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A Comparative Performance Evaluation of EIGRP in a Mininet/FRRouting-Emulated Network and a Physical Cisco Network

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تقييم مقارن لأداء بروتوكول التوجيه *EIGRP* في شبكة محاكاة باستخدام *Mininet* وشبكة *Cisco*/*FRRouting* فعلية

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Abstract:
Enhanced Interior Gateway Routing Protocol (EIGRP) is typically deployed on dedicated hardware routers, whereas emulation platforms such as Mininet allow routing software to be tested in virtualized environments. In this context, this study investigates the performance of EIGRP in a Mininet/FRRouting emulated network and compares it with an equivalent physical network built with Cisco routers and switches, evaluating network stability and performance. Because FRR support one router per host in this setup, the emulated routers were distributed across four PCs and interconnected through GRE tunnels over a LAN. To achieve this objective, experiments were conducted using the Mininet-based emulation environment. Both networks used the same four-router ring topology and were evaluated under normal operating conditions and link-failure scenarios. The evaluation focused on several key performance metrics, including convergence time, round-trip time (RTT), and quality-of-service (QoS) metrics during RTP/MPEG-2 video streaming between end devices (packet loss, throughput, delay, and jitter). These metrics were used to assess the network's responsiveness to topology changes, data transmission efficiency, and ability to maintain service quality during network failures. The results showed that the emulated environment achieved a convergence time of 2-4 seconds compared with 5-8 seconds in the physical network when a query process was triggered. Furthermore, the emulated environment demonstrated a lower measured RTT of 1.0-1.2 ms, compared with 2.7 ms in the traditional network. During video streaming, the SDN-based environment exhibited a packet loss rate of less than 5%, compared with 35-45% in the physical network during failure, and achieved a throughput of up to 2.5 Mbps, compared with approximately 0.5 Mbps in the physical network. In addition, the emulated environment exhibited more stable delay and jitter performance during link failure. These differences may reflect variations in router implementation, hardware, and link capacity between the two testbeds; the results remain dependent on the experimental architecture and emulation condition and should not be taken as evidence of general superiority of either approach.

Keywords: EIGRP, Mininet, FRRouting, Convrgence time, QoS.

الملخص:
يتم إعداد بروتوكول EIGRP على موجهات مخصصة، بينما تتيح منصات المحاكاة مثل Mininet اختبار برمجيات التوجيه في بيئات افتراضية. تهدف هذه الدراسة إلى تحليل أداء بروتوكول التوجيه EIGRP عند استخدامه في شبكة محاكاة باستخدام Mininet/FFRouting ومقارنته بشبكة فعلية مماثلة مبنية بأجهوة Cisco, وتقييم استقرار الشبكة وكفاءتها. ونظرًا لأن FRR يدعم موجهًا واحدًا لكا جهاز في هذا الإعداد، وزعت موجهات المحاكاة على أربعة حواسيب وتم ربطها بأنفاق GRE عبر شبكة محلية LAN. ولتحقيق هذا الهدف أجريت تجارب باستخدام بيئة Mininet, واستخدمت الشبكتان طوبولجيا حلقية تتكون من أربعة موجهات، مع تقييم الأداء في ظل ظروف تشغيل اعتيادية وسيناريوهات تعطل الوصلات وشملت عملية التقييم مجموعة من مؤشرات الاداء الرئيسية، تمثلت في زمن التقارب (Convergence Time)، وزمن الذهاب والإياب (Round-Trip Time, RTT)، ومؤشرات جودة الخدمة (QoS) أثناء بث مقطع فيديو بترميز MPEG-2 عبر RTP (فقدان الحزم ومعدل النقل والتأخير والتذبذب) بين الأجهزة الطرفية. وتهدف هذه المؤشرات إلى تقييم سرعة استجابة الشبكة للتغيرات الطارئة وكفاءة نقل البيانات ومدى قدرتها في الحفاظ على جودة الخدمة عند حدوث الاعطال. اظهرت النتائج أن بيئة المحاكاة حققت زمن تقارب يتراوح بين 2-4 ثوانٍ، مقارنة بزمن 5-8 ثوانٍ في الشبكة الفعلية عند تفعيل عملية الاستعلام (Query Process). كما سجلت بيئة المحاكاة زمن ذهاب وإياب (RTT) مقاسًا اقل، تراوح بين 1.0 و1.2 مللي ثانية، مقارنة بنحو 2.7 مللي ثانية في الشبكة الفعلية. وأثناء بث الفيديو، أظهرت بيئة المحاكاة معدل فقدان للحزم أقل من 5%, مقارنة بنحو 35-45% في الشبكة الفعلية أثناء التحويل إلى مسار بديل عند تعطل الوصلة. كذلك حققت بيئة المحاكاة معدل نقل بيانات وصل إلى 2.5 ميجابت في الثانية، مقارنة بنحو 0.5 ميجابت في الثانية في الشبكة الفعلية. إضافة إلى ذلك، أظهرت بيئة المحاكاة استقرارا أفضل في أداء التأخير والتذبذب في التأخير (Jitter) أثناء تعطل الوصلات. وقد تعكس هذه الفروق اختلافات في تطبيق الموجه والعتاد وسعة الروابط بين البيئتين، ولا ينبغي اعتبارها دليلا على تفوق عام لأي من النهجين، إذ ترتبط النتائج ببنية البيئة التجريبية وظروف المحاكاة المستخدمة.

