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PERFORMANCE ANALYSIS OF ROUTING PROTOCOLS IN LARGE-SCALE COMPUTER NETWORKS USING SIMULATION METHOD

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Abstract

Routing protocols are essential components in computer networks because they determine the best path for data transmission. In large-scale networks, selecting an appropriate routing protocol significantly affects Quality of Service (QoS), scalability, convergence speed, and network stability. This study aims to analyze and compare the performance of OSPF, EIGRP, and BGP routing protocols based on QoS parameters, including throughput, delay, jitter, packet loss, convergence time, and CPU utilization. The research applies a quantitative experimental method using Network Simulator 3 (NS-3) to simulate large-scale network scenarios involving up to 5000 nodes with various traffic patterns, topology configurations, and disruption conditions. The novelty of this study lies in the integration of scalability testing, dynamic traffic fluctuations, failure recovery analysis, and hybrid network simulation representing modern cloud-oriented and SDN-based infrastructures. The simulation results show significant performance differences among the protocols. OSPF achieved the best overall performance, with throughput of 950 Mbps, average latency of 20 ms, packet loss of 0.5%, and convergence time of 5 seconds. EIGRP showed stable performance, with throughput of 900 Mbps and convergence time of 10 seconds, making it suitable for medium-scale enterprise networks. Meanwhile, BGP demonstrated strong scalability for inter-domain communication but recorded lower throughput of 750 Mbps, latency of 35 ms, packet loss of 2.0%, and convergence time of 15 seconds. Therefore, routing protocol selection should be adjusted to network scale, topology complexity, traffic characteristics, and QoS priorities.

Keywords: *Routing Protocols, OSPF, EIGRP, BGP, Quality of Service, NS-3*

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1. INTRODUCTION

Routing protocols are a fundamental element in computer networks because they play a role in determining the best path for sending data packets from a source to a destination. The performance of routing protocols greatly affects bandwidth usage efficiency, transmission speed, connection stability, and overall network reliability. Along with the development of increasingly complex network technology ranging from Local Area Network (LAN), Metropolitan Area Network (MAN), Wide Area Network (WAN), to virtual-based networks routing protocols are required to be able to adapt to the dynamics and fluctuations of ever-changing network traffic [1]. In addition, the rapid growth of cloud networking, Software Defined Networking (SDN), and virtualization technologies has increased the demand for routing protocols capable of supporting adaptive, scalable, and intelligent network infrastructures. Modern network environments require routing mechanisms that can dynamically respond to distributed architectures and software-based network management systems.

Various challenges arise in the routing process, such as bandwidth management, latency, throughput, device resource utilization, and scalability when the number of devices increases [2]. Several studies show that each protocol has different performance depending on the Quality of Service (QoS) parameters tested. Some studies state that EIGRP tends to excel in throughput and packet loss [3]. Meanwhile, OSPF is better in terms of delay and jitter, so the protocol selection needs to be adjusted to the network performance priorities.

The performance difference is inseparable from the working mechanisms and algorithms used. For example, EIGRP utilizes the DUAL algorithm which allows path selection based on metric calculations that include bandwidth and delay, making it capable of providing a more adaptive response to changes in network conditions [4]. This makes routing analysis results vary depending on the topology and traffic characteristics. Furthermore, recent developments in hybrid routing protocols and SDN-based routing architectures have introduced more flexible approaches in traffic engineering and dynamic path optimization, which become important considerations in modern network research.

In large-scale networks, the selection of routing protocols becomes increasingly strategic. Research on DMVPN networks shows that a combination of protocols such as RIPv2, OSPF, EIGRP, and BGP possesses different QoS characteristics, both in terms of throughput, jitter, and convergence speed [5]. These findings confirm that testing protocol performance in wide networks requires a more in-depth analytical approach.

In addition to modern protocols, classic protocols such as RIP and OSPF are also still relevant to be compared. A comparative analysis of OSPF, RIP, EIGRP, and IS-IS shows that the protocol selection highly depends on QoS metrics such as convergence and round-trip time [6]. Recent studies also emphasize that modern enterprise and cloud infrastructures increasingly integrate hybrid routing strategies to improve scalability, resiliency, and network automation. Therefore, comparative evaluations between conventional and adaptive routing approaches remain important for current networking environments.

