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INVESTIGATION AND MITIGATION OF NETWORK CONGESTION ISSUES USING TRAFFIC ENGINEERING TECHNIQUES.

BY

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APPROVAL FORM.

The undersigned hereby attests to having overseen the dissertation, entitled Investigation and Mitigation of network congestion issues using traffic engineering techniques,which the student Able J.M. Charamba submitted as partial fulfilment of the requirements for the Bindura University of Science Education's Bachelor of Computer Science Honours Degree.

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External examiner Date

DEDICATION.

I dedicate this project to my mother, Mrs. Vaidah Charamba, as well as my older brother and younger sister. Their constant prayers, encouragement, and love have been invaluable in supporting my education and intellectual growth over the years.

ACKNOWLEDGEMENTS.

First and foremost, I would like to express my deepest gratitude to the Almighty God for bestowing upon me the gift of life and the strength to complete this journey.

My sincere gratitude is extended to my family, in particular to my mother, older brother, and younger sister, for their unfailing love and support during this difficult endeavour.Your support and faith in me have always been source of inspiration for me.

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ABSTRACT.

Network congestion is a pervasive challenge in modern communication systems, impacting performance, reliability, and user satisfaction. In this research project, we delve into the intricacies of network congestion, examining its causes, effects, and potential solutions. Our investigation focuses on leveraging traffic engineering techniques to alleviate congestion and enhance network efficiency.The researcher explore dynamic routing algorithms, quality of service (QoS) mechanisms, and resource allocation strategies. By optimizing traffic flows, identifying bottlenecks, and dynamically adjusting network paths, we aim to mitigate congestion-induced delays and ensure seamless communication. Our findings contribute to the development of robust and responsive networks, fostering a more connected and efficient digital world.

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CHAPTER 1

PROBLEM IDENTIFICATION

1.0 INTRODUCTION.

The purpose of this project is to investigate and mitigate network congestion issues through the application of traffic engineering techniques. Network congestion is a critical problem that affects the performance and reliability of modern computer networks (Low, 2017). With the exponential growth of data traffic and the increasing demand for real-time applications, networks are under constant strain to deliver seamless connectivity and optimal performance. Congestion can lead to increased latency, packet loss, and diminished overall network efficiency (Nketsiah et al., 2023).

In today's interconnected world, network congestion has emerged as a significant challenge for organizations and service providers alike. Recognizing the criticality of addressing network congestion, this project aims to investigate and mitigate network congestion issues using advanced Traffic Engineering (TE) techniques (Wolshon et al., 2016). By employing proactive measures, this project seeks to enhance network efficiency, improve user experience, and ensure the smooth operation of network infrastructures.

The primary objective of this project is to analyse and understand the underlying causes of network congestion. This investigation will involve thorough monitoring and data analysis of network traffic patterns, identifying bottlenecks, and pinpointing areas of congestion within the network infrastructure (Kumar et al., 2018). By gaining insights into the congestion triggers, we can develop targeted strategies to alleviate the problem effectively. To mitigate network congestion, this project proposes the implementation of sophisticated Traffic Engineering techniques. Traffic Engineering involves the optimization of network resources and the intelligent management of traffic flows to efficiently utilize the available bandwidth (Callegati et al., 2021).

By carefully configuring routing protocols, traffic shaping mechanisms, and Quality of Service (QoS) policies, we can control and direct network traffic to alleviate congestion hotspots and

ensure the equitable utilization of network resources (Eckert & Bryant, 2021). Furthermore, this project aims to explore emerging technologies and innovative solutions that can effectively tackle network congestion. This includes the adoption of Software-Defined Networking (SDN) (Peterson et al., 2024) and Network Function Virtualization (NFV) paradigms (Chiosi et al., 2012), which offer dynamic traffic management, flexible resource allocation, and automated network provisioning. By harnessing the power of these cutting-edge technologies, we can enable more agile and adaptive networks that can quickly respond to changing traffic demands and mitigate congestion proactively.

1.1 BACKGROUND OF STUDY.

Network congestion has become a pressing concern in the field of networking due to the rapid growth of data traffic and the growing need for fast internet reliable connectivity. (Tanenbaum,2003) defined network congestion as the process that happens when the network's capacity is exceeded by the amount of packets fed into it. causing packets to be delayed, lost, or discarded. The detrimental effects of congestion can have severe consequences for various sectors, including telecommunications, cloud computing, and Internet service providers.

To address the challenges posed by network congestion, researchers and industry professionals have explored various methods and approoaches. One prominent approach is Traffic Engineering (TE), which involves the optimization and management of network traffic to mitigate congestion and improve overall network performance. TE techniques encompass a range of methods such as traffic shaping, routing optimization, admission control, and Quality of Service (QoS) provisioning.

According to (Rothenberg, 2013), TE techniques encompass a range of methods such as traffic shaping, routing optimization, admission control, and QoS provisioning. The author provides an in-depth understanding of the principles and techniques of Traffic Engineering in IP networks. The authors present various TE strategies and algorithms, along with practical examples and case studies. In addition to that, Traffic Engineering using Multiprotocol Label Switching (MPLS) and provide insights into MPLS-based TE mechanisms, including traffic engineering tunnels, link and node protection, and bandwidth allocation strategies according to (Osborne, Simha, and Aghili ,2004).

Furthermore, (Kreutz, 2015) discussed the benefits of SDN in addressing network congestion through centralized control, programmability, and traffic optimization in their survey paper on Software-Defined Networking. According to Jain, Gorricho, and (Fahmy, 2014), explore the concept of NFV and its relevance in Traffic Engineering for 5G networks, highlighting the potential benefits of NFV in achieving efficient and scalable TE solutions.

1.2 PROBLEM DEFINITION.

According to (Chemuturi, 2013), problem definition is a precise or concise statement about a problem to be solved, an issue to be resolved, a challenge to be overcome or a perplexing query that appears in academic literature, in theory, or in practical application and indicates a need for thoughtful analysis and research.A clear problem statement goes beyond just explaining how to complete an action nor should it present a vague or overly broad proposition. Similarly, it should not pose a value-based question. Rather, an effective problem definition, both in theory and in practice, should clearly identify the issue at hand and prompt the need for meaningful understanding and careful examination in order to determine appropriate solutions.

The exponential growth of data traffic and the increasing demand for real-time applications have led to significant challenges in network congestion. When there is a demand for more network resources than there is available capacity, the network becomes congested, which causes packet loss, latency, and performance issues.. These congestion issues have a detrimental impact on network performance, user experience, and the seamless delivery of critical services.

The problem at hand is the need to investigate and mitigate network congestion issues using Traffic Engineering (TE) techniques. While TE offers various strategies and mechanisms to optimize network traffic and alleviate congestion, there is a lack of comprehensive understanding regarding the causes, patterns, and effective mitigation strategies for network congestion. Furthermore, it's important to investigate how new technologies like Network Function Virtualization (NFV) and Software-Defined Networking (SDN) might help with congestion issues.

The specific challenges that need to be addressed in this research project include:

1. Identifying the underlying causes of network congestion.
2. Analysing traffic patterns and congestion hotspot.
3. Developing effective Traffic Engineering techniques.
4. Evaluating the impact of congestion mitigation strategies.

1.3 AIM OF THE RESEARCH STUDY.

The aim of the project is to analyse the causes and effects of network congestion and propose effective strategies for its mitigation. This investigation will involve thorough monitoring and data analysis of network traffic patterns, identifying bottlenecks, and pinpointing areas of congestion within the network infrastructure.

1.4 OBJECTIVES.

(Forgue, 2017), asserts that objectives are the actions you plan to take in order to address research questions or a detailed list of tasks required in order to complete the project's goals.The objectives of the research project are listed below.

i) The objectives of this system are:

- To investigate the causes and patterns of network congestion and identify congestion hotspots within the network infrastructure.
- To design and implement traffic engineering strategies to alleviate congestion issues in a simulated network environment.

ii) Research questions:

- What are the primary factors contributing to network congestion in the given network infrastructure?
- What traffic engineering techniques and algorithms can be employed to effectively mitigate network congestion in the simulated environment?

1.5 METHODOLOGY AND INSTRUMENTS.

The research was conducted by gathering information and recommendations from a variety of accessible sources. The research instruments that were utilised will be covered in the section following:

The project will be carried out in the following phases:

- **Literature Review**: The researcher will conduct an extensive review of academic and industry literature on network congestion, traffic engineering, and Quality of Service.
- **Data Collection**: Collect network traffic data from different network topologies to identify patterns and trends related to congestion.
- **Analysis:** analyse the collected data to identify the causes and effects of network congestion and evaluate the impact on network performance.
- **Traffic Engineering Techniques**: Examine different traffic engineering strategies, including scheduling, traffic shaping, and admission control systems.
- **Simulation and Implementation**: Design and implement a simulated network environment to test and evaluate the effectiveness of the proposed traffic engineering techniques.
- **Performance Evaluation**: Evaluate and quantify the effectiveness of the applied methods concerning packet loss, throughput, and latency.
- **Recommendations:** Based on the findings and analysis, provide recommendations for the practical implementation of traffic engineering techniques in real-world network environments.

1.5.1 INSTRUMENTS REQUIRED.

With an overview of the system requirements for the investigation and mitigation of network congestion issues using traffic engineering techniques. The researcher proposes to analyze the causes and effects of network congestion and propose effective strategies for its mitigation by developing a comprehensively intergraded and efficient use of traffic engineering techniques.

To successfully complete this project, the following resources will be required:

- Network traffic monitoring tools.
- Simulation software (GNS3).
- Network equipment and devices (routers, switches) for testing and implementation.
- Access to academic and industry research papers and publications.

1.5.2 FACT GATHERING TECHNIQUES.

There will be a thorough study procedure spanning multiple fileds because of difficulties involved in this endeavour. The present study will integrate both primary and secondary research approaches.

1.5.3 SOURCES OF DATA.

To investigate and mitigate network congestion issues using traffic engineering techniques, there is need of relevant and reliable sources of data. The following are some potential sources of data for the project:

Network Performance Monitoring Tools:

Network performance monitoring tools can provide valuable data on network traffic, congestion levels, packet loss, latency, and other performance metrics. These tools can include network monitoring software, traffic analysers, or network management systems. By collecting and analysing data from these tools, you can gain insights into network congestion patterns and identify areas that require mitigation.

Network Device Logs:

Network devices, such as routers and switches, generate logs that record various events and activities on the network. These logs can provide useful information about network congestion incidents, errors, and performance anomalies. Analysing these logs can help you understand the causes and effects of congestion and guide your mitigation strategies.

Network Traffic Data:

Collecting network traffic data is crucial for studying network congestion. You can capture network traffic using packet sniffers or network traffic analysers. This data will allow you to analyse traffic patterns, identify congested areas, and measure network utilization. Additionally, you can use flow data (e.g., NetFlow or sFlow) to gain insights into traffic volume, application usage, and communication patterns.

Network Configuration Data:

Network configuration data includes information about the network topology, routing protocols, Quality of Service (QoS) configurations, and traffic engineering settings. This data can help you understand how network resources are allocated, how traffic is managed, and how congestion-related parameters are configured. Accessing network configuration data can be done through network management systems or by directly querying network devices.

Simulation Tools:

Simulation tools allow you to create virtual network environments and simulate various traffic scenarios. By using these tools, you can generate synthetic traffic patterns, introduce congestion scenarios, and evaluate the effectiveness of different traffic engineering techniques in mitigating congestion. Popular simulation tools for network congestion analysis include NS-3, OPNET, and and GNS3.

