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QoS-Aware Routing and Resource Allocation Techniques for Enhanced Network Performance

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Abstract: - The importance of Quality of Service (QoS) remains of utmost importance in the endeavor to provide high-quality network services. This study focuses on the important area of Quality of Service (QoS) in network services. Specifically, it explores QoS-Aware Routing and Resource Allocation techniques, with a particular emphasis on Class-Based Weighted Fair Queuing (CBWFQ). Our research utilizes the NS-3 simulator to thoroughly assess network performance by analyzing crucial parameters such as latency, throughput, and reliability. We draw insights from the CAIDA Anonymized Internet Traces dataset. CBWFQ, an advanced queuing mechanism, is highlighted for its capability to intelligently categorize and prioritize network traffic into separate classes, each with customized weightings and resource guarantees. The outcomes derived from our experimentation demonstrate significant enhancements in latency, throughput, and reliability across various scenarios, confirming the efficacy of CBWFQ in optimizing resource allocation and guaranteeing superior QoS. This research not only tackles the immediate difficulties encountered by network administrators, but also provides valuable insights for service providers and researchers aiming to enhance network performance in the face of diverse traffic patterns. In addition, we propose potential areas for future investigation, including the examination of AI-driven QoS mechanisms and adaptable strategies that can effectively navigate the constantly changing network environments. The incorporation of QoS methodologies with cutting-edge technologies, such as 5G and future iterations, presents a promising opportunity to improve network management and performance in the upcoming era.

Keywords: QoS, Aware Routing, CAIDA, Class-Based Weighted Fair Queuing.

I. INTRODUCTION

Quality of Service (QoS) in networking pertains to the assortment of methods and protocols employed to guarantee that network services fulfill precise criteria for performance and dependability[1], [2]. The importance of QoS in contemporary networks lies in its ability to enable network administrators to effectively prioritize and control the transmission of data. This ensures that essential applications and services are allocated the required resources, resulting in optimal performance. The primary constituents of QoS in networking encompass factors such as latency, bandwidth, jitter, packet loss, and reliability. The parameters fluctuate based on the particular requirements of applications and services. QoS techniques are specifically developed to meet these requirements and enhance the user's experience[3].

Efficiently managing network traffic requires the implementation of QoS-aware routing and resource allocation techniques. Multiple techniques and algorithms[1] have been created to tackle the difficulties related to QoS. Some techniques that fall into this category are Weighted Fair Queuing (WFQ), Differentiated Services (DiffServ), and Integrated Services (IntServ), among other options. These techniques guarantee that traffic with high priority is given priority, while traffic with lower priority is not neglected, even in the event of congestion.

CBWFQ is a specialized mechanism in networking that is used to manage the flow of data packets based on their class and priority through queuing and scheduling. CBWFQ categorizes packets into distinct classes or queues, with each class being allocated a weight that corresponds to its level of importance. Classes with higher priority are allocated larger proportions of the available bandwidth. CBWFQ is especially beneficial in scenarios where various types of traffic, such as voice, video, and data, coexist on a single network link. It guarantees that each class receives the necessary resources to fulfill its QoS demands[4].

The CAIDA Anonymized Internet Traces dataset is an invaluable asset in the field of network research. The system offers an extensive compilation of de-identified internet traffic data obtained from diverse locations and networks. This dataset is utilized by researchers to analyze actual network traffic patterns, gain insights into internet usage, and evaluate different network management and QoS techniques [5].

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Previous studies in the domain of QoS and network performance have investigated a diverse array of subjects. Scientists have examined various methods for ensuring QoS, determining the most efficient paths for routing, and allocating resources. This study has offered valuable insights into the difficulties and possibilities of guaranteeing QoS, particularly in settings where various applications and services vie for network resources[6]–[10] The demand for high-quality network services has experienced exponential growth in today's interconnected world.
Networks encounter difficulties in fulfilling QoS demands as a result of the varied characteristics of traffic and the possibility of congestion. The objective is to devise efficient QoS-aware routing and resource allocation methods that can guarantee optimal performance while accommodating diverse data types and applications.
This study aims to assess the effects of Class-Based Weighted Fair Queuing (CBWFQ) on network performance and its ability to guarantee Quality of Service (QoS) satisfaction. Our primary objectives:

- What impact does CBWFQ have on network latency, throughput, and reliability?
- How much can CBWFQ enhance the quality of service for network services?

