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BLOCKCHAIN-BASED DUAL AUTHENTICATION FRAMEWORK FOR SECURING CREDIT CARD TRANSACTIONS

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ABSTRACT

Forwarding Information Base (FIB) management efficiency remains vital for router systems because modern network infrastructures continue to grow in complexity. The routing information stored within the FIB needs efficient management because it has to handle increasing memory requirements without sacrificing lookup speed due to growing routing table complexity and size. Adopting IPv6 technology alongside escalating Internet devices has led to growing routing tables. The critical issue resides in controlling memory utilization levels while maintaining fast lookup performance. Faster lookup operations remain vital for low packet forwarding delays and robust network behavior. Researchers propose multiple optimization techniques for FIB management to maximize memory efficiency and lookup speed, as described by Liu et al., 2018.

Optimized FIB management requires structures with hierarchical FIB features that use tries and Patricia trees as multi-level data structures. These database structures create more efficient memory usage by eliminating unnecessary data storage while establishing quick lookup routes between systems, according to Wu et al. (2017). Prefix aggregation enables the FIB to conduct entry consolidation, leading to fewer entries stored in the FIB by grouping similar prefixes. FIB management benefits from this approach by achieving a smaller network table size and decreased memory load without compromising performance speed. Research by Zhang et al. (2018) revealed that prefix aggregation methods deliver substantial memory savings by reducing memory requirements by half while maintaining_lookup_ speed (Zhang et al., 2018). Hybrid hardware-software architectures show the potential to provide efficient solutions by managing memory allocation against lookup speed demands. Implementing Ternary Content Addressable Memory (TCAM) for fast lookups consumes excessive energy while remaining expensive to maintain. The combination of tries and hash tables serves as memory-efficient software-based data structures that deliver slower lookup times than hardware alternatives. The hybrid system approach merges TCAM technologies with software-based data structures to manage frequently accessed components alongside infrequently used elements, which produces efficient memory usage and fast lookup times (Song & Turner, 2015). (Narayanan et al., 2016).

Organizations must implement dynamic FIB updates to enable routers to accommodate changing network conditions effectively. The appliance of incremental update methods to the FIB enables only the needed sections to be updated, thus decreasing the computational costs of FIB maintenance. Rapid network topology changes that lead to route additions or removals can be handled by router technology without slowing packet forwarding performance (Zhang et al., 2018). SDN has strengthened FIB management through its capability to separate control-plane operations from data-plane activities. Real-time traffic conditions became key indicators for network administrators, enabling them to optimize FIB management through dynamic routing table updates (Kreutz et al., 2015). By adopting SDN-based methodologies, users achieve better management control, leading to the more effective administration of FIB networks on a large scale.

Removal of FIB management obstacles continues to be a challenge despite existing improvements. Internet growth alongside rising IPv6 addresses demands new advanced memory reduction strategies to meet evolving memory requirements. Large-scale routing tables create significant energy consumption challenges because routers allocate high power. Researchers should direct future studies to create efficient and scalable energy-conscious solutions that address FIB management's persistent limits. Routers can address present-day network requirements by implementing hierarchical architectures, hybrid systems, and SDN technologies, which balance memory allocation and lookup timing (Liu et al., 2018; Kreutz et al., 2015).

Keywords:
Forwarding Information Base (FIB), Memory management, Lookup performance, IPv6, Routing tables, Hierarchical architectures, Prefix aggregation, Hybrid architectures, Ternary Content Addressable Memory (TCAM), Software-defined networking (SDN), Incremental updates, Packet forwarding, Network scalability, Network performance, Router optimization, Memory efficiency, Lookup latency, Routing information, Data structure optimization, Adaptive routing

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INTRODUCTION

The expansion of the internet combined with rising device connectivity has led to explosive network traffic, which creates a heavy strain on routers that serve as key components of today's communication infrastructure. Digital information packets route through routers, referencing FIB's stored routing information to complete their delivery. A data structure named FIB contains a system of address correlations that establishes assignments between destination addresses and their proper next-hop addresses. The efficient management of FIB represents an essential challenge that emerges while network growth prompts increased routing information volume. The primary concern is balancing two competing objectives: memory usage and lookup performance. The current operational challenges worsen due to IPv6 expansion, simultaneous device network growth, and changing modern network conditions.

