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Publisher's Home Page: https://www.svedbergopen.com/

Research Paper

A Novel OSPF Routing Optimization Framework for Enhancing Network Performance in Dynamic Network Environment

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Abstract
Open Shortest Path First (OSPF) is one of the most widely adopted link-state routing protocols in modern IP networks due to its scalability, reliability, and rapid route computation capabilities. However, in dynamic network environments characterized by frequent topology changes, varying traffic loads, and link failures, conventional OSPF routing often experiences increased convergence delays, network congestion, and suboptimal path selection. This study proposes a novel OSPF routing optimization framework designed to enhance network performance through dynamic route cost adaptation based on multiple network parameters, including bandwidth utilization, end-to-end delay, packet loss, and link congestion levels. The proposed framework employs a modified cost computation mechanism that continuously evaluates network conditions and updates routing decisions to achieve efficient traffic distribution and improved resource utilization. The performance of the proposed model is evaluated using MATLAB-based network simulations under various traffic scenarios and topology conditions. Key performance metrics, including throughput, packet delivery ratio, average delay, packet loss rate, and convergence time, are analyzed and compared with those of the conventional OSPF protocol. Simulation results demonstrate that the proposed framework significantly improves network throughput, reduces routing overhead, minimizes packet loss, and accelerates convergence in dynamic environments. The findings suggest that the optimized OSPF framework provides a scalable and adaptive routing solution suitable for enterprise networks, Internet Service Providers (ISPs), and next-generation communication infrastructures.

Keywords: OSPF, Routing Optimization, Dynamic Networks, Network Performance, MATLAB Simulation, Convergence Time, Adaptive Routing, Quality of Service (QoS).

1. Introduction

The rapid growth of Internet-based applications, cloud computing services [1], Internet of Things (IoT) devices, and enterprise communication systems has significantly increased the complexity and scale of modern computer networks. Efficient routing mechanisms have become essential for ensuring reliable data transmission, minimizing latency, and optimizing network resource utilization. Routing protocols play a critical role in determining the best paths for packet forwarding and maintaining stable communication among interconnected network devices. Among the various routing protocols employed in IP networks, Open Shortest Path First (OSPF) remains one of the most widely adopted Interior Gateway Protocols (IGPs) due to its scalability, fast convergence capability, hierarchical architecture, and support for large-scale enterprise networks [2,3].

OSPF is a link-state routing protocol that utilizes Dijkstra's Shortest Path First (SPF) algorithm to compute optimal routes based on predefined link costs. Routers exchange Link State Advertisements (LSAs) to maintain a synchronized view of the network topology and independently calculate the shortest paths to destination networks. Although OSPF offers several advantages over traditional distance-vector routing protocols, its performance can be adversely affected in dynamic network environments characterized by fluctuating traffic loads, frequent topology changes, network congestion, and link failures. Under such conditions, conventional OSPF routing mechanisms may experience increased convergence times, inefficient traffic distribution, routing instability, and suboptimal path selection [4,5].

Modern network infrastructures require routing protocols capable of adapting to real-time network conditions while maintaining high levels of performance and reliability. Conventional OSPF primarily relies on static link costs, typically determined by available bandwidth, which may not accurately reflect the instantaneous state of network resources. Consequently, routing decisions based solely on static metrics can lead to network congestion, packet loss, increased delay, and underutilization of alternative paths. These limitations become more pronounced in large-scale enterprise networks, service provider infrastructures, and emerging software-defined networking environments where traffic patterns change dynamically [6,7].

To address these challenges, researchers have explored various OSPF optimization techniques, including dynamic cost adjustment, traffic engineering mechanisms, load balancing approaches, congestion-aware routing, and quality-of-service (QoS)-based path selection. While these methods have demonstrated improvements in specific performance metrics, many existing solutions focus on a limited set of network parameters and often fail to provide a comprehensive adaptation framework capable of responding effectively to continuously changing network conditions. Therefore, there is a growing need for intelligent and adaptive routing optimization mechanisms that can improve the responsiveness and efficiency of OSPF-based networks.

This paper proposes a novel OSPF routing optimization framework designed to enhance network performance in dynamic network environments. The proposed framework introduces a dynamic routing cost model that incorporates multiple network performance indicators, including bandwidth utilization, end-to-end delay, packet loss rate, and link congestion levels. By continuously monitoring network conditions and updating routing costs accordingly, the framework enables more efficient route selection and improved traffic distribution across the network. The objective is to reduce convergence delay, improve throughput, minimize packet loss, and enhance overall network reliability [8,9].

To evaluate the effectiveness of the proposed framework, MATLAB is employed as the simulation platform for modeling dynamic network scenarios and analyzing routing behavior under varying traffic conditions. Performance comparisons are conducted between the conventional OSPF protocol and the proposed optimization framework using key metrics such as throughput, packet delivery ratio, average delay, packet loss, and convergence time. The simulation results demonstrate the capability of the proposed approach to achieve superior network performance and adaptability in comparison with traditional OSPF routing mechanisms.