الكلمات المفتاحية: EIGRP, Mininet, FRRouting, QoS ، زمن التقارب.

Introduction:

In modern communication networks, one of the most critical challenges is determining the optimal path for data transmission (Gangopadhyay & Sarkar, 2024). An effective routing mechanism must guarantee full reachability to all potential destinations while dynamically maintaining backup paths to mitigate network failures caused by link disruptions or congestion. Traditionally, dynamic routing protocols like Enhanced Interior Gateway Routing Protocol (EIGRP) have played a pivotal role in maintaining network resilience and enabling fast failover through adaptive path selection (Shahid et al., 2024).

However, as network scale and dynamic traffic demands expand, traditional network architectures face significant constraints due to the tight coupling between the control plane and the data plane, which limits centralized management and rapid adaptability (Zoraida & Indumathi, 2024). To address these structural limitations, Software-Defined Networking (SDN) has emerged as a transformative paradigm that decouples the control plane from the data plane, enabling centralized, programmable control and more flexible traffic management across network devices (Bannour et al., 2018).

While EIGRP is widely deployed in traditional networks, comparing its operational performance, stability, and multimedia Quality of Service (QoS) in an emulate environment with its performance in a physical network is an important research question. Due to the high cost and complexity of building large-scale physical testbeds, emulation environments using Mininet paired with open-source routing suites like FRRouting (FRR) provide a realistic platform for advanced architecture evaluation (Mnyandu et al., 2025). Although Mininet is widely used as SDN emulation platform, it serves in this study only as a virtualized network environment: no SDN controller is used, and EIGRP remains a distributed routing protocol. Therefore, this paper investigates the performance of EIGRP in a Mininet/FRR emulated network and compares it with an equivalent physical network built with Cisco devices, evaluating key metrics, includeing convergence time, Round-Trip Time (RTT), throughput, packet loss, and jitter- under normal operating conditions and link-failure scenarios (Martinez et al., 2024).

Architecture and Topology:

To conduct this study the emulation environment over which the EIGRP routing protocol operates must first be defined. Due to the high cost and physical complexity associated with building and testing physical network infrastructures, emulation and virtualization data are typically relied upon to evaluate the performance of advanced routing protocols such as EIGRP. In this context, the virtual network is built using the renowned network emulator Mininet, which operates as a virtual host environment on a Linux operating system (such as the Ubuntu distribution) inside personal computers (PCs) (Bwalya & Zimba, 2021).

Mininet is commonly used for SDN experiments; here is it used only to create the virtual nodes and liks, and no SDN controller is involved Since the EIGRP (through open-source suites like FRRouting) requires running routing processes as independent daemon for each routing node, running multiple FRR routers within a single virtual instance was avoided to ensure accurate measurement of convergence time and resource consumption (Mnyandu et al., 2025).