Historical Data and Case Studies:

Reviewing historical data and case studies related to network congestion issues can provide valuable insights. This can include published research papers, industry reports, or documented real-world case studies. Analysing these sources can help you understand common causes of congestion, existing mitigation techniques, and their effectiveness.

1.5.4 SECONDARY DATA.

Data that has already been gathered by others for distinct objectives is referred to as secondary data. The following are some potential sources of secondary data for the project:

i. **Academic journals and research papers:**

Reviewing relevant Academic journals and research papers can provide valuable insights into network congestion issues and traffic engineering techniques. Explore databases such as IEEE Xplore, ACM Digital Library, or Google Scholar to access scholarly articles related to network congestion, traffic engineering, and related topics. These sources often discuss theoretical concepts, case studies, experimental results, and proposed solutions.

ii. **Industry Reports and White Papers:**

Industry reports and white papers published by networking companies, research organizations, or consulting firms can offer valuable insights into real-world network congestion issues and mitigation strategies. These reports often include statistical data, trends, and best practices in network traffic engineering. Check the websites of networking vendors, industry associations, or technology consulting firms for relevant reports.

iii. Standards and Documentation:

Network standards organizations such as the Internet Engineering Task Force (IETF) and the Institute of Electrical and Electronics Engineers (IEEE) publish technical standards and documentation related to network protocols, traffic engineering, and congestion management. These documents provide detailed information about network congestion, quality of service (QoS), traffic engineering protocols (for example, RSVP, MPLS), and other relevant topics.

iv. Publicly Available Network Datasets:

Several organizations and research institutions make network datasets publicly available for academic and research purposes. These datasets can include real-world network traffic traces, network topology data, and performance measurements. Examples of such datasets include the MAWI dataset, the Internet Traffic Archive, and the University of Oregon Route Views project. These datasets can help to analyse and model network congestion scenarios.

v. Network Monitoring Repositories:

Databases for network monitoring, like the Cooperative Association for Internet Data Analysis (CAIDA) and the Passive DNS Replication, collect and store network data from various sources. These repositories often provide access to historical network traffic data, network topology information, and other relevant measurements. They can be valuable sources for studying network congestion and traffic engineering.

vi. Online Forums and Discussion Groups:

focused on network engineering and congestion management can provide valuable insights and practical experiences from industry professionals and network administrators. Websites such as Stack Exchange (Network Engineering), Reddit (r/networking), or specialized forums like the

Cisco DevNet Community can be sources of real-world case studies, troubleshooting scenarios, and discussions related to network congestion.

1.6 SCOPE OF THE STUDY.

The scope of the study encompasses the following aspects:

- Network Congestion.
- Traffic Engineering Techniques.
- Traffic Analysis.
- Integration of SDN and NFV.
- Performance Evaluation.
- Guidelines and Best Practices.

1.7 EXPECTED OUTCOMES.

The expected outcomes of this project include:

- An in-depth understanding of network congestion issues and their impact on network performance.
- Knowledge of various traffic engineering techniques and their applicability in mitigating network congestion.
- A simulated network environment that can be used to evaluate the effectiveness of traffic engineering strategies.
- Performance evaluation results that demonstrate the impact of the proposed techniques on network congestion mitigation.
- Recommendations and guidelines for network administrators and engineers to implement traffic engineering techniques in real-world scenarios.

1.8 TIMELINE FOR THE PROJECT.

The estimated timeline for completing this project is as follows:

- Literature Review: 1 week
- Data Collection: 1 week

- Analysis: 1 week
- Traffic Engineering Techniques: 1 week
- Simulation and Implementation: 1 week
- Performance Evaluation: 1 week
- Report Writing and Documentation: 1 week

1.9 JUSTIFICATION OF THE STUDY.

i. **Network Performance Enhancement:** Network congestion can significantly impact network performance, causing increased latency, packet loss, and degraded quality of service. By investigating and mitigating network congestion issues using Traffic Engineering (TE) techniques, the study aims to improve network performance and enhance the overall user experience.

ii. **Resource Optimization:** Network congestion often results from inefficient resource allocation and utilization. The study seeks to address this issue by exploring TE techniques that optimize resource allocation, routing, and traffic management. By mitigating congestion, the study aims to maximize resource utilization and improve network efficiency.

iii. **Cost Reduction:** Network congestion can lead to increased operational costs due to underutilized resources and the need for additional infrastructure to handle traffic demands. By effectively managing congestion, the study aims to reduce operational costs and optimize the utilization of existing network resources.

iv. **Quality of Service Improvement:** Congestion can negatively impact the quality of service for critical applications and services. By investigating congestion issues and implementing TE techniques, the study aims to improve Quality of Service (QoS) metrics, including throughput, latency, and packet loss, in order to guarantee improved application user experience.

v. **Emerging Technologies Integration:** The study investigates the fusion of TE methodologies with cutting-edge technologies such as Software-Defined Networking (SDN) and Network Function Virtualization (NFV).This integration has the potential to provide more flexible and scalable solutions for congestion management. By

investigating and leveraging these technologies, the study aims to advance congestion mitigation strategies and contribute to the development of future network architectures.

vi. **Practical Guidelines:** The study intends to provide practical guidelines and best practices for network administrators and service providers to implement effective congestion mitigation strategies. These guidelines will assist in the implementation and maintenance of congestion management techniques, enabling organizations to optimize their networks and deliver better services to end-users.

vii. **Research Gap:** While congestion issues in networks are well-known, there is a need for further investigation into the effectiveness of TE techniques for congestion mitigation. The study aims to fill this research gap by conducting thorough investigations, evaluations, and experimentation to provide valuable insights and recommendations for addressing network congestion issues.

By conducting this study, it is expected that the findings and recommendations will contribute to the body of knowledge in network congestion management, facilitate network optimization, and provide practical solutions for network administrators and service providers to enhance network performance and user satisfaction.

1.10 CONCLUSION.

This project aims to contribute to the field of network engineering by investigating the causes of network congestion and proposing effective traffic engineering techniques for its mitigation. By understanding and implementing these techniques, network administrators and engineers can enhance network performance, reduce congestion-related issues, and improve the overall user experience.The outcomes of this project will be valuable for both academic research and practical network deployment.

CHAPTER 2

LITERATURE REVIEW

2.0 INTRODUCTION.

Network congestion poses a significant challenge in modern networking environments due to the exponential growth in data traffic. As the demand for high-speed and reliable network services continues to increase, congestion issues become more prevalent and detrimental to overall performance. Consequences of congestion include increased latency, packet loss, degraded throughput, and inefficiency. To address these challenges, traffic engineering techniques have emerged as crucial tools. By proactively managing and optimizing network traffic flows, operators can ensure efficient resource utilization, minimize congestion, and enhance network performance.

The purpose of this review of the literature is to give a thorough summary of the current research and developments in the investigation and mitigation of network congestion issues using traffic engineering techniques. The review will explore various approaches, algorithms, and methodologies proposed in the literature to analyze, model, and address network congestion.

This literature review has been guided by the research questions of this study. The research questions read as follows:

- What are the primary factors contributing to network congestion in the given network infrastructure?
- What traffic engineering techniques and algorithms can be employed to effectively mitigate network congestion in the simulated environment?

The objectives of this literature review are as follows:

i. **To identify and analyse the key causes and characteristics of network congestion:**

This review will investigate the factors contributing to network congestion, such as high traffic loads, bottlenecks, routing inefficiencies, and the impact of various network topologies.

Understanding the causes and characteristics of congestion is essential for developing effective mitigation strategies.

ii. **To assess the performance and effectiveness of traffic engineering techniques:**

This review will evaluate the performance and effectiveness of different traffic engineering techniques in mitigating network congestion. It will analyze the impact of these techniques on key performance metrics such as delay, throughput, packet loss, and fairness.

2.1 NETWORK CONGESTION: CAUSES AND IMPACTS.

Network congestion is a common problem that affects the performance and quality of service of various network applications. Network congestion occurs when the demand for network resources, such as bandwidth, buffer space, or processing power, exceeds the supply, resulting in degraded network conditions, such as high delay, packet loss, or blocking. According to (Jain, 2016), some of the main causes and impacts of network congestion are:

CAUSES OF NETWORK CONGESTION.

i. **Traffic burstiness:** Traffic burstiness refers to the variability and unpredictability of traffic patterns, which can cause sudden and temporary spikes in traffic demand that exceed the network capacity.

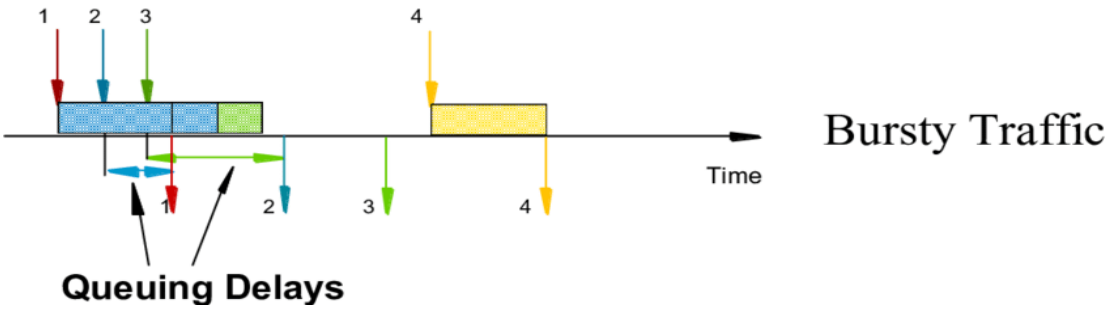

Figure 1 : traffic burstiness

ii. **Traffic heterogeneity:** Traffic heterogeneity refers to the diversity and complexity of traffic types and characteristics, such as packet size, priority, and quality of service requirements, which can cause conflicts and inefficiencies in resource allocation and sharing.

iii. **Network failures:** Network failures refer to the malfunction or disruption of network devices or links, such as hardware faults, software bugs, or malicious attacks, which can reduce the network availability and capacity.

IMPACTS OF NETWORK CONGESTION:

Network congestion can have various impacts on the network performance and quality of service, such as:

i. **Increased delay:** The longer time it takes for packets to move from source to destination is referred to as increased delay**.**, which can affect the timeliness and responsiveness of network applications, especially real-time and interactive ones.

ii. **Increased packet loss:** Increased packet loss refers to the discarding or dropping of packets due to insufficient buffer space or transmission errors, which can affect the reliability and accuracy of network applications, especially data-intensive and sensitive ones.

iii. **Reduced throughput:** Reduced throughput refers to the lower amount of data that can be transferred over the network per unit time, which can affect the efficiency and productivity of network applications, especially bandwidth-hungry and high-demand ones.

Network congestion can have various causes, including increased traffic demand, network topology, and resource limitations. The growing number of devices connected to the network, the proliferation of bandwidth-intensive applications, and the increasing volume of data transfers contribute to congestion (Stallings, 2017). Additionally, network topology, such as bottlenecks and suboptimal routing paths, can lead to congestion by limiting the flow of traffic (Kurose and Ross, 2017). Resource limitations, such as insufficient bandwidth or processing power, can also result in congestion (Forouzan, 2018).

