



Application of RED and PCQ Algorithms for Network Traffic Management in CBT Systems

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ABSTRACT

The digital transformation in education has encouraged the adoption of computer-based tests (CBT) using video content, which demands stable and efficient network performance. This study aims to evaluate the performance of two queue management algorithms, namely Random Early Detection (RED) and Per Connection Queue (PCQ), in maintaining the quality of service (QoS) of school networks during online video-based examinations. A case study approach was applied using a real network topology in a school environment, and QoS parameters such as throughput, delay, packet loss, and jitter were measured. The implementation was conducted using a MikroTik RB450Gx4 router configured with simple queue settings for each algorithm. The results show that PCQ provides more consistent performance under high user loads, achieving an average throughput of 56,482 bps and lower delay compared to RED. Conversely, RED performs better in scenarios with a small number of users. The study recommends using PCQ for networks with dynamic and dense user environments, while RED is more suitable for low-traffic conditions where latency stability is crucial. These findings offer practical guidance for managing bandwidth and improving the quality of CBT delivery in educational settings.

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1. INTRODUCTION

The implementation of computer-based tests (CBT) in educational evaluation systems has become essential in line with the increasing digitalization of schools [1]. One rapidly growing form of CBT is the use of video as a testing medium to assess practical and simulation-based skills. While the use of video enhances the validity of assessment, it also requires high-performance and consistently stable network infrastructure [1].

In many educational institutions, limited network infrastructure remains a major challenge, especially during simultaneous examinations involving numerous participants. Disruptions such as buffering, transmission delays, and video quality degradation can hinder the smooth conduct of the tests and negatively impact students' learning outcomes. Therefore, a technical solution is needed to intelligently manage network traffic, particularly under high-usage conditions. Simulation-based explorations involving the A* pathfinding algorithm [2], and omni-wheel robots have previously been discussed [3].

One approach to addressing these issues is the implementation of data queue management algorithms, such as Random Early Detection (RED) and Per Connection Queue (PCQ). RED functions as a congestion avoidance mechanism by randomly dropping packets before the queue reaches full capacity [4], while PCQ ensures fair bandwidth distribution among active connections [5]. Although both algorithms have been widely utilized in general network management, their application in educational network environments serving video-based CBT systems remains scarcely explored. Network traffic management has become a critical aspect in maintaining Quality of Service (QoS), particularly in high-density environments such as Computer-Based Test (CBT) laboratories. When traffic surges significantly, as during simultaneous online examinations, the risk of delay, packet loss, and network congestion increases, thereby reducing overall system efficiency.

Various Active Queue Management (AQM) approaches have been developed to anticipate such network challenges. One of the most well-known AQM algorithms is Random Early Detection (RED), which probabilistically drops packets before the queue becomes full. However, conventional RED has limitations, particularly due to its fixed packet-dropping parameters that are not adaptive to dynamic network conditions [6]. To address RED's rigidity, numerous researchers have proposed enhanced algorithmic variations. For instance, the mDBetaRED algorithm [7] introduces dynamic adjustment to better adapt to mixed network characteristics.

The adaptive AAQM model manages packet queues in router buffers to prevent congestion and packet loss, demonstrating superior performance over other AQM methods, especially under high-traffic conditions with high throughput and acceptable delay levels [6]. EX-RED was developed to dynamically tune RED parameters based on traffic load or the number of active connections [8]. Additionally, the

packet-dropping functions in RED have been modified into nonlinear forms to respond more effectively to varying levels of congestion, as implemented in algorithms such as QERED and TR-RED [9], [10].

Artificial intelligence approaches have also begun to be integrated into network congestion management, as seen in the use of decision tree models in DREaD, as well as in DAIM-RED and its further development, DRL-RED, which manage congestion adaptively through overflow prediction and automatic parameter adjustment [11], [12]. These models have demonstrated improved network performance, queue stabilization, and enhanced Quality of Service under complex traffic conditions [12].