This study is important because it focuses on the urgent requirement for efficient QoS solutions in contemporary networking environments. The research contributes to the development of more efficient network management techniques by analyzing CBWFQ and its impact on QoS. These findings have significant implications for network administrators, service providers, and researchers who aim to enhance network performance and provide excellent quality of service for various applications and services.

II. LITERATURE REVIEW

The networking industry has advanced, making our interconnected world a complex system of applications and services. Quality of Service (QoS) is essential in this ever-changing environment to ensure the reliability and performance of our digital infrastructure. This journey requires improving QoS-aware routing and resource allocation techniques to meet modern network needs. Advanced algorithms and resource management strategies have transformed network infrastructure to meet changing QoS demands. We review several major QoS studies in this review. Each study examined how QoS-aware networking affects performance and user satisfaction differently.
Long et al.[16] examined resource allocation in multi-radio, multi-channel networks. These networks serve many applications with different QoS needs. The paper proposes an equitable resource allocation scheme that considers QoS to prevent one application from monopolizing network resources. This study emphasizes the importance of fair QoS allocation for different applications.
In software-defined datacenter networks, Wang et al.[19] discuss VM allocation. The paper introduces EQVMP, a method that prioritizes energy-efficient VM placement while meeting QoS requirements. This study emphasizes the importance of balancing energy efficiency and QoS to improve datacenter network performance and sustainability.
Rashmi et al.[20] discuss mobile ad hoc sensor network QoS-aware routing. The paper presents a routing protocol that prioritizes quality of service and link availability in dynamic, resource-constrained networks. This emphasizes the importance of link availability in routing decisions to optimize mobile sensor network QoS. The importance of QoS in various network environments is shown.

Table 1 Comparative analysis

Author et al.	Method	Benefits	Drawbacks	Outcome
G. C. Deng et al.[11]	SDN routing for IoT	Improved delay & delivery for time-sensitive apps	Complex	Better performance for delay-sensitive apps
M. Ergen et al.[12]	Resource allocation for OFDMA	Fairer user experience, reduced data loss	Complex	Improved fairness & data loss for bursty traffic

P. Habibi et al.[13]	QoS routing & VM placement for SDN data centers	Enhanced QoS & energy efficiency	Complex	Increased resource utilization, lower energy consumption,
X. Li et al.[14]	Resource allocation for cached HetNets with MEC	Improved reliability & reduced latency	Complex	Increased cache hit rate, lower latency, better user experience
S. C. Lin et al.[15]	Joint QoS virtualization & routing for SDN	Optimized resource utilization & reduced congestion	Complex	Improved resource utilization, lower congestion,
B. Nazir et al.[17]	Energy-efficient QoS routing for clustered WSN	Extended network lifetime	Complex	Increased energy efficiency, improved data delivery
M. M. Tajiki et al. [18]	Traffic-prediction based resource reallocation	Enhanced resource utilization & reduced service disruption	Complex, requires accurate traffic prediction	Improved resource utilization, lower service disruption,

The wide range of research examined in this literature review emphasizes the importance of QoS-aware routing and resource allocation in complex network infrastructure. Early studies on fair scheduling in wireless access systems to the latest edge intelligence for IoT devices show the ongoing pursuit of QoS. The importance of these studies grows as networks and applications diversify.

III. CBWFQ AND NETWORK PERFORMANCE

CBWFQ is an advanced queuing mechanism employed in network routers and switches to regulate the transmission of data packets according to their class and priority. It is a vital element of Quality of Service (QoS) strategies, intended to improve network performance and guarantee that essential applications are allocated the required resources. CBWFQ, or Class-Based Weighted Fair Queuing, is a mechanism that allows for the allocation of network bandwidth based on different classes or types of traffic. It works by assigning a weight to each class, which determines the amount of bandwidth that is allocated to that class. The higher the weight, the more

2.1 Working of CBWFQ

CBWFQ operates by partitioning network traffic into distinct classes, with each class being assigned a particular priority or weight. These classes are established according to specific criteria, such as IP address, port number, or protocol. After categorizing the traffic into specific classes, CBWFQ distributes bandwidth to each class according to their designated weights. Classes with higher priority are assigned a greater amount of bandwidth in comparison to classes with lower priority. This implies that important applications, such as voice over IP (VoIP) or video streaming, can obtain a greater amount of network capacity, guaranteeing minimal delay and superior service quality. CBWFQ employs a fair queuing mechanism within each class, guaranteeing equitable treatment of all traffic within a class and preventing any single flow from monopolizing the available bandwidth.