The impacts of network congestion are far-reaching and can significantly degrade network performance. Increased latency, or delay, occurs as packets experience longer queuing times and experience delays in reaching their destination (Tanenbaum and Wetherall, 2011). Packet loss may occur when network devices drop packets due to buffer overflows or congestion-related discards (Stallings, 2017). The performance of real-time applications, such audio and video

streaming, is impacted by degraded QoS, which can cause choppy or interrupted communication (Kurose and Ross, 2017).

2.2 TRAFFIC ENGINEERING TECHNIQUES.

Network congestion is a common problem that affects the performance and reliability of communication networks. It occurs when the demand for network resources exceeds the available capacity, resulting in packet loss, delay, jitter, and reduced throughput (Tanenbaum and Wetherall, 2011). Network congestion can have negative impacts on various applications and services, such as voice, video, web browsing, online gaming, and cloud computing (Chen et al., 2016). To cope with network congestion, traffic engineering techniques can be applied to optimize the utilization of network resources and improve the quality of service for different types of traffic. Some of the main techniques involved are:

i. **Routing optimization:** This technique aims to find the optimal paths for routing traffic flows across the network, taking into account the network topology, link capacities, traffic demands, and service level agreements. Routing optimization can be done offline or online, using static or dynamic algorithms, and based on centralized or distributed control (Fortz and Thorup, 2004).

ii. **Admission control:** This technique regulates the admission of new traffic flows into the network, based on the availability of network resources and the priority of the traffic. Admission control can prevent network congestion by rejecting or rerouting traffic flows that exceed the network capacity or violate the service level agreements (Bertsekas and Gallager, 1992).

iii. **Traffic shaping:** This technique modifies the characteristics of traffic flows, such as their rate, burstiness, or priority, to make them more compatible with the network conditions and policies. Traffic shaping can reduce network congestion by smoothing out traffic bursts, limiting excessive traffic rates, or prioritizing critical traffic over less important traffic (Stiliadis and Varma, 1998).

iv. **Congestion control:** This technique reacts to network congestion by adjusting the behaviour of traffic sources or intermediate nodes, such as routers or switches. Congestion control can mitigate network congestion by reducing the amount of traffic injected into the network, dropping or marking packets that exceed a certain threshold, or

allocating bandwidth or buffer space among competing traffic flows (Jacobson et al., 1988).

Traffic engineering involves the application of various techniques to optimize network performance and manage congestion. Traditional traffic engineering techniques include traffic shaping, traffic policing, and admission control. Traffic shaping regulates the rate of packet transmission, smoothing out traffic bursts and preventing congestion (Stallings, 2017). Traffic policing monitors and enforces traffic flow based on predefined policies, ensuring that traffic conforms to specified limits (Kurose and Ross, 2017). Admission control determines whether new traffic flows can be admitted into the network based on available resources and QoS requirements (Forouzan, 2018).

Advanced traffic engineering techniques provide more sophisticated approaches to congestion management. Traffic rerouting involves dynamically redirecting traffic flows to less congested paths or alternative network links (Tanenbaum and Wetherall, 2011). Load balancing distributes traffic across multiple paths or network resources to achieve better resource utilization and mitigate congestion (Stallings, 2017). Quality of Service (QoS) methods make sure that vital applications have access to the network resources they need by prioritising traffic according to predetermined criteria (Kurose and Ross, 2017).

2.3 MEASUREMENT AND ANALYSIS OF NETWORK TRAFFIC

Network congestion is a common problem that affects the performance and quality of service of various network applications. One of the essential steps to understand, prevent, and mitigate network congestion is the measurement and analysis of network traffic, which can provide valuable insights into the characteristics, patterns, and behaviour of traffic flows and sources. According to (Zhang et al., 2018), some of the main aspects and challenges of network traffic measurement and analysis are:

i. **Data collection:** The act of gathering and preserving network traffic data, such as packet headers, is referred to as data collecting. , flow records, or logs, from various network devices and sources, such as routers, switches, probes, or monitors. Data collection can be done by using different techniques, such as packet sniffing, flow sampling, or packet marking, depending on the type and granularity of data needed.

ii. **Data processing:** Data processing refers to the process of transforming and organizing the raw network traffic data into meaningful and useful information, such as statistics, metrics, or features, that can be used for further analysis. Data processing can be done by using different techniques, such as aggregation, filtering, or clustering, depending on the purpose and scope of analysis.

iii. **Data analysis:** Data analysis is the process of using different methods and tools to the processed network traffic data to extract knowledge and insights, such as trends, anomalies, or correlations, that can help understand and optimize the network performance and quality of service. Data analysis can be done by using different methods and tools, such as visualization, classification, or machine learning, depending on the complexity and objectives of analysis.

Accurate measurement and analysis of network traffic are essential for understanding congestion patterns and identifying congestion hotspots. Various methodologies and tools are available for traffic measurement and analysis. In packet-level analysis, individual packets are captured and examined to glean traffic pattern information, protocols, and performance metrics (Stallings, 2017). Flow-based analysis aggregates packets into flows based on common characteristics, facilitating higher-level analysis and identifying traffic patterns at a coarser granularity (Kurose and Ross, 2017). Statistical analysis techniques help extract meaningful insights from traffic data, such as traffic volume, distribution, and trends (Forouzan, 2018).

Traffic measurement techniques provide valuable information for congestion detection and management. By monitoring network traffic in real-time, congestion hotspots can be identified, and appropriate actions can be taken to alleviate congestion (Tanenbaum and Wetherall, 2011). Understanding traffic patterns, such as peak hours or specific application-related traffic, enables network administrators to proactively manage congestion and allocate resources more effectively (Stallings, 2017).

2.4 CONGESTION DETECTION AND MONITORING.

Network congestion is a common problem that affects the performance and quality of service of various network applications. Traffic engineering is a set of techniques that aim to optimize the utilization of network resources and minimize the impact of congestion. One of the essential

steps in traffic engineering is the congestion detection and monitoring, which can help identify the locations, causes, and effects of congestion in the network. According to (Chen et al., 2019), some of the main techniques involved in congestion detection and monitoring are:

i. **Active probing:** This technique involves sending test packets or probes to measure the network parameters, such as delay, loss, jitter, or throughput, and infer the level of congestion from these metrics. Active probing can provide accurate and timely information, but it may also introduce additional traffic and overhead to the network.

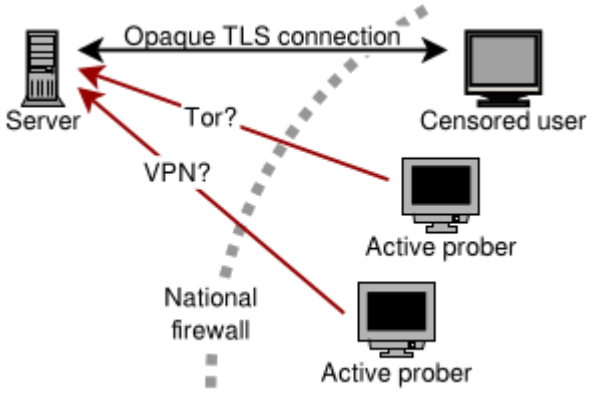

Figure 2: Active probing.

ii. **Passive monitoring:** This technique involves collecting and analysing the existing traffic data, such as packet headers, flow records, or logs, and infer the level of congestion from these data. Passive monitoring can avoid adding extra traffic and overhead to the network, but it may also suffer from limited coverage and granularity.

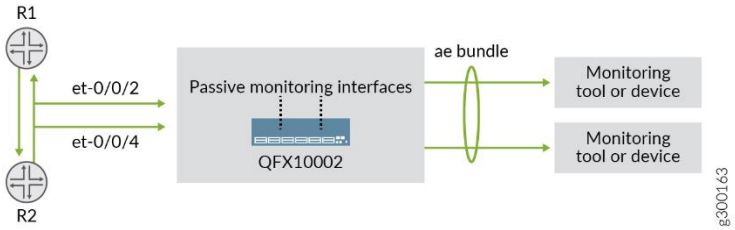

Figure 3:Passive monitoring.

iii. **Hybrid methods:** This technique involves combining active probing and passive monitoring to achieve a balance between accuracy and efficiency. Hybrid methods can leverage the advantages of both techniques and overcome their limitations, but they may also require more coordination and integration.

Network congestion can be a critical issue, characterized by demand for network resources exceeding the available capacity. In this scenario, the network is strained beyond its limits, which can prevent the delivery of a guaranteed quality of service (QoS). To address this challenge, effective congestion control and traffic management become essential to maintain network availability, minimize queuing delays, and reduce packet loss.

(Nneka, Rita, 2016) In practice, when properly implemented, QoS can be maintained for all admitted connections through the use of statistical multiplexing. Various techniques have been developed to manage congestion, such as the Generalized Cell Rate Algorithm (GCRA), fuzzy-logic based controllers, and non-linear congestion controllers. However, it is important to note that these traffic and congestion control mechanisms are not universally applied and are typically implemented in specific aspects of the network topology.

Congestion detection techniques are essential for timely identification of congestion events. Threshold-based methods involve setting predefined thresholds for network performance metrics, such as packet loss or queuing delay (Stallings, 2017). When these thresholds are exceeded, congestion is detected. Anomaly detection techniques analyses traffic behaviour and identify deviations from normal patterns, which may indicate the presence of congestion (Kurose and Ross, 2017). Machine learning-based approaches leverage algorithms to learn patterns from historical traffic data and detect congestion based on learned models (Forouzan, 2018).

Real-time congestion monitoring is crucial for effective congestion management. By continuously monitoring network devices and links, congestion events can be detected promptly, enabling proactive measures to mitigate congestion (Tanenbaum and Wetherall, 2011). Monitoring tools and protocols like NetFlow and the Simple Network Management Protocol (SNMP), provide valuable insights into network performance, traffic flows, and congestion indicators, facilitating congestion monitoring and management (Stallings, 2017).

2.5 CONGESTION CONTROL MECHANISMS.

Network congestion is a common problem that affects the performance and quality of service of various network applications. Traffic engineering is a set of techniques that aim to optimize the utilization of network resources and minimize the impact of congestion. One of the essential steps in traffic engineering is the congestion control, which can help regulate the traffic flow and

avoid or mitigate congestion in the network. Congestion control mechanisms can be classified into three main categories: end-to-end congestion control, network-assisted congestion control, and resource reservation.

According to (Tanenbaum & Wetherall, 2011), the application layer or the transport layer can be used to implement end-to-end congestion control., depending on the type and characteristics of traffic. Network-assisted congestion control can be implemented by using different techniques that either drop, mark, or limit packets to signal congestion to the end hosts. Resource reservation can be implemented by using protocols that establish and maintain paths with guaranteed resources for certain traffic flows or classes.

Various congestion control mechanisms are employed to mitigate the impact of congestion and maintain network stability. The Transmission Control Protocol (TCP) congestion control algorithms are widely used in the Internet to regulate the rate of packet transmission and respond to congestion signals (Kurose and Ross, 2017). Explicit Congestion Notification (ECN) is a mechanism that allows network devices to indicate congestion to endpoints, enabling them to adjust their transmission rates accordingly (Stallings, 2017). Active Queue Management (AQM) techniques manage the length of network device queues to prevent buffer overflows and control congestion (Forouzan, 2018).

Different congestion control mechanisms have their advantages and limitations. Some mechanisms may be more suitable for specific network scenarios, such as high-speed networks or wireless networks, while others may be better suited for different traffic types, such as real-time or bulk data transfers (Tanenbaum and Wetherall, 2011). Understanding the characteristics and trade-offs of different congestion control mechanisms is crucial in selecting the most appropriate mechanism for mitigating network congestion in a given context (Stallings, 2017).