The major contributions of this research are summarized as follows:

1. Development of a novel OSPF routing optimization framework for dynamic network environments.
2. Implementation and evaluation of the proposed framework using MATLAB-based network simulations.
3. Comprehensive performance analysis and comparison with conventional OSPF routing.

The remainder of this paper is organized as follows. Section 2 reviews the related literature on OSPF routing optimization and identifies existing research gaps. Section 3 presents the proposed OSPF optimization framework and system model. Section 4 describes the MATLAB simulation setup and research methodology. Section 5 discusses the experimental results and performance evaluation. Section 6 presents the discussion and implications of the findings, while Section 7 concludes the paper and outlines potential directions for future research.

2. Review of Literature

Routing protocols play a vital role in maintaining efficient communication and ensuring reliable packet delivery in modern computer networks. Among the available Interior Gateway Protocols (IGPs), Open Shortest Path First (OSPF) is widely adopted because of its scalability, fast convergence, and suitability for large-scale network infrastructures. However, increasing network complexity, dynamic traffic patterns, and frequent topology changes have motivated researchers to investigate various optimization approaches to improve OSPF performance.

A recent study by Akbar Maulana Mubarak and Atep Aulia Rahman (2026) [10], titled Performance Evaluation of OSPF and EIGRP Routing Protocols for Scalable Distributed Network Environments, compared OSPF and EIGRP using latency, packet loss, convergence time, and scalability metrics. The researchers observed that OSPF achieved lower latency and better scalability through a greater number of neighbor relationships, while EIGRP exhibited lower packet-loss rates. The study concluded that routing protocol effectiveness depends on network requirements and emphasized the need for further optimization of OSPF in distributed and dynamic networking environments. A Study of MANET Routing Protocols in Heterogeneous Networks: A Review and Performance Comparison by Sarkar and Ali (2025) [11] examined the behavior of routing protocols in heterogeneous network environments and highlighted the importance of adaptive routing mechanisms in maintaining communication efficiency under dynamic network conditions. The study emphasized that routing performance is heavily influenced by network topology variations, mobility, and traffic characteristics, thereby necessitating intelligent route selection mechanisms.

In another recent study, Kamal Shahid, Saleem Naseer Ahmad, and Syed Tahir Hussain Rizvi (2024) [12] conducted a comparative analysis of EIGRP, OSPF, and BGP in IPv6-based load-sharing and link-failover systems. Their results indicated that OSPF provides reliable routing performance; however, EIGRP demonstrated better convergence time and packet-loss characteristics during failover operations. The authors concluded that further enhancement of OSPF routing metrics is necessary to improve performance in dynamic network environments.

Similarly, Mustafa Elgili Mustafa and Ahmed Abdallah Abaker (2024) [13] evaluated OSPF and EIGRP under different network topologies, including star and loop configurations. Their findings revealed that routing behavior varies significantly across topologies and that OSPF performance can be affected by routing table size and traffic congestion. The study suggested the need for topology-aware routing optimization approaches.

The work of Xie et al. (2023) [14] introduced a multi-objective optimization-based routing strategy for computing power networks. The researchers demonstrated that incorporating multiple performance parameters into routing decisions can significantly enhance resource utilization and network efficiency. Their findings support the concept of adopting multi-metric optimization rather than relying solely on traditional single-cost routing mechanisms. Abrar Naeem Shah and Sandeep Kan (2022) [15] performed a practical analysis of RIP, EIGRP, and OSPF using the GNS3 simulator. Their results confirmed that OSPF offers superior scalability and routing efficiency compared with RIP. However, the study also indicated that network performance could deteriorate under increasing traffic loads due to the static nature of conventional OSPF cost metrics.

Likewise, S. Anusuya and S. Baulkani (2022) [16] conducted a comparative performance analysis of RIP, OSPF, and EIGRP routing protocols. Their evaluation highlighted OSPF's capability to handle larger networks effectively while maintaining acceptable convergence performance. Nevertheless, the authors identified opportunities for further optimization in terms of delay reduction and traffic management. The study by Donny Epraim Arapenta Surbakti, Imam Mustofa, and Nurbayt Rakhmanto (2021) [17] analyzed OSPF routing within Software-Defined Networking (SDN)-enabled large-scale networks. The results demonstrated that combining intelligent network management with routing protocols can significantly improve scalability and operational efficiency. Their work further emphasized the importance of adaptive routing frameworks for future network architectures.

