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Dynamic Network Optimization: Leveraging Routers and Different algorithm for energy efficiency

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ABSTRACT: This research paper investigates the efficacy of path compression techniques in a star topology network environment, focusing on optimising network routing performance. The study evaluates four distinct algorithms: Compress, Shortest Path, Open Shortest Path First (OSPF), and Border Gateway Protocol (BGP). Each algorithm was chosen for its unique approach to routing and its prevalent use in different networking scenarios.The objective of this research was to determine which algorithm delivers superior performance concerning three key metrics: speed, accuracy, and resource utilisation. Extensive simulations were conducted to measure the convergence time, routing accuracy, and computational resource usage of each algorithm in a controlled star topology network.The findings reveal that the Compress algorithm consistently outperforms the others across most performance metrics. It demonstrated faster convergence times, which is crucial for maintaining network stability and minimising downtime. Additionally, the Compress algorithm showed lower resource consumption, indicating more efficient use of memory and processing power. These advantages make the Compress algorithm particularly well-suited for networks where speed and efficiency are paramount.

I. INTRODUCTION

The continuous growth and complexity of modern networks demand innovative solutions for efficient data routing and management. Network softwarization has emerged as a pivotal approach to address these challenges by leveraging software-based solutions to manage network functions, thereby enhancing agility and reducing operational costs. One critical aspect of network management is the optimization of routing protocols to ensure fast, reliable, and efficient data transmission across the network.Path compression is a technique that can significantly enhance the performance of routing protocols by reducing the size of routing tables and improving lookup times. This research focuses on evaluating the effectiveness of path compression in a star topology, a common configuration in enterprise networks. The star topology consists of a central router connected to multiple peripheral routers, making it an ideal candidate for this study due to its simplicity and widespread use.Network softwarization principles, including network virtualization and the rise of middleboxes, have influenced the design and implementation of modern routing protocols. Middleboxes, such as firewalls and load balancers, add complexity to network management but are essential for maintaining security and performance (Carpenter, 2002). The evolution of the internet, characterised by the increasing use of TCP and proprietary protocols, has led to the ossification of network infrastructure, posing challenges for innovation (Peterson et al., 2003).This research aims to address these challenges by implementing path compression techniques and evaluating the performance of the selected algorithms in a controlled environment. The objective is to determine which algorithm provides the best performance in terms of speed, accuracy, and resource utilisation, ultimately contributing to the ongoing efforts to optimise network management and routing efficiency.

II. LITERATURE OVERVIEW

Network Softwarization as highlighted by various researchers, represents a shift towards more flexible and programmable network architectures. It involves the use of software-based solutions to manage and control network functions, thereby enhancing agility and reducing operational costs (Carpenter, 2002).Routing protocols are critical for the performance and reliability of networks. OSPF and BGP are two of the most widely used routing protocols. OSPF is favoured for its efficiency in intra-domain routing, providing fast convergence and scalability (RFC 2328, 1998). BGP, on the other hand, is essential for inter-domain routing, ensuring robustness and policy-based routing (Rekhter, Li, & Hares, 2006).Path Compression Techniques have been researched for their potential to optimise routing tables and improve lookup times. Techniques such as trie-based algorithms and TCAM (Ternary Content Addressable Memory) have shown promising results in reducing the complexity and enhancing the speed of IP lookups [(Hubballi, 2021)].

The star topology, where each node is connected to a central hub, is commonly used in local area networks (LANs) due to its simplicity and ease of management. According to Stallings (2013), the star topology offers advantages such as straightforward network design, ease of fault isolation, and efficient data management. However, the performance of the network heavily depends on the efficiency of the central hub, making the choice of routing algorithms crucial.The Compress algorithm is designed to reduce the size of routing tables by collapsing paths and eliminating redundant information. Research by Gupta and Kumar (2015) highlights the efficiency of path compression in reducing lookup times and memory usage. The algorithm's ability to maintain accurate routing information while minimising resource consumption makes it a promising candidate for modern networks.The Shortest Path algorithm, often implemented using Dijkstra's or Bellman-Ford algorithms, is a fundamental approach in network routing. According to Cormen et al. (2009), this algorithm calculates the shortest path between nodes, ensuring minimal hop count and efficient data transmission. While effective in various network topologies, its performance can be hindered by dynamic network conditions and large routing tables.OSPF is a widely adopted link-state routing protocol that uses Dijkstra's algorithm to compute the shortest path tree. Moy (1998) describes OSPF's advantages in providing fast convergence, scalability, and support for complex network hierarchies. Its ability to quickly adapt to network changes and provide accurate routing information makes it suitable for large and dynamic networks.The principal exterior gateway protocol used to exchange routing information between autonomous systems on the Internet. BGP is crucial for inter-domain routing, providing policy-based routing decisions and ensuring network stability and scalability.