These findings suggest that enhancements to RED—when combined with traffic grouping logic or connection-based bandwidth allocation—offer significant practical value. Based on the reviewed literature, it can be concluded that the integration of adaptive RED with PCQ, which ensures fair bandwidth distribution, represents a highly relevant and robust solution for CBT laboratory networks. This hybrid approach enables adaptive, probabilistic congestion control while maintaining equitable traffic distribution per user, resulting in a more stable, responsive, and efficient system.

This study is conducted to address the aforementioned needs by focusing on the analysis and performance comparison of RED and PCQ algorithms in managing school network traffic. The evaluation is based on key Quality of Service (QoS) parameters, namely throughput, delay, packet loss, and jitter. By understanding the strengths and limitations of each algorithm in real-world application contexts, this research aims to contribute meaningfully to the development of educational network systems that are more responsive and equitable in supporting technology-based assessments.

1.1 THEORETICAL REVIEW

Network management is a critical aspect in ensuring Quality of Service (QoS) within data communication systems, particularly in environments experiencing high simultaneous traffic, such as video-based computer-based testing (CBT) implementations in schools. Therefore, efficient and fair queue control algorithms are required to handle traffic loads effectively.

QoS parameters used to evaluate network performance include throughput, delay, packet loss, and jitter. Throughput refers to the rate of successfully transmitted data per unit of time. Delay measures the time taken for data to travel from sender to receiver. Packet loss indicates the percentage of data packets lost during transmission, while jitter quantifies the variation in packet arrival times. These four parameters are crucial in ensuring user experience within a network, especially for video-based transmissions [13].

The Random Early Detection (RED) and Per Connection Queue (PCQ) algorithms are two widely adopted approaches in queue management. RED operates based on the principle of Active Queue Management (AQM), which randomly drops packets as the queue begins to fill, preventing total congestion. By applying lower (minth) and upper (maxth) threshold values, RED calculates the probability of packet dropping using the following equation:

$$P_d = P_{max} \cdot \frac{avgq - min_{th}}{max_{th} - min_{th}}$$

Where P_d represents the packet dropping probability, $avgq$ is the average queue length, min_{th} , max_{th} denote the lower and upper threshold values, respectively, and P_{max} is the maximum packet drop probability.

To clarify the operational logic of the RED algorithm, the following conceptual illustration presents the decision flow for packet dropping based on queue threshold levels:

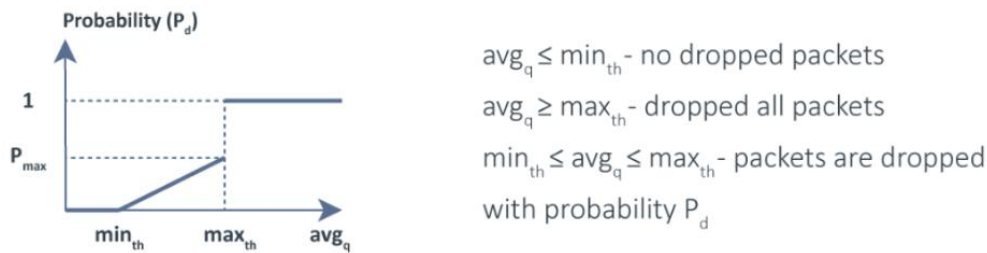


Figure 1. Conceptual Illustration of the RED Algorithm Mechanism with Packet Drop Thresholds (minth, maxth)

On the other hand, the Per Connection Queue (PCQ) algorithm allocates bandwidth evenly based on active connections, whether defined by IP address, port number, or user identity. PCQ is an advancement of the Stochastic Fairness Queuing (SFQ) algorithm, offering greater flexibility in traffic classification. Compared to SFQ, PCQ provides a more balanced distribution of bandwidth under high-traffic conditions [14].