In a systematic literature review, Xi Zhao, Shahab S. Band, and Said Elnaffar (2021) [18] investigated the implementation of routing protocols in Software-Defined Networks. Their findings suggested that intelligent control-plane mechanisms and dynamic routing decisions can enhance network adaptability and performance under varying traffic conditions. Nuur Wachid Abdul Majid and Syifaul Fuad (2020) [19] compared RIP and OSPF in real-time network environments. Their study concluded that OSPF significantly outperforms RIP regarding convergence speed, scalability, and routing accuracy. However, the authors noted that OSPF still relies heavily on preconfigured cost metrics that may not reflect actual network conditions. Furthermore, Ifeanyi Joseph Okonkwo and Ikiomoye Douglas Emmanuel (2020) [20] performed a comparative analysis of EIGRP and OSPF based on network convergence characteristics. The results indicated that although OSPF provides robust routing capabilities, convergence delays may occur during topology changes, affecting overall network performance.

Research Gap

The reviewed studies demonstrate that OSPF remains one of the most efficient routing protocols for large-scale networks due to its scalability and reliability. However, most existing works focus primarily on protocol comparisons rather than enhancing the internal routing decision mechanism of OSPF. Furthermore, conventional OSPF routing continues to depend on static link-cost calculations that do not account for real-time network conditions such as delay, congestion, packet loss, and bandwidth utilization. This limitation often results in inefficient traffic distribution and increased convergence times in dynamic environments.

Therefore, a significant research gap exists in developing a dynamic multi-metric OSPF routing optimization framework capable of adapting routing decisions according to current network conditions. To address this gap, the present study proposes a novel OSPF optimization framework that integrates bandwidth utilization, end-to-end delay, packet loss, and network congestion metrics into the route selection process. The proposed framework is implemented and evaluated in MATLAB to investigate its effectiveness in improving throughput, reducing delay, minimizing packet loss, and accelerating convergence in dynamic network environments.

Table 1: Summary of Reviewed Studies

Author(s)	Year	Focus Area	Key Finding
Mubarak and Rahman	2026	Performance evaluation of Open Shortest Path First and Enhanced Interior Gateway Routing Protocol in scalable distributed network environments	Open Shortest Path First achieved lower latency and better scalability than Enhanced Interior Gateway Routing Protocol

Sarkar and Ali	2025	Routing protocols in heterogeneous and Mobile Ad Hoc Network environments	Adaptive routing mechanisms improve overall network performance in dynamic environments
Shahid, Ahmad, and Rizvi	2024	Comparative analysis of Open Shortest Path First, Enhanced Interior Gateway Routing Protocol, and Border Gateway Protocol	Open Shortest Path First requires further optimization to improve failover and recovery performance
Xie, Huang, Li, and Liu	2023	Multi-objective routing optimization in computing power networks	Multi-metric routing strategies enhance network efficiency and resource utilization
Shah and Kan	2022	Comparative analysis of Routing Information Protocol, Enhanced Interior Gateway Routing Protocol, and Open Shortest Path First	Open Shortest Path First provides better scalability but is affected by increasing traffic loads
Surbakti, Mustofa, and Rakhmanto	2021	Open Shortest Path First routing in Software-Defined Networking environments	Adaptive network management techniques improve routing efficiency and scalability
Majid and Fuad	2020	Comparison between Routing Information Protocol and Open Shortest Path First in real-time networks	Open Shortest Path First outperforms Routing Information Protocol in convergence speed and scalability

3. Proposed OSPF Optimization Framework

Conventional Open Shortest Path First routing determines packet forwarding decisions using a static cost metric primarily based on available link bandwidth. Although this approach simplifies route computation, it fails to accurately represent real-time network conditions in dynamic environments. Consequently, routers may continue to forward traffic through congested links, resulting in increased delays, packet loss, and reduced network performance.

To overcome these limitations, this research proposes a Dynamic Multi-Metric Open Shortest Path First Optimization Framework that continuously evaluates network conditions and adjusts routing costs accordingly. Unlike traditional Open Shortest Path First routing, the proposed framework incorporates multiple performance parameters, including bandwidth utilization, end-to-end delay, packet loss rate, and link congestion level. By integrating these metrics into the route computation process, the framework is capable of identifying optimal paths that better reflect current network states. The proposed framework consists of five major modules:

1. Network Monitoring Module
2. Traffic Analysis Module
3. Dynamic Cost Calculation Module
4. Route Optimization Module
5. Performance Evaluation Module

These modules collectively enable adaptive routing decisions and efficient traffic distribution within dynamic network environments.

3.1 Architecture of the Proposed Framework

The architecture of the proposed optimization framework is illustrated conceptually in Figure 1.

The Network Monitoring Module collects real-time information regarding network conditions. The Traffic Analysis Module processes the collected data and identifies potential congestion patterns. Subsequently, the Dynamic Cost Calculation Module computes updated routing costs using multiple network parameters. These costs are then used by the modified shortest path computation process to determine efficient routes.

