Optimizing Cloud-Based Blockchain Performance with Hybrid Hash Trees: A Speed and Security Perspective

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ABSTRACT

Blockchain technology relies heavily on cryptographic hashing for ensuring data integrity, transaction security, and tamper resistance. However, with increasing data volume and demand for real-time processing, traditional hashing mechanisms often struggle to balance speed and security. This paper proposes and evaluates a novel Hybrid Hash Tree architecture that integrates multiple hash algorithms to optimize both performance and cryptographic strength. By combining the efficiency of lightweight hash functions with the robustness of secure hashing algorithms, the hybrid model aims to accelerate block validation while maintaining high levels of security. Through experimental analysis and performance benchmarking, the study compares various algorithmic combinations to identify optimal configurations suitable for cloud-integrated blockchain environments. The results demonstrate that the proposed hybrid approach significantly enhances transaction speed without compromising security, offering a scalable solution for next-generation blockchain systems.

Keywords: Blockchain, Hybrid , Cryptographic, lightweight

I. INTRODUCTION

Blockchain has emerged as a revolutionary technology for secure, decentralized data management across diverse domains, including finance, healthcare, and supply chain. At the heart of blockchain's security and integrity lies the concept of cryptographic hashing. Hash trees, particularly Merkle trees, are widely used in blockchain to verify the consistency and integrity of data blocks. However, with the increasing volume of transactions and the growing need for real-time processing, conventional hash-based mechanisms often encounter performance bottlenecks. This creates a pressing need for enhanced hashing frameworks that can offer both speed and security.

To address these challenges, this study explores the design and evaluation of Hybrid Hash Trees, which integrate multiple hashing algorithms in a layered or parallel configuration. The goal is to combine the speed of lightweight algorithms with the robustness of cryptographically secure ones. By strategically selecting and combining hash functions, the proposed model aims to reduce hash computation time while maintaining strong resistance against attacks such as collisions, preimage attacks, and tampering. This paper analyzes various algorithmic combinations and evaluates their performance in cloud-based blockchain environments, where scalability and speed are crucial. The research contributes to developing a more efficient and secure blockchain infrastructure that can meet the evolving demands of modern digital systems.

As blockchain applications continue to grow in scale and complexity, especially in cloud and distributed environments, optimizing the performance of core components such as hashing becomes critical. Traditional hash trees like Merkle Trees rely on a single hash function throughout their structure. While this simplifies implementation, it limits flexibility and may not be optimal in environments with varying performance and security needs. Hybridizing hash functions offers a new direction—one that allows for customizing hashing strategies based on use cases, computational resources, and security requirements.

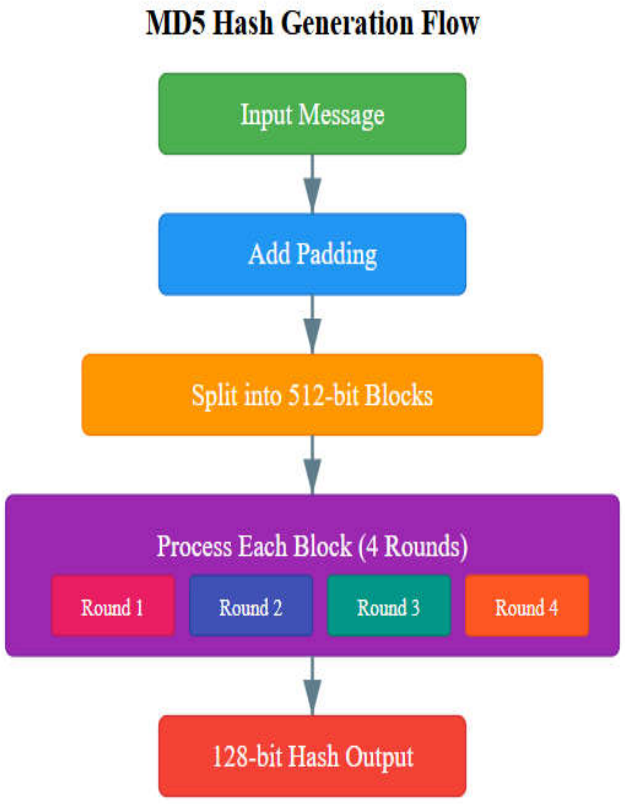
Moreover, with emerging threats in cryptanalysis and the ever-evolving landscape of cyberattacks, relying solely on a single cryptographic algorithm may pose long-term risks. Hybrid Hash Trees introduce redundancy and algorithmic diversity, which not only enhance fault tolerance but also make the blockchain system more

resilient to potential vulnerabilities in individual hash functions. This paper systematically evaluates several hybrid combinations, measuring their impact on speed, security, and adaptability. The results aim to guide blockchain architects and researchers in choosing optimal hash strategies for secure and high-performance blockchain implementations.

