A Critical Analysis on Path metric evaluation of network routing algorithms for Virtual Networking in Cloud Environment

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Abstract. The routing algorithms optimize the speed, cost and bandwidth requirement of any network such as in network virtualization framework in Cloud. The network data or packets can be sent through the selected path mainly with the help of dynamic routing protocols like Enhanced Interior Gateway Routing Protocol (EIGRP), and Open Shortest Path First (OSPF). These network protocols enable the routing techniques by choosing the path metrices like bandwidth, delay or latency, cost in simple and layered network systems those uses IPv4 as well as IPv6. In this work, the metric components are explored to observe for the best path selection. Interdependencies of bandwidth and packet deleivery latency or delay are related for testing it's effect in the network configurations. GNS3 is used for simulation in EIGRP and OSPF for a dual stack mode of network (IPv4 and IPv6). The observations made so far can be useful for analysing best path routing or otherwise ensuring valuable insights in cloud environment. A critical qualitative analysis is provided to promote researhes towards this direction.

Keywords: Routing Algorithm, Cloud computing, Enhanced Interior Gateway Routing Protocol, Open Shortest Path First, Path metric, Load balancing in dual stack configuration.

1. Introduction

The path metric evaluation in network routing algorithms plays a pivotal role in optimizing routing performance in virtualized cloud networks [29, 30]. With the increasing complexity and dynamic nature of cloud environments, traditional path metrics like hop count, bandwidth, and delay are being enhanced with more sophisticated metrics tailored to meet the unique demands of cloud networking. Studies suggest that routing protocols such as OSPF and EIGRP, when used in virtualized environments, must incorporate adaptive path metrics to ensure efficient routing under varying load conditions and to support scalability in multi-tenant setting. Therefore, path metric evaluation is crucial for ensuring optimal traffic distribution, minimizing network congestion, and improving overall network reliability in cloud infrastructures. Additionally, some researchers have proposed new metrics, such as load balancing, link utilization, and network stability, to better align with cloud services' elasticity and resource demands . As cloud environments rely on virtualized network components, the ability of routing algorithms to adapt their path metrics in real-time becomes increasingly important for maintaining service quality and minimizing latency . Thus, understanding and optimizing these path metrics are essential for effective virtual network management in cloud computing.

Routing algorithms are critical components of network protocols, enabling efficient data packet delivery across complex network infrastructures. They determine optimal paths by analyzing factors such as network topology, distance, and bandwidth [1, 18]. These algorithms are broadly categorized into distance-vector and link-state approaches. Distance-vector algorithms, such as the Routing Information Protocol (RIP), rely on simple metrics like hop count and exchange routing information with neighboring routers [1, 2]. Conversely, link-state algorithms, exemplified by Open Shortest Path First (OSPF), construct a comprehensive view of the network topology by disseminating link-state advertisements, allowing routers to calculate shortest paths with high precision. The choice of routing algorithm significantly impacts network performance, adaptability, and resilience, ensuring stable operations even amid dynamic network conditions [3,4,19]. Their role in modern networking can not underscore their importance in optimizing resource utilization and achieving reliable data communication [5, 7].

Therefore, routing protocols play a pivotal role in fixing up the running configurations by networking in determining the optimal paths for data transmission across diverse network infrastructures. Among these protocols, the Enhanced Interior Gateway Routing Protocol (EIGRP) stands out as an advanced distance-vector protocol with hybrid characteristics, combining elements of both distance-vector and link-state approaches. Developed by Cisco, EIGRP automates routing configurations while offering robust features such as fast convergence, minimal bandwidth usage through partial updates, and support for multiple network layer protocols like IPv4 and IPv6. A key innovation in EIGRP is the Diffusing Update Algorithm (DUAL), which ensures loop-free and reliable routing decisions, enhancing network stability and performance. Additionally, EIGRP supports load balancing, including unequal-cost path routing, allowing for flexible resource utilization across complex networks [9]. These attributes make EIGRP particularly well-suited for scalable, large-scale environments, where efficient routing and resource optimization are critical [10, 11, 12].