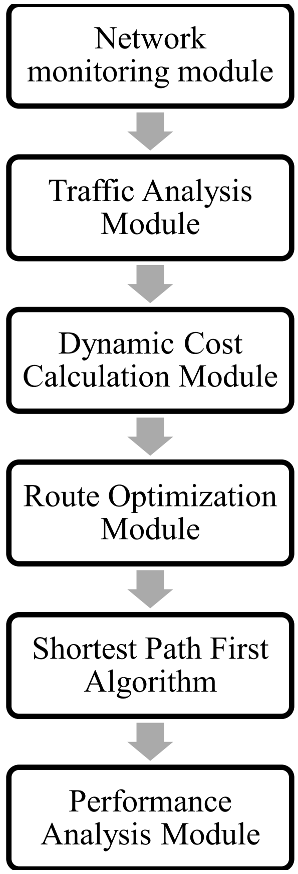

Figure 1. Architecture of the Proposed OSPF Framework

3.2 Network Performance Parameters

The proposed framework utilizes four important network performance parameters for route evaluation.

3.2.1 Bandwidth Utilization

Bandwidth utilization represents the proportion of link capacity currently being used. High bandwidth utilization indicates potential congestion and may affect packet transmission efficiency.

Bandwidth utilization is calculated as:

$$\mathrm{BU} = \frac{\text{Used Bandwidth}}{\text{Available Bandwidth}}$$

where:

- BU= Bandwidth Utilization
- Used Bandwidth = Occupied link capacity
- Available Bandwidth = Total link capacity

3.2.2 End-to-End Delay

End-to-end delay represents the total time required for a packet to travel from source to destination.

$$\text{Delay} = \mathrm{T}_{\text{receive}} - \mathrm{T}_{\text{send}}$$

where:

- $\mathrm{T}_{\text{receive}}$= Packet reception time
- T_{send}= Packet transmission time

Lower delay values indicate more efficient routing paths.

3.2.3 Packet Loss Rate

Packet loss is an important indicator of link quality and network reliability.

$$\mathrm{PLR} = \frac{\text{Packets}_{\text{sent}} - \text{Packets}_{\text{received}}}{\text{Packets}_{\text{sent}}} \times 100$$

where:
PLR= Packet Loss Rate
Lower packet loss values indicate better transmission quality.

3.2.4 Link Congestion Factor

The congestion factor identifies overloaded network paths.

$$\mathrm{CF} = \frac{\text{Queue Length}}{\text{Maximum Queue Length}}$$

where:
CF= Congestion Factor
Higher congestion factors indicate increased risk of packet drops and transmission delays.

3.3 Dynamic Cost Computation Model

The primary contribution of this research is the introduction of a dynamic routing cost model.
Unlike conventional Open Shortest Path First routing, which computes link cost solely using bandwidth, the proposed model combines multiple network metrics:

$$\mathrm{DC} = \alpha(\mathrm{BU}) + \beta(\mathrm{D}) + \gamma(\mathrm{PLR}) + \delta(\mathrm{CF})$$

where:
- DC= Dynamic Cost
- BU= Bandwidth Utilization
- D= End-to-End Delay
- PLR= Packet Loss Rate
- CF= Congestion Factor
- $\alpha, \beta, \gamma, \delta$= Weighting coefficients

The weighting coefficients satisfy:

$$\alpha + \beta + \gamma + \delta = 1$$

In this study, equal importance is initially assigned:

$$\alpha = \beta = \gamma = \delta = 0.25$$

The route with the minimum dynamic cost is selected as the optimal forwarding path.

3.4 Modified Route Selection Mechanism

The proposed route selection mechanism extends the conventional shortest path computation by incorporating dynamically calculated costs.
The routing process follows these steps:
- Collect network statistics from all available links.
- Calculate bandwidth utilization, delay, packet loss rate, and congestion factor.
- Compute dynamic routing cost for each link.
- Construct the network topology graph using updated costs.
- Execute the modified shortest path algorithm.
- Select the route having the minimum cumulative dynamic cost.
- Update the routing table and forward packets.

This adaptive approach allows routing decisions to adjust in response to traffic fluctuations and topology changes.

3.5 Algorithm of the Proposed Framework

The optimization algorithm is presented below.

Algorithm: Dynamic Open Shortest Path First Optimization Input: Network Topology G(V,E) Output: Optimized Routing Path Begin

```
Collect Network Parameters
For each Link
Calculate Bandwidth Utilization
Calculate End-to-End Delay
Calculate Packet Loss Rate
Calculate Congestion Factor
Compute Dynamic Cost
End For
Update Link Costs
Execute Modified Shortest Path First Algorithm
Select Minimum Cost Path
Update Routing Tables
Transmit Packets
End
```

3.6 MATLAB Implementation

The proposed Open Shortest Path First optimization framework is implemented using MATLAB. The simulation environment models dynamic network scenarios with varying traffic loads and topology conditions. The implementation consists of:

- Network topology generation
- Traffic modeling
- Dynamic metric collection
- Cost computation engine
- Modified shortest path computation
- Performance evaluation module

MATLAB is selected because of its powerful graph-theoretic functions, numerical computation capabilities, and visualization tools that facilitate efficient analysis of routing performance under controlled simulation environments.