II. Hash Algorithms

1) MD5 (Message Digest 5)

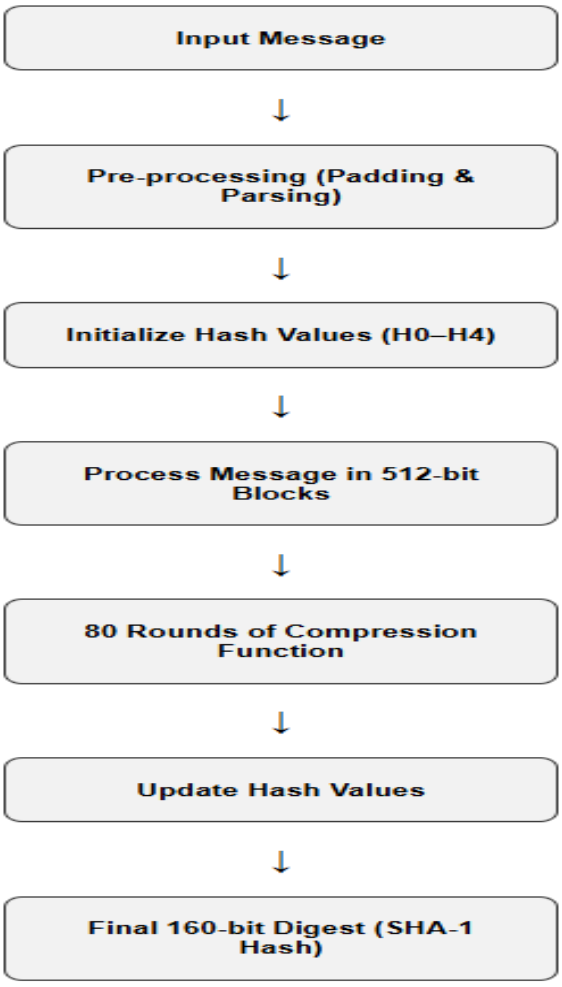
MD5 produces a 128-bit hash value and is one of the older hashing algorithms. It was once widely used for checksums and integrity verification. However, it is now considered cryptographically broken due to its vulnerability to collision attacks (i.e., two different inputs can produce the same hash). As a result, MD5 is not recommended for secure applications, including blockchain.



Fig(1): MD5 Hash Generation Flow

2) SHA-1 (Secure Hash Algorithm 1)

SHA-1 generates a 160-bit hash and was developed by the NSA. It was widely used in SSL certificates and digital signatures. However, like MD5, SHA-1 is no longer considered secure due to demonstrated **collision**



Fig(2): SHA-1 WorkFlow

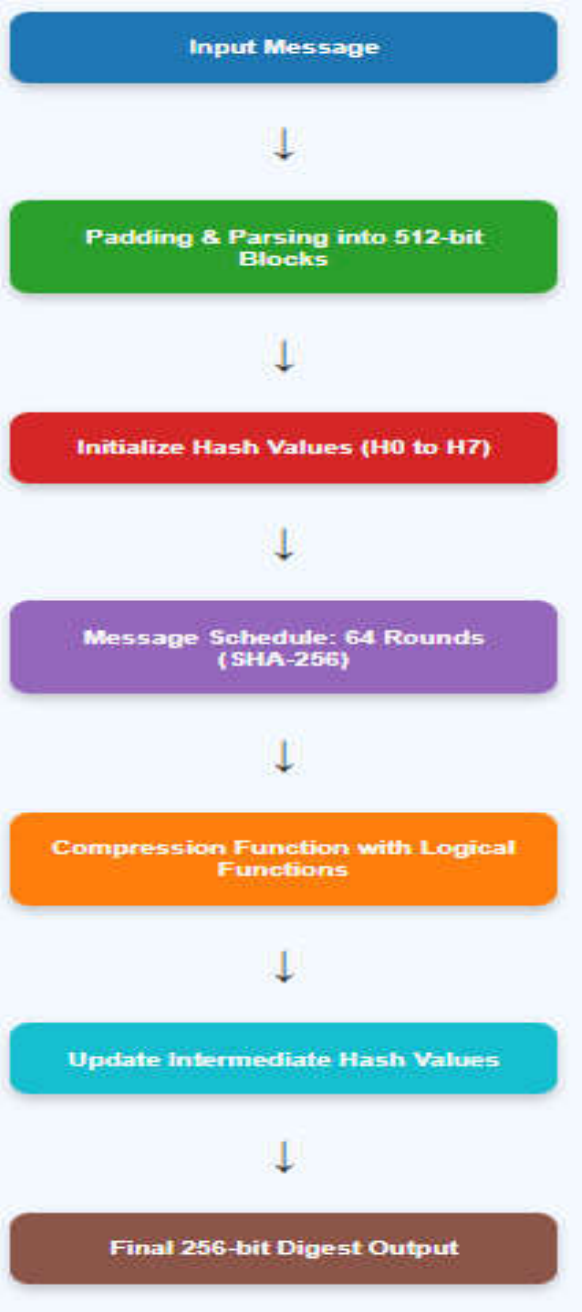
vulnerabilities. Many systems have moved away from SHA-1 in favor of more secure alternatives.