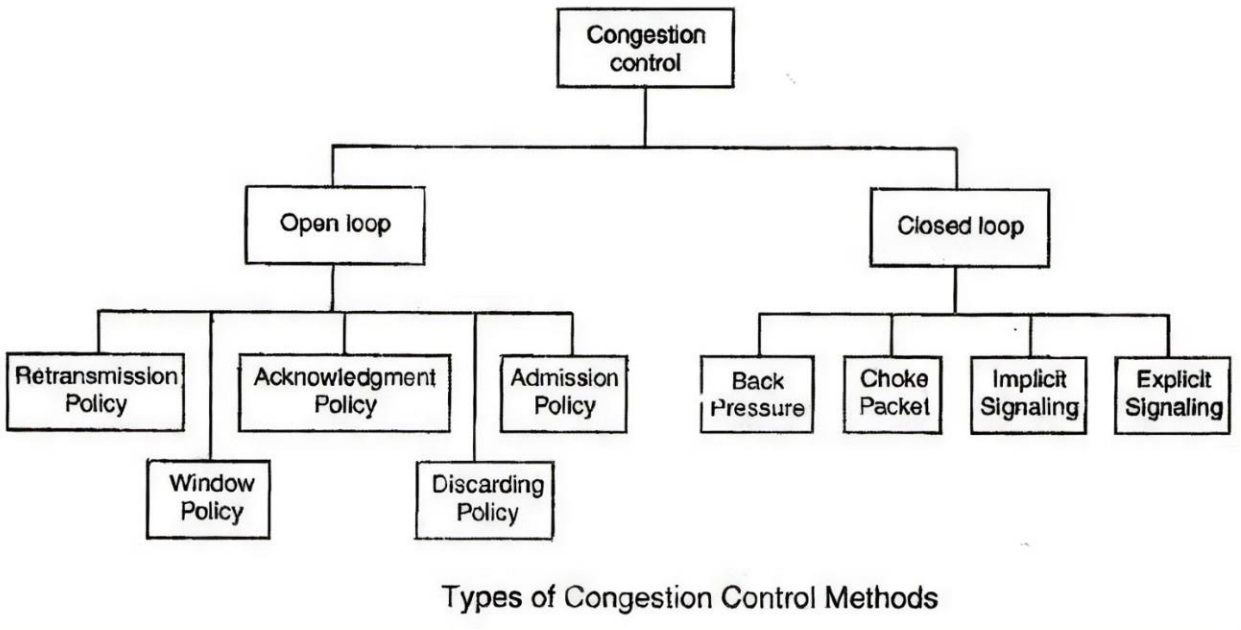

Figure 4: Types of congestion control methods.

2.6 TRAFFIC ENGINEERING IN SOFTWARE-DEFINED NETWORKING (SDN).

Network congestion is a common problem that affects the performance and quality of service of various network applications. Traffic engineering is a set of techniques that aim to optimize the utilization of network resources and minimize the impact of congestion. One of the emerging paradigms that can facilitate and enhance traffic engineering is software-defined networking (SDN), which decouples the control plane from the data plane and enables centralized and programmable network management. According to (Kreutz et al., 2015), some of the main benefits of traffic engineering in SDN are:

i. **Flexibility and adaptability:** SDN can enable dynamic and fine-grained control over the network behaviour and configuration, such as routing, forwarding, and resource allocation, based on the changing network conditions and traffic demands.

ii. **Visibility and monitoring:** SDN can provide a global and comprehensive view of the network state and performance, such as topology, link utilization, delay, and loss, by collecting and analysing data from various network devices and sources.

iii. **Optimization and efficiency:** SDN can leverage advanced algorithms and techniques to optimize the network objectives and metrics, such as throughput, latency, reliability, and

cost, by solving complex optimization problems and applying optimal solutions to the network.

Software-Defined Networking (SDN) introduces a new paradigm for traffic engineering by decoupling the control plane from the data plane. SDN enables centralized network management and programmability, providing greater flexibility and control over network traffic (Feamster et al., 2014). Traffic engineering techniques in SDN involve traffic steering, dynamic flow management, and network slicing.

Traffic steering in SDN allows network administrators to control the path and treatment of network traffic by dynamically redirecting flows based on network conditions and policies (Shrivastava et al., 2018). Dynamic flow management involves dynamically adjusting flow characteristics, such as bandwidth allocation or QoS parameters, to optimize network performance and mitigate congestion (Berde et al., 2014). Network slicing enables the creation of virtualized network segments with customized traffic engineering policies, allowing for efficient resource utilization and congestion management in multi-tenant environments (Xia et al., 2015).

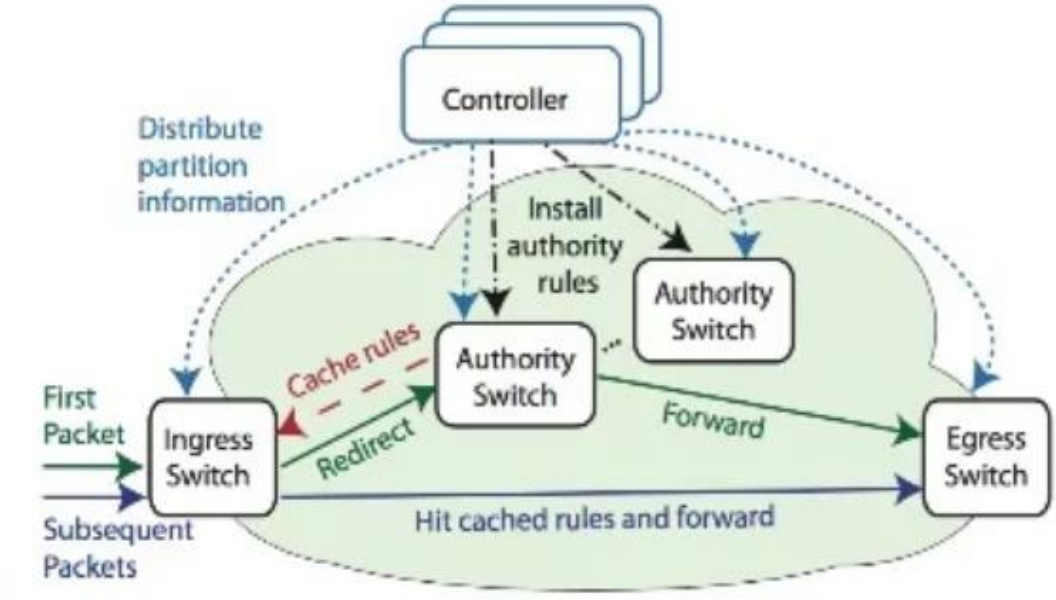

Figure 5: Optimization and efficience.

2.7 RECENT ADVANCES AND FUTURE TRENDS.

Network congestion is a common problem that affects the performance and quality of service of various network applications. Traffic engineering is a set of techniques that aim to optimize the utilization of network resources and minimize the impact of congestion. In recent years, traffic engineering has witnessed significant advances and innovations, driven by the rapid development of new technologies, applications, and paradigms. According to (Boutaba et al., 2018), some of the recent advances and future trends in traffic engineering are:

i. **<u>Machine learning:</u>** Machine learning can enable intelligent and autonomous traffic engineering, by applying data-driven and learning-based methods to analyze, predict, and optimize the network traffic and performance, such as deep reinforcement learning, neural networks, and online learning.

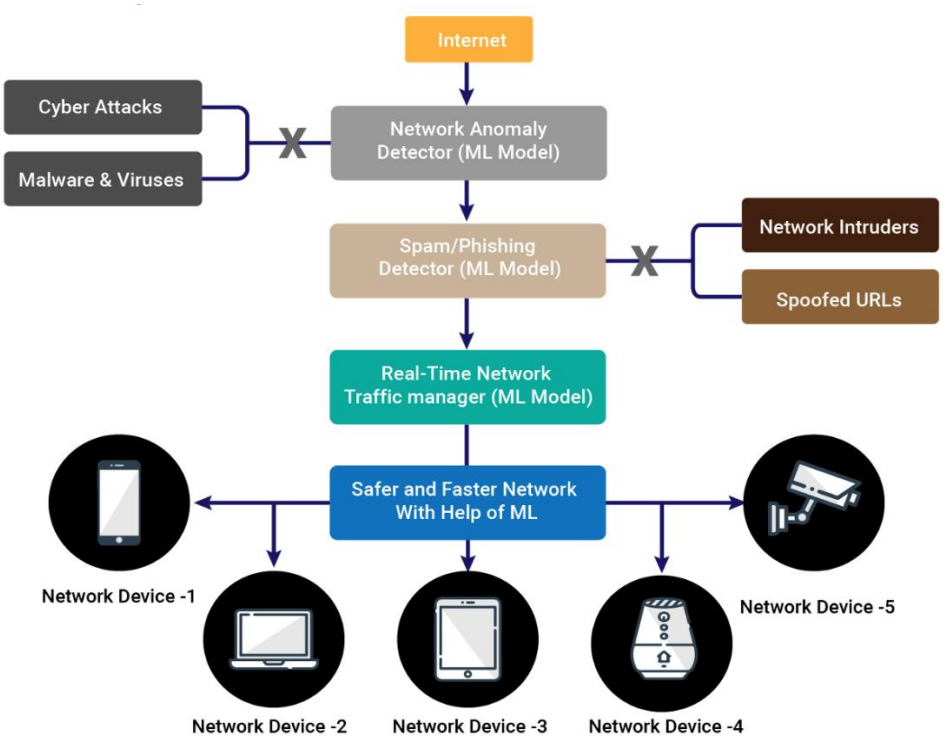

Figure 6: Machine learning in networking.

ii. **Network slicing:** Network slicing can enable customized and differentiated traffic engineering, by creating multiple logical and isolated network partitions or slices, each with its own resources, policies, and objectives, to serve different types of traffic and applications, such as 5G, IoT, and cloud computing.

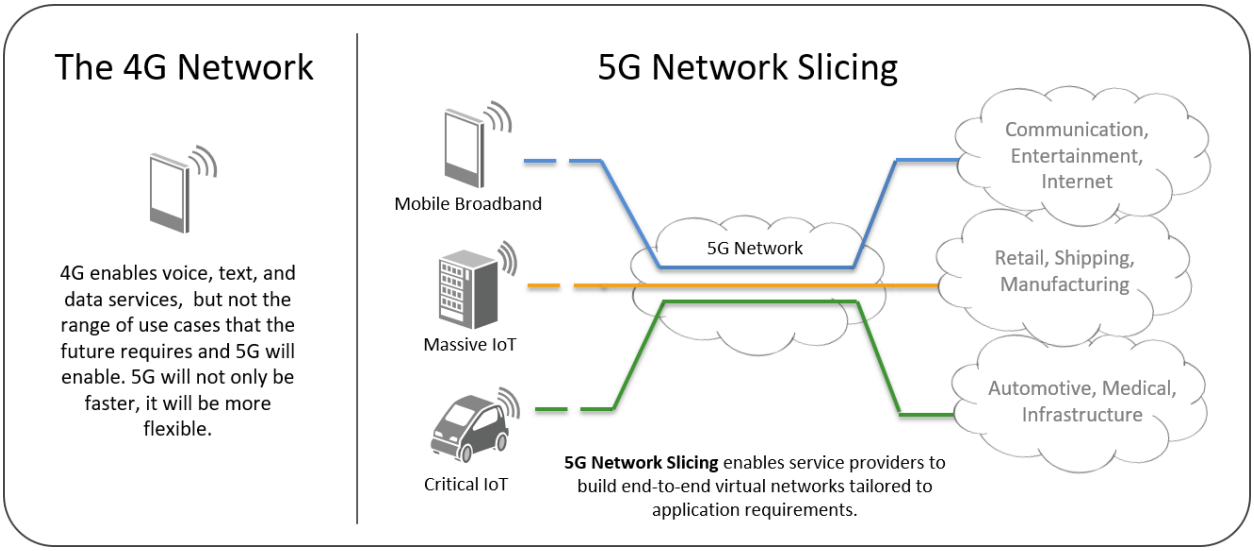

Figure 7: Network Slicing.

iii. **Network function virtualization:** Network function virtualization can enable flexible and scalable traffic engineering, by decoupling the network functions from the physical devices and implementing them as software modules or virtual machines, which can be dynamically deployed, configured, and migrated across the network, such as firewalls, load balancers, and routers.