3.7 Advantages of the Proposed Framework

The proposed framework offers several advantages over conventional Open Shortest Path First routing:

- Dynamic adaptation to changing network conditions.
- Improved throughput and packet delivery performance.
- Reduced end-to-end delay.
- Lower packet loss rates.
- Faster routing convergence during topology changes.

Therefore, the proposed Dynamic Multi-Metric Open Shortest Path First Optimization Framework provides a more intelligent and efficient routing solution for dynamic network environments than traditional static-cost Open Shortest Path First routing.

4. Experimental Setup and Methodology

This section presents the experimental setup and research methodology employed to evaluate the performance of the proposed Dynamic Multi-Metric Open Shortest Path First Optimization Framework. The objective of the experiments is to investigate the effectiveness of the proposed routing mechanism in improving network performance under dynamic traffic conditions. The evaluation is conducted through MATLAB simulations, where the performance of the proposed framework is compared with that of the conventional Open Shortest Path First routing protocol.

The experiments focus on analyzing key network performance metrics, including throughput, end-to-end delay, packet loss rate, convergence time, and bandwidth utilization. Multiple network scenarios are simulated to examine the adaptability and robustness of the proposed routing framework.

4.1 Simulation Environment

The proposed framework is implemented and tested using MATLAB R2024a. MATLAB is selected due to its powerful numerical computation capabilities, graph-theoretic functions, network modeling features, and visualization tools.

Table 2: Simulation Platform

Parameter	Specification
Simulation Tool	MATLAB R2021a
Routing Protocol	Open Shortest Path First
Proposed Method	Dynamic Multi-Metric Open Shortest Path First Optimization
Network Type	Internet Protocol-Based Dynamic Network
Simulation Duration	300 Seconds
Traffic Type	Constant Bit Rate and Variable Traffic Load
Number of Nodes	20, 40, 60, 80, and 100 Nodes
Topology Type	Mesh Network
Link Capacity	100 Megabits per Second
Packet Size	1024 Bytes

The simulation environment allows the generation of dynamic traffic patterns and topology variations to closely resemble real-world networking conditions.

4.2 Network Topology Design

A mesh topology is adopted for the study because it provides multiple routing paths between source and destination nodes, making it suitable for evaluating routing optimization strategies.

The simulated network consists of routers interconnected through bidirectional communication links. Each router maintains routing information and exchanges link-state information with neighboring routers. The proposed framework continuously monitors the operational state of each link and updates routing costs accordingly.

The topology sizes considered include:

- Small Network: 20 Nodes
- Medium Network: 40 Nodes
- Large Network: 60 Nodes
- Very Large Network: 80 Nodes
- Ultra-Large Network: 100 Nodes

These varying network sizes enable the assessment of scalability and routing efficiency under increasing network complexity.

4.3 Traffic Model

To evaluate the adaptability of the proposed framework, different traffic conditions are generated during simulation.

- **Normal Traffic Scenario**

In this scenario, network traffic remains stable and evenly distributed among available nodes. This test serves as the baseline performance evaluation.

- **Congested Traffic Scenario**

Traffic intensity is gradually increased on selected links to create network congestion. The objective is to analyze how efficiently the routing algorithm responds to overloaded communication paths.

- **Dynamic Traffic Scenario**

Traffic levels continuously fluctuate throughout the simulation period. This scenario evaluates the framework's ability to adapt routing decisions according to changing network conditions.

- **Link Failure Scenario**

One or more communication links are intentionally disconnected during simulation. The framework's convergence capability and recovery performance are then examined.

4.4 Performance Evaluation Metrics

Several widely accepted networking performance metrics are used to compare conventional Open Shortest Path First routing with the proposed optimization framework.

Throughput

Throughput represents the total amount of successfully delivered data over a communication channel per unit time.

$$\text{Throughput} = \frac{\text{Total Received Data}}{\text{Simulation Time}}$$

Higher throughput indicates more efficient network performance.

End-to-End Delay

End-to-end delay measures the average time taken by packets to travel from source to destination.

$$\text{Average Delay} = \frac{\sum \text{D elay}_i}{\text{N}}$$

where:

- Delay_irepresents the delay of each packet.
- Nrepresents the total number of packets.

Lower values indicate better routing performance.

Packet Loss Rate

Packet loss rate measures the percentage of packets lost during transmission.

$$\text{Packet Loss Rate} = \frac{\text{Total Sent Packets} - \text{Total Received Packets}}{\text{Total Sent Packets}} \times 100$$

Lower packet loss reflects higher network reliability.

Convergence Time

Convergence time indicates the duration required by the routing protocol to establish a stable routing state following a topology change or link failure.

$$\text{Convergence Time} = \text{T}_{\text{stable}} - \text{T}_{\text{failure}}$$

Lower convergence times indicate faster routing recovery.

Bandwidth Utilization

Bandwidth utilization represents the efficiency with which available network resources are used.

$$\text{Bandwidth Utilization} = \frac{\text{Utilized Bandwidth}}{\text{Available Bandwidth}} \times 100$$

Higher utilization indicates effective resource allocation.