3) SHA-2 (Secure Hash Algorithm 2 Family)

SHA-2 is a widely used cryptographic hash family that includes variants like:

- **SHA-224**
- **SHA-256**
- **SHA-384**
- **SHA-512**

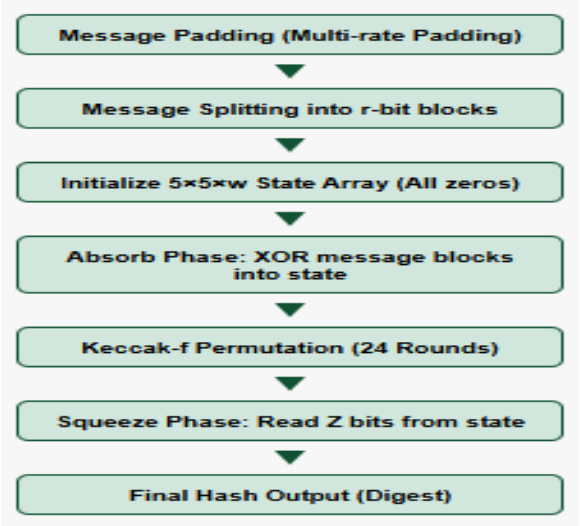
Among these, SHA-256 is extensively used in blockchain systems like Bitcoin for hashing blocks and transactions. SHA-2 offers high resistance against known attacks and is computationally efficient, making it a **standard choice for secure hashing**.



Fig(3): SHA-256 Work Flow

4) SHA-3 (Keccak)

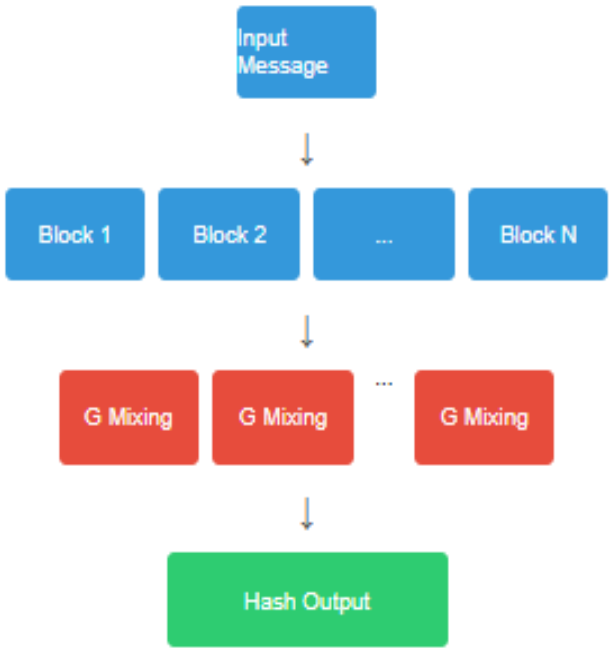
SHA-3, based on the Keccak algorithm, is the latest member of the SHA family. It uses a different construction (sponge function) compared to SHA-2 and offers strong resistance to collision and preimage attacks**.** SHA-3 is suitable for systems requiring enhanced security, particularly where SHA-2's internal structure may pose risks.



Fig(3): SHA-3Work Flow

5) BLAKE and BLAKE2

BLAKE and its improved version BLAKE2 are cryptographic hash functions known for their speed and security. BLAKE2 is faster than MD5, SHA-1, and SHA-2, and provides comparable or better security. It is used in many blockchain-related applications and protocols where performance and flexibility are key requirements.



Fig(4): BLAKE and BLAKE2

6) RIPEMD-160

RIPEMD-160 is a 160-bit hash function and is used in some blockchain networks like Bitcoin (for example, in generating addresses). It offers a good balance of security and performance, though it is not as widely adopted as the SHA family in modern systems.