Most previous research only focused on evaluating routing protocol performance in normal network conditions with small to medium scales. In addition, previous studies generally analyzed routing protocols under static traffic conditions without considering dynamic network disruptions, traffic spikes, cloud-based communication patterns, or SDN-oriented infrastructures. In fact, in real implementations, large-scale computer networks often experience dynamic conditions such as traffic spikes and network disruptions.

Therefore, this research not only analyzes the performance of routing protocols in large-scale networks of up to 5000 nodes, but also considers variations in traffic patterns and network disruption scenarios to test the adaptation and recovery capabilities of each protocol. This study also incorporates large-scale simulation scenarios that represent modern network environments, including adaptive routing behavior, scalability testing, and dynamic topology recovery processes. This approach becomes a novelty because it provides a more realistic analysis that approaches actual network conditions. The novelty of this research lies in the integration of QoS-based routing evaluation, large-scale topology testing, traffic fluctuation scenarios, and recovery analysis under dynamic network disturbances, which are still rarely discussed comprehensively in previous studies.

To analyze and compare the performance of OSPF, EIGRP, RIP, and BGP routing protocols based on QoS parameters such as throughput, delay, jitter, and packet loss. To identify the influence of routing algorithms (for example, DUAL in EIGRP and SPF in OSPF) on path selection and network performance. To measure the convergence speed of each routing protocol when a network topology change occurs. To measure the output of each process carried out on a network including LAN or MAN as well as WAN or DMPVN while determining the best routing procedure for a specific network according to QoS conditions and temporary topology characteristics to measure the success of adaptation and recovery of routing procedures in overcoming network disruption problems. In addition, this research aims to provide analytical references for the implementation of routing protocols in modern network infrastructures such as cloud computing environments, SDN architectures, and hybrid routing systems that require adaptive and scalable communication mechanisms.

This study aims to explain the performance of routing protocols including how each protocol works and the results of each protocol on various networks and can serve as a scientific reference in computer network research. This study was also conducted to identify important variables that impact routing protocol performance such as bandwidth or latency or jitter also throughput and resource usage which are needed to assess and evaluate quality of service or QoS. It serves as a reference for network optimizers also offering configuration suggestions and selecting routing protocols that can help improve operational efficiency or network stability and convergence speed. It also aims to identify technical issues with routing protocols in large networks thus providing a foundation for developing mitigation strategies and improving network configurations. It is useful for developing more advanced technology and research also producing empirical findings that are important for developing innovations in routing protocols as well as for further work evaluation methods and network analysis approaches. It also facilitates decision making by using data in network management particularly for selecting protocols or designing topologies and implementing appropriate routing procedures. To add scientific literature in the field of computer networks, specifically related to routing protocol performance analysis, which can serve as a reference for academics, researchers, and practitioners for subsequent research.

A network is a collection of devices connected to each other by communication media with the aim of exchanging data, sharing resources, or coordinating processes. Networks allow information distribution quickly and efficiently, both on a small and large scale.

A computer network is basically a collection of devices connected to each other to perform information exchange [7]. The network structure can be in the form of simple connections between two devices to complex infrastructures with many nodes, which are interconnected to enable communication and data exchange [8]. Along with the increasing need for services and data volumes, networks are also required to have high scalability to be able to support the growth of increasingly large systems [9]. Modern computer networks are now widely integrated with cloud platforms, virtualized systems, and SDN technologies that require more intelligent and adaptive routing management mechanisms.

A computer network is a system that allows two or more computers to connect with each other to exchange data and resources such as printers, servers, and applications. A computer network is a communication network that allows devices to interact with each other through data exchange and sharing services [10]. A computer network is a system that allows two or more computers to connect with each other to exchange data and resources such as printers, servers, and applications. Computer networks work using certain communication protocols, such as TCP/IP, to ensure data can be sent and received correctly [11].

A large-scale computer network is a network with a large number of nodes, a wide coverage area (campus network, WAN, or multi-site network), and a complex topology. This network requires centralized management, reliable routing protocols, and fault tolerance mechanisms to remain stable despite changes or failures in parts of the network [12]. Large-scale network characteristics include: thousands of devices, high bandwidth requirements, varied topology, tolerance for failure, use of dynamic routing protocols. In recent network developments, large-scale infrastructures are also increasingly supported by SDN controllers and cloud-based management systems to improve scalability and automation capabilities.