The use of routing protocols like Enhanced Interior Gateway Routing Protocol (EIGRP) and Open Shortest Path First (OSPF) has become increasingly significant in cloud computing network virtualization frameworks [13]. These protocols enhance the scalability, efficiency, and reliability of virtualized networks by optimizing routing in dynamic and multi-tenant environments [14]. EIGRP, with its hybrid approach (combining distance-vector and link-state features), provides fast convergence and supports unequal-cost load balancing, making it ideal for cloud frameworks requiring high availability and adaptability. On the other hand, OSPF, a pure link-state protocol, excels in large and complex cloud networks due to its comprehensive topology awareness and ability to efficiently adapt to changes. In virtualized environments, OSPF's hierarchical design facilitates segmentation and traffic optimization, ensuring seamless interconnectivity between virtual and physical network segments. The integration of these protocols into cloud network virtualization frameworks supports efficient resource allocation, high throughput, and reduced latency, making them essential for modern cloud infrastructure [13, 14].

The preliminary study explores GNS3's use to simulate OSPF and EIGRP routing protocols in cloud environments. Performance metrics such as convergence time and packet delay were analyzed, showing EIGRP's efficiency in terms of quicker convergence. Real-time application simulations, like video and voice services, were included to test protocol behavior under varied network conditions [15]. In [16], OSPF and EIGRP based routing topologies are designed with GNS3, focusing on key protocol parameters like hello intervals and transmission delays. It highlights GNS3's flexibility in emulating network designs, showing how EIGRP outperforms OSPF in terms of speed and adaptability in dynamic cloud frameworks. Further, GNS3's role in simulating hybrid protocols like EIGRP and pure link-state protocols such as OSPF are found in [17, 22]. It evaluates protocol performance and highlights GNS3's capability in pre-deployment testing, especially in cloud networking. Emphasis is placed on protocol scalability and stability under dynamic cloud environments [13, 20, 21].

The major contribution of this article are as follows:
1. Enhanced Understanding of Routing Protocols provide a comparative analysis of routing algorithms, such as RIP, OSPF, and EIGRP, emphasizing their roles in achieving efficient, reliable, and scalable data transmission across modern network infrastructure.

2. Evaluation of EIGRP and OSPF in Cloud Networks relating the concepts of integration of routing protocols in cloud computing virtualization frameworks is highlighted, showcasing their adaptability, efficiency, and hierarchical designs in multi-tenant, dynamic environments.

3. Significance of Hybrid Protocols with EIGRP's hybrid nature, combining distance-vector and link-state features, is outlined as a significant advancement, offering benefits like fast convergence, loop-free routing with DUAL, and load balancing.

4. Role of GNS3 in Network Simulation to prove utility in simulating EIGRP and OSPF protocols in cloud environments is explored, demonstrating its capability to analyze performance metrics like convergence time and packet delays under varying network conditions.

5. Impact on Cloud Networking Optimization with the findings to underline how routing protocols enhance resource allocation, reduce latency, and improve throughput in virtualized environments, making them indispensable for modern cloud-based infrastructures.

Therefore, these contributions highlight the relevance of routing algorithms and simulation tools in current research and operational excellence in cloud computing. Section 1 is used to describe the research article. Section 2, is introduced for literature survey, Section 3 is for example experimentation with GNS3 with EIGRP in dual stack, whereas Section 4 concludes the document.

2. Literature review

Routing protocols such as RIP, OSPF, and EIGRP are integral to modern network infrastructure, enabling efficient, reliable, and scalable data transmission. RIP (Routing Information Protocol), introduced as one of the earliest distance-vector protocols, uses hop count as its primary metric, making it suitable for smaller and static networks but limiting its scalability and convergence speed [17]. In contrast, OSPF, a link-state protocol described comprehensively in RFC 2328 [19], builds a detailed map of the network topology. This approach enables precise path computation and rapid adaptation to network changes, making it well-suited for large, dynamic network environments [18]. EIGRP, a Cisco-proprietary hybrid protocol, combines the simplicity of distance-vector algorithms with advanced features of link-state protocols. It supports faster convergence, robust load balancing, and the handling of multiple network layer protocols, offering significant adaptability and efficiency in complex network scenarios. Additionally, EIGRP's Diffusing Update Algorithm (DUAL) ensures loop-free and reliable routing, further enhancing its utility in scalable infrastructures [21]. These protocols cater to distinct network requirements, with RIP serving simpler networks and OSPF and EIGRP excelling in dynamic, large-scale environments.