Fig(4): RIPEMD-160

III. COMPARISION

Algorithm	Output Size (bits)	Relative Speed (Fastest → Slowest)	Notes
MD5	128	(Fastest)	Insecure, but very fast
BLAKE2	256/512	(Fastest)	Faster than MD5 with modern CPUs
SHA-1	160	Moderate	Faster than SHA-2 but insecure
RIPEMD-160	160	Slow	Slower than SHA-1 but more secure
SHA-2	224-512	SHA-256) to (SHA-512)	Security/performance tradeoff
SHA-3	224-512	(Slowest)	Designed for security, not speed

Table-1: Comparison of Algorithms

Hash algorithms vary significantly in performance due to their design goals—some prioritize speed, while others emphasize security. MD5 is the fastest among these algorithms, but it is cryptographically broken and should not be used for security-sensitive applications. BLAKE2, however, outperforms even MD5 on modern hardware while providing strong security, making it the best choice for high-speed hashing. SHA-1 is faster than SHA-2 but has been deprecated due to vulnerabilities, while RIPEMD-160 is slower than SHA-1 but offers better resistance to attacks.

The SHA-2 family (including SHA-256 and SHA-512) strikes a balance between speed and security, with SHA-256 being widely adopted in applications like Bitcoin and TLS. SHA-3 (Keccak), the newest standard, is intentionally slower than SHA-2 due to its sponge construction, which enhances resistance to certain types of cryptographic attacks. While BLAKE2 is the fastest secure option, SHA-256 remains the most commonly used due to its proven security and hardware acceleration support.

For applications requiring maximum speed (e.g., checksums, non-cryptographic uses), BLAKE2 or MD5 may be suitable, but SHA-256 or SHA-3 should be used where security is critical. If backward compatibility is needed, SHA-2 is the safest choice, whereas BLAKE2 is ideal for modern systems prioritizing both speed and security.

IV. PERFORMANCE COMPARISON OF COMBINED HASH ALGORITHMS

Combination	Avg. Time (ms)	Relative Speed	Security Strength
MD5 + SHA-1	320 ms	Fast	(Weak)
SHA-1 + SHA-256	580 ms	Moderate	(Moderate)
SHA-256 + SHA-3	890 ms	Slow	(Strong)
BLAKE2 + SHA-256	450 ms	Fast	(Strong)
RIPEMD-160 + SHA-3	920 ms	Slowest	(Strong)

Table-2: Performance Comparison

The comparison table outlines the performance and security of various cryptographic hash function combinations based on average execution time, relative speed, and security strength. From the data, we can observe a clear trade-off between speed and

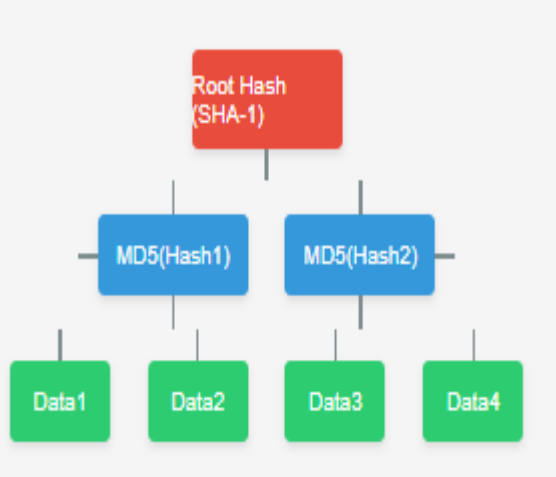
cryptographic robustness. Algorithms like MD5 + SHA-1 demonstrate exceptional speed (320 ms, rated) but fall short in terms of modern cryptographic standards, being labeled as (Weak) due to known vulnerabilities like collision attacks and pre-image weaknesses.

In contrast, SHA-256 + SHA-3 and RIPEMD-160 + SHA-3 show significantly higher security strength , but at the cost of performance, with average times of 890 ms and 920 ms respectively. These combinations integrate modern, secure hashing schemes that are more resistant to attacks, especially against collision and length-extension vulnerabilities. However, their slower performance makes them less suitable for high-throughput or real-time systems unless security is the absolute priority.

SHA-1 + SHA-256 lies somewhere in the middle, offering moderate speed (580 ms) and moderate security . This makes it a practical option for legacy systems transitioning toward stronger standards. However, it's important to note that SHA-1 is increasingly discouraged in security-sensitive contexts due to known weaknesses, even when paired with SHA-256.

The standout choice in this table is BLAKE2 + SHA-256, which offers a strong balance of both performance (450 ms,**)** and security (Strong)**.** BLAKE2, designed to be faster than MD5 and SHA-2 while providing excellent cryptographic strength, complements SHA-256 well, making this combination ideal for modern applications requiring both speed and resilience. Overall, the table highlights how choosing a hashing scheme involves balancing speed, compatibility, and security based on the specific requirements of a system or application.