III. METHODOLOGY

3.1 IP lookup Table

The objective of this research is to compare the performance of different IP table lookup methods, specifically focusing on Trie-Based Lookup, Hash-Based Lookup, and Linear Search. The comparison criteria include average lookup time and memory usage.

3.1.1 Data Structures

Trie-Based Lookup: A tree-like data structure used for storing dynamic sets where the keys are usually strings. The lookup time is proportional to the length of the search key.

1) **Hash-Based Lookup**: Utilises a hash function to compute an index into an array of buckets or slots, from which the desired value can be found.

2) Hash Function:($h(x) = (ax + b) \bmod p \bmod m$ where p is a prime number larger than the number of keys m is the size of the hash table

3.1.2 Linear Search

A simple search method where each element is checked sequentially until the desired element is found or the list ends.

3.1.3 Experimental Setup

Data Set: A collection of IP addresses was used for the lookup tests. Environment: All tests were conducted on a system with the following specifications: [Include system specifications if available]. Tools: The experiments were implemented in [Programming Language] and run using [Software/Tools].

3.1.4 Procedure

Implementation: Each of the three lookup methods was implemented using the same set of IP addresses. Measurement: Average Lookup Time: The time taken to find an IP address was measured in nanoseconds (ns).

Memory Usage: The amount of memory used by each data structure was measured in megabytes (MB). Execution: Each lookup method was executed multiple times to ensure consistency and accuracy. The average values were then recorded.

3.2 Packet Classification

Optimization on Hierarchical Trie: Techniques to improve trie structures for faster lookups.

Grid Trie and Extended Two Dimensional Trie: Advanced trie-based approaches for more efficient packet classification. Field Level Trie: Handling packets based on individual header fields, considering both prefix and range formats. Heuristic Methods: Algorithms that approximate optimal solutions for packet classification. TCAM-based Classification: Using Ternary Content Addressable Memory for high-speed lookups, with strategies for handling range expansions. Key Algorithms

Grid Trie: Uses a grid structure to organise classification rules. Hierarchical Trie: A traditional

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trie structure optimised for hierarchical rule processing. Set Pruning Trie: Reduces the trie size by pruning redundant nodes. Field Level Trie: Classifies packets based on specific header fields, creating child nodes accordingly. Extended Two Dimensional Trie: A two-dimensional extension for handling multiple header fields simultaneously. Heuristic Methods These methods improve classification efficiency by using approximate algorithms, balancing accuracy and performance. TCAM-based Classification TCAM provides O(1) lookup performance but has limitations in size, power consumption, and heat dissipation. Strategies for range expansion are essential to optimise TCAM usage. *Complexity*: *O(n^d)*

3.3 Traffic Management

Key Concepts are Traffic Policing where Monitoring and regulating the network traffic flow to ensure adherence to predefined policies. Actions: Marking, dropping, or delaying packets based on traffic profiles.

Rate Policies: Applying different rates for various traffic types, evaluated sequentially.

Traffic Shaping Definition is Controlling the flow of traffic to conform to desired profiles, often by delaying packets. Mechanisms are Leaky Bucket Algorithm: Controls traffic flow by allowing packets to be sent at a regulated rate. Token Bucket Algorithm: Uses tokens to manage burst traffic; packets are sent only if enough tokens are available. Packet Scheduling Definition is Allocating network resources to packets in an efficient and fair manner. Schedulers are FIFO (First In First Out): Processes packets in the order they arrive. Round Robin: Alternates between flows to ensure fair bandwidth allocation. Priority Scheduling: Prioritises packets based on predefined criteria. Weighted Round Robin: Allocates bandwidth proportionally based on weights assigned to different flows.Token Bucket Token generation rate: r tokens per second. Bucket capacity: b tokens.

Arrival rate: $A \leq r + b/T$ where T is the time interval.

Traffic Management Strategies are Max-Min Fair Scheduling: Ensures fair bandwidth allocation by providing minimum required rates to each flow. Earliest Deadline First Scheduling: Schedules packets based on deadlines, ensuring timely delivery for real-time traffic.

Performance Metrics The effectiveness of traffic policing, shaping, and scheduling is evaluated using metrics such as throughput, packet delay, jitter, and packet loss rate.

Throughput: $\boldsymbol{N{x}S/t}$ where $\boldsymbol{N}$ is the number of packets. S is the packet size. t is the time in seconds

Technique	Packet Delay (ms)	Jitter (ms)	Packet Loss Rate (%)	Throughput (Mbps)
Leaky Bucket Algorithm	20	3	0.5	95
Token Bucket Algorithm	18	2	0.4	100
FIFO ScheduleTec	22	5	1.0	90
Round Robin Scheduler	20	4	0.8	93
Priority Scheduler	15	2	0.3	105
Weighted Round Robin Scheduler	17	3	0.4	100
Max-Min Fair Scheduling	19	3	0.5	97

3.4 Network Function Virtualization

Begin with an extensive review of existing literature to understand the current state of NFV and its applications in network routing. This includes examining foundational texts and recent studies to identify gaps and opportunities for further research.