In [23], the research work evaluates the performance of EIGRP, OSPF, and BorderBGP in dynamic network environments. It highlights EIGRP's fast convergence, superior fail over mechanisms, and efficient load balancing using its hybrid nature. By leveraging GNS3 and Wireshark for simulations, the paper provides insights into the reliability and adaptability of EIGRP in scenarios involving fluctuating traffic and link failures, emphasizing its suitability for scalable cloud networks. In [24], GNS3 is used in designing and analyzing network architectures, particularly focusing on simulating complex routing protocols like EIGRP and OSPF. The paper demonstrates GNS3's ability to emulate real-world network behaviors, allowing researchers to evaluate convergence times, packet delays, and overall protocol performance under varying conditions. It highlights how the platform supports detailed experimentation without requiring extensive hardware infrastructure. In another research work, GNS3 is used to simulate network scenarios for comparing EIGRP and OSPF performance metrics, including convergence duration and failure recovery times. The research underscores GNS3’s flexibility and precision in simulating dynamic network changes and validating protocol efficiency in diverse setups [26].

In [26], The research paper discusses how routing algorithms, including EIGRP and OSPF, help optimize network performance in software-defined networking (SDN) environments, specifically focusing on minimizing delays and improving throughput for cloud applications. It emphasizes the role of routing protocols in ensuring efficient load balancing and network resource utilization. In another research paper [27], it explores how routing protocols such as EIGRP and OSPF enhance cloud network performance, particularly in managing resource allocation and reducing latency. It highlights how these protocols are integrated into virtualized cloud environments to ensure efficient data transmission and lower network delays [28]

Table 1. Comparative Study: EIGRP vs. OSPF in Cloud Computing Virtualization

Feature	**EIGRP (Enhanced Interior Gateway Routing Protocol)**	**OSPF (Open Shortest Path First)**
Protocol Type	Hybrid of Distance-Vector and Link-State	Link-State
Routing Algorithm	DUAL (Diffusing Update Algorithm)	Dijkstra’s Algorithm
Convergence Time	Faster due to precomputed backup routes	Slower but efficient with hierarchical design
Scalability	Suitable for medium-scale networks	Excellent for large, multi-area clouds
Configuration Complexity	Simple, optimized for Cisco environments	Complex, requires detailed area design
Interoperability	Limited to Cisco devices	Broad compatibility due to open standards
Traffic Engineering	Basic; limited path control	Advanced; supports MPLS and Quality of Service (QoS)
Load Balancing	Equal and unequal cost load balancing supported	Equal cost multi-path only
Resource Utilization	Low overhead, efficient bandwidth use	Higher resource use due to link-state ad-

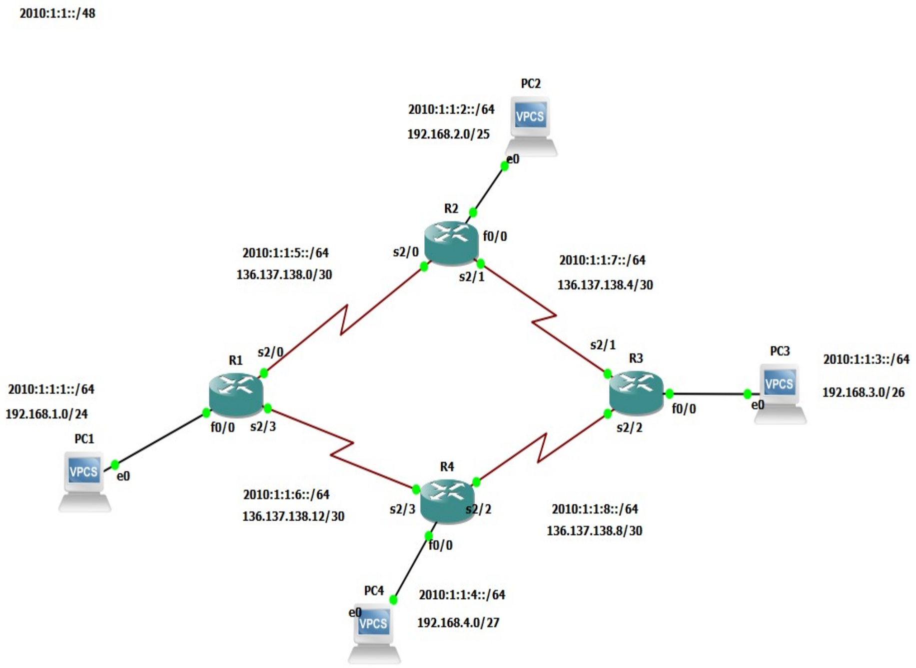
Feature	**EIGRP (Enhanced Interior Gateway Routing Protocol)**	**OSPF (Open Shortest Path First)**
		vertisements
Fault Recovery	Fast, thanks to precomputed feasible successors	Hierarchical fault isolation through area boundaries
IPv6 Support	Supported, but requires additional configuration	Natively supported and widely used in IPv6 networks
Cloud Use Cases	Private/hybrid cloud environments with Cisco hardware	Multi-tenant public clouds and heterogeneous networks