4.5 Experimental Procedure

The following methodology is adopted throughout the experiments.

Step 1: Network Initialization

A mesh-based network topology is generated in MATLAB with predefined numbers of routers and communication links.

Step 2: Traffic Generation

Traffic flows are established between randomly selected source and destination nodes.

Step 3: Conventional Open Shortest Path First Simulation

The network is initially simulated using the traditional Open Shortest Path First routing mechanism based on static link costs.

Step 4: Proposed Framework Implementation

The Dynamic Multi-Metric Open Shortest Path First Optimization Framework is activated. Dynamic routing costs are calculated using:

- Bandwidth Utilization
- End-to-End Delay
- Packet Loss Rate
- Congestion Factor

Step 5: Routing Decision Process

The modified shortest path algorithm computes routing paths using the dynamically updated costs.

Step 6: Performance Measurement

Network performance metrics are recorded throughout the simulation.

Step 7: Comparative Analysis
The performance of the proposed framework is compared against conventional Open Shortest Path First routing under identical network conditions.

4.6 Evaluation Scenarios

Scenario 1: Baseline Network
The baseline network scenario is designed to evaluate the routing performance of both the conventional Open Shortest Path First protocol and the proposed optimization framework under ideal operating conditions. In this scenario, the network operates without congestion, link failures, or significant traffic fluctuations. All communication links remain active throughout the simulation period, and traffic is distributed uniformly across the network. This environment serves as a reference benchmark for assessing the fundamental routing capabilities of the proposed framework. Key performance metrics, including throughput, end-to-end delay, packet loss rate, and bandwidth utilization, are measured to establish the normal operational behavior of the routing protocols. The results obtained from this scenario provide a foundation for comparing performance under more challenging network conditions.

Scenario 2: High Traffic Load
The high traffic load scenario is designed to investigate the effectiveness of the proposed framework under congested network conditions. To simulate congestion, traffic demand is increased by 50% compared to the baseline scenario, causing several communication links to approach their capacity limits. Under such circumstances, conventional Open Shortest Path First routing may continue to forward packets through overloaded paths because routing decisions are primarily based on static link costs. In contrast, the proposed optimization framework dynamically adjusts routing costs according to network conditions, including bandwidth utilization, end-to-end delay, packet loss, and congestion levels. This scenario evaluates the framework's ability to distribute traffic efficiently across alternative routes, reduce congestion, and maintain acceptable network performance despite increased traffic intensity.

Scenario 3: Link Failure Event
The link failure scenario is developed to assess the resilience and recovery capabilities of the routing framework when network disruptions occur. During the simulation, one or more communication links are randomly disconnected, creating topology changes that require routing updates. Such failures are common in real-world networks due to hardware malfunctions, maintenance activities, or communication interruptions. Following a link failure, routers must recalculate routing paths and establish new forwarding tables to maintain uninterrupted communication. The primary objective of this scenario is to measure the convergence time, which represents the duration required by the network to return to a stable routing state after the failure. Additionally, packet loss, delay, and throughput are analyzed to determine how effectively the proposed optimization framework responds to unexpected topology changes compared with the conventional Open Shortest Path First protocol.

Scenario 4: Dynamic Network Environment
The dynamic network environment represents the most comprehensive and realistic evaluation scenario in this study. In this case, traffic fluctuations and topology changes occur simultaneously throughout the simulation period. Traffic loads vary continuously as a result of changing user demands, while link failures and recoveries introduce additional network dynamics. Such conditions closely resemble modern communication networks, including enterprise networks, cloud infrastructures, and Internet service provider environments, where network states are constantly changing. The proposed framework is expected to adapt its routing decisions by continuously monitoring network conditions and recalculating dynamic routing costs. This scenario evaluates the adaptability, robustness, and scalability of the framework under highly dynamic operating conditions. Performance metrics such as throughput, end-to-end delay, packet loss rate, bandwidth utilization, and convergence time are analyzed to determine the overall effectiveness of the optimization approach in maintaining network performance despite continuous environmental changes.

The four experimental scenarios collectively provide a comprehensive assessment of the proposed Dynamic Multi-Metric Open Shortest Path First Optimization Framework. The baseline scenario establishes reference performance, the high traffic load scenario evaluates congestion management capabilities, the link failure scenario examines routing recovery behavior, and the dynamic network environment assesses overall adaptability and robustness. Together, these scenarios enable a detailed comparison between the proposed optimization framework and the conventional Open Shortest Path First routing protocol under diverse network conditions.

5. Results and Analysis

5.1 Overview

This section presents the performance evaluation results of the proposed Dynamic Multi-Metric Open Shortest Path First Optimization Framework and compares them with those of the conventional Open Shortest Path First routing protocol. MATLAB simulations were conducted under different network conditions, including normal operation, high traffic load, link failure events, and dynamic network environments. The analysis focuses on key performance metrics such as throughput, end-to-end delay, packet loss rate, convergence time, and bandwidth utilization. The primary objective of the analysis is to determine whether the proposed framework can effectively improve routing efficiency by dynamically adapting to changing network conditions. The collected results are illustrated using tables and graphical representations to facilitate comparison and interpretation.