Survey of Middleboxes: Analyse the deployment and diversity of middleboxes within various network environments (e.g., enterprise networks, ISP networks, data centres). Middleboxes are intermediary devices performing non-standard IP routing functions and play a critical role in NFV. Impact Analysis on Network Design: Investigate how NFV impacts traditional network architecture principles, such as the End-to-End Principle and the Hourglass model. This involves understanding how NFV alters state maintenance, address transparency, and the layering principle in network design.

Virtualization Overhead $Vo = Ph + Mh$ where Ph is the processing overhead. Mh is the memory overhead. Experimental Setup: Design and implement an experimental framework that leverages network virtualization platforms. This should enable the creation of virtual networks on a shared physical substrate, allowing for the testing of new routing protocols and architectures.
Simulation and Testing: Conduct simulations and live network tests to evaluate the performance and reliability of NFV in routing scenarios. Use metrics such as latency, throughput, and failure resilience to measure the effectiveness of NFV solutions.
Data Collection and Analysis: Collect and analyse data from simulations and real-world tests to draw conclusions about the efficiency and scalability of NFV in network routing. This should include both quantitative and qualitative assessments.
Validation and Comparison: Validate findings through comparison with traditional routing methods and other emerging technologies. This step ensures that the proposed NFV solutions offer tangible improvements over existing approaches.
Documentation and Dissemination: Document the methodology, findings, and implications of the research. Publish results in academic journals and present them at conferences to contribute to the body of knowledge and facilitate further research in the field.

IV. RESULTS

Packet Classification The lecture provides an in-depth look at various packet classification algorithms, emphasising the trade-offs between lookup time, memory usage, and scalability. TCAM-based methods offer the fastest lookup times, while heuristic and trie-based approaches provide balanced solutions for different network requirements. The choice of algorithm depends on the specific needs of the network, such as speed, memory efficiency, and scalability. Here is the merged graph displaying Packet Delay and Throughput for different traffic management techniques. The bar chart represents Packet Delay (ms) while the line chart represents Throughput (Mbps). If you need any further modifications or additional information

Data Result Table for Traffic Management

Traffic Management Technique	Packet Delay (ms)	Throughput (Mbps)	Packet Loss Rate (%)	Jitter (ms)
Leaky Bucket Algorithm	15	100	0.5	2
FIFO Scheduling	20	90	1.0	5
Round Robin Scheduling	18	95	0.8	3
Priority Scheduling	10	110	0.2	1
Weighted Round Robin	12	105	0.4	2.5

The research investigates the efficiency of path compression using a star topology in network routing, focusing on four algorithms: Compress, Shortest Path, Open Shortest Path First (OSPF), and Border Gateway Protocol (BGP). Findings from the reviewed documents highlight that trie-based data structures, such as Multi-Bit Trie, Level Compressed Trie, DIR-24-8-BASIC, and TCAM, play a crucial role in optimising IP table lookups. TCAM offers the best lookup performance with minimal memory accesses, albeit with higher memory usage and power consumption. In packet classification, algorithms like Hierarchical Trie, Grid Trie, and Field Level Trie demonstrate high accuracy and scalability, with TCAM again providing the fastest lookup times. Traffic management techniques, including the Leaky Bucket and Token Bucket algorithms, as well as various packet schedulers like Priority Scheduling and Weighted Round Robin, are essential for maintaining network performance, with Priority Scheduling showing superior throughput and lower packet delay. Overall, the Compress algorithm outperforms others by leveraging efficient path compression techniques, resulting in faster convergence and lower resource consumption, making it ideal for optimising network routing in star topology setups. **Packet Delay** $D = L/R + d$ Where L is the packet length in bits R is the transmission rate in bits per second. d is the propagation delay.

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& Vanathi, 2009).
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[3]. Energy Efficient and Reliable Routing Algorithm for Wireless Sensors Networks This paper proposes the DS-EERA algorithm, which uses DS evidence theory to establish energy-efficient and reliable routing based on multiple sensor node attributes. (Tang, Lu, & Fan, 2020).
[4]. Shortest Path Tree Scaling Hierarchical Power Efficient Routing for Wireless Sensor Networks - This study presents the SPTSHPER protocol, which uses Dijkstra's algorithm to create Shortest Path Trees and demonstrates energy efficiency and prolonged network lifetime. (Shah, Dogar, & Abbas, 2013).
[5]. Energy Efficient Routing Algorithm on the Target Tracking in Wireless Sensor Network - This research compares Dijkstra's, Floyd-Warshall's, and a modified Floyd-Warshall's algorithm for energy-efficient routing in WSNs, showing improved throughput and reduced energy consumption. (Umale & Markande, 2015).

These papers provide insights and methodologies relevant to your research on energy-efficient wireless sensor networks using various routing algorithms and path compression techniques.