To overcome these constraints, the virtual nodes for the EIGRP protocol were distributed across multiple physical computers and interconnected using Generic Routing Encapsulation (GRE) tunnels (Markova & Markov, 2026). This architecture allows the emulator to reproduce a complex network topology, supporting reliable and accurate emulation of the exchange of Hello messages and the route computations of the Dual algorithm inherent to EIGRP, as well as verifying its actual efficiency in managing data flows and multimedia QoS compared to physical network.

The proposed routing architecture relies on running the network protocol as an independent software process inside each virtual node performing the router's tasks, which enables the exchange of routing information between devices, similar to real networks. FRR was adopted to run EIGRP separately on each router node within the virtual topology, in order to measure performance efficiency and response speed. Because FRR runs routers as Linux-based hosts, each host is limited to a single router; the topology was split and each PC runs one router.

This distribution required establishing communication channels between the host systems running Mininet using GRE tunnels. Through these tunnels, the Mininet instance exchange data packet and EIGRP packets (Hello, Update, Query, and Reply) so that they operat as a single connected network (Tamgno et al., 2022). In addition, the interconnection the instances require virtual switches acting as network bridges to terminate the GRE tunnel ports, which carry the EIGRP route updates between nodes.

Figure (1) illustrates the proposed architecture, where each unit represents an independent physical computer in the emulate network. Each physical computer consists of three main software layers:

- The underlying operating system, such as Ubuntu.
- The network emulation layer, Mininet, which creates the virtual devices (Gupta et al., 2022).
- The routing services layer, where FRR, is executed inside each virtual router to manage the EIGRP protocol.

Furthermore, the figure shows how the physical computers communicate via GRE tunnels, allowing every data packet to be routed to the target router through these links. In addition, Mininet relies on python scripts to design the required topology, with each script defining the part of the network that runs on its assigned physical computer.

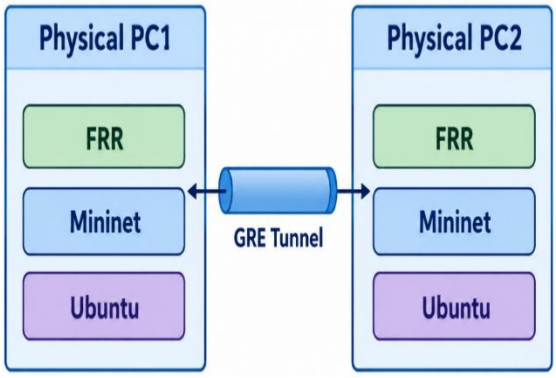


Figure (1): Architecture proposed for every PC and communication using GRE.

Topology Design:

To evaluate the efficiency and reliability of the EIGRP, the design required redundancy and alternative paths to the same destination. This necessitated a ring topology instead of simple linear structures, as illustrated in figure (2). This choice allows traffic to be rerouted through the alternate path when a link fails. Furthermore, to avoid traffic bottlenecks resulting from low-speed serial links between routers, data traffic was routed through central switches acting as virtual bridges. Four routers (R1 to R4), each on an independent PC (PC1 to PC4), were used, running FRR to support EIGRP. The routers separate the subnets, which range from 40.0.0.0/8 to 90.0.0.0/8. The transmitting host (40.0.0.2/8) is connected to R1, while the receiving host (70.0.0.2/8) is connected to R3 and acts as the end point of the data-flow test. Because the routers are partitioned across PC1 to PC4, the PCs are connected through a physical LAN, via a network interface card on each, to enable communication through GRE

tunnels. The addresses 192.168.0.1 to 192.168.0.4 are allocated exclusively to these physical interfaces.

Table (1): Network configuration and IP addressing scheme.