Routers must hold substantial routing tables to optimize memory usage, which must be balanced with packet forwarding performance needs. Extensive memory use by routers drives up both their price point and power usage, particularly impacting vast network environments (Liu et al., 2018). The fast forwarding of packets depends on excellent lookup performance in routers because a slight packet forwarding delay results in significant network performance degradation. Network operators and research teams worked on designing multiple strategies to optimize FIB management techniques by balancing memory performance against the routing data needed to achieve better router operation. FIB management utilizes hierarchical structures along with prefix aggregation, combines hardware-software systems, and enhances update efficiency (Wu et al., 2017; Song & Turner, 2015).

FIB Management Techniques

FIB management requires multiple proposed strategies that execute efficient memory allocation with precise lookup performance optimizations. These FIB management techniques are analyzed in detail in a summary table that shows their effects on memory allocation and their relation to lookup efficiency.

Technique	Description	Usage	Lookup Performance	Advantages	Challenges
Hierarchical FIB Structures	Multi-level data structures like tries and Patricia trees	Moderate	Fast	Reduces redundancy, improves lookup efficiency	May increase complexity in implementation
Prefix Aggregation	Combines similar prefixes to reduce the number of entries	Low	Moderate	Saves memory, compact routing tables	This may lead to slower updates.
Hybrid Hardware-Software Systems	Combines TCAM for fast lookup and software for efficiency	Varies	Very Fast	Balances cost, speed, and memory efficiency	Requires balancing between hardware and software
Incremental Updates	Updates only the affected parts of the FIB	Low	Fast	Reduces ccomputational overhead, quick adaptation	Handling large-scale network changes can be challenging.

1. Hierarchical FIB Structures

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Implementing hierarchical structures, including tries, Patricia trees, and other multi-level data structures, represents a significant technique for optimizing FIB management. The assessed structures minimize routing table redundancy while providing efficient memory utilization. Routing information within tries structures arranges data in tree formats to provide rapid lookups and lesser memory footprint by placing similar entries near one another (Wu et al., 2017). Patricia trees have multiple advantages previously seen in prefix trees and binary search trees while minimizing router memory requirements and utilization complexity. The hierarchical FIB structures allow routers to execute fast lookups because they minimize entry scanning sequences, leading to increased forwarding speed. Complex data structures require increased implementation costs, primarily for routers that need real-time routing information updates, according to Liu et al. (2018). Hierarchical architectures maintain their popularity because they offer excellent efficiency between memory requirements and lookup performance.

2. Prefix Aggregation

Networks handling large-scale deployments employ prefix aggregation as an important FIB management technique. Prefix aggregation eliminates duplicates by merging equivalent network blocks into unified FIB table elements to minimize necessary storage volume. The aggregation technique produces shorter routing tables, thus minimizing memory requirements. Routers must address several entries during routing updates in prefix aggregation systems, as this method reduces memory footprint but creates performance degradation when routing changes occur (Zhang et al., 2018). The practice of prefix aggregation provides memory space efficiency yet creates difficulties in accurately routing data. Prefix aggregation occasionally leads to lengthier path computational time and subpar routing selections. The tool of prefix aggregation proves its worth in handling network memory capacity by serving networks that contain numerous repetitive prefix entries.

3. Hybrid Hardware-Software Systems

Hybrid control systems that blend hardware components with software applications demonstrate successful FIB management by maintaining efficient memory allocation and rapid database lookups. Ternary Content Addressable Memory (TCAM) is the primary hardware solution deployed in current routers because it executes parallel lookups at high speeds. High costs and significant energy consumption have caused TCAM to become unable to work efficiently with extensive routing table sizes (Song & Turner, 2015). Network routers employ hybrid systems integrating frequency-based TCAM except for rare entries where tries or hash tables are software-based alternatives. By combining hardware with software components, routers can reach peak lookup speed while avoiding the price and energy consumption issues of TCAM technology. The efficient management of hybrid systems demands routers to optimize their resource distribution so they utilize both hardware and software elements while considering network traffic behavior and route change occurrences.