3. Analysis of Dynamic routing with Simulators

The transition from IPv4 to IPv6 has brought to light variations in the way that EIGRP determines metrics for path selection. While latency and bandwidth affect IPv4's path selection, they have different effects on IPv6. The IPv6 metric value remains unchanged when customizing EIGRP's composite metrics (load, reliability, and MTU). Moreover, it is usually not recommended to modify EIGRP's K values because this may cause router performance problems [1]. It was discovered that EIGRP outperformed OSPF and BGP in terms of throughput and convergence speed. Among the three, OSPF had the least amount of packet delay. The research indicates that although EIGRP exhibits faster convergence and throughput, OSPF might be a more appropriate choice for settings where the least amount of packet delay is crucial. [2]

3.1. Experimentation with GNS3

A route metric is a value used by routing protocols to determine the most efficient path for data to travel across a network. The metric is a numerical representation of the "cost" associated with a route, where lower values typically indicate more preferred routes. Different routing protocols calculate metrics based on various factors such as hop count, bandwidth, delay, reliability, and load. For example, RIP uses hop count as its metric, while EIGRP uses a composite metric that considers bandwidth, delay, load, and reliability. Metrics play a crucial role in route selection, helping routers decide the best path for forwarding packets and ensuring optimal network performance (Fig. 1). The figure depicts a network topology consisting of four routers (R1, R2, R3, R4) connected in a mesh fashion. Each router has multiple interfaces with IPv6 and IPv4 addresses configured, as shown by the unique IP addressing on each link. The network also includes four virtual PCs (PC1, PC2, PC3, and PC4) connected to the routers, each with a specific IP address range. The global prefix 2010:1:1::/48 is used for the experiment. The figure highlights connections between the routers via various serial and FastEthernet interfaces, with the focus on different IPv6 subnets between the routers and end devices. This topology could be used for simulating routing protocols like EIGRP or OSPF to analyze routing paths and network performance across the virtualized network environment.



Observation-1: The metric component value of EIGRP (Bandwidth and delay) in an IPV4-IPV6 dual stack network is explored. The evaluation shows how metric values for IPV4 as well as IPV6 in every hop count can be associated in networks.

Observation 2: The metric component of EIGRP (Only Bandwidth, no delay) in an internetwork with all possible routes are used (Load balancing) for a particular destination. Not the best route path is chosen only.

Table 2. presents a comparative study of the performance of EIGRP with IPv4 and IPv6 based on a simulated network environment using GNS3, as depicted in the provided topology. Key parameters such as convergence time, network utilization, and overall performance are compared for both IPv4 and Ipv6.