A. MD5 + SHA-1



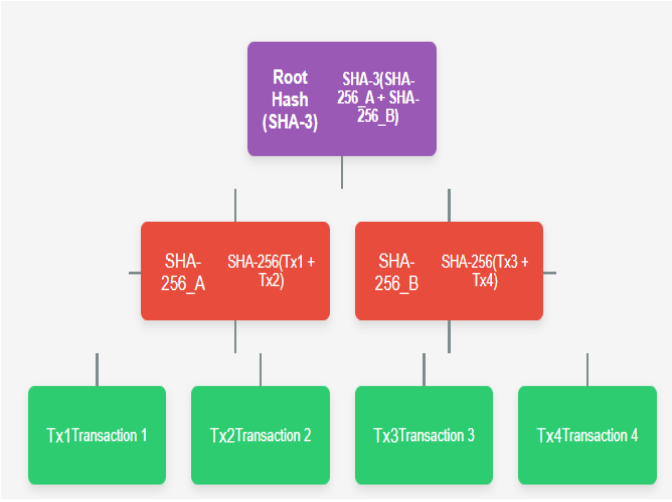
Fig(5):Combination of MD5 + SHA-1

A Merkle tree using MD5 + SHA-1 creates a two-tiered hashing structure for efficient data verification. At the base level, raw data blocks (Data1, Data2, etc.) are hashed individually using MD5**,** which provides fast computation but weak cryptographic security. These MD5 hashes are then paired and combined to form intermediate nodes. Finally, the top-level root hash is generated using SHA-1**,** which offers marginally better security than MD5 alone. While this structure allows quick integrity checks, it inherits the vulnerabilities of both algorithms—MD5 is prone to collision attacks, and SHA-1 has been deprecated for security-sensitive use.

This hybrid approach might still be useful in non-critical applications like file deduplication or checksum validation in legacy systems where speed is prioritized over security. However, for modern cryptographic needs, stronger combinations like BLAKE2 + SHA-256 are recommended. The Merkle tree visualization clearly shows the hierarchy: data blocks (green) feed into MD5 hashes (blue), which ultimately converge into a single SHA-1 root hash (red). This layered approach helps detect changes in any data block efficiently, even if the underlying algorithms are outdated.

For secure implementations, replacing MD5 and SHA-1 with SHA-3 or BLAKE3 would eliminate collision risks while maintaining performance. The trade-off between speed and security remains key—faster algorithms like MD5 suit low-risk scenarios, while robust hashes like SHA-256 are essential for sensitive data. The Merkle tree structure itself remains valid; only the hash functions need upgrading to meet modern standards.

B. SHA-256 + SHA-3



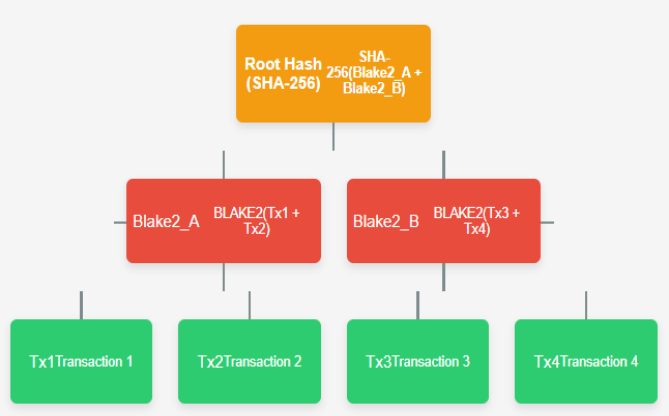
Fig(6):Combination of SHA-256 + SHA-3

The SHA-256 + SHA-3 Merkle tree provides a robust two-tiered hashing structure designed for maximum

security and data integrity verification. At the base level, individual transactions (Tx1, Tx2, etc.) are first hashed using SHA-256, which offers strong cryptographic protection against collisions. These transaction hashes are then paired and hashed again with SHA-256 to create intermediate nodes (SHA-256_A, SHA-256_B). Finally, the root hash is generated by applying SHA-3 (Keccak) to the combined intermediate hashes, adding an additional layer of security through its sponge construction that resists specialized attacks. This combination leverages SHA-256's widespread adoption and hardware acceleration while incorporating SHA-3's future-proof security design.