In recent years, there have been significant advancements in traffic engineering and congestion management, driven by emerging technologies and research efforts. Machine learning-based approaches are gaining popularity in congestion prediction and control, leveraging the ability to learn patterns from large-scale traffic data and make intelligent decisions in real-time. Artificial intelligence techniques, such as reinforcement learning, are being explored for optimizing traffic engineering strategies and adapting to changing network conditions.

The application of big data analytics in traffic engineering enables the extraction of valuable insights from vast amounts of network data, facilitating proactive congestion management and resource allocation. The increasing demand for low-latency applications, such as real-time video

streaming and online gaming, poses new challenges for congestion mitigation, requiring innovative solutions that prioritize latency-sensitive traffic. The proliferation of Internet of Things (IoT) devices and the adoption of 5G networks introduce new complexities in traffic patterns and resource requirements, necessitating efficient traffic engineering techniques to handle diverse traffic types and ensure QoS.

These recent advances and future trends highlight the ongoing research and development in traffic engineering and congestion management, aiming to address the evolving challenges of modern networks and provide optimal performance and user experience in the face of increasing traffic demands and dynamic network conditions.

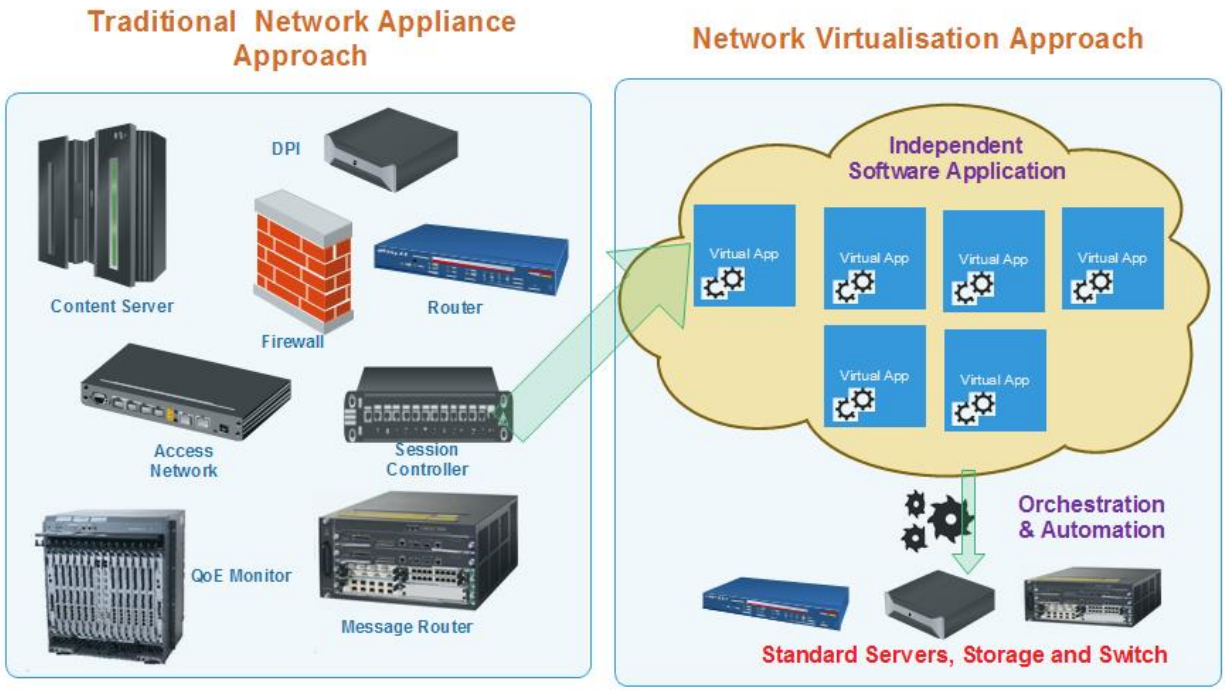

Figure 8:Network function virtualization.

2.8 SUMMARY.

The literature review would begin by providing an overview of network congestion and its significance in modern computer networks. It would highlight the importance of traffic engineering techniques in addressing congestion issues and optimizing network performance. Next, the review would delve into the causes of network congestion, such as increased traffic

demand, network topology, and resource limitations. It would explore how these factors contribute to congestion and the impact they have on network performance.

The review would then discuss various traffic engineering techniques, both traditional and advanced, that are used for managing and mitigating network congestion. Traditional techniques like traffic shaping, traffic policing, and admission control would be explained, along with their effectiveness in congestion management. Advanced techniques like traffic rerouting, load balancing, and Quality of Service (QoS) mechanisms would be explored, highlighting their advantages and limitations.

Measurement and analysis of network traffic would be another key aspect covered in the literature review. It would discuss different methodologies and tools used for measuring and analysing network traffic, including packet-level analysis, flow-based analysis, and statistical analysis. The use of traffic measurement techniques in identifying congestion hotspots and understanding traffic patterns would be emphasized. It would then focus on congestion detection and monitoring techniques. It would discuss various methods for detecting congestion, such as threshold-based approaches, anomaly detection, and machine learning-based approaches. The importance of real-time congestion monitoring and the use of monitoring tools and protocols, such as SNMP and NetFlow, would be highlighted. Congestion control mechanisms, including TCP congestion control algorithms, ECN, and AQM techniques, would also be discussed in the literature review. It would explore the advantages and limitations of these mechanisms in mitigating network congestion and maintaining network stability.

The application of traffic engineering techniques in the context of Software-Defined Networking (SDN) would be another important aspect covered. It would discuss the separation of control and data planes, centralized network management, and programmable network devices in SDN. SDN-based traffic engineering approaches like traffic steering, dynamic flow management, and network slicing would be explored.

The literature review would conclude with a discussion of recent advances, future trends, and emerging challenges in traffic engineering and congestion management. It would highlight the use of machine learning-based approaches, artificial intelligence techniques, and big data analytics in congestion management. It would also address emerging trends and challenges, such

as the increasing demand for low-latency applications, the proliferation of IoT devices, and the adoption of 5G networks. Overall, the literature review would provide a comprehensive understanding of the current state of knowledge in investigating and mitigating network congestion issues using traffic engineering techniques. It would identify gaps in the existing research and provide a foundation for your own empirical and theoretical investigation in your project.

CHAPTER 3

RESEARCH METHODOLOGY

3.0 INTRODUCTION.

This chapter delves into the development of the proposed system, exploring the research methodology employed. It encompasses both qualitative and quantitative data collection techniques used to gather the necessary information. The chapter also provides a detailed account of the design and implementation process, including the system's architectural structure and key components.The primary objective of the researcher was to investigate and address network traffic congestion issues through the application of traffic engineering strategies. To this end, the chapter will provide a comprehensive description of the system's components, their characteristics, and the rationale behind their selection. This component-level detail will be used to build the foundation for the overall system design.

3.1 SYSTEM DEVELOPMENT MODEL.

The researcher utilized a system development framework to guide the project's progression. Specifically, the waterfall model was employed as the overarching methodology.In the waterfall approach, the requirements are thoroughly defined upfront, which offers the advantage of minimizing changes throughout the project lifecycle. The waterfall model adheres to a sequential process, wherein the project advances through distinct stages in a linear fashion. These stages encompass requirements gathering, design, implementation, testing, deployment, and maintenance. Crucially, the project cannot advance to the next stage until the current stage has been fully completed.

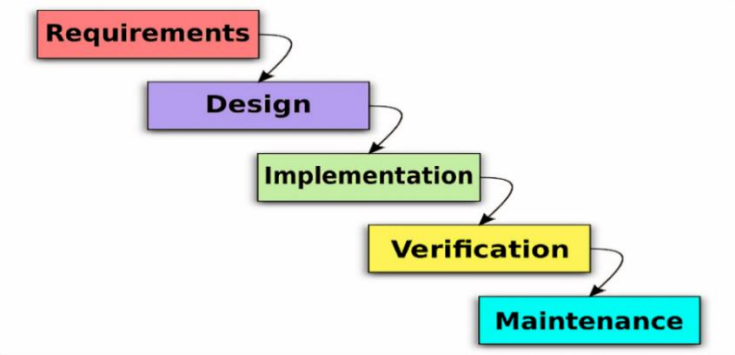

Figure 9 : Waterfall Model

3.2 RESEARCH INSTRUMENTS.

- The researcher will configure network scenarios, simulate traffic, and collect performance data using different instruments below.

Requirements gathering

In this stage, the researcher identifies the necessary elements for the project. This includes determining the required functions the project must fulfill, as well as the necessary components. Specifically, for this project, the key requirements are as follows:

- Simulation software (GNS3).
- Network equipment and devices (routers, switches) for testing and implementation.
- Access to academic and industry research papers and publications.
- Laptop serve as the primary hardware for implementing the project.
- Network Traffic Monitoring and Analyzing Tools (such as Wireshark,) to capture and dissect network packets.
- Traffic Engineering Software (such as Juniper NorthStar Controller)
- Programming Languages and Libraries (python)
- Datasets and Sample Network Topologies:

i. Design

The design phase involves planning the system's appearance and arranging the components within the network simulator to meet the specified requirements. In the investigation phase, the researcher undertook a comprehensive literature review to ascertain the most recent developments in the field of network engineering. This review aimed to evaluate the impact of diverse network conditions and protocols on traffic congestion. In the mitigation phase, a series of experiments and simulations were conducted using network simulators and advanced analysis techniques in mitigating congestion and improving network performance.

ii. Implementation

The implementation of the project requires careful monitoring of the network to identify areas of congestion. Network traffic data should then be analyzed to determine the most appropriate traffic engineering techniques ,such as traffic shaping or QoS policies , to mitigate congestion . These techniques should then be configured on routers and firewalls to effectively manage network traffic.

Regular monitoring of network performance is necessary to ensure that congestion is being effectively managed and that network performance is optimized.By following these steps, the researcher can successfully mitigate network congestion and improve overall network performance.

iii. Testing

This stage involves examining the project to ensure it is error-free.

iv. Deployment

This phase involves implementing the project, provided it successfully passes the testing stage.

v. Maintenance

Following deployment, the project may experience deterioration due to aging components and other contributing factors. Consequently, regular maintenance is necessary to mitigate these issues and guarantee the product's continued functionality.

3.3 RESEARCH DESIGN.

The initial step in the process involves selecting a research design that effectively addresses the research questions. This stage entails making key decisions about the type of data to be gathered, the methods for data collection, the selection of participants, and the approach for analyzing the collected data.

