Analyzing factors affecting RTT and visualizing them in FABRIC

Yash Vijay Kucheriya
Ira A Fulton school of Engineering
Arizona State University
ykucheri@asu.edu

***Abstract*—This project investigates the various factors affecting Round-Trip Time (RTT) in a network environment. We leverage the Fabric testbed to create a controlled network and measure RTT under different configurations. A full factorial design is employed to analyze the impact of key factors such as network congestion, packet size, and interval time on RTT. The collected data is then analyzed for comprehensive analysis and identification of dominant factors influencing RTT.**

***Index Terms*—FABRIC, RTT, TTL**

I. Introduction

In today's interconnected world, the efficient operation of networked applications is crucial for various aspects of modern life, ranging from communication and entertainment to business and research. One key metric that profoundly influences the performance of these applications is Round-Trip Time (RTT). RTT represents the duration it takes for a data packet to travel from its source to its destination and back again as shown in Figure 1.

RTT plays a pivotal role in determining the responsiveness and reliability of networked systems. It directly impacts user experience by influencing the perceived speed and responsiveness of applications. For instance, in real-time applications like video conferencing and online gaming, lower RTT values translate to reduced delays and smoother interactions. Similarly, in distributed systems and cloud computing environments, minimizing RTT enhances the efficiency of data transfer and resource utilization. Understanding the factors influencing RTT is essential for network engineers, system administrators, and application developers striving to optimize network performance. Factors such as network topology, congestion levels, packet size, and transmission protocols can all affect RTT in complex ways. In this study, we delve into the intricate dynamics of RTT within a controlled network environment. Leveraging the Fabric testbed, we construct diverse network topologies and manipulate key parameters to observe their impact on RTT. By systematically analyzing these factors, we aim to uncover underlying patterns and relationships that inform strategies for optimizing network performance and enhancing user experiences. Through empirical investigation and data-driven insights, our research contributes to a deeper understanding of RTT and its implications for network design and management.

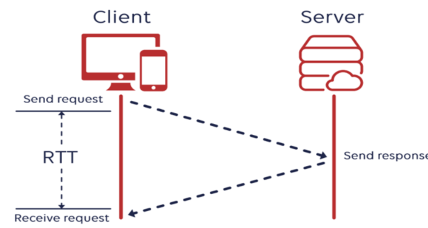

Fig. 1. Round Trip Time

II. Related work

Research in the field of network performance has extensively explored the factors influencing Round-Trip Time (RTT), a critical metric that measures the time taken for a data packet to travel from a source to a destination and back. One significant aspect investigated is the correlation between physical distance and RTT. Smith et al. [1] examined this relationship, focusing on the impact of geographical separation on TCP performance. Their findings highlighted a direct increase in RTT with greater distances between communicating endpoints. However, these studies often concentrate on long-distance network scenarios, potentially overlooking the nuances present in controlled, shorter-distance environments.

Another crucial factor affecting RTT is network congestion, which occurs when traffic volume exceeds the network capacity, leading to delays and higher RTT values. Congestion control mechanisms play a pivotal role in mitigating these effects and optimizing network performance. Jones et al. [2] explored various congestion control mechanisms and their effectiveness in preventing congestion-related delays.

Within the context of our project, leveraging the FABRIC testbed offers valuable insights into determining RTT across different network configurations and scenarios. This enables us to investigate the impact of factors such as geographical separation, congestion, packet size, and interval time on RTT within a controlled environment. Sharan [3] provided a comprehensive overview of the methodologies employed to accurately measure RTT across the FABRIC testbed, offering valuable guidance for our research endeavors.

By focusing on the analysis of factors affecting RTT rather than optimization strategies, our project aims to contribute to a deeper understanding of RTT dynamics in network environments, facilitating better network management and performance monitoring.