Description	IP address	Subnet	Physical PC	Node
Router1 Gateway	40.0.0.1	40.0.0.0/8	PC1	R1
Transmitting host	40.0.0.2	40.0.0.0/8	PC1	H1 (Sender)
Router3 Gateway	70.0.0.1	70.0.0.0/8	PC3	R3
Receiving host	70.0.0.2	70.0.0.0/8	PC3	H2 (Receiver)
Management and RGE interconnection	192.168.0.1 to 192.168.0.4	192.168.0.0/24	PC1 – PC4	Physical LAN

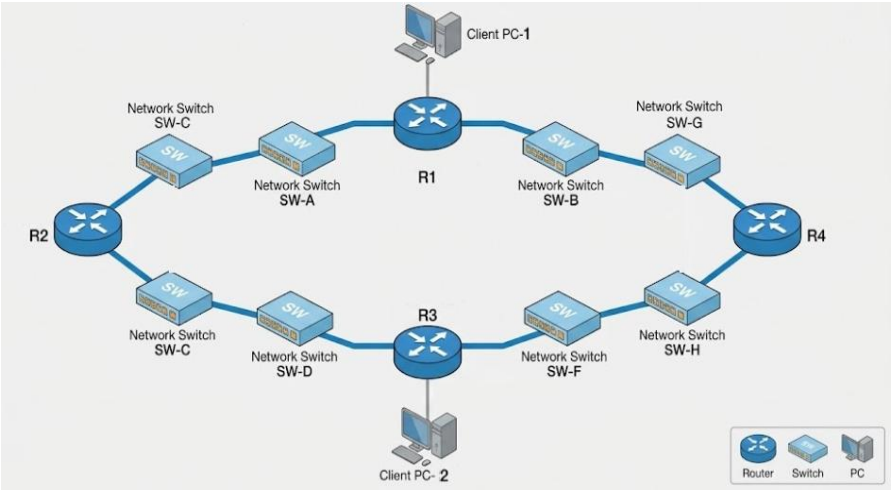


Figure (2): Proposed SDN ring topology testbed Architecture for EIGRP protocol Evaluation.

The same network topology was also deployed in a physical network using Cisco routers and switches for comparison. The two testbeds therefore differ not only in platform, as the emulated network requires four independent PCs to run EIGRP, but also in router software, hardware, and link capacity, as detailed in the experimental setup.

Test bench and results:

This section presents the experimental testbed setup, hardware/software specifications, and the comparative evaluation results between the physical network and the emulated Mininet/FRR network using EIGRP. The performance evaluation is conducted from two main perspectives:

1. **Network stability and Convergence:** Evaluated using Convergence Time (following a link failure) and Round-Trip Time (RTT).
2. **Multimedia Quality of Service (QoS):** Evaluated during an active RTP video stream by measuring throughput/consumed bandwidth, packet loss rate, delay, and jitter (Altonen et al., 2020) (Macias-Rivera et al., 2026).

The hardware and software specifications of both setups are detailed in table (2).

Table (2): Hardware and Software specifications.

Component/Parameter	Physical Network (Cisco)	Emulated Network (Mininet & FRR)
Routing protocols	EIGRP (configured on Cisco IOS)	EIGRP (configured via FRR daemon)
Routing and Switching devices	Cisco 2621XM, Routers and Cisco catalyst 3560 POE 24-port Switches	Emulated Linux Routers inside Mininet and Open vSwitch (OVS) virtual bridges
Host components	Dedicated physical lab hardware	PC1- PC4 (Intel Core i3-4160@3.60 GHz, 6 GB RAM
Operating system	Cisco IOS v12.x	Ubuntu Linux/Mininet Emulator
Inter-Node Interconnection	Physical Fast Ethernet Cables and serial Links	GRE Tunnels over a physical LAN
Video streaming tool	VLC Media player v2.2.4 (MPEG-2, RTP stream)	VLC Media player v2.2.4 (MPEG-2, RTP stream)

Convergence Time and RTT Tests:

In EIGRP, dynamic Route selection and recovery rely on the DUAL (Diffusing Update Algorithm), which maintains backup paths (known as Feasible successors, FS) in its topology table.