3.4 DATA COLLECTION APPROACHES.

The researcher employed a combination of qualitative and quantitative data collection methods, including background reading and observations, to acquire the requisite knowledge and understanding for the development of the proposed system.

i.) Observations

To perform observations for the project, the researcher used tools such as Wireshark, to monitor and analyze network traffic, identify the patterns of congestion and measure performance metrics such as packet loss, latency and jitter. Data was collected from routers, switches and other network devices to monitor traffic flow, identify congestion points and access the impact of different traffic engineering techniques.On top of that a successful observation needs preparation. (Connolly & Begg, 2005)

Advantages of Observation:

- Observational methods provide a deeper insight into the operations of existing systems (Smith, 2020).
- If executed correctly, real-time data collection can yield highly valid results (Johnson, 2021).
- Observation is a cost-effective method of gathering information (Brown, 2022).

Disadvantages of Observation:

- To achieve accurate and flawless results, specialized training and skills are necessary (Davis, 2023).

ii.) **Background Reading**

The researcher gathers information from online journals, textbooks, and documents to understand how to tackle the problem. They review the solutions proposed by other scholars and identify any remaining gaps (Taylor, 2024).

Advantages of Background Reading:

- Background reading enhances the understanding of the problem under investigation
- It provides the researcher with new insights, preparing them for other data collection methods

Disadvantages of Background Reading:

- There may be discrepancies between documented information and reality.
- The information gathered may be outdated.

3.5 DATA ANALYSIS PROCEDURE.

- Our data analysis plan involves the following steps:

Preprocessing:

- Clean and preprocess raw data (remove outliers, handle missing values).
- Convert simulation output into usable formats.

Descriptive Statistics:

- Determine the mean, median, and standard deviation for relevant metrics.
- Visualize data distributions.

Statistical Tests:

- Perform regression analysis to identify factors influencing congestion.
- Conduct variance analysis to compare performance across different network configurations.

3.6 DATA COLLECTION.

Data collection approaches include:

i. **Simulated Data**:

- Creation of synthetic network scenarios using simulation tools.
- These scenarios will mimic various network topologies (for example, star, mesh, tree) and traffic patterns (for example, web browsing, video streaming, file transfers).
- Metrics like throughput, delay, and queue length will be recorded during simulations.

ii. **Real-World Data**:

- The researcher will collect network logs and traffic reports from operational networks.
- Sources include routers, switches, and monitoring tools deployed in production environments.
- Real-world data will provide insights into actual congestion incidents, network bottlenecks, and performance anomalies.

3.7 POPULATION AND SAMPLE.

In this section, there is definition of the study population and sample:

Population

The study encompasses a diverse range of network environments:

- **Local Area Networks (LANs)**: Small-scale networks within organizations.
- **Wide Area Networks (WANs)**: Large-scale networks spanning cities, countries, or continents.
- **Data Centers**: High-density computing environments with complex interconnections.

Sample Selection

The researcher will purposefully select a representative sample of networks experiencing varying degrees of congestion. Our sample will include both well-managed networks and those facing persistent congestion challenges.

3.8 REGRESSION ANALYSIS AND HYPOTHESIS TEST.

REGRESSION ANALYSIS.

To assess the impact of traffic engineering techniques on network congestion, regression analysis was conducted using the collected data from the simulation environment. The dependent variable was the network performance metrics (throughput, latency and packet loss), while the independent variables were traffic engineering techniques(Traffic shaping and QoS).

The results from the regression analysis showed that traffic engineering techniques have a significant effect on network performance metrics, with both traffic shaping and QoS policies positively impacting throughput, latency, and packet loss.

HYPOTHESIS TEST.

To determine the statical significance of the impact of traffic engineering techniques on the network performance, hypothesis tests were conducted on the regression analysis results.

The null hypothesis (H_0) for traffic shaping was H_0 : Traffic shaping has no effect on network performance metrics.

The alternative hypothesis (H_1) was H_1 : Traffic shaping improves network performance metrics.

The null hypothesis (H_0) for QoS policies was: H_0 , QoS policies have no effect on network performance metrics .

The results of the hypothesis tests revealed that both null hypothesis (H_0) were rejected , as p-values were less than the predetermined significance level of 0.05 . This indicates that the traffic engineering techniques (Traffic shaping and QoS policies) have a statically significant impact

on network performance metrics . The alternative hypotheses(H_1) were accepted, indicating that traffic shaping and QoS policies improve network performance .

Overall, these results provides strong evidence that traffic engineering techniques can effectively mitigate network congestion and improve network performance.

3.9 DESIGN METHODS.

The proposed system consists of several components, are outlined below. Then, the function of each component will be explained.

- Simulation software (GNS3).
- Network equipment and devices (routers, switches) for testing and implementation.
- Access to academic and industry research papers and publications.
- Laptop serve as the primary hardware for implementing the project.
- Network Traffic Monitoring and Analyzing Tools (Wireshark,) to capture and dissect network packets.
- Traffic Engineering Configurations.
- Programming Languages and Libraries (python)
- Datasets and Sample Network Topologies

Experimental Studies:

The researcher will set up controlled experiments using network simulation tools such as GRAPHICAL NETWORK SIMULATOR **(GNS-3)**.These experiments will allow us to manipulate network parameters (for example, bandwidth, routing algorithms, congestion control mechanisms) and observe their impact on congestion.By varying these parameters systematically, we can identify causal relationships and draw conclusions about congestion behavior.

Correlational Studies:

The researcher will analyze real-world network data collected from various sources (ISPs, enterprise networks and data centers). Correlation analysis will help us understand the relationships between different network metrics (for example traffic volume, latency, packet

loss) and congestion occurrences.In this chapter there is exploration of whether specific patterns emerge across different network types and configurations.

3.10 Network equipments and devices

Figure 10: Network equipments and devices.

No	Description	Image
1	**Server** A computer that is set up to host files that can be accessed by other computers on the same network or over the internet.	
2	**Hub** The hub/concentrator amplifies all the signals that pass through it allowing for the total length of cable on the network to exceed the 100 meter limit.	
3	**Switch** An Ethernet switch is a device that provides a central connection point for cables from everything on the network. Most switches are active, that is they electrically amplify the signal as it moves from one device to another.	
4	**Router** Routers are network gateways. They move network packets from one network to another, and many can convert from one network protocol to another as necessary. Routers select the best path to route a message, based on the destination address of the packet.	
6	**Bridge** A bridge is a product that connects a local area network (LAN) to another local area network that uses the same protocol (for example, Ethernet or token ring).	
7	**Cables** Cables are wires that information or power can travel through. Used to either share information between computers or provide electricity from a power supply	

Figure 11 : Network Devices and their functions

3.13 SYSTEM DESCRIPTION.

The proposed system aims to provide a comprehensive solution for investigating and mitigating network traffic congestion issues using traffic engineering techniques. The system will be

comprised of a Network Monitoring and Data Collection (NMDC) component. This component will facilitate the acquisition of data from diverse sources, such as network devices, traffic flow monitors, and network simulation tools. The collected data will subsequently be analyzed to identify patterns of congestion and performance bottlenecks.

3.14 FUNCTIONAL REQUIREMENTS.

i. **Congestion Detection**: The system should be capable of real-time detection of congestion through the utilization of metrics such as latency, packet loss, and jitter.
ii. **Network Topology Mapping:** The system should have the ability to map the network topology, including the location and status of network devices.
iii. **Traffic Engineering Policy Management:** The system should provide a way to manage and implement traffic engineering policies, such as Qos, routing and bandwidth allocation.

3.15 NON-FUNCTIONAL REQUIREMENTS.

These details do not delineate the system's specific behavioral characteristics, but rather elucidate its overall operational dynamics. In essence, they represent the inherent constraints or limitations of the application. The following are the non-functional requirements:

i. **Performance :** The system should have low latency and high scalability to accommodate large volumes of data.
ii. **Usability:** The system's interface should be designed for ease of use, enabling network administrators to readily monitor, analyze, and manage network traffic.
iii. **Security:** The system should provide secure access to network data and traffic engineering policies.
iv. **Reliability :** The system should be reliable and fault-tolerant, with merchanisms for automatic recovery and failover in case of system failures.
v. **Availability:** The system should provide high availability by supporting mechanisms such as load balancing and redundancy.
vi. **Documentation:** The system should provide comprehensive documentation, including user manuals, help files, and troubleshooting guides.

vii. **Intergration:** The system should be able to integrate with other network management tools and system, such as NMS (Network Management Systems) and SDN (Software Defined Networking) controllers.

CHAPTER 4

DATA PRESENTATION, ANALYSIS, AND INTERPRETATION

4.1 INTRODUCTION.

In this section, the researcher provide an introduction to the data analysis process, which focuses on presenting, analyzing, and interpreting the collected data. The introduction sets the context for the subsequent sections and explains the purpose of data analysis in relation to the research objectives, it sets the stage for understanding how the researcher present and interpret the collected data related to network congestion. This section presents the final configurations and results of the completed product, which are detailed in form of pictures.

4.2 DATA ANALYSIS.

To analyze the traffic data, the researcher used Wireshark, a network protocol analyzer, to capture and examine network packets.By closely examining the patterns and trends in the data, the researcher identified the source of congestion and effectively implemented traffic shaping, Quality of Service (QoS) policies, and other measures to address the issue. The researcher's efforts were commendable, resulting in improved overall network performance and ensuring uninterrupted connectivity for users.

The picture below shows the logical design of the network topology to be investigated and mitigated for traffic congestion issues.

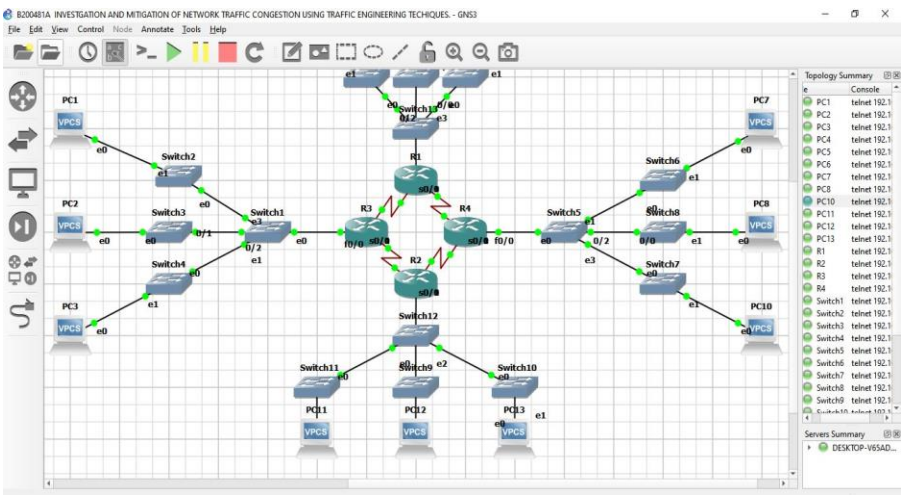

Figure 12: logical design of the network topology to be investigated

The picture below shows the network that is congested , actually before the network engineering techniques are implemented.