To enhance clarity, the operational principle of PCQ in managing bandwidth distribution among connections is illustrated as follows:

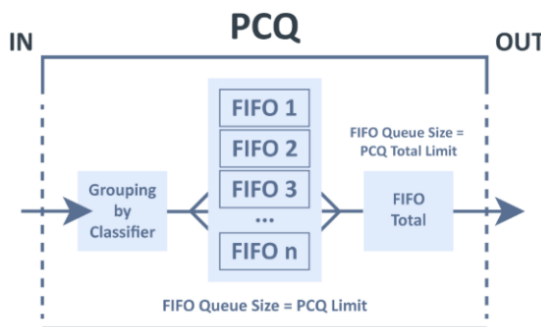


Figure 2. Bandwidth Allocation Diagram Based on Active Connections in the PCQ Algorithm

RED has proven effective in reducing delay; however, its performance becomes inconsistent as the number of users increases [1]. In contrast, PCQ excels in maintaining stable throughput and minimizing packet loss, particularly under high-traffic conditions [15]. Other studies have emphasized that RED is more suitable for network environments with moderate traffic levels [4].

Most prior research has focused on general network environments such as ISPs or laboratory setups, with limited exploration of RED and PCQ implementations in school networks, particularly those utilizing video-based CBT systems. Therefore, this study seeks to fill that gap by conducting direct experiments within a school environment to empirically evaluate the effectiveness of both algorithms in relation to Quality of Service (QoS).

2. RESEARCH METHODOLOGY

This study employed an experimental case study design to comprehensively evaluate and compare the performance of two queue management algorithms—Random Early Detection (RED) and Per Connection Queue (PCQ)—in supporting video-based Computer-Based Test (CBT) environments. In addition to measuring classical Quality of Service (QoS) metrics, the study analyzed detailed network traffic patterns captured via packet inspection to assess each algorithm's responsiveness and fairness under varying user loads (5, 10, and 15 users).

The experimental setup was deployed at a vocational high school in Jakarta, which has a local area network (LAN/WLAN) infrastructure and fixed broadband access. The location was chosen due to its real-world application of video-based CBT and its ongoing challenges with traffic congestion and fairness during assessments. Data was gathered over a one-month period during planned test simulations.

The network used a consistent topology across all tests, with a MikroTik router (RB450Gx4, RouterOS v6) serving as the central traffic control point. A simple queue mechanism was used to implement RED and PCQ alternately, with identical hardware, IP distribution, and access scenarios. A total of 20 student computers were configured to simulate CBT sessions by streaming preloaded 5-minute video segments simultaneously.

The network topology used in the study is illustrated in Figure 3. In this topology, a MikroTik router functions as the central traffic management device. Two separate test scenarios were conducted: the first using the RED algorithm and the second using the PCQ algorithm, both under identical network topologies and user loads.