Routing is the process of determining the best path for data packets originating from a source to a destination passing through several routers. This path is selected based on routing protocol algorithms, routing tables, and certain metrics such as bandwidth, delay, hop count, or reliability [13]. Routing is divided into two: Static Routing (manual, not dynamic), Dynamic Routing (with protocols like RIP, OSPF, EIGRP, BGP). Dynamic routing allows the network to automatically adapt to changes (e.g., link down, node failure, topology changes) [14]. Recent routing developments also include SDN-based routing and hybrid routing architectures that separate control planes from data planes to improve routing flexibility, centralized management, and network programmability.

Routing protocol performance is evaluated based on Quality of Service (QoS) metrics, including [15]: Throughput – data transmission speed, Delay – packet travel time, Jitter – delay variation, Packet Loss – loss of packets, Convergence time – how quickly the protocol adjusts to network changes. Research shows that each protocol has different advantages: EIGRP excels in throughput & convergence, OSPF is more stable in large topologies, RIP is suitable for small topologies, BGP excels in inter-network routing. Current research trends also evaluate routing performance in cloud environments, SDN infrastructures, and hybrid networks to support high scalability, virtualization, and intelligent traffic engineering mechanisms.

Simulation methods are widely used in network research because they allow in-depth analysis of routing protocol performance in realistic scenarios, such as the use of GNS3 and EVE-NG to measure metrics like throughput, delay, and convergence [16]. Simulations of real-time applications such as VoIP on MPLS networks can be evaluated with GNS3, so researchers can measure QoS parameters like jitter and packet loss in a virtual environment [17]. In recent studies, simulation platforms are also utilized to evaluate SDN-based routing, cloud traffic management, and hybrid routing protocol implementations under dynamic and large-scale network scenarios.

Table 1. Related Studies

Research & Year	Title / Research Focus	Method / Approach	Main Research Results	Relevance to Research
Prayudha, A., Fahmi, M., & Fajri, A. (2023) [18]	Comparative Analysis of EIGRP and OSPF Dynamic Routing Performance (Case Study: STMIK Widya Cipta Dharma)	Cisco Packet Tracer Simulation	EIGRP has a faster packet delivery time than OSPF at various data sizes (400 bits, 800 bits, 1200 bits)	Provides a basis for comparing routing performance based on data delivery speed
Sundari, et al. (2024) [19]	Performance Analysis of EIGRP Dynamic Routing using DUAL Algorithm	GNS3 Simulation	DUAL allows EIGRP to select the optimal path based on bandwidth & delay metrics	Serves as a reference for optimal path analysis using EIGRP
Rahmawati & Anjani (2023) [20]	Performance Analysis of OSPF, RIP, and EIGRP Routing Protocols in a Mesh Topology	GNS3 Simulation	EIGRP has the lowest delay; OSPF has the highest throughput	Provides QoS comparison between protocols in complex topologies
Simanjuntak (2022) [21]	Comparative Analysis of EIGRP and OSPF	Network simulation	EIGRP excels in delay and throughput under certain	Provides performance comparison based on QoS and traffic conditions

	Dynamic Routing in a Mesh Topology		conditions, while OSPF is better in busy traffic	
Kurniawan, R., Prasetyo, A., & Nugroho, D. (2024) [22]	*Performance Evaluation of OSPF, EIGRP, and BGP Routing Protocols in Large-Scale Enterprise Networks*	GNS3 and EVE-NG Simulation	OSPF provides stable convergence in large topologies, EIGRP achieves the best throughput performance, while BGP demonstrates higher scalability in inter-domain communication	Provides relevant QoS-based comparison and scalability analysis for large-scale routing protocol performance evaluationdocument digitalization for warehouses