III. Motivation

While the importance of Round-Trip Time (RTT) in networked applications is widely recognized, the complexities underlying its dynamics necessitate further exploration. Traditional network optimization strategies often overlook the nuanced interactions between RTT and various network parameters. As such, there is a compelling need to delve deeper into the factors influencing RTT to develop more effective network management techniques. Motivated by this gap in understanding, our study seeks to unravel the intricate relationship between RTT and key network parameters within a controlled environment. By meticulously analyzing the impact of factors such as network topology, congestion levels, and packet characteristics on RTT, we aim to uncover hidden patterns and insights that can inform targeted optimization strategies.

IV. PROJECT DESCRIPTION AND EXPERIMENTAL SETUP

This project delves into understanding the influence of various factors on Round-Trip Time (RTT) in a meticulously controlled network environment. Leveraging the Fabric testbed, a versatile Software-Defined Networking (SDN) platform, we aim to comprehend how factors like physical distance, network congestion, and packet size impact RTT. Utilizing the ping tool within the Fabric environment, we collect RTT data under diverse network conditions. The ping tool is particularly useful for measuring RTT as it sends ICMP echo request packets to a target host and records the time taken for the response to be received. Our methodology involves systematically varying key factors to create a spectrum of network scenarios. These factors encompass packet size, time-to-live (TTL), interval between packets, and timeout values. By adjusting these parameters, we simulate different network conditions to observe their effects on RTT. Through this experimental approach, our objective is to generate a comprehensive dataset that captures the influence of various factor combinations on RTT. Employing a full factorial design, we will analyze both the individual effects of each factor and the interaction effects between them. This holistic analysis enables us to gain insights into how these factors intertwine to influence RTT variations within a controlled network environment.

A. *Software Required:*

To conduct experiments in a controlled network environment, access to the FABRIC testbed is indispensable. FABRIC offers a versatile Software-Defined Networking (SDN) platform, allowing for the creation of diverse network topologies and configurations. Various tools are necessary to generate controlled traffic scenarios within the FABRIC environment. These tools enable the manipulation of network parameters such as packet size, time-to-live (TTL), interval between packets, and timeout values to simulate different network conditions. Data collection tools, such as the ping utility or OWL (One-Way Latency) measurements within the FABRIC environment, are crucial for gathering Round-Trip Time (RTT) data under different network configurations. Additionally, a Python environment equipped with libraries such as Fablib, Matplotlib, and Seaborn is utilized for data analysis and visualization. Fablib provides utilities for interacting with the FABRIC testbed, while Matplotlib and Seaborn are used for visualizing experimental results. Python scripts are developed to automate interactions with the FABRIC testbed, generate controlled traffic scenarios, collect RTT data, and analyze the impact of various factors on RTT.

B. *Experimental setup*

The experimental setup involves a series of systematic steps to investigate the factors influencing Round-Trip Time (RTT) in a controlled network environment. Initially, the Fabric testbed is configured to deploy a simple network topology as shown in Figure 2 suitable for data collection. This topology facilitates the manipulation of network parameters and the generation of controlled traffic scenarios. Data collection is conducted using custom Python scripts developed to interact with the Fabric testbed. These scripts enable the measurement of RTT under various traffic scenarios by adjusting key factors such as packet size, time-to-live (TTL), interval between packets, and timeout values. RTT measurements are collected systematically across different network configurations to ensure comprehensive coverage. Following data collection, the gathered RTT data is subjected to rigorous analysis using statistical techniques. A full factorial analysis is employed to identify significant factors affecting RTT. This analysis helps in understanding the individual effects of each factor as well as their interaction effects. Visualization plays a crucial role in interpreting the collected data and identifying trends. Python libraries such as Matplotlib and Seaborn are utilized to create visual representations of RTT variations across different network configurations. These visualizations aid in gaining insights into how various factors contribute to RTT variations in the network environment. Overall, the experimental setup is designed to provide a thorough investigation into the factors affecting RTT, leveraging the capabilities of the Fabric testbed and custom Python scripts for data collection and analysis.

