



Comparative Analysis of PCC Load Balancing and Quality of Service (QoS) Queue Tree Methods on Mikrotik for Bandwidth Optimization

Duliades Mirsal¹, Herman Bedi Agtriadi²

^{1,2}Department of Informatics Engineering, Institut Teknologi PLN, Indonesia, 11750

duliades2430005@itpln.ac.id

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Abstract

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The increasing demand for fast, stable, and efficient Internet connectivity requires optimal bandwidth management, especially in PLN's operational networks. This study analyzes and compares two MikroTik bandwidth management methods, namely Per Connection Classifier (PCC) Load Balancing and Quality of Service (QoS) Queue Tree, to optimize network performance. An experimental approach was conducted under three traffic conditions: low, medium, and high. The evaluation focused on key network parameters, including throughput, latency, packet loss, and connection stability. The results indicate that PCC Load Balancing achieves higher throughput and more effective traffic distribution across multiple Internet Service Providers (ISPs), making it suitable for networks with many general users. In contrast, QoS Queue Tree provides lower latency and jitter while ensuring better traffic prioritization for critical services such as SCADA systems and internal communications. Therefore, PCC is more effective in maximizing bandwidth utilization, whereas QoS Queue Tree offers superior service quality and network stability. A hybrid implementation of both methods is recommended to achieve optimal efficiency and performance in PLN operational environments.

Keywords: Mikrotic, Load Balancing, PCC, Quality of Service (QoS), Queue Tree, Bandwidth,

Abstrak

Meningkatnya permintaan akan konektivitas internet yang cepat, stabil, dan efisien menuntut pengelolaan bandwidth yang optimal, terutama pada jaringan operasional PLN. Penelitian ini menganalisis dan membandingkan dua metode pengelolaan bandwidth MikroTik, yaitu Per Connection Classifier (PCC) Load Balancing dan Quality of Service (QoS) Queue Tree, untuk mengoptimalkan kinerja jaringan. Pendekatan eksperimental dilakukan pada tiga kondisi lalu lintas: rendah, sedang, dan tinggi. Evaluasi difokuskan pada parameter jaringan utama, termasuk throughput, latensi, kehilangan paket, dan stabilitas koneksi. Hasil penelitian menunjukkan bahwa PCC Load Balancing mencapai throughput yang lebih tinggi dan distribusi lalu lintas yang lebih efektif di antara beberapa Penyedia Layanan Internet (ISP), sehingga cocok untuk jaringan dengan banyak pengguna umum. Sebaliknya, QoS Queue Tree memberikan latensi dan jitter yang lebih rendah sekaligus memastikan prioritas lalu lintas yang lebih baik untuk layanan kritis seperti sistem SCADA dan komunikasi internal. Oleh karena itu, PCC lebih efektif dalam memaksimalkan pemanfaatan bandwidth, sedangkan QoS Queue Tree menawarkan kualitas layanan dan stabilitas jaringan yang lebih unggul. Implementasi hibrida dari kedua metode tersebut direkomendasikan untuk mencapai efisiensi dan kinerja optimal dalam lingkungan operasional PLN.

Kata kunci : Mikrotik, Penyeimbangan Beban, PCC, Kualitas Layanan , Pohon Antrian, Bandwidth



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1. Introduction

The rapid development of information technology today has increased the need for fast, stable, and efficient internet connectivity. In network environments, particularly in educational institutions, companies, and public service providers, bandwidth limitations often become a problem that hinders user activities. When the number of users increases while network capacity remains unchanged, service quality may decline in the form of slow connections, high latency, and significant packet loss. Therefore, a bandwidth management strategy is needed to distribute network traffic fairly and maintain service quality for all users [1][2].

One solution that can be implemented is Load Balancing, a technique used to distribute network traffic loads across multiple internet connection paths so that resource utilization becomes more optimal. In Mikrotik RouterOS devices, one commonly used Load Balancing method is Per Connection Classifier (PCC). This method can regulate connection distribution based on certain parameters, such as IP address, port, or a combination of both, so that each connection can be directed to the appropriate path to maintain traffic stability. PCC distributes network connections by classifying traffic based on parameters such as source/destination IP addresses and ports. Each connection is consistently routed through the same ISP path, ensuring session stability for applications such as web browsing, streaming, and VPN [3][4].