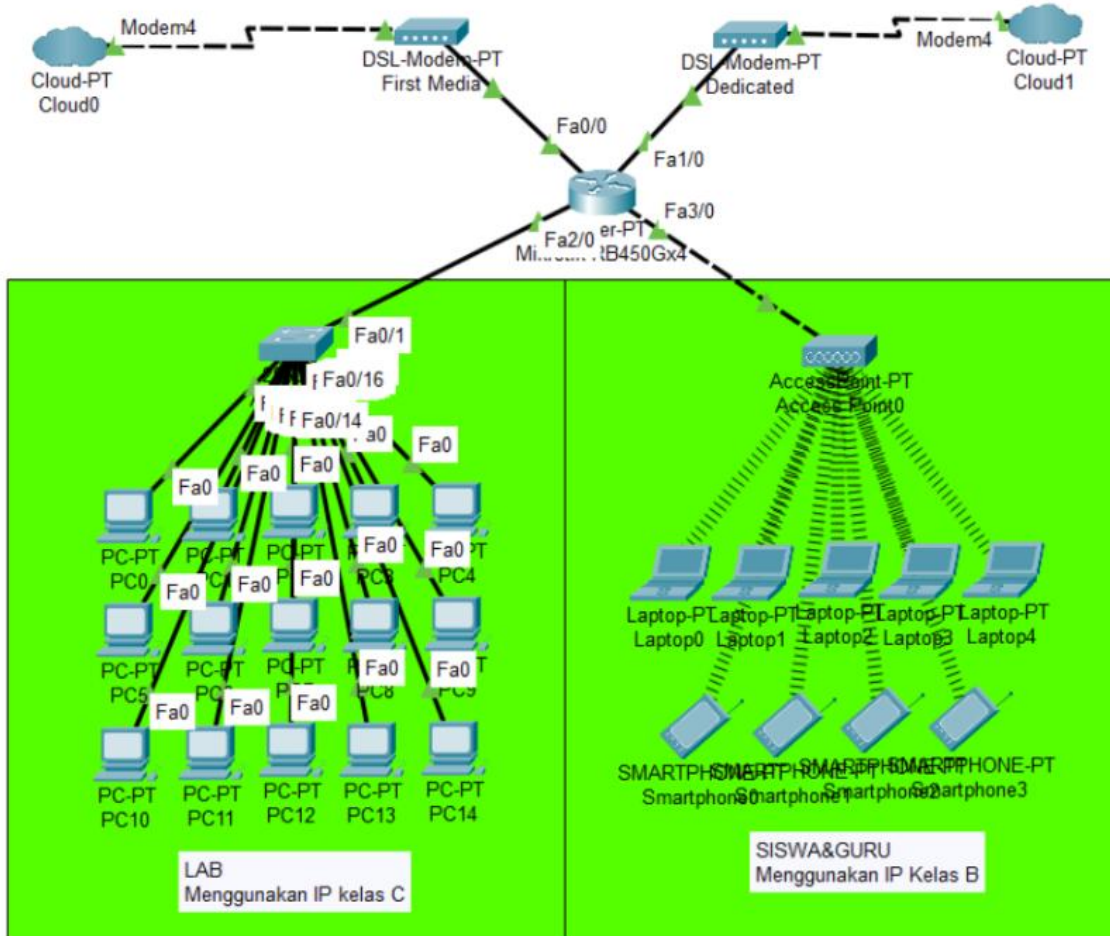


Figure 3. Network Topology Used in the Implementation of RED and PCQ Algorithms

The hardware and software components utilized in this study are summarized in Table 1 below.

Table 1. List of Hardware and Software Used in the Study.

No	Device	Specification / Description
1	MikroTik Router	RB450Gx4, RouterOS v6
2	Switch	TP-Link TL-SF1024D, 24 ports
3	Access Point	TP-Link TL-WR840N
4	Client Computers	20 units, Windows OS, LAN & WLAN connectivity
5	Winbox	MikroTik configuration tool
6	Wireshark	Packet traffic analysis tool
7	Speedtest CLI	Throughput measurement utility
8	Spreadsheet (Excel/Google)	QoS data processing and analysis

The implementation was carried out systematically through the following stages:

1. Network Topology Design

This stage included IP address allocation, CBT traffic segmentation, and planning of test paths.

2. Algorithm Configuration

Configuration of RED and PCQ queue algorithms was conducted using the simple queue feature in MikroTik.

3. Video-Based CBT Simulation

A simulation was conducted by simultaneously playing ± 5 -minute videos on 20 client computers.

4. Traffic Monitoring and Logging

Real-time traffic monitoring and data logging were performed using Wireshark and other measurement tools during the simulation.

5. QoS Data Collection

Data collected included throughput, delay, packet loss, and jitter for each algorithm scenario.

6. Data Analysis

The average of each QoS parameter was calculated and compared between the RED and PCQ methods.

The data were analyzed quantitatively and benchmarked against network quality standards based on TIPHON (Telecommunications and Internet Protocol Harmonization Over Networks) recommendations, which classify network performance into categories of excellent, good, fair, and poor, according to the parameter thresholds specified in ITU-T G.1010.