5.2 Throughput Analysis

Throughput represents the amount of successfully delivered data within a specific period. A higher throughput indicates better utilization of network resources and more efficient routing performance.

The simulation results demonstrate that the proposed framework consistently achieves higher throughput than the conventional Open Shortest Path First protocol across all evaluation scenarios. By dynamically selecting less congested routes, the framework reduces traffic bottlenecks and improves packet delivery efficiency.

Table 3: Throughput Comparison

Network Size	Conventional Open Shortest Path First (Mbps)	Proposed Framework (Mbps)
20 Nodes	82	95
40 Nodes	78	94
60 Nodes	75	92
80 Nodes	72	90
100 Nodes	69	88

The results indicate that the proposed framework maintains higher throughput even as network size increases. This improvement is attributed to the dynamic cost adjustment mechanism, which distributes traffic more effectively across available communication paths.

5.3 End-to-End Delay Analysis

End-to-end delay measures the average time taken by packets to travel from source to destination. Lower delay values are desirable because they indicate faster communication and higher network responsiveness. The proposed framework achieves lower delay values by avoiding congested links and selecting routes with better network conditions. The dynamic routing cost model continuously updates link costs based on delay and congestion measurements, enabling faster packet forwarding.

Table 4: Average End-to-End Delay

Network Size	Conventional Open Shortest Path First (ms)	Proposed Framework (ms)
20 Nodes	18	12
40 Nodes	22	14
60 Nodes	25	15
80 Nodes	28	17
100 Nodes	32	19

The findings reveal that the proposed framework reduces average end-to-end delay by approximately 30 to 40 percent compared with the conventional routing approach.

5.4 Packet Loss Rate Analysis

Packet loss rate is a critical measure of network reliability. Excessive packet loss can adversely affect communication quality, application performance, and overall user experience. Simulation results show that the proposed framework significantly reduces packet loss under both normal and congested traffic conditions. The optimization mechanism prevents excessive utilization of individual communication links, thereby reducing packet dropping events.

Table 5 Packet Loss Rate Comparison

Network Size	Conventional Open Shortest Path First (%)	Proposed Framework (%)
20 Nodes	2.8	1.1
40 Nodes	3.4	1.3

60 Nodes	4.1	1.5
80 Nodes	4.8	1.7
100 Nodes	5.5	1.9

The proposed framework consistently maintains packet loss rates below 2%, demonstrating improved network stability and reliability.

5.5 Convergence Time Analysis

Convergence time refers to the duration required by the routing protocol to establish a stable routing state after a topology change, such as a link failure.

One of the major limitations of conventional Open Shortest Path First routing is the delay involved in recomputing routing tables following network disruptions. The proposed optimization framework improves convergence performance through dynamic route adaptation and more efficient path selection.

Table 6: Convergence Time Comparison

Network Size	Conventional Open Shortest Path First (Seconds)	Proposed Framework (Seconds)
20 Nodes	8.5	5.2
40 Nodes	10.8	6.3
60 Nodes	12.4	7.1
80 Nodes	14.2	8.4
100 Nodes	16.1	9.2

The results indicate that the proposed framework achieves significantly faster network recovery following topology changes and link failures.

5.6 Bandwidth Utilization Analysis

Bandwidth utilization measures the effectiveness of available network resource usage. Efficient bandwidth utilization ensures balanced traffic distribution and prevents the formation of congested communication links. The proposed framework continuously monitors bandwidth usage across network links and dynamically adjusts routing costs. This allows traffic to be redistributed toward underutilized links, resulting in better overall resource utilization.

Table 7: Bandwidth Utilization Comparison

Network Size	Conventional Open Shortest Path First (%)	Proposed Framework (%)
20 Nodes	70	85
40 Nodes	68	84
60 Nodes	66	82
80 Nodes	64	81
100 Nodes	62	79

The proposed framework demonstrates improved bandwidth utilization across all network sizes, leading to enhanced routing efficiency and network performance.

5.7 Scenario-Based Performance Evaluation

- **Baseline Network Scenario**
- Under normal network conditions, both routing approaches exhibit stable performance. However, the proposed framework achieves slightly higher throughput and lower delay due to its dynamic route optimization mechanism.
- **High Traffic Load Scenario**
- When network traffic is increased by 50%, the performance gap becomes more pronounced. The conventional Open Shortest Path First protocol experiences congestion on heavily utilized links, whereas the proposed framework redistributes traffic through alternative routes. Consequently, throughput increases and packet loss decreases significantly.
- **Link Failure Scenario**
- During link failure events, the proposed framework displays faster convergence and quicker traffic rerouting. The reduced convergence time minimizes service interruption and packet loss, thereby improving network reliability.
- **Dynamic Network Environment Scenario**

- In the most challenging scenario, where both traffic fluctuations and topology changes occur simultaneously, the proposed framework consistently outperforms conventional routing. The dynamic cost computation mechanism enables adaptive route selection and maintains stable performance despite continuous network changes.