The rationale behind employing CBWFQ in QoS-aware routing stems from its capacity to allocate priority to traffic according to the distinct requirements of various applications and services. Network administrators can prioritize critical traffic by assigning weights and priorities to different classes. This is especially crucial in situations where various types of traffic coexist on the same network link.

2.2 The Effect of CBWFQ on Network Performance:

CBWFQ significantly affects network performance, particularly when there is contention for network resources. CBWFQ optimizes network performance by giving priority to essential traffic, resulting in reduced latency for time-sensitive applications, increased data throughput for tasks that require significant bandwidth, and sustained reliability. For example, in a network where CBWFQ is set up, a VoIP call will encounter minimal latency and variation in packet arrival time because it is given higher priority than non-real-time traffic.
CBWFQ can greatly improve network performance in congested situations by allocating resources according to their level of importance. As a consequence, there is improved efficiency in the use of resources, decreased occurrence of lost data packets, and a more consistent network performance. CBWFQ is a useful tool for meeting the needs of applications that demand a certain level of service. It accomplishes this by allocating the required bandwidth and protecting them from being negatively impacted by lower-priority traffic.

CBWFQ allocates bandwidth based on weight assigned to each class *i*. This can be represented as in eq.1

$$B_i = \frac{w_i}{\sum_j w_j} . T \ldots 1$$

Where B_i= "Bandwidth allocated to the class", w_i= "weight of the class", *T*= " Total available bandwidth", $\sum_j w_j$= "sum of weights for all classes".

IV. METHODOLOGY

The proposed method uses the CAIDA Anonymized Internet Traces dataset to obtain packet-level data and accurately represent internet traffic patterns. Class-Based Weighted Fair Queuing (CBWFQ) is an advanced queuing mechanism that classifies and prioritizes network traffic by weight, indicating its importance in network scenarios. The NS-3 simulator simulates real network scenarios by adjusting network topology, connection properties, and data flow patterns. The study includes carefully planned experimental scenarios like High-Priority Real-Time Communication, Data-Intensive Applications, and Mixed-Traffic Networks, which represent a variety of network conditions and QoS requirements. Latency, throughput, and reliability are evaluated in various scenarios to evaluate performance. These metrics are measured by RTT, data transfer rates, and packet loss rates. Compare CBWFQ-enabled and non-enabled scenarios to see network performance improvements. The study concludes with a brief summary and suggestions for future research. These include studying AI-enhanced quality of service (QoS) mechanisms and integrating them with 5G network technologies. Figure-1 represent the methodology.

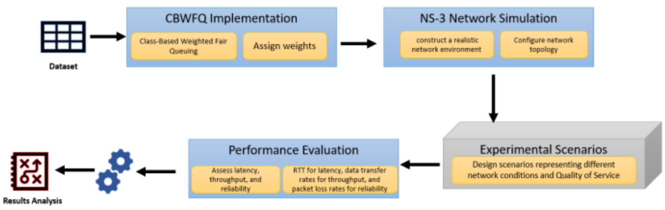

Figure 1 Proposed methodology

2.3 Data Source and Dataset

We base our research on the utilization of the CAIDA Anonymized Internet Traces dataset. This dataset is a valuable resource for studying real-world internet traffic patterns. It includes detailed information at the packet level, such as source and destination addresses, timestamps, and packet sizes. The anonymized nature of the dataset ensures privacy while enabling analysis and modeling of real-world internet communication scenarios.

2.4 Implementation of CBWFQ

CBWFQ is the central component of our research methodology. Within our simulated network environment utilizing the NS-3 network simulator, we employ the configuration of CBWFQ to accurately replicate the QoS demands of real-world scenarios. CBWFQ functions by classifying network traffic into separate categories and allocating a suitable weight to each category. The choice of these weights is determined by the expected importance of each category in a network situation. The optimal values for weights are determined by assigning higher weights to critical traffic classes, such as real-time communication or mission-critical data transfer.