Table 2. Comparative study of performance of EIGRP with IPV4 and IPV6 using GNS3

Parameter	**EIGRP with IPv4**	**EIGRP with IPv6**
Convergence Time	Generally faster in IPv4 due to more mature support and optimizations. Typically, convergence occurs in seconds.	Slightly slower due to the added complexity of IPv6 headers and address calculations. However, the difference is minimal in smaller networks.
Resource Utilization	IPv4 uses less overhead compared to IPv6, as IPv6 addresses are larger and require more processing power.	Higher resource consumption due to the larger IPv6 address space and additional processing overhead for addressing.
Routing Table Size	IPv4 routing tables are smaller due to the shorter address size.	Larger routing tables are observed in IPv6 due to the 128-bit address size.
Scalability	EIGRP with IPv4 supports large networks but might face issues in extremely large-scale environments due to address limitations.	EIGRP with IPv6 is more scalable with the ability to support a much larger number of IP addresses, making it more suited for expanding networks.
Compatibility	IPv4 is widely supported, making it more compatible in mixed network environments.	IPv6 requires specific hardware and software configurations, but it is the future standard for new networks.
Protocol Overhead	IPv4 has smaller headers (20 bytes). EIGRP's protocol overhead is relatively lower for IPv4.	IPv6 has larger headers (40 bytes), resulting in increased overhead for EIGRP when compared to IPv4.
Ease of Configuration	IPv4 configuration is simpler and more widely understood, requiring fewer adjustments in devices.	IPv6 requires more complex configuration due to its larger address space and routing changes. However, GNS3 simplifies the configuration process.
Network Performance	IPv4 performs well in smaller, stable networks but faces bottlenecks in high-demand, high-traffic environments.	IPv6 can handle modern high-traffic, highly scalable cloud networks better, though performance difference is not significant for typical configurations.
Security	IPv4 can be secured with IPsec, but it is not always required.	IPv6 has mandatory IPsec support, improving security by default, which may enhance overall network security in sensitive

Parameter	EIGRP with IPv4	EIGRP with IPv6
		cloud environments.

While both IPv4 and IPv6 perform similarly in many aspects when using EIGRP as the routing protocol, IPv6 is better suited for modern, large-scale cloud and virtualized environments due to its larger address space and future-proof capabilities. However, IPv4 still provides a simpler, faster solution with lower resource consumption for smaller networks.

3.2. Common Simulators for Routing in virtualization Protocols

Simulators like Cisco Packet Tracer, GNS3, and EVE-NG provide virtual environments to configure and test routing protocols like EIGRP and OSPF. The basic features include (1) allow users to explore protocol behavior, (2) troubleshoot configurations, and (3) understand concepts such as convergence, neighbor formation, and route selection, (4) while Packet Tracer is beginner-friendly, GNS3 and EVE-NG support more advanced and real-world emulation scenarios, often using actual vendor images. The below mentioned simulators are popularly useful such as: (1) Cisco Packet Tracer**: b**est for beginner-level configuration (2) GNS3: Excellent for real-world emulation with actual IOS images, (3) EVE-NG (Emulated Virtual Environment-Next Generation): Perfect for complex lab setups involving multi-vendor scenarios, (4) Boson NetSim: Focused on certification preparation.

4. Conclusion and Future work

In this work, we have explored the crucial role of dynamic routing protocols EIGRP and OSPF in optimizing network routing in cloud virtualization frameworks. The analysis of key metrics such as bandwidth, delay, latency, and cost has highlighted their inter-dependencies and the significant impact they have on the selection of the best routing path. Through simulations conducted in GNS3, we examined dual-stack network configurations using both dual stack (IPv4 and IPv6), providing valuable insights into their performance. The findings indicate that EIGRP and OSPF, while offering distinct benefits, both play essential roles in cloud networking, where fast convergence, low latency, and efficient resource allocation are critical. The interaction between bandwidth and latency was observed to be particularly important, influencing overall network efficiency. The work emphasizes the need for intelligent path selection to enhance the performance of cloud applications and services, thereby contributing to the optimization of cloud network infrastructures. One promising direction is the incorporation of AI-driven algorithms and machine learning techniques to further optimize path metric evaluation and selection based on real-time network conditions. Additionally, expanding the simulations to include more complex cloud network architectures and multi-cloud environments could provide further insights into how different protocols adapt to large-scale, dynamic conditions. Moreover, further investigation into hybrid routing protocols that combine the strengths of both EIGRP and OSPF, or explore the integration of these protocols with emerging technologies such as Software-Defined Networking (SDN) and Network Function Virtualization (NFV), could open new doors for improving resource allocation, reducing network congestion, and enhancing overall cloud network performance. Future work could also explore the impact of emerging IPv6 features on routing performance, particularly in the context of cloud networks where scalability and address space are crucial. As cloud networks continue to evolve, understanding how routing protocols impact performance, security, and reliability will be vital. Continued qualitative and quantitative analysis, along with simulations and real-world testing, will help drive innovations that shape the future of cloud network optimization.

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