Evaluation was carried out not only based on average QoS values, but also by considering the performance stability of each algorithm under both light and heavy traffic conditions. The test results serve as the basis for developing recommendations on queue management algorithm selection for video-based educational network

3. RESULTS AND DISCUSSION

This study compared the performance of two queue management algorithms—Random Early Detection (RED) and Per Connection Queue (PCQ)—under simulated Computer-Based Test (CBT) environments with varying user loads (5, 10, and 15 users). The evaluation focused on key Quality of Service (QoS) metrics: throughput, delay, jitter, and packet loss. Additionally, traffic characteristics such as packet count, total data, and top source load were analyzed to provide a comprehensive view of network behavior.

3.1 Throughput Analysis

The throughput is summarized in Table 1, the total traffic summary provides insights into how each algorithm manages packet flow under different user loads.

Scenario	Packets	Data(Bytes)	Avg Packet Size (B)	Top Source Load (Packets)
PCQ 5	6,372	1.86 MB	292 B	3,112
PCQ 10	8,134	2.59 MB	318 B	3,538
PCQ 15	5,781	1.93 MB	335 B	2,935
RED 5	7,704	2.41 MB	313 B	3,777
RED 10	5,289	1.82 MB	343 B	2,485
RED 15	5,406	1.63 MB	302 B	2,547

Table 1. Total Traffic Summary

Analysis of the traffic patterns revealed that the RED algorithm exhibited a tendency towards unfair distribution, as indicated by more dominant top-talker IP addresses. In contrast, PCQ demonstrated better user fairness and was able to handle more traffic volume under higher loads, suggesting a more equitable distribution of bandwidth among users. Furthermore, RED showed a noticeable decline in throughput and traffic stability as the number of users increased from 10 to 15.

3.2 Quality of Service (QoS) Analysis

Data was obtained through observation using Wireshark, Speedtest CLI, and manual logging, followed by quantitative analysis. The average values for each QoS parameter were measured and are presented in Table 2, with a detailed breakdown of performance across different user loads provided in the subsequent sections.

Table 2. Average QoS Measurement Results for RED and PCQ

Parameter	RED	PCQ
Throughput	41.679 bps	56.482 bps
Delay	47.61 ms	41.63 ms
Packet Loss	4.97%	4.62%
Jitter	6.37 ms	5.43 ms

To enhance clarity, a performance comparison between RED and PCQ is illustrated in Figure 4.

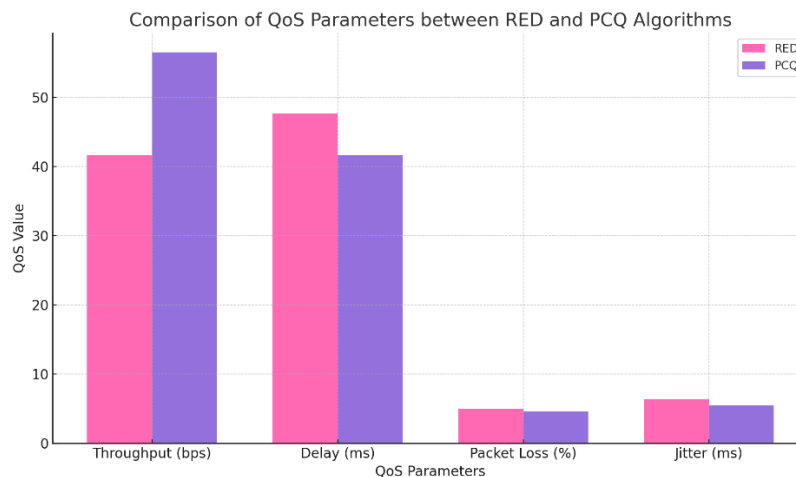


Figure 4. Visualization of QoS Parameter Comparison between RED and PCQ Algorithms

3.2.1 Throughput Analysis

As shown in Figure 1, the throughput performance varied with the number of users. At a low user count (5 users), RED slightly outperformed PCQ (63.758 bps vs. 49.407 bps). However, as the user load increased, PCQ demonstrated greater stability and significantly higher throughput. At 10 users, PCQ achieved 68.699 bps compared to RED's 48.851 bps, and at 15 users, PCQ's throughput was 51.341 bps compared to RED's 43.056 bps. This indicates that PCQ is more efficient at distributing bandwidth evenly, a finding that aligns with previous research highlighting PCQ's effectiveness under high-traffic conditions [5].