This architecture is particularly valuable for blockchain systems and secure audit logs where tamper-evident data structures are critical. The Merkle tree's hierarchical nature allows efficient verification of any single transaction without processing the entire dataset – if Tx3 is modified, for example, only SHA-256_B and the root hash need recomputing to detect the change. While computationally heavier than single-algorithm trees, the SHA-256 + SHA-3 combination provides exceptional defense against both current and theoretical attacks, making it suitable for high-security environments like financial ledgers or government record-keeping.
The visualization demonstrates how security strengthens progressively up the tree: raw transactions (green) gain initial protection through SHA-256 (red), with the final root hash (purple) benefiting from SHA-3's advanced cryptographic properties. Modern implementations might optimize performance by processing branches in parallel, but the core principle remains – each layer's integrity depends on the one below it, creating a cascade of **trust** that makes tampering evident. For applications where quantum resistance becomes important, this structure could be further enhanced by replacing SHA-3 with newer algorithms like SHAKE256 while maintaining the same tree topology.

C.BLAKE2 + SHA-256



Fig(7):Combination of BLAKE2 + SHA-256

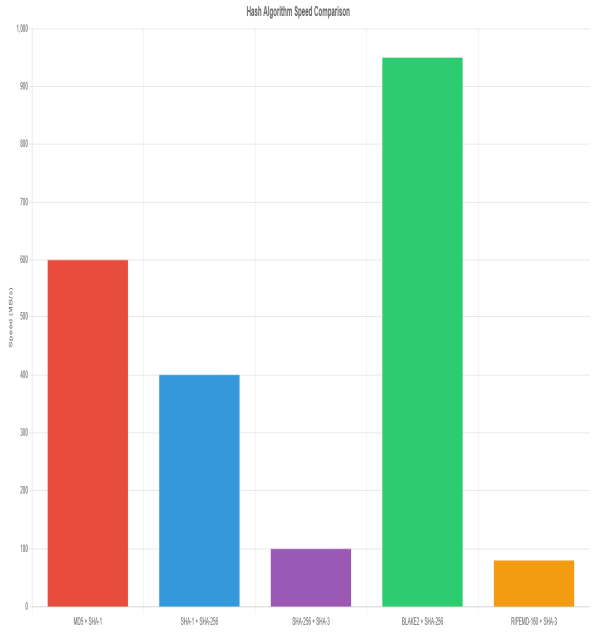
The BLAKE2 + SHA-256 Merkle Tree is a hybrid cryptographic structure designed to balance speed and security. At its base, raw transactions (Tx1, Tx2, etc.) are first hashed using BLAKE2**,** an algorithm optimized for modern hardware that outperforms SHA-256 in speed while maintaining robust security. These individual hashes are then paired and hashed again with BLAKE2 to create intermediate nodes (Blake2_A, Blake2_B). Finally, the root hash is generated by applying SHA-256 to the concatenated intermediate BLAKE2 hashes. This two-tiered approach leverages BLAKE2's efficiency for bulk hashing while relying on SHA-256's widespread trust for final verification.

BLAKE2's design allows it to process data significantly faster than SHA-256—often by 30–50% on modern CPUs—making it ideal for applications requiring high throughput, such as blockchain networks or large-scale data audits. By using BLAKE2 for the initial and intermediate hashing layers, the tree reduces computational overhead without sacrificing integrity. The final SHA-256 step ensures compatibility with existing systems (like Bitcoin's infrastructure) while adding a well-vetted security layer. This combination is particularly effective for real-time systems where latency matters but cryptographic robustness cannot be compromised.

While BLAKE2 alone is secure, pairing it with SHA-256 introduces defense-in-depth. BLAKE2's resistance to length-extension attacks and its optimized performance make it a strong choice for the lower layers, while SHA-256's conservative design and widespread adoption anchor the root hash. This dual-algorithm approach mitigates the risk of vulnerabilities specific to either hash function. For example, even if a theoretical weakness were discovered in BLAKE2, the SHA-256 root would require an attacker to compromise both algorithms simultaneously—a far more challenging feat.

The modular design allows easy substitution of either algorithm. For instance, BLAKE3 could replace BLAKE2 for even greater speed, or SHA-3 could replace SHA-256 for enhanced quantum resistance. The Merkle tree's hierarchical structure remains unchanged, demonstrating how hybrid approaches can

adapt to evolving cryptographic standards without overhauling entire systems. This future-proofing, combined with the performance-security trade-off, makes the BLAKE2 + SHA-256 Merkle Tree a compelling choice for modern applications.