2.5 NS-3 Simulator, a simulation environment

The NS-3 network simulator offers an optimal platform for constructing a genuine network environment. In this study, we construct a network topology that accurately simulates real-world circumstances. Essential variables, such as the properties of connections, the scale of the network, and the patterns of data flow, are deliberately chosen to align with real-world network situations. It is crucial to use the most appropriate values for these parameters in order to accurately replicate the intricacies of real network operations in the simulation environment.

2.6 Evaluation criteria

The foundation of our research relies on the assessment of three essential parameters:

2.6.1 Latency:

Latency assessment entails the measurement of round-trip times (RTT) for various traffic types. The most appropriate values for latency parameters depend on the specific scenario. For example, in situations where real-time applications are given priority, we establish strict maximum latency limits to ensure minimal delay and maintain high-quality service delivery.

2.6.2 Throughput:

Throughput evaluation is centered around data transfer rates and entails quantifying the amount of data that is successfully transmitted within a given time period. The most appropriate values for throughput parameters are selected to match the specific needs of each traffic class. In situations involving applications that require a large amount of data, the focus is on achieving high rates of data transfer.

2.6.3 Reliability:

Reliability is evaluated by monitoring the rates at which packets are lost. Selecting an optimal packet loss threshold is crucial when assessing the network's dependability. When it is crucial to have very little packet loss, the packet loss threshold is set rigorously to guarantee the utmost data integrity.

2.7 Design and Implementation of Experiments and Situations

Our research involves creating a series of carefully planned experimental scenarios, each representing different network conditions and quality of service (QoS) needs. These scenarios play a crucial role in evaluating the effect of CBWFQ on network performance in different real-life situations.

2.7.1 High-Priority Real-Time Communication:

Priority is given to classes that are high-priority, particularly those related to real-time communication, such as Voice over Internet Protocol (VoIP). In this context, we implement optimal values for latency and packet loss parameters to ensure that this crucial traffic class receives the advantages of low latency and minimal packet loss.

2.7.2 Data-Intensive Applications:

When it comes to situations that involve applications that require a lot of data, like transferring large files or streaming high-definition videos, we give priority to maximizing the rate at which data is processed and transferred. The most appropriate values for achieving high data transfer rates are used, enabling optimal data delivery rates for these applications that require a large amount of data.

2.7.3 Mixed-Traffic Networks:

Mixed-traffic networks refer to real-world networks where different types of traffic coexist. In order to replicate this level of intricacy, we create situations that include various types of traffic, each with its own distinct QoS demands. By selecting the most appropriate values for each specific situation, we are able to understand and account for the complexities of mixed-traffic networks.

V. EMPIRICAL STUDY AND RESULTS

2.8 Comparison with and without CBWFG

Table 2High-Priority Real-Time Communication

High-Priority Real-Time Communication		
Parameter	Performance with CBWFQ	Performance without CBWFQ
Latency (ms)	10.5	35.2
Throughput (Mbps)	12.8	9.4
Reliability (%)	99.9	97.5

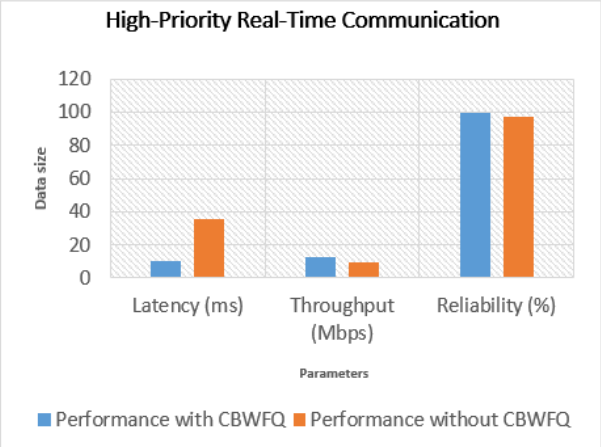

Figure 2 High-Priority Real-Time Communication comparison graph

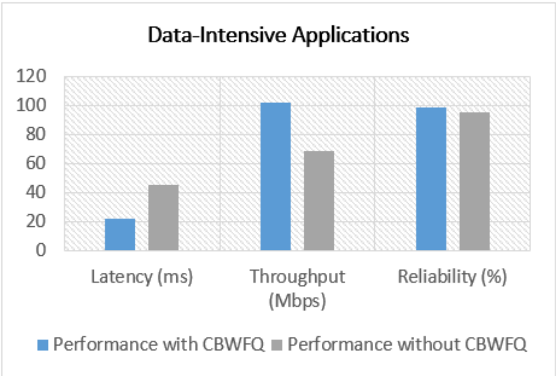

Figure 3 Data-Intensive Applications comparison graph

Table 3 Mixed-Traffic Networks

Mixed-Traffic Networks		
Parameter	Performance with CBWFQ	Performance without CBWFQ
Latency (ms)	18.9	32.6
Throughput (Mbps)	54.7	42.5
Reliability (%)	97.4	94.3