3.3 Delay Analysis

The average delay observed for PCQ was 41.63 ms, which was consistently lower than RED's 47.61 ms. The detailed latency analysis in Figure 2 illustrates this trend. While RED showed a lower delay at 5 users (39.27 ms vs. 47.32 ms), PCQ's performance proved superior as the user count increased. At 10 users, PCQ maintained a significantly lower delay of 37.03 ms compared to RED's 56.24 ms. This responsiveness is critical for video-based applications, as noted by Bandhaso et al. who found that PCQ's connection-based allocation is more responsive to traffic fluctuations than RED's random dropping mechanism [4].

3.4 Packet Loss Analysis

Both algorithms exhibited acceptable packet loss rates, but PCQ consistently performed better or comparably. At 5 users, PCQ's packet loss was notably lower (0.1%) than RED's (0.4%). Both methods performed similarly at 10 users (0.5%). At 15 users, RED showed a slight edge (0.5% vs. PCQ's 0.6%). However, on average, PCQ's overall packet loss rate of 4.62% was lower than RED's 4.97%. RED's random packet dropping as the queue fills can lead to data loss spikes during peak traffic

3.5 Jitter Analysis

PCQ recorded a lower average jitter of 5.43 ms compared to RED's average of 6.37 ms. This indicates that PCQ provides more consistent packet arrival intervals, a crucial factor for maintaining audio-video synchronization in streaming applications. This finding is consistent with other studies that have highlighted PCQ's superior jitter stability in scenarios with a large number of active users [15].

3.6 General Discussion

Overall, the results consistently demonstrate that the PCQ algorithm provides more stable and superior performance across all tested QoS parameters, particularly under high-traffic conditions. While RED is efficient under light network loads, it fails to maintain performance and fairness when faced with a higher number of concurrent users, a common scenario in modern digital assessment platforms. The PCQ 10-user configuration emerged as the optimal setup, effectively balancing network utilization and user fairness, which resulted in the highest throughput, minimal latency, and consistent jitter and packet loss. These findings provide empirical evidence supporting the use of PCQ for real-time, media-driven educational networks.

4. CONCLUSION AND RECOMMENDATION

Based on the results and analysis of the implementation of the Random Early Detection (RED) and Per Connection Queue (PCQ) algorithms in a school network used for video-based Computer-Based Testing (CBT), it can be concluded that PCQ delivers superior performance in managing high-traffic network environments. This is demonstrated by its higher throughput, lower delay, and more stable and minimal packet loss and jitter levels. Therefore, PCQ is more suitable for online exam scenarios with many users active simultaneously, while RED may still be a viable alternative under light to moderate traffic conditions.

However, this study was conducted within the constraints of a single school environment, with a fixed number of devices and limited traffic scenarios. Therefore, the generalization of these findings should be considered with caution. Future research is encouraged to expand testing to diverse network conditions and institutional settings. Additionally, exploring the integration of intelligent control

systems based on machine learning for dynamic queue management, as well as the combination of queue management algorithms with network security mechanisms, would be valuable for enhancing the overall efficiency and stability of educational networks.