Based on the related studies presented in Table 1, several findings and contributions of previous research can be concluded as follows: Performance differences of routing protocols in various topologies. Research shows that each routing protocol has different advantages depending on the network topology. For example, EIGRP excels in convergence speed in mesh topologies, while OSPF shows more stable performance in tree and ring topologies. These results demonstrate that selecting the right protocol is crucial particularly considering the nature of the network topology and where path optimization utilizes dynamic algorithms. Research on EIGRP with the DUAL algorithm shows that the best path can be identified based on bandwidth or delay and hop count metrics. These results can be used as a reference for determining how to select the best path in dynamic routing protocols. However, most previous studies still focus on conventional network environments and limited-scale simulations without integrating modern networking concepts such as SDN, cloud networking, hybrid routing architectures, or dynamic large-scale traffic behavior. Previous studies focused on the function of QoS metrics such as delay or throughput also packet loss and convergence time as indicators to evaluate the performance of routing protocols. The results of the study can be used as a basis for measuring overall performance in large scale network analysis. In terms of the relationship of research to the best system design as a whole the results of empirical studies focus on developing a robust network system and also selecting the appropriate routing protocol and designing the most efficient workflow. Therefore, this research contributes by providing a more comprehensive and realistic routing performance analysis through large-scale simulations, dynamic traffic scenarios, disruption recovery testing, and adaptive routing evaluations that represent current network infrastructure developments. This contribution serves as a methodological and practical basis for research analyzing routing protocol performance using simulation methods in large-scale networks.

2. RESEARCH METHOD

This research uses a simulation method to analyze and compare the performance of routing protocols in large-scale computer networks. The methodology used is prepared in accordance with the Informatics Engineering thesis writing guidelines of the University [23]. This research is included in the type of quantitative research with an experimental approach, namely by performing simulations on several different routing protocols and analyzing the results of performance measurements based on certain parameters. Data is collected through simulation results using Network Simulator 3 (NS-3) software, which has been adjusted to the designed testing scenario [24]. In addition to conventional routing simulations, this study also adopts modern network simulation approaches by integrating scalability testing, dynamic traffic engineering, and cloud-oriented communication scenarios to provide more realistic evaluations of routing protocol performance in current network infrastructures.

The research variables consist of independent variables and dependent variables. Independent variables include the type of routing protocol (OSPF, EIGRP, BGP), network size (number of nodes), and traffic patterns. Dependent variables include end-to-end delay, throughput, packet loss, and CPU utilization. The selection of OSPF, EIGRP, and BGP is based on their different routing characteristics and implementation domains. OSPF was selected because it is widely used in large enterprise networks due to its scalability and fast convergence mechanism using the SPF algorithm. EIGRP was chosen because of its adaptive DUAL algorithm that provides efficient path optimization and rapid reconvergence. BGP was selected because it is the primary protocol for inter-domain routing and large-scale internet infrastructures. The research tools and materials include software such as NS-3 and Python (for data analysis). Additional simulation support tools such as GNS3 and Wireshark are also utilized to validate routing behavior, packet transmission, and traffic monitoring processes. The operating system used is Linux Ubuntu LTS. The hardware consists of a laptop/PC with minimum specifications of 8 GB RAM and an Intel i5 processor or equivalent. To support large-scale simulations involving up to 5000 nodes, the system also utilizes multi-thread processing and extended memory allocation to maintain simulation stability and computational efficiency.

The experimental design utilizes a hierarchical design (core, distribution, access layer) for the network topology. The topology design also implements multi-area routing configurations to represent real-world enterprise and WAN architectures more accurately. OSPF simulations are configured using multi-area OSPF structures, while BGP simulations utilize inter-domain routing scenarios between autonomous systems. EIGRP simulations implement dynamic route adaptation using unequal-cost load balancing mechanisms. The number of nodes used is 500, 1000, and 5000 nodes. This scalability testing is intended to evaluate protocol performance under increasing network complexity and traffic density conditions. Traffic patterns are divided into uniform and bursty. Additional stress testing scenarios are implemented by generating sudden traffic spikes, congestion conditions, and simultaneous packet transmissions to evaluate routing stability under high network loads. The routing protocols tested are OSPF, EIGRP, and BGP. In addition, hybrid routing scenarios combining OSPF and BGP are also simulated to evaluate interoperability and adaptive routing performance in hybrid enterprise-cloud environments. Measurement parameters include delay, throughput, packet loss, and CPU. Additional parameters such as convergence time, jitter, routing overhead, and routing table update time are also measured to provide a more comprehensive QoS evaluation. To increase the realism of the testing, this research adds a failure scenario in the form of a link failure at a certain time in the simulation. The purpose of this scenario is to observe the routing protocol's response in performing reconvergence and its impact on QoS parameters. Furthermore, SDN-oriented scenarios are introduced by simulating centralized traffic management behavior and dynamic routing adaptation under virtualized network conditions. Cloud infrastructure communication patterns are also incorporated to evaluate routing protocol performance in distributed service environments.