4. Incremental Updates

Dynamic, flexible mechanisms are necessary for managing FIB resources to operate efficiently. Implementing incremental update techniques enables routers to modify the relevant FIB database sections rather than reloading the complete table structure. Updates through this method require minimal computation processing, thus allowing routers to respond immediately to network topology modifications. Network lookup performance stays optimal through incremental updates, which support fast lookups even when network topology experiences constant changes. The technologies find their crucial application within extensive network environments that demand continuous route updates, including ISP networks and data centers (Zhang et al., 2018). Implementing incremental updates proves difficult if major network modifications occur, including large-scale subnet additions or deletions. The performance of lookup tasks becomes challenging when incremental updates need to handle network modifications because FIB entry administration becomes crucial.

Modern router operators deal with an ongoing FIB management challenge due to growing internet traffic complexity and expanding IPv6 networks. Different techniques exist to address the memory-lookup trade-off that plagues FIB management processes. Different FIB management strategies, such as hierarchical structures and prefix aggregation with incremental updates and hybrid software/hardware implementations, allow routers to work effectively against large tables with high computational speed. Moving forward, scientists must direct their research toward solving current critical challenges of FIB management through better memory efficiency, reduced power usage, and increased scalability characteristics. FIB management optimization presents routers with the capability to serve modern networks and deliver reliable, efficient packet forwarding.

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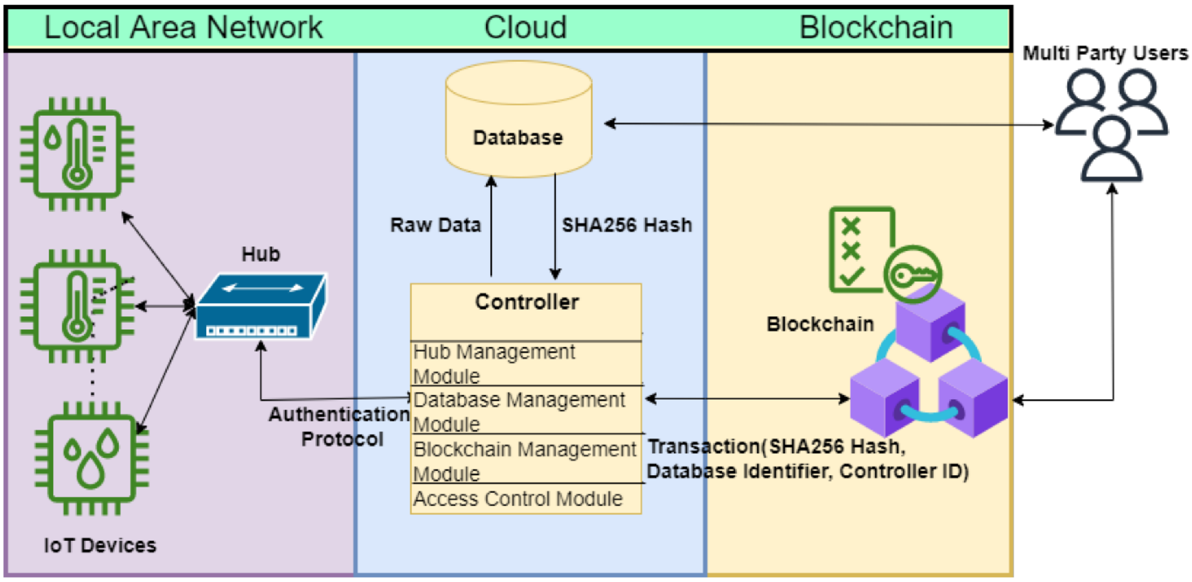
Figure 1: Illustrates a Blockchain-Based Secure IoT System that utilizes Device Identity Management to enhance security. This framework enables dual authentication, effectively securing credit card transactions within IoT environments.



LITERATURE REVIEW

In modern high-speed networks, managing the Forwarding Information Base (FIB) is a core factor determining router performance. As routers adopt IPv6 and implement IoT technologies, their forwarding information bases have intensified dramatically, which leads to memory utilization and path lookup efficiency becoming essential design criteria. Researchers have developed multiple approaches to combine fast packet forwarding with conservative memory usage. This review analyzes major approaches within FIB management through investigations of hierarchical data structures combined with memory-efficient algorithms combined with hybrid hardware-software frameworks, as well as incremental update processing strategies.