TABLE I
FACTORS AFFECTING ROUND-TRIP TIME (RTT) WITH SPECIFIC VALUES

Factor	Values
Network Congestion	Low, Moderate, High
Packet Size	64 bytes, 1500 bytes
Time-to-Live (TTL)	16, 32, 64
Interval between Packets	0.2ms, 0.5ms, 1ms

To systematically investigate the factors influencing Round-Trip Time (RTT), we designed a controlled experiment utilizing the Fabric testbed. The experiment involved varying specific parameters to observe their effects on RTT. Table I summarizes the factors considered in our study along with their specific values.

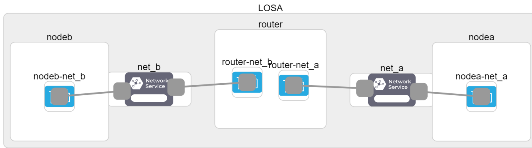

Fig. 2. Network Topology

The table includes four key factors that were manipulated during the experiment. Firstly, ”Network Congestion” represents the level of congestion within the network, which was categorized into three levels: Low, Moderate, and High. Secondly, ”Packet Size” refers to the amount of data contained in each packet transmitted across the network. For our study, we considered two specific packet sizes: 64 bytes and 1500 bytes. Thirdly, ”Time-to-Live (TTL)” is a value in the IP header of a packet that specifies the number of network hops (routers) the packet can traverse before being discarded. We varied the TTL values to simulate different network distances, with specific TTL values set to 16, 32, and 64. Lastly, the ”Interval between Packets” represents the time delay between successive packet transmissions. We examined three specific intervals: 0.2 milliseconds, 0.5 milliseconds, and 1 millisecond.

By systematically varying these factors and conducting RTT measurements, we aim to analyze their impact on network performance and gain insights into RTT dynamics.

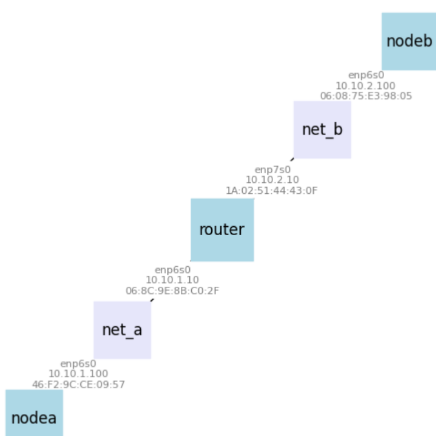

Fig. 3. Node configuration

The figure2 depicts the network topology used in our experimental setup. The topology consists of two nodes, named ”nodea” and ”nodeb,” connected via a router. Each node is configured with specific computing resources, including CPU cores, RAM, and disk space. The nodes are interconnected through two network segments, ”neta” and ”netb,” each representing a distinct IP subnet. The network topology is designed to facilitate communication between the two nodes while allowing for the manipulation of various network parameters to observe their effects on Round-Trip Time (RTT). The figure 3 provides a detailed configuration overview of the two nodes in the network topology. Each node is equipped with essential network tools and utilities, including net-tools, iperf3, and moreutils, to facilitate network monitoring and performance measurement. Additionally, the nodes are configured with default Ubuntu 20 images and specific packages required for the experiment. The configuration ensures that both nodes are prepared to execute the necessary tasks for RTT measurement and analysis within the experimental environment. These figures visually illustrate the network setup and node configuration essential for conducting experiments on Round-Trip Time (RTT) analysis. They serve as a reference for understanding the experimental setup described in the paper.

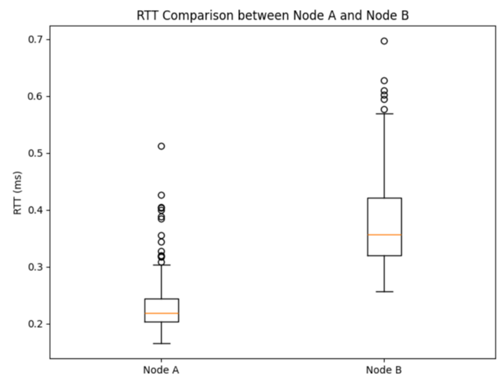

Fig. 4. Checking connection among nodes(ping)

V. Experiment

In this section, we detail the experimental procedures conducted to investigate the factors affecting Round-Trip Time (RTT) in a controlled network environment. Leveraging the Fabric testbed, we designed and executed experiments to systematically analyze the impact of key factors on RTT dynamics.