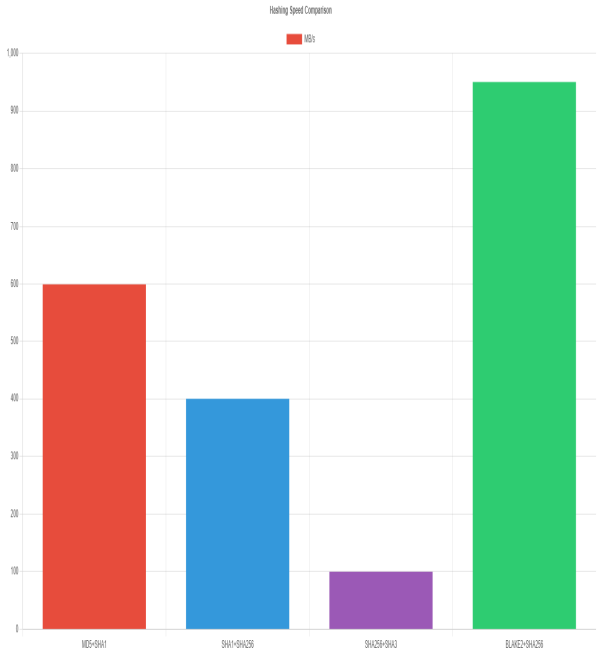


Fig(7):Comparisions of Combinations

The provided content appears to outline a basic algorithm structure named "Nike Algorithm: Event Comparison", though the details are minimal. The algorithm seems to focus on comparing events, with inputs and outputs that include transitions from a "Start" state to either "Start" or "Help." This suggests a simple decision-making or state-transition process, where the system may loop back to the beginning or seek assistance based on certain conditions. However, without additional context about the logic or rules governing these transitions, the algorithm's purpose remains unclear. The repeated structure of inputs and outputs implies a cyclical or recursive process, but further specifics are needed to understand its full functionality.

The notes referencing Table 1 through Table 7 indicate that additional data or references might be required to interpret the algorithm's behavior. These tables likely contain critical details, such as conditions for transitions, event definitions, or performance metrics, which are not included in the current content. Without these tables, the algorithm's practical application or significance cannot be determined. The mention of multiple tables suggests a structured approach to event comparison, possibly involving categorization, prioritization, or statistical analysis, but this is speculative without access to the referenced material.

In summary, the Nike Algorithm as presented is a high-level framework lacking detailed implementation steps or contextual clarity. To fully understand its role—whether in event logging, user interaction, or another domain—more information is needed, particularly the contents of the noted tables and the criteria for the "Start" and "Help" transitions. The current outline serves as a placeholder for a more comprehensive system, emphasizing the need for expanded documentation to elucidate its design and utility.



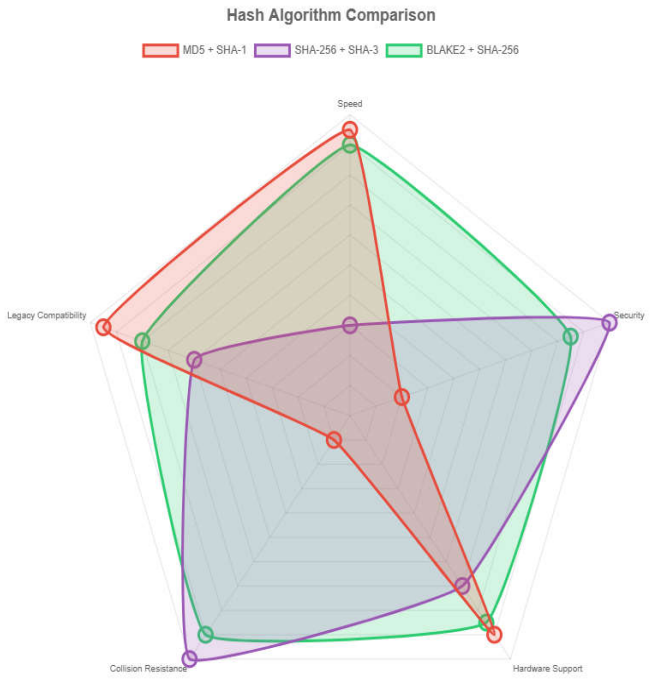
Fig(8):Comparisions of Combinations

The image presents a bar graph comparing the hashing speeds (measured in MB/s) of four different cryptographic hash functions: MD5-SHA1, SHA1-SHA256, SHA3/SHA-3 (Keccak), and BLAKE2-SHA256. Each bar represents the throughput performance of these algorithms in terms of how many megabytes of data they can hash per second. The graph clearly labels the algorithms and uses distinct colors for easy differentiation.