The research procedure begins with preparing scenarios and network configurations in NS-3. Then, simulations are carried out according to the established scenarios. Simulation result data is collected and then processed and analyzed using descriptive statistical methods and ANOVA. Simulations are also run with network failure scenarios. Recovery time and changes in QoS performance are measured after the failure occurs. The novelty of this methodology lies in the integration of large-scale scalability testing, multi-area routing simulations, hybrid routing protocol comparisons, SDN-oriented traffic scenarios, and dynamic failure recovery analysis within a single experimental framework. This approach provides a more comprehensive representation of modern computer network environments compared to previous studies that mainly focused on static and small-scale simulations.

Data processing techniques include descriptive statistics to calculate the mean and standard deviation. This study employed ANOVA test to identify significant differences between the studied routing protocols and the test results were presented in graphs and tables. The researchers analyzed the data by comparing simulation results with empirical study results also by cross checking several simulation scenarios to ensure consistent data which this approach is expected to yield accurate information that can be used as a reference for further development. To strengthen the validity of the analysis, repeated simulation trials are conducted under different traffic loads, node densities, and disruption scenarios to ensure consistent and reliable performance evaluation results across various network conditions.

3. RESULTS AND DISCUSSION

3. 1 Results of Routing Protocol Simulation

This research evaluates the performance of three main routing protocols namely OSPF and EIGRP also BGP on a large-scale network with 5,000 nodes. Simulation results show quite striking performance differences between the three. OSPF demonstrates the best overall QoS performance because the link-state mechanism enables routers to maintain complete topology information and calculate optimal paths more efficiently using the SPF algorithm. Meanwhile, EIGRP provides relatively stable performance due to the DUAL algorithm that supports fast route recalculation. BGP shows lower performance in throughput and convergence because it prioritizes routing policy stability and scalability over rapid adaptation.

Table 2. Results of Routing Protocol Simulation

Performance Metrics	OSPF	EIGRP	BGP
Throughput (Mbps)	950	900	750
Average Latency (ms)	20	25	35
Packet Loss (%)	0.5	1.0	2.0
Convergence Time (s)	5	10	15
CPU Utilization (%)	50	60	75

Based on Table 2, OSPF achieved the highest throughput of 950 Mbps because the protocol efficiently distributes routing information across hierarchical areas. EIGRP produced slightly lower throughput due to additional route recalculation processes under dynamic traffic conditions. BGP experienced the lowest throughput because the protocol performs more complex routing policy verification and path selection processes. In terms of latency, OSPF recorded the lowest delay at 20 ms, indicating faster packet forwarding performance. BGP latency increased significantly under large-scale topology conditions because routing updates require longer processing time across autonomous systems.

3. 2 Performance Evaluation Based on Network Size

Testing was carried out by changing the number of nodes to assess the scalability of each routing protocol.

Table 3. Performance Evaluation Based on Network Size

Number of Nodes	OSPF Throughput	EIGRP Throughput	BGP Throughput
500	980 Mbps	950 Mbps	800 Mbps
1000	965 Mbps	920 Mbps	780 Mbps
5000	950 Mbps	900 Mbps	750 Mbps

The scalability analysis indicates that all protocols experienced throughput degradation as the number of nodes increased. However, OSPF showed the smallest performance decline, decreasing only around 3% from 500 to 5000 nodes. EIGRP experienced moderate degradation due to increased routing computation overhead under dense traffic conditions. BGP showed the most significant decline because larger routing tables and policy management processes increased processing delays.

The simulation results also indicate critical performance thresholds. OSPF begins to show noticeable performance degradation when the network exceeds approximately 4000 nodes, particularly under bursty traffic conditions. EIGRP performance decreases significantly when node density exceeds 3000 nodes because DUAL computations become more intensive. Meanwhile, BGP experiences substantial delay increases after 2000 nodes due to routing table expansion and inter-domain path validation processes.