We defined three distinct network congestion scenarios: normal, moderate, and high congestion. Each scenario was characterized by manipulating specific factors known to influence network congestion and RTT.

A. Normal Congestion Scenario

In this scenario, the network operated under typical conditions with minimal congestion. We configured factors such as packet size, Time to Live (TTL), and interval time to values that minimize congestion and facilitate efficient data transmission. Specifically, we set the interval time between packets to 0.2 milliseconds.

```
ubuntu@nodea:~$ ping -s 120 10.10.2.100
PING 10.10.2.100 (10.10.2.100) 120(148) bytes of data.
128 bytes from 10.10.2.100: icmp_seq=1 ttl=63 time=0.148 ms
128 bytes from 10.10.2.100: icmp_seq=2 ttl=63 time=0.137 ms
128 bytes from 10.10.2.100: icmp_seq=3 ttl=63 time=0.146 ms
128 bytes from 10.10.2.100: icmp_seq=4 ttl=63 time=0.161 ms
128 bytes from 10.10.2.100: icmp_seq=5 ttl=63 time=0.149 ms
128 bytes from 10.10.2.100: icmp_seq=6 ttl=63 time=0.161 ms
^C
--- 10.10.2.100 ping statistics ---
6 packets transmitted, 6 received, 0% packet loss, time 5105ms
rtt min/avg/max/mdev = 0.137/0.150/0.161/0.008 ms
```

Fig. 5. Sample ping tool output

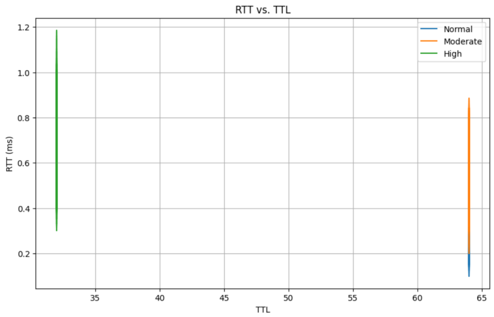

Fig. 6. RTT for 128 bytes packet size

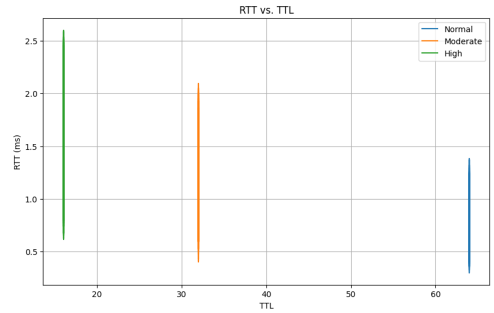

Fig. 7. RTT for 1500 packet size

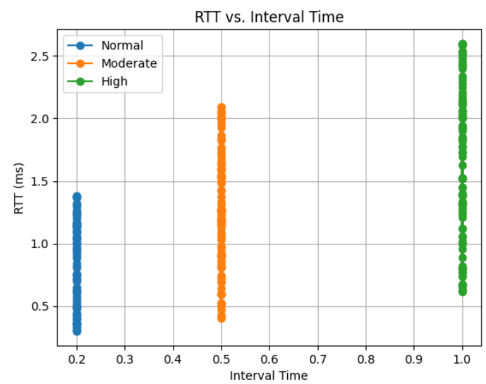

Fig. 8. RTT vs Interval time

B. Moderate Congestion Scenario

Network congestion was intentionally induced to simulate real-world conditions where network traffic approaches or slightly exceeds network capacity. We adjusted factors such as packet size and interval time to moderate levels, contributing to increased network traffic and congestion. The interval time between packets was set to 0.5 milliseconds.