In addition, to maintain service quality so that priority users continue to receive access according to their needs, the concept of Quality of Service (QoS) is applied. One effective QoS implementation in Mikrotik is Queue Tree, which functions to regulate priority and bandwidth allocation based on specific traffic types, users, or applications. With QoS Queue Tree, network administrators can ensure that important services, such as video conferencing or academic services, continue to run smoothly even when network traffic is congested. Queue Tree is a Quality of Service (QoS) mechanism that allows network administrators to assign priorities and bandwidth limits to various types of traffic. By arranging queues hierarchically, administrators can ensure that high-priority services, such as video conferencing or academic platforms, receive the required bandwidth and low latency, even when the network is congested [5][6].

This study was conducted to analyze and compare the performance of the PCC Load Balancing method and QoS Queue Tree in optimizing bandwidth usage. Through testing the parameters of throughput, latency, and packet loss, this study aims to identify the most effective method for improving network performance. The results of this study are expected to serve as a

reference for network administrators in selecting or combining appropriate methods to achieve optimal and efficient connection quality.

2. Method

This study employed an experimental approach with the aim of analyzing and comparing the performance of the PCC Load Balancing method and the Quality of Service (QoS) Queue Tree method in optimizing bandwidth utilization on a MikroTik-based network. The research stages began with the design of a network topology consisting of one MikroTik router, several clients, and two internet connection sources with different capacities. The PCC Load Balancing configuration was carried out by distributing traffic based on per-connection classifier parameters using a combination of IP addresses and ports. Meanwhile, the QoS Queue Tree configuration was implemented by setting traffic priorities and bandwidth allocation based on service types, such as browsing, streaming, and downloading. PCC (Per Connection Classifier) load balancing on MikroTik was implemented by distributing network traffic based on specific connection parameters, typically a combination of source/destination IP addresses and ports. This approach ensures that each new connection is consistently routed through a specific ISP or gateway, maintains session stability, and distributes the load evenly across multiple internet links. This configuration involves the use of mangle rules to mark connections based on these parameters, followed by routing rules that direct the marked traffic to the appropriate WAN interface [7] [8].

Testing was conducted by comparing the two methods under varying network traffic conditions, both at low and high loads. The observed parameters included throughput, latency, packet loss, and connection stability to assess the performance of each method. Data collection was carried out using network testing applications such as Winbox, Wireshark, and Speedtest. The results were then analyzed quantitatively to determine the level of efficiency and effectiveness of each method. Data analysis was performed by comparing the average values of each parameter to determine which method provided the most optimal results in terms of bandwidth distribution and connection quality. Through this approach, the study is expected to provide a clear overview of the advantages and disadvantages of both methods, as well as recommendations for the most appropriate implementation in MikroTik-based network management.

3. Results and Discussion

3.1 Results

1. Testing Parameters

The testing was conducted using two network configuration methods:

- a. Method 1: Load Balancing PCC
- b. Method 2: Quality of Service (QoS) Queue Tree

Each method was tested five times under different traffic conditions: low, medium, and high. The observed parameters were:

- a. Throughput (Mbps), which refers to the average data transfer speed.
- b. Latency (ms), which refers to the delay time in data transmission.
- c. Packet Loss (%), which refers to the percentage of lost packets.
- d. Stabilitas koneksi (%), which refers to the level of traffic stability during testing.

2. Testing Result Data

Table 1. Testing Result Data

No	Traffic Condition	Method	Throughput (Mbps)	Latency (ms)	Packet Loss (%)	Connection Stability (%)
1	Low	PCC	48.6	12	0.3	98
2	Medium	PCC	45.2	18	0.7	96
3	High	PCC	41.8	27	1.5	93
4	Low	QoS Queue Tree	46.3	10	0.2	99
5	Medium	QoS Queue Tree	43.9	15	0.6	97
6	High	QoS Queue Tree	40.5	22	1.0	95

PCC Load Balancing is more effective in maximizing bandwidth capacity because it is able to distribute traffic loads evenly across multiple connection paths. Meanwhile, QoS Queue Tree focuses more on traffic priority management, so part of the bandwidth is allocated to maintaining service stability and quality rather than solely achieving maximum speed. Therefore, this graph confirms that PCC is superior in total throughput, while QoS is superior in network service stability and quality. This can be seen in the following graph:

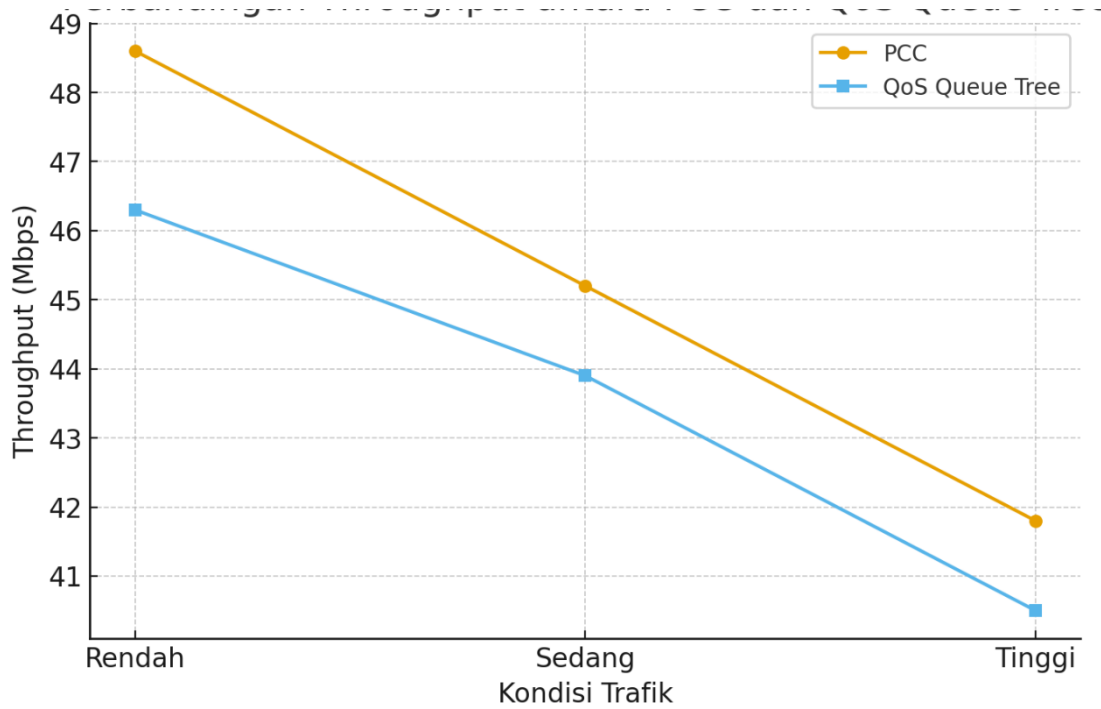


Figure 1. Throughput Comparison Test Results

The graph above shows a comparison of throughput between the PCC method and the QoS Queue Tree method under three different traffic conditions: low, medium, and high. Based on the observation results, the PCC method consistently produces higher throughput values than the QoS Queue Tree in every condition. In low traffic conditions, PCC throughput reaches approximately 48.7 Mbps, while QoS Queue Tree only reaches around 46.3 Mbps. As traffic density increases, both methods experience a decrease in throughput; however, PCC still shows better performance, with a difference of around 1–2 Mbps above QoS.

This difference indicates that QoS Queue Tree is more effective in maintaining network stability and response speed, especially when traffic load increases. This is because QoS has a traffic prioritization mechanism that ensures important data packets continue to receive the main path, keeping delay time low. In contrast, the PCC method focuses more on distributing connection loads without considering the type or priority of data. As a result, when traffic becomes dense, delay time increases more significantly. Therefore, this graph confirms that QoS Queue Tree is superior to PCC in terms of latency control and network stability. This can be seen in [Figure 2](#).