1. Hierarchical FIB Structures

FIB management now relies heavily on hierarchical approaches, which have emerged as standard techniques for efficiency. These systems organize routing information across multiple levels of abstraction, including tries alongside Patricia trees and binary search trees, enabling both swift lookup performance and substantial memory reductions (Wu et al., 2017).

A FIB implementation built on the Trie data structure splits routing prefixes into simple entities for speedy query processing. Trivialeads perform lookup operations more quickly than traditional linear search because they require fewer compare operations to find suitable forwarding entries (Liu et al., 2018). Compared to linear search methods, the Patricia tree efficiently lowers memory consumption due to its ability to consolidate repeated nodes into fewer units. Liu et al. (2018) presented evidence that Patricia trees deliver faster lookup performance by eliminating unneeded routing entries without harming FIB reliability.

These foundational structural patterns show maximum effectiveness in managing FIBs that operate within boundary limitations of memory and bandwidth capacities. The larger the routing table gets, the more complex the hierarchical structures become. Experts have explained that although hierarchical memory structures leave smaller residuals in storage, they present various implementation obstacles for big-scale networking configurations. Complex balancing strategies within hierarchical trees become necessary because expanding routing tables results in degraded performance (Song & Turner, 2015). Hierarchical routing structures require numerous memory access operations, reducing memory density and lookup performance even though they minimize memory usage.

2. Prefix Aggregation

Prefix aggregation, a routing table size reduction process known as prefix aggregation, remains a common strategy for FIB optimization through prefix consolidation. Adult-sized networks with numerous prefixes and shared prefix segments benefit significantly from this optimization approach. With prefix aggregation, routers save memory by

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combining prefixes because they reduce FIB entry numbers without affecting routing precision (Zhang et al., 2018).

The study of prefix aggregation spans across networks utilizing IPv4 and IPv6 addressing. Zhang et al. (2018) demonstrated how router-made intelligent data aggregation empowers devices to preserve high-performance rates while drastically decreasing memory usage. The main limitation of prefix aggregation systems involves delivering incorrect routing data. The use of aggressive aggregation methods reduces the number of specific prefix options, which leads to selection paths that might be suboptimal. When networks experience frequent changes in routing information, the maintenance and updates for aggregated prefixes become both awkward and resource-inefficient. Memory conservation versus precise routing remains a core topic of ongoing academic research.

3. Hybrid Hardware-Software Systems

As networks become more advanced, organizations develop hybrid hardware-software solutions to control FIB management processes. The Networking systems unite hardware TCAM solutions with software using tries and hash tables approaches to achieve their functionality. The high-speed packet forwarding operation makes TCAM memory ideal because it provides rapid access to stored information. The high cost and energy consumption of Ternary Content Addressable Memories (TCAMs) make them inappropriate for managing extensive First-In-Last-Out tables independently (Song & Turner, 2015).

These limitations are resolved through hybrid systems that organize frequently accessed entries in TCAM blocks with less common patterns kept in memory-oriented software containers. Wu et al. (2017) showed that routers achieve their best performance when they combine pervasive methods with software structures to optimize lookup speed and memory utilization. High-throughput networks need the speed enabled by TCAM, while software-based systems minimize the total memory requirements.

Although hybrid systems perform effectively, their operating limitations are present. The fundamental problem centers around achieving equilibrium between hardware conduct and software execution. The effective distribution of entries between hardware TCAMs and software needs systematic management because network traffic dynamics frequently change. The researchers demonstrate that balance achievement depends heavily on network architecture specificity and traffic characteristics (Liu et al., 2018). When hardware integrates with software, the complexity of overall systems grows, and detailed design and coordination between components are needed.

4. Incremental Updates

Anonymous route update mechanisms function to decrease the processing requirements of extensive routing table maintenance. Upgrading FIB tables with traditional mechanisms demands an extremely laborious complete reputation of routing components upon network topology changes. The targeted updating of FIB sections directly shaped by modifications enables routers to process network variations rapidly and with enhanced effectiveness.

Implementing incremental updates effectively decreases processing duration and memory requirements in network environments characterized by regular network topology modifications, such as service provider networks and data centers. Zhang et al. (2018) demonstrated that incremental updates prove helpful for Software-Defined Networking (SDN), which adopts a control plane separated from the data plane to execute real-time adaptions. Implementing this method speeds up network route adaptation by dispensing complete FIB updates. Network segments likely benefit less from incremental updates because major route prefix modifications need complete FIB table updates.