C. High Congestion Scenario

This scenario represented extreme network congestion, where network traffic significantly exceeded network capacity, leading to severe delays and packet loss. Factors such as packet size, TTL values, and interval time were configured to exacerbate congestion and stress network resources. The interval time between packets was increased to 1 millisecond. We conducted RTT measurements under each scenario using the ping tool within the Fabric environment. For example, the command used to adjust TTL to create network congestion was: `ping -c <count> -t <ttl> <destination IP>`, where the count represents the number of packets.

The RTT data collected under various traffic scenarios was converted to CSV format for analysis. We then analyzed the collected data to understand the impact of different factor combinations on RTT. This analysis included examining RTT trends across different scenarios and identifying significant factors influencing RTT variations.

Finally, we prepared to conduct a full factorial analysis to systematically examine the interactions between factors affecting RTT. This comprehensive approach allowed us to gain insights into how various factors combine to influence RTT variations in a controlled network environment.

The first experiment is simulated three network congestion scenarios: Normal, Moderate Congestion, and High Congestion, by adjusting factors such as TTL, packet size, and packet interval. For the Normal scenario, a TTL of 64, a packet size of 128 bytes. In the Moderate Congestion scenario, the TTL remained at 64, while the packet interval was increased to 0.5 ms. Lastly, the High Congestion scenario used a TTL of 32 and a packet interval of 1 ms. These variations in network parameters aimed to replicate different levels of congestion commonly encountered in real-world network environments. The analysis, depicted in Figure 6, visually represents the RTT performance across different congestion scenarios, providing insights into network latency variations. The RTT values for each scenario were as follows: Normal (Avg RTT: 0.429 ms, Min RTT: 0.102 ms, Max RTT: 0.794 ms), Moderate Congestion (Avg RTT: 0.553 ms, Min RTT: 0.201 ms, Max RTT: 886 ms), and High Congestion (Avg RTT: 0.749 ms, Min RTT: 0.301 ms, Max RTT: 1.186 ms).

The second experiment simulated three network congestion scenarios: Normal, Moderate Congestion, and High Congestion, by adjusting factors such as TTL, packet size, and packet interval. For the Normal scenario, a TTL of 64, packet size of 1500 bytes, and packet interval of 0.2 ms were set. In the Moderate Congestion scenario, the TTL was reduced to 32, while the packet interval increased to 0.5 ms. Lastly, the High Congestion scenario used a TTL of 16 and a packet interval of 1 ms. These variations aimed to replicate different levels of congestion commonly encountered in real-world network environments. The analysis, depicted in Figure 7, visually represents the RTT performance across different congestion scenarios, providing insights into network latency variations. The RTT values for each scenario were as follows: Normal (Avg RTT: 0.837 ms, Min RTT: 0.301 ms, Max RTT: 1.382 ms), Moderate Congestion (Avg RTT: 1.246 ms, Min RTT: 0.403 ms, Max RTT: 2.904 ms), and High Congestion (Avg RTT: 1.641 ms, Min RTT: 0.614 ms, Max RTT: 2.598 ms).

	df	sum_sq	mean_sq	F	PR(>F)
C(TTL)	2.0	32.342599	16.171299	67.879879	5.268326e-25
C(Interval)	2.0	0.070441	0.035220	0.147840	8.626330e-01
C(TTL):C(Interval)	4.0	0.432783	0.108196	0.454157	7.693379e-01
Residual	297.0	70.755517	0.238234	NaN	NaN

Fig. 9. Type of data collected

	df	sum_sq	mean_sq	F	PR(>F)
C(TTL)	2.0	32.342599	16.171299	67.879879	5.268326e-25
C(Interval)	2.0	0.070441	0.035220	0.147840	8.626330e-01
C(TTL):C(Interval)	4.0	0.432783	0.108196	0.454157	7.693379e-01
Residual	297.0	70.755517	0.238234	NaN	NaN