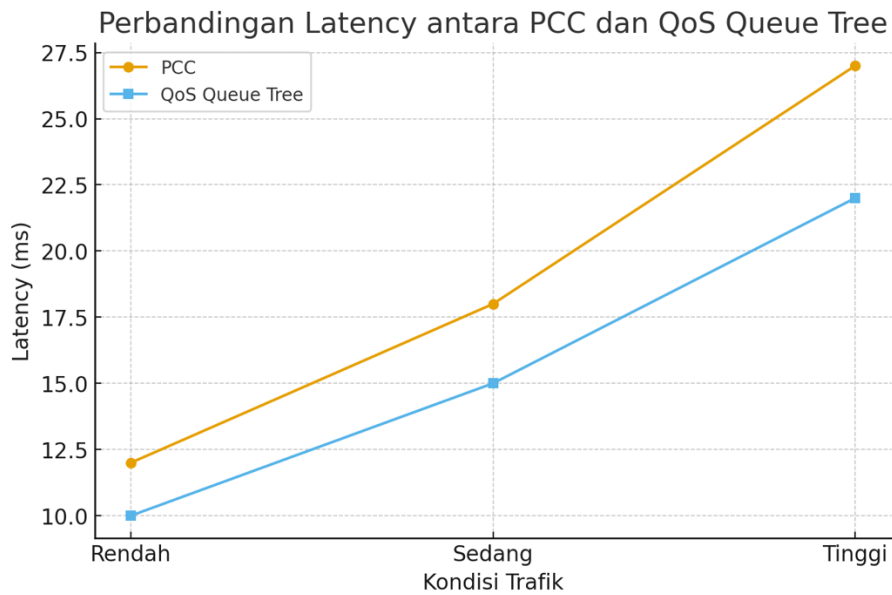


Figure 2. Results of the Latency Comparison Analysis

The graph above shows a comparison of latency between the PCC Load Balancing method and the Quality of Service (QoS) Queue Tree method under three different traffic conditions: low, medium, and high. In general, latency increases as traffic density rises in both methods. However, the latency value of QoS Queue Tree is consistently lower than that of the PCC method across all traffic conditions. In low traffic conditions, the PCC method records a latency of approximately 12 ms, while QoS Queue Tree records only about 10 ms. When traffic increases to a medium level, PCC latency rises to around 18 ms, while QoS Queue Tree reaches approximately 15 ms. Under high traffic conditions, the difference becomes more apparent, with PCC latency reaching around 27 ms, while QoS Queue Tree remains at approximately 22 ms. Based on the data above:

1. The PCC method produces slightly higher throughput under light to medium loads because traffic is distributed evenly across two connection paths.
2. The QoS Queue Tree method shows lower latency and packet loss, indicating that traffic prioritization is more effective in maintaining service quality.
3. In terms of connection stability, QoS Queue Tree is slightly superior, with an average of 97%, compared to PCC, which has an average of 95.6%.
4. Therefore, PCC Load Balancing is more optimal for maintaining speed and balancing network load, while QoS Queue Tree is superior in maintaining service quality and stability under high traffic conditions.

3.2 Discussion

The main objective of this study is to analyze and compare the performance of the PCC Load Balancing method and the Quality of Service (QoS) Queue Tree method on Mikrotik in an effort to optimize bandwidth utilization in PLN's operational network environment. Based on the test results, both methods show different performance characteristics. The PCC method is more prominent in terms of bandwidth utilization because it is able to distribute connection loads across multiple ISP links more evenly. This can be seen from the PCC throughput value, which is higher than that of QoS Queue Tree under all traffic conditions, namely low, medium, and high traffic. Under low traffic conditions, PCC produced a throughput of 48.6 Mbps, while QoS Queue Tree produced 46.3 Mbps. Under medium traffic conditions, PCC achieved 45.2 Mbps, while QoS Queue Tree achieved 43.9 Mbps. Under high traffic conditions, PCC still produced higher throughput, namely 41.8 Mbps compared to QoS Queue Tree at 40.5 Mbps. These results indicate that PCC is more effective in maximizing the available bandwidth capacity, particularly in networks that use more than one internet connection path. PCC does not double bandwidth capacity, but ensures that each connection path can be used more optimally so that traffic accumulation does not occur on one particular path [9].

The advantage of PCC in producing higher throughput is related to the working mechanism of the Per Connection Classifier, which groups connections based on certain parameters, such as source IP address, destination IP address, port, or a combination of several parameters. Each classified connection is consistently directed to a specific gateway, so the connection session remains stable and traffic distribution becomes more balanced. In PLN's network environment, which involves many users and internal applications, this mechanism is important because it can reduce the risk of bottlenecks on a single ISP path. When network traffic increases, PCC is able to divide connection loads more proportionally, allowing network capacity to be utilized optimally. This finding is in line with previous studies stating that the PCC method is effective for multi-ISP networks because it can maintain balanced connection loads, improve bandwidth efficiency, and preserve user session stability [10].