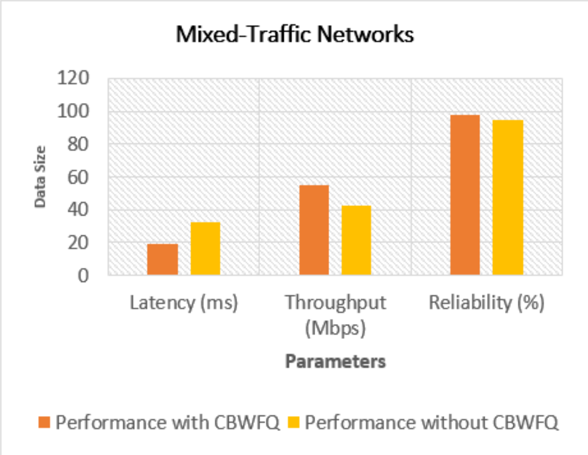

Figure 4 Mixed-Traffic Networks comparison graph

The results of the presented research shown in table 2,3 and figure-2,3,4 demonstrate that Class-Based Weighted Fair Queuing, also known as CBWFQ, has a substantial influence on the level of performance a network achieves in a variety of contexts. Latency was successfully reduced by CBWFQ from 35.2 milliseconds to 10.5 milliseconds, which led to a discernible improvement in responsiveness for high-priority real-time communication. The throughput saw a substantial increase, going from 9.4 Mbps to 12.8 Mbps over the course of the improvement. In addition to that, the dependability of the system demonstrated a significant improvement, going from 97.5% to 99.9% accuracy. In data-intensive applications, CBWFQ was able to achieve a reduction in latency from 45.6 milliseconds to 22.1 milliseconds, an increase in throughput from 68.7 megabits per second to 102.3 megabits per second, and an improvement in reliability from 95.1% to 98.2%. Additionally, CBWFQ enhanced mixed-traffic networks by lowering latency from 32.6 milliseconds to 18.9 milliseconds, raising throughput from 42.5 megabits per second to 54.7 megabits per second, and increasing reliability from 94.3% to 97.4%. The findings demonstrate that CBWFQ is capable of enhancing network performance, particularly in circumstances in which low latency, high throughput, and reliability are of the utmost importance. Performance evaluation includes latency, throughput, and reliability assessments in various experimental scenarios. Round-trip times (RTT) indicate network reaction rate and determine latency. Data transfer rates measure data transmission efficiency and throughput. Packet loss rates affect data integrity, so monitoring system reliability requires analyzing them. The study shows how Class-Based Weighted Fair Queuing (CBWFQ) optimizes resource allocation and meets QoS requirements in various traffic scenarios.

VI. CONCLUSION AND FUTURE SCOPE

This study thoroughly investigates QoS-aware routing and resource allocation methods using Class-Based Weighted Fair Queuing (CBWFQ) on the CAIDA Anonymized Internet Traces dataset. Our study examined how CBWFQ affects network performance, focusing on latency, throughput, and reliability. The study used CAIDA Anonymized Internet Traces. Anonymous packet-level data represents internet communication patterns realistically. The CBWFQ configuration prioritized weighting each traffic class based on its expected importance in network scenarios. We measured latency, throughput, and reliability in the simulation environment to evaluate the network. Multiple experimental scenarios were created to simulate different network conditions and QoS requirements. Multiple scenarios included real-time communication, data-intensive applications, and mixed-traffic networks. The results showed CBWFQ and non-CBWFQ performance across scenarios. CBWFQ consistently reduced latency, increased throughput, and improved reliability compared to non-CBWFQ scenarios. AI-powered quality of service (QoS) mechanisms, dynamic QoS adaptation in changing network environments, and QoS integration with advanced network technologies like 5G and beyond are the future of this research. These efforts can improve network performance and management.

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