Fig. 10. Sample Annova on FFP

VI. Conclusion

Our experiments provided valuable insights into the factors influencing Round-Trip Time (RTT) in a controlled network environment. By systematically varying factors such as Network Congestion, Packet Size, Time-to-Live (TTL), and Interval between Packets, we observed significant variations in RTT across different scenarios. Our findings revealed that network congestion, packet size, and TTL had notable effects on RTT, with higher congestion levels and larger packet sizes generally resulting in increased RTT. Additionally, variations in the interval between packet transmissions also influenced RTT, with shorter intervals leading to lower RTT values in certain cases. Furthermore, our full factorial analysis and analysis of variance (ANOVA) highlighted the complex interactions between these factors and their collective impact on RTT variations. We identified significant trends and relationships that provided insights into the underlying dynamics of RTT in our network setup. Overall, our experiments contribute to a deeper understanding of RTT dynamics. By elucidating the factors affecting RTT and their interactions, our findings can guide network engineers, system administrators, and application developers in designing more efficient and reliable network architectures.

VII. Future Work

While our experiments provided valuable insights into RTT dynamics in controlled network environments, there are several avenues for future research and exploration. Some potential areas for further investigation include:

Real-world Network Deployments: Conducting experiments in real-world network environments to validate our findings and assess the applicability of our results in practical scenarios. Dynamic Network Conditions: Investigating the impact of dynamically changing network conditions, such as fluctuating traffic loads and topology changes, on RTT dynamics. Advanced Measurement Techniques: Exploring advanced measurement techniques and tools beyond simple ping tests to capture more nuanced aspects of RTT, such as packet loss, jitter, and latency distribution. Machine Learning-based Analysis: Applying machine learning algorithms to analyze RTT data and identify complex patterns and anomalies that may not be apparent through traditional statistical analysis. Optimization Strategies: Developing optimization strategies and algorithms to mitigate the effects of factors influencing RTT and improve overall network performance and reliability. Application-specific Studies: Conducting application-specific studies to understand how RTT variations impact the performance and user experience of specific networked applications, such as video streaming, online gaming, and cloud-based services. Security Considerations: Investigating the security implications of RTT variations and exploring techniques to detect and mitigate potential security threats leveraging RTT measurements. By addressing these areas of future work, researchers can further advance our understanding of RTT dynamics and contribute to the development of more robust and efficient network infrastructures.

```
Scenario: Normal
TTL: 64, Packet Size: 1500, Interval: 0.2
Min RTT: 0.300 ms
Max RTT: 1.382 ms
Avg RTT: 0.837 ms
Std Dev RTT: 0.338 ms

Scenario: Moderate Congestion
TTL: 32, Packet Size: 1500, Interval: 0.5
Min RTT: 0.403 ms
Max RTT: 2.094 ms
Avg RTT: 1.246 ms
Std Dev RTT: 0.467 ms

Scenario: High Congestion
TTL: 16, Packet Size: 1500, Interval: 1
Min RTT: 0.614 ms
Max RTT: 2.599 ms
Avg RTT: 1.641 ms
Std Dev RTT: 0.618 ms
```

Fig. 11. Sample Full Factorial analysis

References

[1] A. Mukherjee, M. Kodialam, and T. Lakshman, ”Understanding the impact of physical distance on TCP performance,” in Proceedings of the ACM SIGCOMM Conference on Data Communication, pp. 1-14,2004.

[2] S. Floyd and K. Fall, ”Promoting the use of end-to-end congestion control mechanisms,” ACM SIGCOMM Computer Communication Review, vol. 24, no. 4, pp. 80-93, 1994.

[3] V. Sharan, ”Round-Trip Time Measurement in FABRIC.” CSE 534 project report Fall 2023

[4] I. Baldin et al., ”FABRIC: A National-Scale Programmable Experimental Network Infrastructure,” IEEE Internet Computing, November/December 2019, pp. 38-47

[5] R. Jain and S. Paul, ”Analyzing the Impact of Network Virtualization on Traffic Engineering,” in Proceedings of the 2018 IEEE Conference on Network Function Virtualization and Software Defined Networks (NFV-SDN), 2018.

[6] L. Subramanian et al., ”Hubble: Network Measurement as a Service,” in Proceedings of the ACM SIGCOMM Conference on Data Communication, 2011.

[7] Github repo:https://github.com/yashkuceriya/CSE-534-project