize a Global DAG of Block Headers:** To counteract the security challenges posed by sharding, all committees maintain a global Directed Acyclic Graph (DAG) of block headers. This approach minimizes communication overhead by broadcasting block headers instead of full blocks across the network.
  - **Develop Computation-Efficient Consensus:** A new consensus mechanism leverages the computing power of miners more effectively. Miners are incentivized with lower mining difficulties for proposing resource allocation schemes that optimize based on fairness and efficiency criteria.

- **Components of DASH scheme in blockchain**
  - **1. DAG-Based Blockchain:**
    Utilizes a Directed Acyclic Graph (DAG) to enhance scalability by allowing concurrent block creation, although this increases communication and storage demands.
  - **2. Sharding:** Divides the network into multiple committees that manage and record transactions locally, reducing the need for widespread data broadcast and enhancing processing efficiency.
  - **3. Global DAG Maintenance:** Committees maintain a global DAG to ensure consistency across the blockchain, updating and storing block headers to support secure and coherent data across the network.

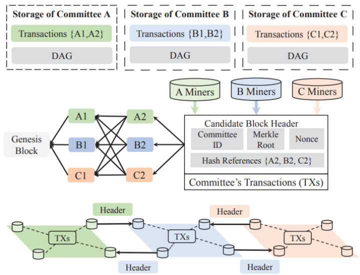


Figure: Blockchain for 6G Networks, DASH [10]

- **Result:** The results demonstrate that the proposed DAG blockchain sharding in spectrum sharing systems, applied to a 100 km² area with complex base station distributions, enhances the cost function value and converges optimally when the network is divided into four large committees. Additionally, the improved Proof of Work (PoW) algorithm significantly enhances spectrum allocation utility and efficiency, consistently outperforming the traditional PoW by incentivizing miners to propose more effective spectrum allocation schemes.

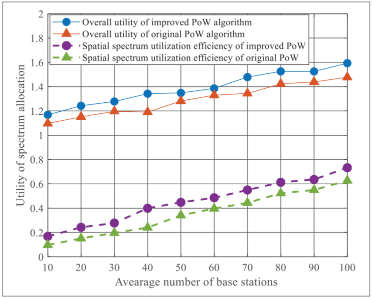


Figure: Comparsion of the utility of proposed approach and PoW. [10]

- **Limitations**: The following points highlight the key limitations of sharding as a blockchain scaling solution.
  - **Complex Transaction Management:** High overhead from managing complex cross-shard transactions reduces throughput.
  - **Security and Load Balancing Issues:** Security risks due to uneven workload distribution and fewer nodes per shard.
  - **Operational and Standardization Challenges:** Difficulties in cross-shard communication and lack of sharding standardization complicate operations.
- **Conclusion:** The article discusses a DAG blockchain with sharding optimized for 6G networks, highlighting its superior throughput, reduced maintenance costs, and improved security over traditional PoW blockchains. It successfully enhanced spectrum efficiency and computation economy in spectrum-sharing applications. Nonetheless, the transition to 6G introduces issues like scalability and adaptation to diverse resources, potentially impacting blockchain consistency and the need for tailored data recording services. The study underscores the necessity for continued research to balance security and performance, particularly in managing delay-sensitive transactions with fewer blocks in the DAG.

Table: Comparison of Research Papers on RIS Technologies

Author	Contributions	Limitations
Hung Dang et al.[1]	Improvement in shard throughput and transaction protocols for large-scale workloads	Challenges in distributed transaction support and failure models in blockchain compared to databases
Alex Manuskin et al.[2]	Introduction of Ostraka architecture for scaling security and performance in blockchain	Design challenges in scalability and resource distribution under increasing demand
Zicong Hong et al.[3]	Introduction of a layered sharding system for blockchain with support for cross-shard transactions	High conflict ratios leading to frequent transaction aborts
Zheng Xu et al.[4]	Development of TxChain for improved scalability and latency, with a novel consensus mechanism	Concerns over consensus security and high communication overhead in scalability

Author	Contributions	Limitations
Zhongteng Cai et al.[5]	Sharding architecture with enhanced cross-shard cooperation and verification mechanisms	Limited cooperation in consensus among shards, and issues with TEE deployment affecting performance
Laizhong Cui et al.[6]	High throughput and security in blockchain for IIoT via the CoDAG protocol	Efficiency and fast consensus challenges in traditional blockchains and IIoT systems
Canhui Chen et al.[7]	TIPS protocol to reduce transaction collision and defend against attacks in DAG-based blockchain	Computational and communication overhead introduced.
Tianyu Wang et al.[8]	Examination of IOTA's performance in IoT through benchmarks and experimental studies	Issues with scalability and transaction fees in IoT environments

Author	Contributions	Limitations
Naina Qi et al.[9]	Proposed DAG-BLOCK for markets with open blocks and segmented market structure.	Faces challenges with security vulnerabilities and untested consensus mechanisms, requiring further development and validation
Jin Xie et al.[10]	Sharding and DAG blockchain applied to 6G networks for enhanced throughput and cost efficiency	Scalability and security challenges in block generation and consensus

Taking all the insights from the papers, after analysis the research gaps, technical requirements, future research could include the following hot topics.This research proposal details a multi-pronged strategy to enhance blockchain scalability and throughput through the following technical innovations:

- **Hybrid Consensus Mechanism:** Utilizes Byzantine Fault Tolerance (BFT) algorithms within shards for fast processing and a Proof-of-Stake (PoS) system across shards for robust security and synchronization.
    - **Intra-Shard Efficiency:** Within each shard, a BFT-like consensus algorithm enables rapid agreement among nodes by requiring only a subset to verify transactions, significantly speeding up the consensus process.
    - **Cross-Shard Security:** The PoS mechanism governs shard interactions and synchronization, ensuring ledger accuracy across the network. This is crucial for maintaining transaction integrity across shards, addressing a common challenge in sharded systems.
    - **Throughput Enhancement:** By separating transaction verification and inter-shard communication duties, the hybrid model permits each network segment to function optimally without delays, thus significantly enhancing overall throughput.
- **Optimized transaction propagation:** Improve the efficiency of transaction propagation and synchronization across the DAG network. Techniques like compact transaction representations, intelligent gossiping protocols, and topology-aware routing can help reduce the communication overhead and latency while ensuring reliable and consistent transaction dissemination

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