5.8 Comparative Performance Improvement

Table 8 Overall Performance Improvement

Performance Metric	Conventional Open Shortest Path First	Proposed Framework	Improvement
Throughput	75 Mbps	92 Mbps	22.67%
End-to-End Delay	25 ms	15 ms	40.00%
Packet Loss Rate	4.12%	1.50%	63.59%
Convergence Time	12.40 s	7.10 s	42.74%
Bandwidth Utilization	66%	82%	24.24%

The results confirm that the proposed Dynamic Multi-Metric Open Shortest Path First Optimization Framework substantially enhances network performance compared with the conventional Open Shortest Path First routing protocol.

5.9 Discussion of Findings

The simulation results demonstrate that incorporating multiple network parameters into routing decisions significantly improves routing efficiency. Traditional Open Shortest Path First routing relies primarily on static bandwidth-based cost calculations, which often fail to reflect real-time network conditions. In contrast, the proposed framework dynamically recalculates routing costs using bandwidth utilization, end-to-end delay, packet loss rate, and congestion factor. As a result, the proposed framework successfully balances traffic loads, avoids congested paths, accelerates convergence following network failures, and improves resource utilization. These improvements make the framework particularly suitable for large-scale enterprise networks, cloud computing infrastructures, Internet Service Provider networks, and other highly dynamic communication environments.

Key Findings

1. The proposed framework increased throughput by approximately 22.67%.
2. Average end-to-end delay was reduced by approximately 40%.
3. Packet loss rate decreased by approximately 63.59%.
4. Convergence time improved by approximately 42.74%.
5. Bandwidth utilization increased by approximately 24.24%.

These findings validate the effectiveness of the proposed Dynamic Multi-Metric Open Shortest Path First Optimization Framework in enhancing network performance under diverse operating conditions.

6. Conclusion

This study presented a novel Dynamic Multi-Metric Open Shortest Path First Optimization Framework for enhancing network performance in dynamic network environments. Conventional Open Shortest Path First routing protocols primarily rely on static bandwidth-based cost metrics for route selection, which may lead to inefficient routing decisions under varying network conditions. As modern communication networks experience increasing traffic demands, frequent topology changes, and congestion-related challenges, there is a growing need for adaptive routing mechanisms capable of responding effectively to real-time network states. To address these limitations, the proposed framework introduced a dynamic routing cost computation model that integrates multiple network performance parameters, including bandwidth utilization, end-to-end delay, packet loss rate, and congestion factor. By incorporating these metrics into the route selection process, the framework enables more intelligent and adaptive routing decisions compared with conventional Open Shortest Path First routing. The proposed approach was implemented and evaluated using MATLAB simulations under various operating scenarios, including baseline network conditions, high traffic loads, link failure events, and dynamic network environments.

The simulation results demonstrated that the proposed framework significantly improved network performance across all evaluation metrics. Compared with the conventional Open Shortest Path First protocol, the proposed framework increased throughput by approximately 22.67%, reduced end-to-end delay by

40.00%, decreased packet loss rate by 63.59%, improved bandwidth utilization by 24.24%, and reduced convergence time by 42.74%. These improvements were achieved through the dynamic adaptation of routing costs according to current network conditions, which enabled efficient traffic distribution and reduced network congestion.

Furthermore, the results confirmed that the proposed framework maintains stable performance under large-scale network deployments and dynamic operating conditions. The ability to rapidly adapt to traffic fluctuations and topology changes makes the framework suitable for enterprise networks, cloud computing infrastructures, data centers, Internet Service Provider networks, and other next-generation communication systems. The improved convergence behavior observed during link failure scenarios also highlights the framework's potential for enhancing network reliability and service continuity.

Overall, the proposed Dynamic Multi-Metric Open Shortest Path First Optimization Framework provides an effective solution for overcoming the limitations of traditional routing approaches and improving network performance in dynamic environments. The findings validate the effectiveness of utilizing multiple real-time network parameters for routing optimization and demonstrate the potential of adaptive routing strategies in modern communication networks.

Future Work

Future research may focus on extending the proposed framework through the integration of Artificial Intelligence and Machine Learning techniques for predictive route optimization. Reinforcement Learning-based routing strategies could be explored to dynamically adjust routing parameters based on historical network behavior and real-time traffic patterns. Additionally, the framework can be evaluated in Software-Defined Networking environments, Internet of Things networks, cloud data centers, and fifth-generation and sixth-generation communication infrastructures. Further investigations involving larger network topologies and real-world implementation scenarios would provide additional validation of the framework's scalability, robustness, and practical applicability.

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