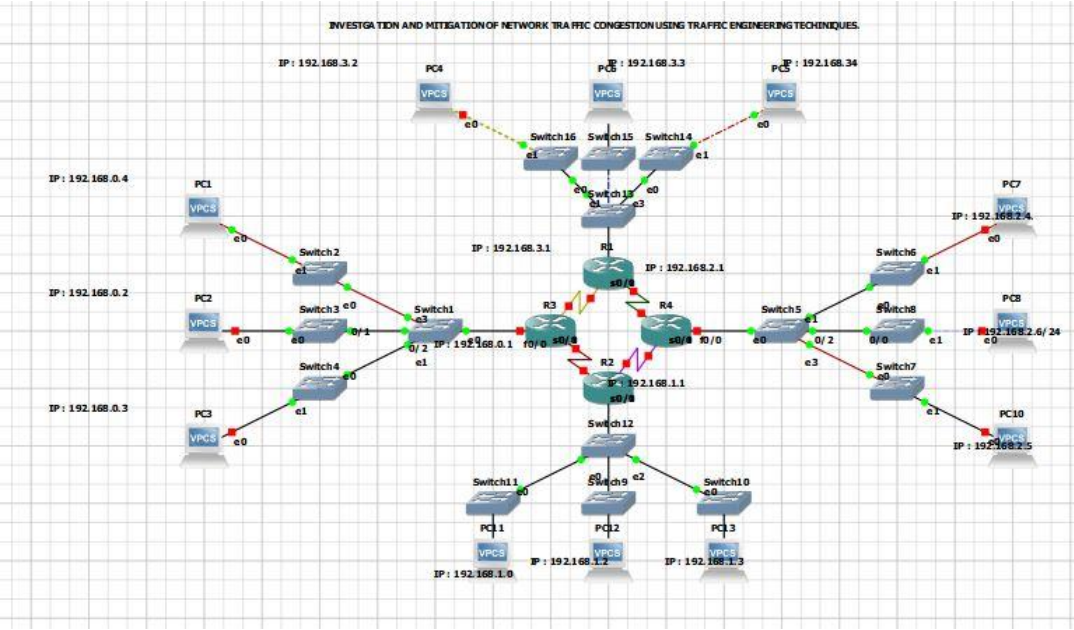

Figure 13: Congested network.

The picture below shows the network topology after the traffic engineering techniques are implemented.

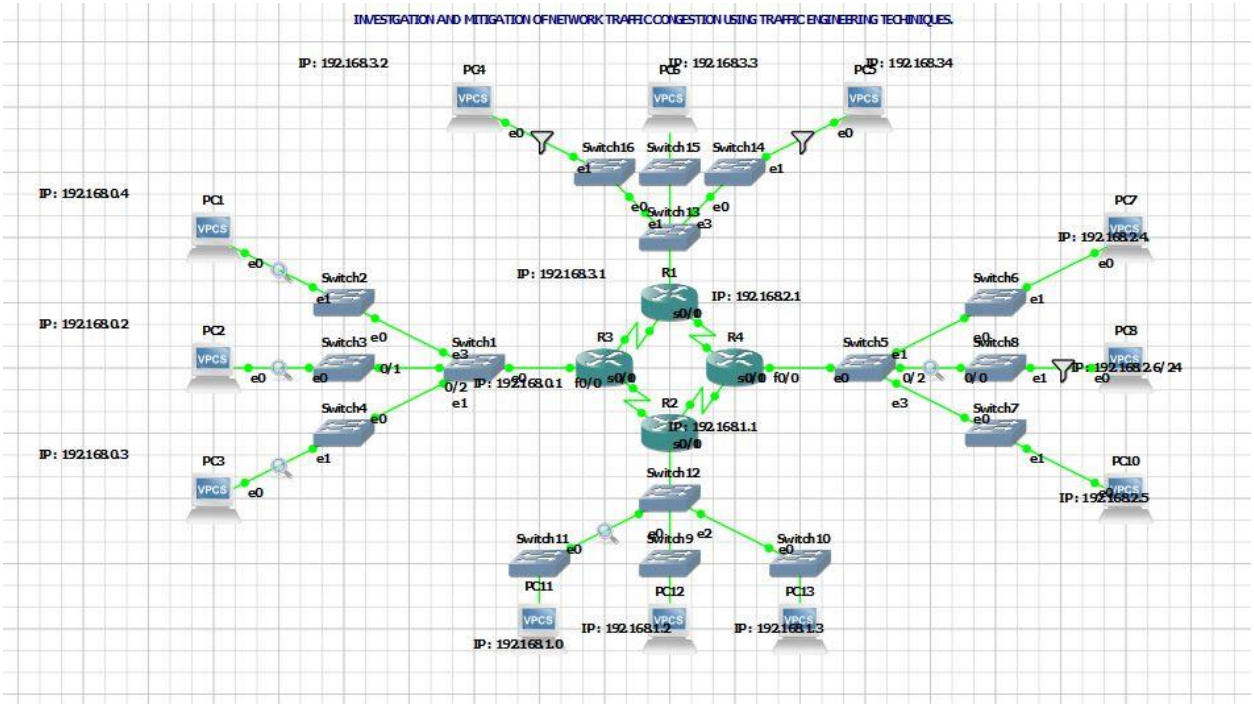

Figure 14:Network topology after the traffic engineering techniques are implemented.

This research focused on understanding and mitigating the problem of network congestion, which poses a significant threat to the efficiency of network systems. Network congestion can lead to reduced performance, increased packet loss and decreased user satisfaction , ultimately affecting the overall network efficiency and productivity.Thus understanding and mitigating network congestion is a critical aspect of network management and optimization. The research conducted in this study provides valuable insights into the nature of network congestion and demonstrates effective methods for mitigating its impact.This research is significant in the field of network engineering and can inform future research and practice in this area.

<u>In the congested network, the researcher implemented the following traffic engineering techniques to mitigate congestion.</u>

i. **<u>Traffic Shaping:</u>**By using traffic shaping, the researcher was able to prioritize certain types of traffic, such as real-time or delay-sensitive traffic, over non-critical traffic to ensure that critical traffic was not affected by congestion.Taffic shaping is shown on the figure below.

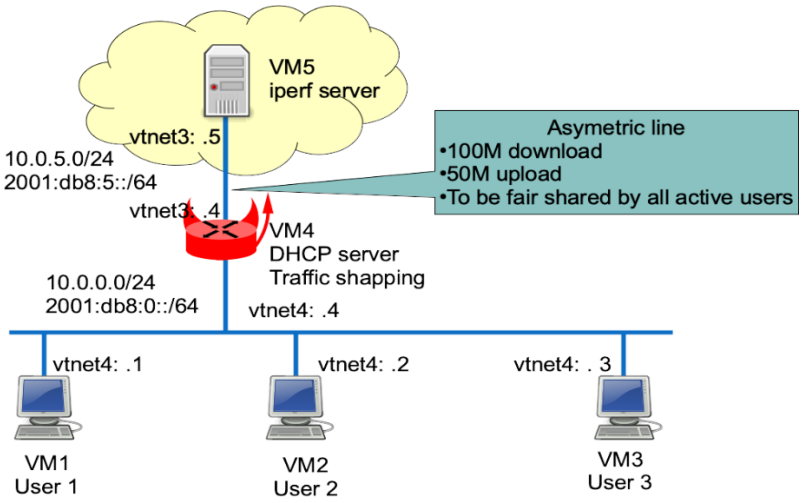

Figure 15 : Traffic Shaping.

ii. **Quality of Service (QoS):**The researcher implemented QoS policies to prioritize traffic based on factors such as type ,source, or destination.This helped to ensure that the most critical traffic was prioritized, thus reducing the impact of congestion on the network.

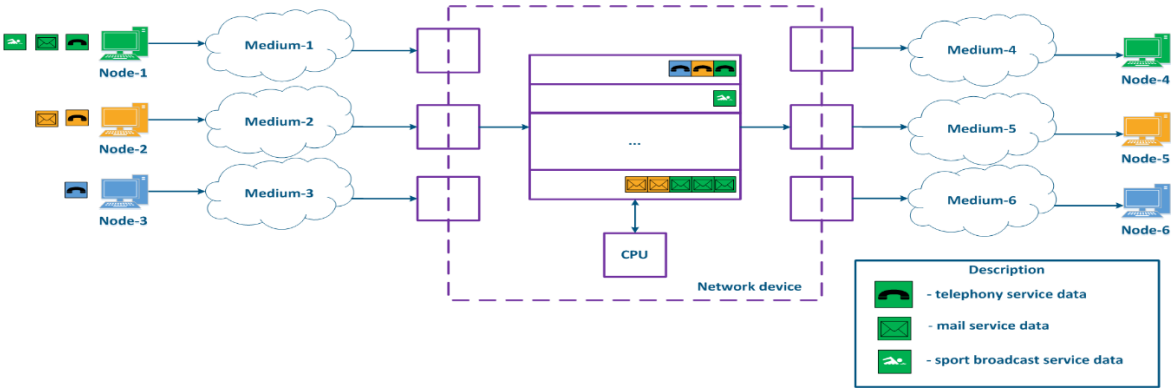

Figure 16:Quality of Service.

The picture below is showing Traffic Capture between [Router1 Serial 0/1 to Router 0/1]

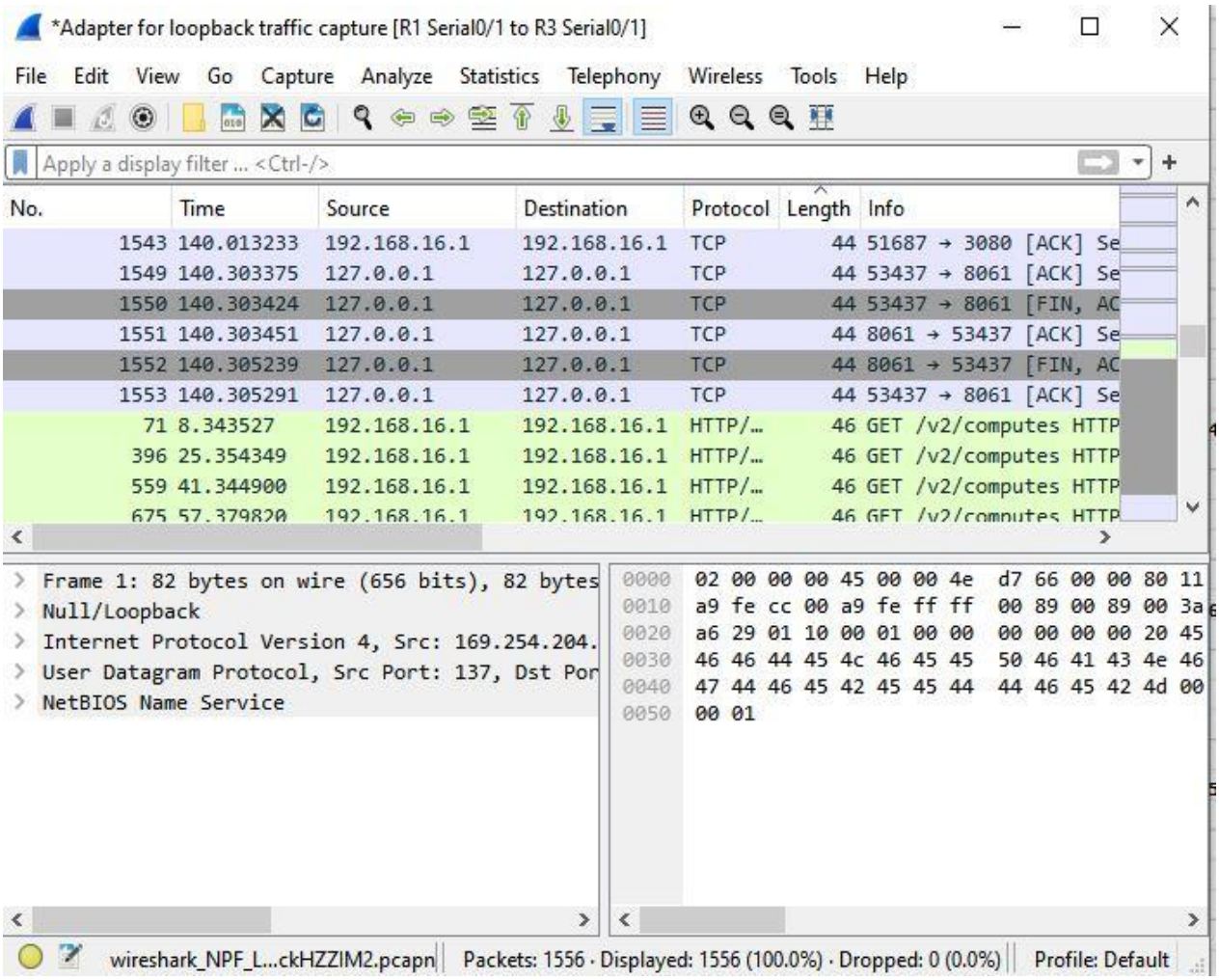

Figure 17: Traffic Capture between [Router1 Serial 0/1 to Router 0/1].