- **Convergence Time Analysis:** During the link-failure scenario (disconnecting the active path between subnets), the convergence time of each network was measured separately.
- **Physical network:** when a query process is triggered (Active State), convergence averages around 5 to 8 seconds.
- **Emulated network:** When a query process was triggered, the convergence time was around 2 to 4 seconds, despite the GRE tunnel overhead and daemon execution within Linux namespaces.
- **Round Trip Time (RTT):**
- **Physical network:** RTT was ~2.7 ms, which may be attributed to packet processing in the older Cisco routers and the physical interfaces.
- **Emulated network:** RTT was ~1.0-1.2 ms, which may be attributed to the software-emulated links and virtual bridges introducing negligible propagation delay compared to physical interfaces.
- **Multimedia Quality of Service (QoS) test:** To measure QoS under real-time conditions, an MPEG-2 video stream (1280x720 resolution) is transmitted via RTP (Real-Time Transport Protocol) using VLC Media player from H1 (40.0.0.2) to H2 (70.0.0.2).
- **Packet Loss Rate:**
- **Physical network:** a packet loss of ~35٪ to 45٪ was recording during failover.
- **Emulated network:** a packet loss rate below <5% was recorded, resulting in smother video playback at the receiver.
- **Consumed Bandwidth and Throughput:**
- **Physical network:** bandwidth remained at around 0.5 Mbps, which may be due to hardware memory constraints, interface buffer limitations and link speed on the older routers, and was accompanied by video distortion during packet drops.
- **Emulated network:** throughput reached up to 2.5 Mbps, accommodating high-bitrate video bursts without buffer starvation.
- **delay and Jitter:**
- **Delay:** the emulated network showed a lower and more predictable transmission delay overall. Spikes in delay on the physical network correspond directly to packet-loss bursts during link transitions.
- **Jitter:** While both networks maintained similar baseline jitter values (~15 – 30ms) during normal operation, the physical network experienced severe jitter spikes (>150ms) during link degradation, whereas the emulated network peaked at only ~35 ms, maintaining more consistent video quality.

Table (3): Summary of measured results for the physical and emulated networks.

Metric	Physical network	Emulated network	Notes
Convrgence time, query process (s)	5-8	2-4	Active state
RTT (ms)	~2.7	~1.0-1.2	Normal operation
Packet loss (%)	35-45	<5	During failover
Throughput (Mbps)	~0.5	Up to 2.5	RTP/MPEG-2 stream
Baseline jitter (ms)	~15-30 (similar in both network)	~15-30 (similar in both network)	Normal operation
Peak jitter (ms)	>150	~35	Link failure

Discussion:

The results of this study present a comparison between the behavior and performance of the EIGRP routing protocol in a physical network versus an emulated network based on Mininet and FRR. The findings indicate that the physical network experienced a slower convergence time (5 to 8 seconds) compared to the emulated network (2 to 4 seconds) despite the GRE tunnel overhead and Linux namespace execution, in the latter. This difference may be related to differences in router implementation, EIGRP timers, and link characteristics between the two testbeds. The emulated network also recorded a lower RTT, around 1.1 ms compared with 2.7 ms, which may be attributed to the absence of physical interface and router processing delays.

Furthermore, when evaluating multimedia Quality of Service (QoS) during link failures and MPEG-2 video streaming, the emulated network showed more stable behavior. It recorded a lower packet loss (under 5% compared with 35%-45%), a higher throughput (2.5 Mbps compared with 0.5 Mbps), and a lower peak jitter (~35 ms compared with spikes exceeding 150 ms in the physical network).

Consequently, in the evaluated setup, the emulated network showed shorter recovery times and better streaming performance than the physical network.

However, since the two testbeds differ in router implementation, hardware, and link capacity, these results should not be generalized to SDN or physical networks in general. To provide a consolidated overview of these findings, Figure (3) presents a performance comparison between the physical and the emulated network.