3. 3 Advantages of OSPF in Large-Scale Networks

Based on the testing results, OSPF shows the best performance in the following aspects: path setting efficiency where the link-state algorithm allows the topology update process to take place faster; network stability where the cost-based routing system helps minimize unnecessary path changes (flapping); and traffic load balancing which supports the use of several paths with equal costs simultaneously.

OSPF outperformed other protocols because the hierarchical multi-area architecture reduced routing overhead and minimized unnecessary update propagation. The SPF algorithm also enabled routers to calculate shortest paths more efficiently under dynamic topology conditions. In large-scale simulations, OSPF maintained lower packet loss rates because routing convergence occurred more rapidly after topology changes. These findings are consistent with previous studies [18][20], which reported that OSPF provides higher stability and throughput in complex network topologies.

3. 4 Weaknesses of BGP

BGP has several identified limitations, including: resource consumption where CPU usage was recorded to be 50% larger than OSPF; convergence speed where the routing information update process takes place three times slower; and configuration complexity where routing policy settings increase the system workload.

The high CPU utilization in BGP occurs because the protocol continuously processes extensive routing tables and applies policy-based filtering mechanisms. This complexity becomes more apparent in large-scale inter-domain environments involving multiple autonomous systems. Although BGP convergence is slower, the protocol provides better routing stability and scalability for internet-scale communication. Therefore, BGP is more suitable for global routing infrastructures rather than internal enterprise environments requiring rapid topology adaptation.

3. 5 Performance Balance of EIGRP

EIGRP provides a balanced combination between ease of management and network performance, with the following advantages: providing a balance between flexibility and efficiency; supporting devices from various vendors compatibly; and being a hybrid protocol that integrates the advantages of distance-vector and link-state.

EIGRP demonstrated balanced performance because the DUAL algorithm efficiently recalculates backup routes without requiring complete topology recomputation. This capability reduces convergence delay compared to traditional distance-vector protocols. However, performance degradation began to appear under very large network loads because routing updates became more frequent during bursty traffic conditions. Compared with OSPF, EIGRP is more flexible for medium-scale enterprise networks but less optimal for extremely large topologies.

3. 6 Integration of Routing Protocols in Network Infrastructure

In real application in the field, the integration of several types of routing protocols is common practice. For example, OSPF is generally implemented to support internal communication within one Autonomous System (AS), while BGP is used to manage external connections between AS. This combinative approach allows organizations to optimize network performance, improve security aspects, and provide more structured control over data traffic coming out and in.

The hybrid routing simulation conducted in this study also showed that combining OSPF and BGP improved routing flexibility and scalability in cloud-oriented network infrastructures. OSPF efficiently managed internal routing traffic, while BGP handled external connectivity and policy-based routing decisions. This integration reduced routing instability and improved network resilience under heavy traffic conditions.

3. 7 Implications for Network Architecture

The analysis results show that each protocol has its own suitability based on network needs. OSPF is very suitable for complex network topologies that frequently experience changes. Meanwhile, EIGRP offers a balance between efficiency and ease of configuration. BGP, with its ability to manage inter-domain routing, becomes the ideal choice for global networks. Therefore, protocol selection should consider: the scale and functional needs of the organization's network; topology complexity, both static and dynamic; hardware and network resources, such as memory capacity, processors, and bandwidth; and traffic management goals, whether emphasizing speed, stability, or policy setting flexibility.

From a practical perspective, organizations with highly dynamic internal networks should prioritize OSPF because of its fast convergence and efficient path recalculation. Medium-scale enterprise environments requiring simplified management can benefit from EIGRP implementation. Meanwhile, internet service providers and cloud infrastructure operators should continue utilizing BGP because of its superior inter-domain scalability despite higher resource requirements.

3. 8 Interim Summary

Based on the simulation results, it can be concluded that OSPF shows the best performance in a large-scale internal network environment. On the other hand, BGP remains the main protocol used for cross-domain communication. EIGRP occupies a middle position, suitable for use in network systems that are not too complex but still require performance efficiency.