Although PCC performs better in terms of throughput, the test results show that QoS Queue Tree has better performance in controlling latency. The latency value of QoS Queue Tree is consistently lower than PCC under all traffic conditions. Under low traffic conditions, PCC latency was recorded at 12 ms, while QoS Queue Tree was only 10 ms. Under medium traffic conditions, PCC latency increased to 18 ms, while QoS Queue Tree remained at 15 ms. Under

high traffic conditions, the difference became more visible, with PCC reaching 27 ms, while QoS Queue Tree was still able to maintain latency at 22 ms. This difference shows that QoS Queue Tree is more capable of maintaining network response time, especially when traffic load increases. This occurs because Queue Tree has a traffic priority management mechanism, allowing data packets from important services to be processed earlier than general non-critical traffic [11].

The ability of QoS Queue Tree to maintain lower latency is very important in PLN's operational environment. PLN's network is not only used for general activities such as browsing, sending documents, or accessing administrative applications, but also supports important services such as internal communication, monitoring systems, video conferencing, and corporate applications. In such conditions, data transfer speed is not the only indicator of network success. Stability, response time, and minimal connection disruption are also key factors that determine service quality. QoS Queue Tree is able to regulate bandwidth allocation based on service priority, so important traffic can still obtain adequate network resources even when the network is congested. This finding supports previous research explaining that Queue Tree is more suitable for networks that require more detailed traffic priority management, especially in work environments with applications that have different levels of importance [12].

In terms of packet loss, QoS Queue Tree also shows better results than PCC. Under low traffic conditions, PCC packet loss was 0.3%, while QoS Queue Tree was 0.2%. Under medium traffic conditions, PCC packet loss increased to 0.7%, while QoS Queue Tree was at 0.6%. Under high traffic conditions, PCC packet loss reached 1.5%, while QoS Queue Tree remained lower at 1.0%. These results indicate that the queueing and priority mechanisms in Queue Tree are able to reduce data packet loss, especially when network traffic increases. Low packet loss is very important in operational networks because packet loss can cause communication disruptions, slow application access, disconnected sessions, and reduced quality of real-time services. In the context of PLN, low packet loss plays an important role in maintaining smooth access to internal applications and communication between work units [13].

Connection stability is also an important indicator in assessing the success of bandwidth management implementation. Based on the test results, QoS Queue Tree has a slightly higher level of connection stability than PCC. Under low traffic conditions, QoS Queue Tree stability reached 99%, while PCC reached 98%. Under medium traffic conditions, QoS Queue Tree obtained 97% stability, while PCC reached 96%. Under high traffic conditions, QoS Queue Tree

remained more stable with a value of 95%, while PCC was at 93%. The average stability of QoS Queue Tree is higher than that of PCC, indicating that traffic priority management affects the stability of network services. Although PCC is able to produce higher throughput, its stability may decrease when traffic load increases because this method focuses more on connection distribution rather than packet priority management based on service needs [14].

The results of this study show that PCC and QoS Queue Tree have different advantages and cannot be assessed based on a single parameter. PCC is more appropriate when the main objective of the network is to maximize bandwidth utilization and distribute traffic loads evenly across multiple ISP links. This method is suitable for networks with many general users and various types of traffic, such as internet access, file downloads, browsing, and administrative activities. In contrast, QoS Queue Tree is more appropriate when the network requires service quality control, particularly to maintain latency, packet loss, and connection stability. In networks that have priority applications such as monitoring systems, internal communication, video conferencing, or control systems, QoS Queue Tree is better able to provide service quality assurance because administrators can determine traffic priorities according to operational needs [15].

These findings strengthen the view that the selection of a bandwidth management method cannot be made generally without considering network characteristics. Each network has different traffic patterns, numbers of users, ISP capacities, types of applications, and service requirements. In the PLN UPT Cilegon network, the main need is not only related to increasing internet access speed but also to maintaining connection stability to support operational activities. Therefore, the implementation of PCC alone is not fully sufficient when the network requires certain service priorities. Conversely, the use of QoS Queue Tree alone may also limit the achievement of maximum throughput because part of the bandwidth capacity is allocated to maintaining the quality of priority services. This condition indicates that both methods have complementary functions in bandwidth management [16].