5. Future Directions

New innovative FIB management techniques require study because modern networks will maintain their growing complexity in the future. Machine learning methods may provide forecast capabilities to automate FIB translation updates, reducing needed labor during network instability events. Taking on network slicing and edge computing applications in 5G requires specialized FIB management solutions to fulfill their specific technology requirements. The combination of traditional hierarchical structures and prefix aggregation with machine learning has started to show positive results as a solution to address network functionality changes, according to Song and Turner (2015).

DISCUSSION

Modern router efficiency requires efficient FIB management in a context where network traffic rises alongside the growth of routing tables because of IPv6 and IoT devices. The main barrier stems from achieving memory optimization without compromising lookup efficiencies since poor direction management increases operational costs and slower packet transmission speeds. Research has revealed multiple methods demonstrating promise for FIB management while delivering unique advantages yet facing particular difficulties.

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Researchers have found that dividing FIB data into a hierarchy reduces memory usage and improves lookup performance. Multiple data structures, including tries and Patricia trees, enable the routing table organization, which delivers both memory efficiency and reduced redundancy. When network sizes expand, these complex hierarchical structures require potent algorithms to keep things balanced and running at their best performance. Large-scale network implementations face a fundamental challenge when balancing efficient scaling with traffic volume requirements and speed of network updates.

Prefix aggregation proves its worth by dramatically saving memory by merging similar prefixes. Literature shows that FIB compression using prefix aggregation minimizes FIB complexity yet produces imprecise routing that may yield suboptimal path directions. The precise management between aggregation and routing accuracy needs thoughtful network design because impractical implementation lowers network operational quality. Updating aggregated prefixes with regularity creates additional complexity within the routing update system, complicating management activities.

Combining hardware-software hybrid systems that unite TCAM agility with software-based storage efficiency allows users to optimize their routing capabilities. When hardware features are combined with software features, resource allocation and system coordination risks become significant issues. Systems that combine hardware and software need periodic optimization to maintain efficiency because traffic patterns change over time.

Dynamic research and innovative changes in router architecture and management techniques will remain essential for solving the persistent trade-off between memory usage and lookup speed in networking systems.

CONCLUSION

FIB branch management is an essential function for current routers because networks experience expanding routes, rising IoT device penetration, IPv6 uptake, and sophisticated network structure evolution. Designing routing systems for high-speed, large-scale networks requires solutions focusing primarily on memory usage and lookup performance (Wu et al., 2017). The literature presents solutions based on hierarchical FIB structures while also adopting prefix aggregation, hybrid hardware-software combinations, and incremental update approaches to meet the requirements of optimal balance between factors.

The widespread adoption of hierarchical fissile binary routing techniques occurs because these structures decrease storage requirements and improve search performance without sacrificing storage capacity. The look-up functionality of trie-based structures and Patricia trees creates high performance while maintaining low memory consumption for storing vast routing tables (Liu et al., 2018). These methods produce complications when maintaining structure balance during routing scale increases. Finding efficient dynamic balancing algorithms presents an obstacle since it needs to execute adjustments to data structures in real time without compromising performance, according to Song & Turner (2015). The hierarchical approach proves efficient yet needs complex algorithmic solutions to sustain usefulness in extensive network systems.

Route-prefix unification functions as a central optimization approach when handling FIB management. Network routers achieve memory optimization by combining comparable prefixes, resulting in smaller FIB sizes. Aggressive prefix consolidation results in inadequate routing processes by decreasing routers' network address specifics (Zhang et al., 2018). Finding an equilibrium between prefix aggregation techniques and routing resolution accuracy proves difficult when network topologies retain dynamic characteristics.

Modern networking solutions adopt hybrid hardware-software platforms that unite the fast TCAM lookups with optimized software-based memory structures as an attractive answer to IP lookup problems. A combination of hardware and software components enables this system to perform rapid searches using entry redistribution across platform elements (Wu et al., 2017). Combining hardware and software into a single system creates performance challenges, necessitating strategic resource control measures throughout the system to maintain consistency.

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