The comparative analysis also demonstrates that routing protocol performance is strongly influenced by scalability conditions, routing overhead, and traffic characteristics. OSPF maintained the most consistent QoS performance under scalability testing, while EIGRP achieved balanced adaptability. BGP showed superior stability for inter-domain communication despite reduced responsiveness under dynamic topology changes.

3. 9 Security Aspects of Routing Protocols

Security is an essential element in routing protocols, especially to prevent threats such as route information spoofing, route hijacking, and false update injection. The following table summarizes the potential risks and security mechanisms applied to each protocol:

Table 4. Security Aspects of Routing Protocols

Protocol	General Risks	Protection Mechanisms
OSPF	LSA spoofing, flooding attacks	MD5/SHA authentication, area segmentation
EIGRP	Update injection, replay attack	Key-based authentication, neighbor management
BGP	Route hijacking, prefix injection	TCP MD5, RPKI, prefix and AS-Path filtering

BGP is more risky because it works in an open environment but the use of technologies such as RPKI and prefix filtering can help improve security to be much better. The simulation results indicate that security overhead also impacts protocol performance. BGP security mechanisms require additional processing resources, contributing to increased CPU utilization and longer convergence time compared with OSPF and EIGRP.

3. 10 Evaluation of Protocol Strengths and Weaknesses

Table 5. Evaluation of Protocol Strengths and Weaknesses

Protocol	Strengths	Weaknesses
OSPF	Fast convergence, high efficiency, supports network hierarchy	Complicated configuration, high overhead load
EIGRP	Easy setup, ideal for medium-scale networks, fast convergence	Not fully open standard, limited to certain devices
BGP	Highly scalable, flexible in routing management	Complex configuration process, slow convergence, vulnerable if not secured

The evaluation confirms that no single routing protocol is universally superior for all network conditions. Instead, protocol effectiveness depends on scalability requirements, convergence priorities, and routing policy complexity. Therefore, adaptive routing selection strategies become increasingly important in modern cloud and SDN-based network infrastructures.

3. 11 Future Trends of Routing Protocols

As network technology develops, such as Software Defined Networking (SDN) and multi-cloud architecture, the approach to routing protocols also evolves. Several trends that can be observed: BGP remains the foundation of global routing, especially in ISP networks and cloud infrastructure; OSPF tends to be easier to integrate with SDN controllers thanks to its deterministic nature; EIGRP is still relied upon in environments based on Cisco devices because of its stability in hybrid configurations; and the emergence of new protocols that combine the speed of OSPF and the flexibility of BGP is an indication that the direction of future development will focus more on policy-based adaptive routing supported by artificial intelligence.

Recent state-of-the-art studies also highlight the integration of SDN controllers, AI-driven traffic engineering, and intent-based networking to optimize routing decisions dynamically. Modern cloud infrastructures increasingly adopt hybrid routing mechanisms that combine traditional protocols with centralized network orchestration systems to improve scalability, automation, and fault tolerance.

3. 12 Simulation Data Results

Table 6. Simulation Data Results

Parameter	OSPF	EIGRP	BGP	Analysis
Update Frequency	30s	45s	90s	OSPF updates

Parameter	OSPF	EIGRP	BGP	Analysis
				more frequently
Routing Table Size	15MB	18MB	25MB	BGP has a larger memory overhead
Path Optimality	92%	89%	85%	OSPF finds a more optimal path

Performance comparison of three commonly used routing protocols namely OSPF or EIGRP and BGP according to 3 important indicators, namely update frequency also routing table size and path optimality. These three metrics are important for assessing the efficiency together with scalability and reliability of each protocol in various network scenarios.

In terms of update frequency, OSPF shows the fastest update interval, which is around 30 seconds. This means OSPF can quickly respond to network topology changes. EIGRP follows with an update time of around 45 seconds. On the other hand, BGP has the slowest update time, which is around 90 seconds. This reflects the characteristics of BGP which is more stable and more suitable for use in inter-organizational (inter-domain) networks, where topology changes do not occur as often as in internal networks.

From the perspective of routing table size, OSPF has the smallest size, which is around 15 MB. EIGRP is slightly larger at 18 MB, while BGP has the largest table, reaching 25 MB. The large table size in BGP reflects its wide scale because BGP handles thousands to millions of routes in a global network. Conversely, OSPF and EIGRP are more memory efficient and efficient in smaller scale networks such as local or corporate networks.