DAFTAR REFERENSI

- [1] M. K. N. Al Fadjri, R. Ritzkal, and A. H. Hendrawan, "Computer Network Analysis Using The Queue System In Mikrotik: Computer Network Analysis Using The Queue System," *Mikrotik, J. Mantik*, vol. 4, no. 1, pp. 483–488, 2020.
- [2] S. Windasari and others, "Eksplorasi Berbasis Simulasi Terhadap Algoritma Pathfinding A* Untuk Navigasi Berbasis GRID," *J. Ekselenta-Jurnal Ilm. Fak. Tek.*, vol. 1, no. 2, pp. 14–24, 2025, [Online]. Available: <https://ojs.sains.ac.id/index.php/ekselenta/article/view/60>
- [3] S. Windasari, "Designing An Omni Wheel Robot," vol. 1, no. 1, pp. 40–48, 2024, [Online]. Available: <https://ojs.sains.ac.id/index.php/ekselenta/article/view/24>
- [4] C. P. Bandhaso, Y. Sutanto, and others, "Analisis dan Implementasi Metode Random Early Detection (RED) Pada Jaringan TCP/IP," *Respati*, vol. 17, no. 2, pp. 51–57, 2022.
- [5] R. Habibi, "A Optimalisasi Internet Warga Menggunakan Kombinasi Type Antrian dan Sistem Pihole," *J. Tek. Inform.*, vol. 14, no. 1, pp. 1–6, 2022.
- [6] B. A.-K. Ali Alshahrani¹, Ahmad Adel Abu-Shareha^{2,*}, Qusai Y. Shambour², "A Fully Adaptive Active Queue Management Method for Congestion Prevention at the Router Buffe," 2023, *Computers, Materials & Continua*. doi: <https://doi.org/10.32604/cmc.2023.043545>.
- [7] J. M. A. Ángel Giménez, Óscar M. Bonastre, José Valero, "Poster: Modified Dynamic Beta RED -- A New AQM Algorithm for Internet Congestion Control," 2023, *Proceedings of the 2023 ACM on Internet Measurement Conference*. doi: <https://doi.org/10.1145/3618257.3624996>.
- [8] Amar A. Mahawish Hassan Jalee.l Hassan, "Developed the EX-RED Algorithm to Find Best Parameters Based on Load Connection Factor," 2023, *Iraqi Journal of Computers, Communications, Control and Systems Engineering*. doi: <https://doi.org/https://doi.org/10.33103/uot.ijccce.23.4.8>.
- [9] T. E. Samuel O. Hassan, A. Rufai, V. Nwaocha, S. Ogunlere, A. Adegbenjo, M. Agbaje, "Quadratic exponential random early detection: a new enhanced random early detection-oriented congestion control algorithm for routers," 2023, *International Journal of Electrical and Computer Engineering (IJECE)*. doi: <http://doi.org/10.11591/ijece.v13i1.pp669-679>.
- [10] and S. A. A. Abdullah, A., Oyebola Akande, "A Triplex Region-Random Early Detection (TR-RED) Algorithm for Active Queue Management in Internet Routers.," 2023, *International Journal of Computing and Digital Systems*. doi: <http://dx.doi.org/10.12785/ijcds/140117>.
- [11] and L. K. M. Kesiezie, Kevikhietuo, "DREaD: Decision Tree-Aided Random Early Detection - An Intelligent Active Queue Management Technique," 2023, *3rd International Conference on Smart Generation Computing, Communication and Networking (SMART GENCON)*. *IEEE*. doi: 10.1109/SMARTGENCON60755.2023.10442782.

- [12] V. X. Chi and D. M. Tuan, “Proposing an AI-based model to manage and control congestion at routers on the internet,” *J. Sci. Technol.*, vol. 8, no. 1, pp. 1–17, 2025, doi: <https://doi.org/10.55401/y1b92w90>.
- [13] M. I. R. Febriansah, “Analisis Bottleneck dan Bufferbloat pada AQM Droptail, RED, dan SFQ di Komunikasi Data TCP Newreno,” *J. Repos.*, vol. 2, no. 9, pp. 1213–1224, 2020.
- [14] A. C. Nurcahyo, L. Firgia, and A. R. Himamunanto, “Perbandingan Algoritma RED, SFQ, Dan AQM Pada Jaringan Enterprise Dengan Vmware ESXI Dan Router OS,” *Inf. Interaktif*, vol. 6, no. 3, pp. 101–110, 2021.
- [15] R. Asasunnaja and B. Sugiantoro, “Analisis Unjuk Kerja TCP Sack Menggunakan Antrian Random Early Detection,” *JISKA (Jurnal Inform. Sunan Kalijaga)*, vol. 7, no. 2, pp. 75–82, [Online]. Available: <https://ejournal.uin-suka.ac.id/saintek/JISKA/article/view/2820>