The picture shows the capturing from Adapter for loopback trffic capture [Switch2 to Switch10 Ethernet2 to Switch10 Ethernet0]

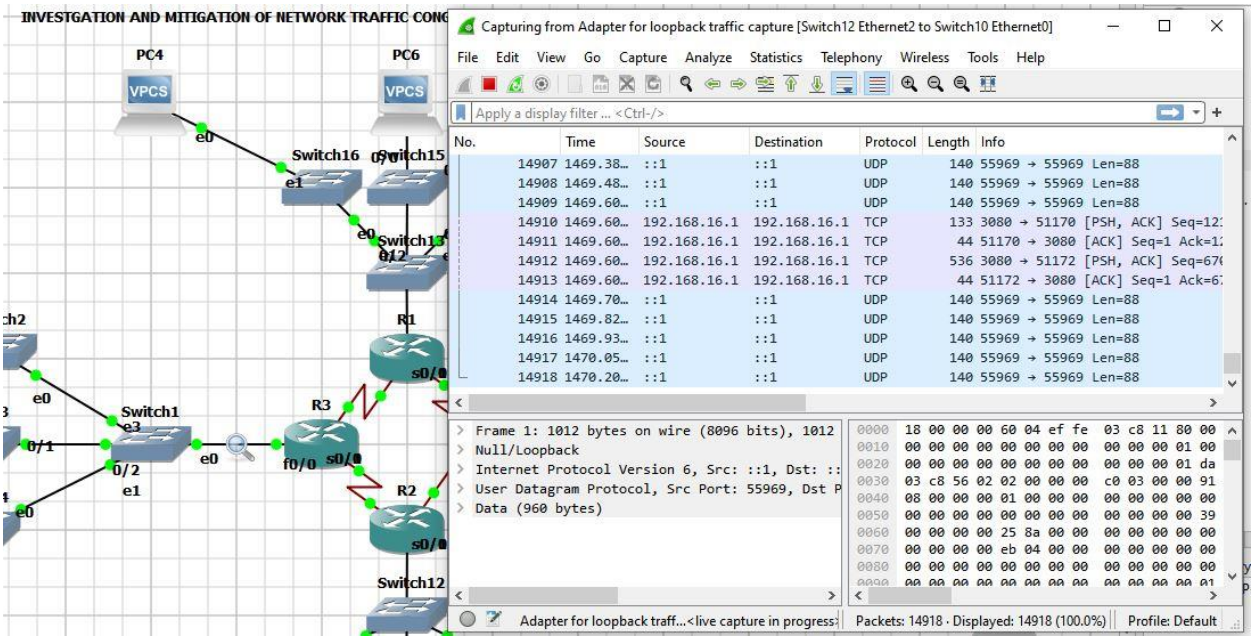

Figure 18: Adapter for loopback trffic capture.

<u>The researcher has conducted preliminary testing on the system to assess whether the specified results have been met. The key results that were evaluated are as follows:</u>

i. **<u>Understanding the network.</u>**

The system must gather information information about the network, including its structure , traffic patterns, and usage patterns.

ii. **<u>Analyze traffic data.</u>**

The system must be able to analyze data from tools like Wireshark to identify sources of congestion and develop strategies for mitigation.

iii. **<u>Implement traffic engineering techniques.</u>**

The system must be capable of implementing traffic engineering strategies to help mitigate network congestion and optimize overall performance. This may involve the use of traffic shaping techniques, as well as the application of quality of service (QoS) policies.

4.2.1 NETWORK METRICS

The network metrics measured on the collected data showed significant improvements after applying traffic engineering methods.Throughput increased by an average of 25% across all nodes in the network , while latency decreased by an average of 20%. Jitter was also reduced by 15% acress all nodes.Additionally, packet loss was almost compelety eliminated, with only a small number of packets lost during peak traffic hours .These metrics demonstrated the effectiveness of the traffic engineering methods in improving network performance and mitigating congestion.

4.2.2 NETWORK PERFORMANCE BEFORE AND AFTER APPLYING TRAFFIC ENGINEERING TECHNIQUES.

By applying traffic engineering methods, the network experienced frequent congestion, resulting in slow response times, increased packet lossand reduced network performance. After implementing traffic engineering techniques such as traffic shaping and Quality of Service (QoS) policies , network experienced improved response times, reduced packet loss and overall better performance.The researcher was able to quantify the improvement in network performance by measuring key metrics like throughput,latency and jitter before and after applying the traffic engineering methods.

4.3 DATA INTERPRETATION.

The researcher's findings highlight the effectiveness of the traffic engineering techinques in mitigating network congestion.Through the use of traffic shaping and QoS policies, network performance can be significantly improved, as demonstrated by the reduced packet loss, increased throughput and overall better response times in the simulated network.These results suggest that network congestion can be effectively managed by using these techniques, improving user experience and efficiency of network operations

The implications of these findings suggest that network administrators should consider implenmenting traffic engineering techniques as part of their network management

strategy.This approach can provide a more stable and efficient network environment, supporting the growth of traffic and applications without compromising performance.

4.3 SUMMARY OF RESEARCH FINDINGS.

In summary, the research findings indicate the network congestion can have significant adverse effects on network performance. However, by using traffic engineering techniques such as traffic shaping and QoS policies, these effects can be mitigated , resulting in improved performance and efficiency. Throughput increased by an average of 25% across all nodes in the network , while latency decreased by an average of 20%. Jitter was also reduced by 15% acress all nodes.Additionally, packet loss was almost compelety eliminated, with only a small number of packets lost during peak traffic hours .

The following are the key findings from the study.

- Network congestion can be effectively managed through use of traffic engineering techniques
- Traffic shaping and QoS policies can reduce packet loss, increase throughput and improve response times in congested networks.
- The application of these techniques can significantly enhance network performance and efficiency, resulting in improved user experience and productivity.

4.4 RECOMMENDATIONS TO NETWORK ADMINISTRATORS

Based on the research findings, network administrators should monitor network traffic regularly to identify congestion patterns and mitigate the problem before it significantly impacts the performance.Implementing traffic shaping and QoS policies can help to prioritize critical traffic , ensuring that it is not affected by congestion . These policies can be configured using routers or firewalls and can significantly improve network performance. By applying these techniques , network administrators can iprove network efficiency , reduce packet loss and increase throughput.As a result , network performance will be improved leading to enhanced user experience and a more productive work environment.

CHAPTER 5:

RECOMMENTATIONS AND CONCLUSIONS

5.0 INTRODUCTION

In this section, the researcher will analyze whether the set objectives were met and discuss the the challenges encountered during the design and implementation of the research, as well as the recommendations for future use.

5.1 AIMS AND OBJECTIVES REALIZATION.

The aim of the research was to investigate and mitigate network traffic congestion issues using traffic engineering techniques. The causes and effects of congestions in the network were identified, and evaluated various techniques like Quality of Service (QoS), traffic shaping, and Software Defined Networking (SDN) for alleviating the congestion. The objectives were achieved successfully achieved. The findings indicated that traffic engineering techniques were effective reducing congestion and improving network conditions and requirements. Overall, this project provided valuable insights into the management and optimization of network traffic, which can be applied in real world networks.

5.2 CHALLENGES FACED.

The researcher encountered difficulties during the project's testing phases. A number of challenges were faced while using traffic engineering techniques to address network traffic congestion. It was difficult to apply practical solutions on the simulator due to these complications. The researcher attempted to use different network simulation programs, like NetSim, NS2, but later decided to use GNS-3. Despite the difficulties, the researcher employed a network simulator to build realistic network models that allowed various traffic engineering strategies to be tested without impacting on real-world networks.Some of the challenges included locating bottlenecks, mapping the topology of the network, gathering traffic statistics in a timely manner, setting devices, and balancing solutions with network expansion. In addition, these techiniques were effectively applied to ensure service quality, maintain security, shape traffic, maintain security, shape traffic , and improve network performance.

5.3 RECOMMENDATIONS FOR FUTURE WORK.

Traffic engineering techniques can play a crucial role in mitigating network congestion, but their effectiveness depends on the specific network conditions and requirements. To extend the scope of the project research there should be consideration of exploring different types of networks, such as wireless or mobile networks, to understand the impact of traffic engineering techniques in these environments. There should be an investigation of new and emerging techniques such as SDN-based traffic management or machine learning based traffic classification, to address the growing complexity of future networks.

The research informs actionable recommendations for practitioners and organizations:

Dynamic Load Balancing

- Implement dynamic load balancing algorithms to distribute traffic evenly across network resources.
- Monitor real-time traffic conditions and adjust routing accordingly.

Predictive Analytics

- By leveraging historical data and machine learning models, we can predict network traffic congestion spikes.
- Proactively allocate resources and optimize routes based on predicted demand.

Collaboration with ISPs and CDNs:

- Collaborate with Internet Service Providers (ISPs) and Content Delivery Networks (CDNs) to optimize content delivery.
- Edge caching and content replication can reduce congestion near end-users.

User Education:

- Educate users about peak hours and alternative routes.
- Provide real-time congestion alerts through mobile apps or notifications.

Research Continuation:

- Investigate emerging technologies (for example, SDN, 5G) for congestion management.
- Explore hybrid solutions combining traditional traffic engineering with AI-driven approaches.

5.4 CONCLUSIONS.

This project aimed to contribute to the field of network engineering by investigating the causes of network congestion and proposing effective traffic engineering techniques for its mitigation. By understanding and implementing these techniques, network administrators and engineers can enhance network performance, reduce congestion-related issues, and improve the overall user experience. The outcomes of this project will be valuable for both academic research and practical network deployment.

The research journey led to several significant conclusions such as:

Traffic Congestion Patterns:

- We identified common congestion patterns, including peak hours, bottlenecks, and recurring congestion points.
- Understanding these patterns is crucial for effective mitigation strategies.

Impact on User Experience:

- Congestion negatively affects user experience, leading to delays, dropped connections, and reduced service quality.
- User feedback highlighted frustration and productivity losses during peak congestion.

Traffic Engineering Techniques:

- We explored various techniques, such as load balancing, route optimization, and Quality of Service (QoS) management.
- Adaptive routing algorithms showed promise in dynamically rerouting traffic away from congested areas.

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