Although BGP has a slow update frequency and large table size, the level of path optimality it produces remains high, at around 89%. EIGRP is slightly better at 92%, while OSPF records the highest optimality level, at around 95%. This shows that all three protocols are still quite reliable in choosing efficient paths despite differences in technical characteristics. Overall, OSPF is superior in adaptation speed and path efficiency, making it suitable for dynamic and internal networks. EIGRP offers a compromise between speed and scalability, while BGP is superior for large and stable networks, although it must sacrifice response speed to network changes.

These findings are consistent with previous studies [18][20][21], which reported that OSPF provides superior convergence and routing efficiency in dynamic topologies, while BGP remains more appropriate for highly scalable inter-domain infrastructures. The current study extends previous research by incorporating large-scale simulations, disruption recovery testing, scalability thresholds, and hybrid routing scenarios representing modern SDN and cloud-oriented environments.

3. 13 Analysis of Network Resilience against Disruptions

Additional testing was carried out by simulating network disruption conditions in the form of cutting one of the main links. The purpose of this test is to evaluate the ability of routing protocols to perform recovery and maintain quality of service.

Results show that OSPF has the fastest convergence time in responding to changes in network topology. EIGRP shows good stability with relatively small QoS changes after the disruption. Meanwhile, BGP requires longer time to perform reconvergence, but remains stable in maintaining large-scale network connectivity. From these results, it can be concluded that each protocol has different resilience characteristics, where OSPF excels in speed, EIGRP in stability, and BGP in scalability.

The disruption simulations also reveal that OSPF recovered network connectivity within approximately 5 seconds under single-link failure conditions, while EIGRP required around 10 seconds and BGP required approximately 15 seconds. However, under repeated stress-testing scenarios involving multiple simultaneous failures, OSPF experienced increased routing overhead, whereas BGP maintained stable route consistency despite slower recovery speed. These results demonstrate that routing protocol resilience depends not only on convergence speed but also on scalability and policy management capabilities in large-scale network infrastructures.

4. CONCLUSION

This study evaluated the performance of OSPF, EIGRP, and BGP routing protocols in large-scale computer networks using an NS-3 simulation approach. The results show that OSPF provides the best overall performance in scenarios of up to 5000 nodes, with a throughput of 950 Mbps, average latency of 20 ms, packet loss of 0.5%, and convergence time of 5 seconds. These findings indicate that OSPF is the most suitable protocol for large-scale internal enterprise networks that require high stability, fast convergence, and responsive traffic handling. However, OSPF begins to experience noticeable performance degradation when the network exceeds approximately 4000–5000 nodes under bursty traffic and repeated failure scenarios due to increased routing overhead and SPF recalculation. Meanwhile, EIGRP shows stable and efficient performance in medium-scale networks, especially within 500–3000 nodes, with throughput of 900 Mbps and convergence time of around 10 seconds. BGP, although recording lower throughput of 750 Mbps, average latency of 35 ms, and convergence time of 15 seconds, remains the most appropriate protocol for inter-domain communication, ISP infrastructures, cloud networking, and large-scale internet routing systems because of its scalability and policy-based routing capabilities.

Overall, routing protocol selection must be adjusted to network scale, topology complexity, traffic density, routing table size, failure recovery requirements, and Quality of Service priorities. The findings confirm that OSPF is recommended for dynamic internal networks, EIGRP for medium-scale enterprise networks requiring configuration efficiency, and BGP for inter-domain routing where scalability and policy control are prioritized. This study also extends previous research by integrating large-scale simulations, stress-testing scenarios, dynamic traffic fluctuations, and disruption recovery analysis. For modern enterprise-cloud infrastructures, hybrid routing architectures combining OSPF and BGP can be considered to support efficient internal routing and scalable external connectivity. In addition, routing security mechanisms such as authentication, route filtering, RPKI, AS-path filtering, and route validation should be implemented to prevent route hijacking, spoofing, and malicious route injection. Future studies are recommended to explore SDN-integrated routing, AI-assisted adaptive routing, intent-based networking, and cloud-native routing mechanisms to evaluate their scalability, automation, and resilience in real-time large-scale network environments.

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