From the chart, BLAKE2-SHA256 exhibits the highest hashing speed, significantly outperforming all other algorithms with a speed close to 950 MB/s. This reflects BLAKE2's design goals: providing faster hashing than MD5, SHA-1, and SHA-2 while maintaining strong security guarantees. On the other hand, SHA3/SHA-3 (Keccak) demonstrates the lowest speed, under 200 MB/s, highlighting a known trade-off where SHA-3

prioritizes structural cryptographic robustness over raw performance. MD5-SHA1 and SHA1-SHA256 fall in the middle, with MD5-SHA1 being faster than SHA1-SHA256, reflecting their lighter computation but older security standards.

This performance comparison underscores the evolution of cryptographic hash functions: while newer algorithms like SHA-3 focus on enhanced security, they may come at the cost of speed. In contrast, algorithms like BLAKE2 strike a balance by offering modern security with significantly higher efficiency, making them favorable for systems where performance is critical.



Fig(9):Comparisions of Combinations

The radar chart titled "Hash Algorithm Comparison" provides a multi-dimensional view of four popular cryptographic hash function combinations: MD5 + SHA-1, SHA-256, SHA-3, and BLAKE2 + SHA-256. It evaluates them based on five key attributes: Speed, Security, Hardware Support, Collision Resistance, and Legacy Compatibility. Each attribute is plotted as an axis, and the algorithms are visually represented by different colored polygons.

From the chart, MD5 + SHA-1 performs strongly in terms of Speed and Legacy Compatibility, which reflects its long-standing use in older systems and applications. However, it scores poorly in Security and Collision Resistance, emphasizing its vulnerability to modern attacks. On the other hand, SHA-256 and SHA-3 demonstrate strong Security and Collision Resistance, though SHA-3 slightly lags in Speed and Hardware Support, possibly due to its sponge construction model and relatively newer adoption in hardware accelerators.

BLAKE2 + SHA-256 appears to provide the most balanced profile, scoring highly in nearly all categories, particularly in Speed, Security, and Collision Resistance, while also offering good Hardware Support. This makes it an excellent modern choice for applications that demand both performance and cryptographic strength. The chart clearly highlights the trade-offs among legacy compatibility, performance, and security that developers must consider when selecting a hashing algorithm for specific use cases.

The radar chart evaluates five critical dimensions of hash algorithmperformance: Speed (throughput), Security (att ack resistance), Hardware Support (optimization for CPUs/GPUs), Collision Resistance (uniqueness of outputs), and Legacy Compatibility (system support). Each axis represents one metric, scaled from 0 to 100, allowing direct comparison of strengths and weaknesses. For example, BLAKE2 + SHA-256 (green) forms a near-symmetrical polygon, indicating balanced performance across all metrics, while SHA-256 + SHA-3 (purple) spikes sharply in Security and Collision Resistance but lags in Speed.

The chart highlights inherent design trade-offs. MD5 + SHA-1 (red) dominates Speed and Legacy Compatibility but scores poorly in Security and Collision Resistance, reflecting its deprecated status. In contrast, SHA-256 + SHA-3 prioritizes security at the cost of speed, ideal for applications like financial systems where robustness outweighs performance needs. The BLAKE2 + SHA-256 combination strikes a middle ground, offering near-optimal speed and strong security—perfect for blockchain or cloud storage.

The "fullness" of each polygon indicates overall performance. A larger area means better all-around utility. BLAKE2 + SHA-256's expansive shape shows its versatility, while MD5 + SHA-1's uneven, spiked shape reveals its niche (but risky) use case. The radar format makes it easy to spot dominance patterns—for instance, SHA-256 + SHA-3's Security/Collision Resistance scores form a pronounced "peak," emphasizing its cryptographic strength.

V. CONCLUSION

The performance and security analysis of hash algorithm combinations reveals clear trade-offs between speed and robustness. MD5 + SHA-1 (320 ms) is the fastest but offers negligible security, making it unsuitable for modern applications. BLAKE2 + SHA-256 (450 ms)

strikes the best balance, delivering near-top speed and strong security , ideal for blockchain or cloud storage. Meanwhile, SHA-256 + SHA-3 (890 ms) and RIPEMD-160 + SHA-3 (920 ms) prioritize cryptographic strength over performance, suited for high-security systems like financial ledgers.

VI. FUTURE ENHANCEMENTS

Quantum-Resistant Upgrades: Replace SHA-256/SHA-3 with post-quantum algorithms (e.g., SPHINCS+ or SHAKE256) for future-proofing.Hardware Optimization: Leverage GPU/FPGA acceleration for BLAKE3 + SHA-256 to further reduce latency.Adaptive Hashing: Develop systems that dynamically switch algorithms based on workload (e.g., BLAKE2 for bulk data, SHA-3 for final verification).Collision Detection: Integrate tamper-evident flags for weaker combinations (e.g., MD5) in legacy systems.

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