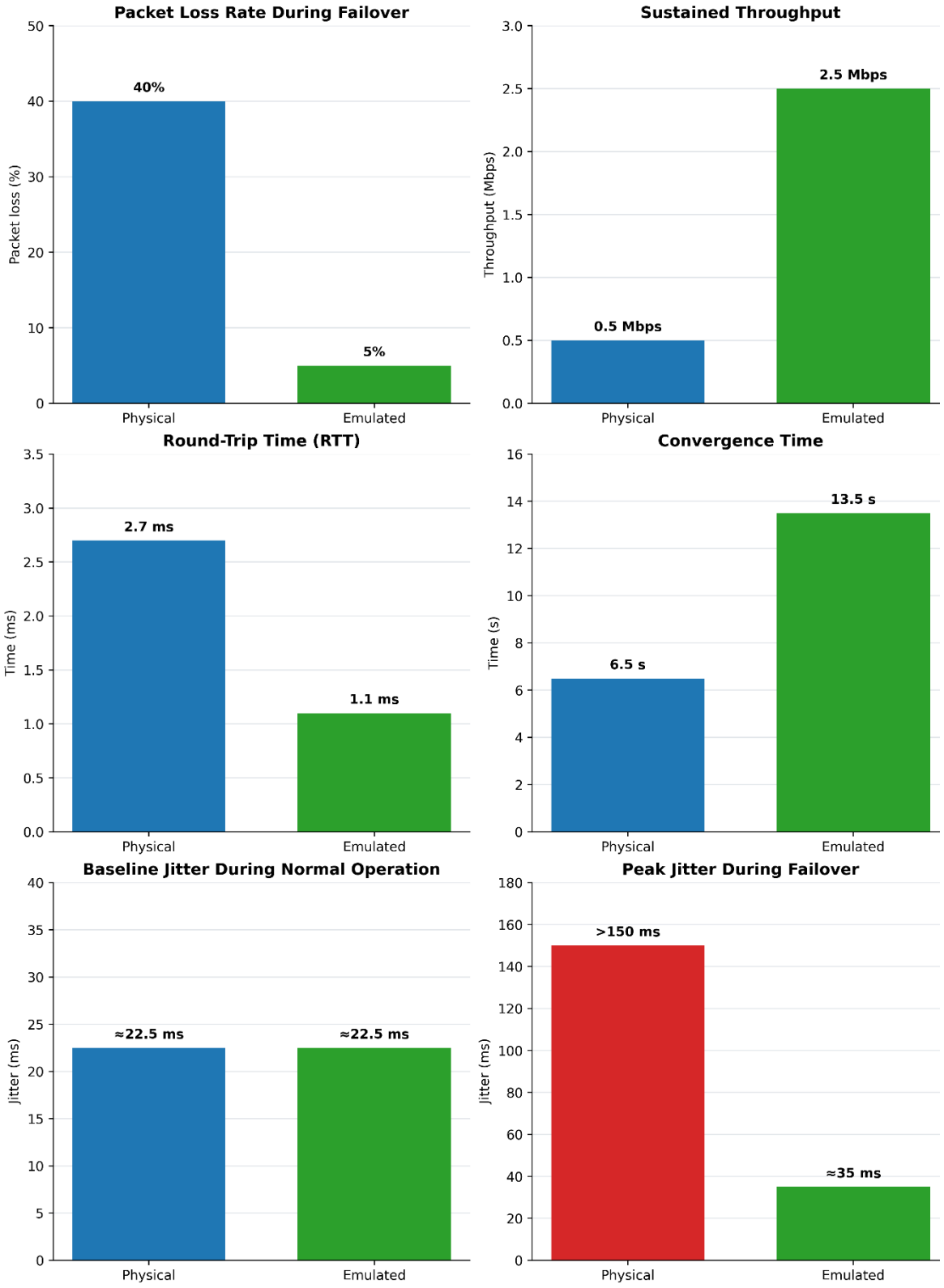


Figure (3): Performance Comparison, Physical vs. Emulated network (EIGRP).

Conclusion:

This study conducted a performance evaluation EIGRP in a Mininet/FRR emulated network compared with an equivalent physical Cisco network. In the evaluated setup, the emulated network recorded a faster convergence time (2-4 seconds compared with 5-8 seconds) despite GRE tunneling overhead and process isolation in Linux namespaces, and showed advantages in data transmission efficiency and QoS. Specificalyy, it recorded a lower RTT (about 1.1 ms compared with 2.7 ms) and packet loss rate (under 5% compared with 35%-45%), and higher throughput (2.5 Mbps compared with 0.5 Mbps) during active video streaming. Moreover, it maintained a lower peak jitter (~35 ms) during link failures. These differences may reflect differences in router implementation, hardware, and link capacity between the two testbeds, and should therefore not be generalized. The results also indicate that performance figures obtained in emulation may differ considerably from those of physical networks, so emulated results should be validated on physical equipment. Future work may repeat the scenarios with equalized link speeds and timers across both testbeds, and evaluate EIGRP alongside an SDN controller.

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