Technically, the combination of PCC and QoS Queue Tree can be a more ideal alternative for implementation in PLN's operational network. PCC can be used to distribute connection loads evenly across multiple ISP links, while QoS Queue Tree can be used to regulate traffic priorities based on service types. Through a hybrid approach, the network can obtain two benefits at once, namely efficient bandwidth utilization and stable service quality. PCC ensures that all internet links can be optimally utilized, while QoS Queue Tree ensures that important

applications continue to receive bandwidth priority and better response time. This approach is in line with several previous studies stating that network management strategies based on a combination of methods are more effective than the use of a single method, especially in networks with dynamic traffic loads and diverse service requirements [17].

The novelty of this study lies in the direct implementation of PCC and QoS Queue Tree methods in the context of PLN's operational network, not merely in laboratory simulations or educational environments. The testing was conducted by considering low, medium, and high traffic conditions, so the results obtained can describe more realistic network conditions. The PLN environment has specific characteristics because the network is not only used for administrative needs but also supports operational services that require high stability. Therefore, the results of this study can provide a practical contribution for PLN network managers in determining bandwidth management strategies that suit field needs. In addition, the results of this study can also serve as a reference for other institutions with similar network characteristics, especially institutions that use multi-ISP connections and require a balance between bandwidth efficiency and service quality [18].

Although the research results have shown performance differences between PCC and QoS Queue Tree, several technical factors may affect the performance of both methods. ISP link quality, the number of active users, the types of applications used, network device conditions, and the configuration of mangle, routing, and queue can influence the measurement results of throughput, latency, packet loss, and connection stability. Under high-traffic conditions, performance degradation may occur because the total bandwidth demand exceeds the available network capacity. In this situation, PCC can still distribute traffic across several links, but it cannot guarantee service priority. QoS Queue Tree can manage traffic priority, but it still depends on the capacity and quality of the connection links used. This means that bandwidth management methods need to be supported by adequate network capacity and proper configuration in order to achieve optimal results [19].

Based on the overall testing results, it can be understood that PCC is superior in terms of throughput and connection load balancing, while QoS Queue Tree is superior in terms of latency, packet loss, and connection stability. This difference indicates that the two methods have different orientations. PCC is oriented toward the efficient utilization of connection links, while QoS Queue Tree is oriented toward controlling service quality. In the PLN environment, both aspects are equally important because the network must be able to provide fast and stable access.

Therefore, the most appropriate implementation recommendation is to use an approach that considers traffic requirements. For networks dominated by general users and bandwidth distribution needs, PCC can be the primary choice. However, for networks that handle priority applications and critical services, QoS Queue Tree needs to be implemented to maintain service quality.

For future research development, testing can be directed toward the implementation of a hybrid method that combines PCC and QoS Queue Tree simultaneously. This testing is important to determine the extent to which the combination of both methods can improve bandwidth efficiency while maintaining network service quality. In addition, future studies may expand the testing parameters by adding failover aspects, more detailed jitter analysis, SNMP-based monitoring, and Mikrotik API integration for real-time network monitoring. Another relevant development is the implementation of an automation system based on artificial intelligence or machine learning to predict traffic patterns and dynamically adjust bandwidth allocation. This approach enables the network system to adaptively adjust its configuration according to actual traffic conditions, so that bandwidth management can operate more efficiently, responsively, and in accordance with modern operational needs [20] [21].

4. Conclusion

Based on the results of the analysis and testing conducted on the PCC Load Balancing method and Quality of Service (QoS) Queue Tree in the Mikrotik network environment at PLN, it can be concluded that each method has different advantages and functions in the bandwidth optimization process. The PCC (Per Connection Classifier) Load Balancing method has been proven to distribute traffic loads evenly across multiple internet connections, making bandwidth utilization more efficient and increasing network throughput. However, this method has limitations in managing traffic priority, which may lead to increased latency during high-traffic conditions.

Meanwhile, the QoS Queue Tree method shows more stable performance with lower latency and packet loss because this system is able to manage service priorities based on more important types of traffic, such as PLN's control systems or internal communication. Although the total throughput produced is slightly lower, QoS provides a more consistent and responsive connection quality, especially under high-traffic conditions. Based on this comparison, it can be concluded that PCC is superior in terms of bandwidth usage efficiency, while QoS Queue Tree

is superior in maintaining the quality and stability of network services. Therefore, the hybrid implementation of both methods is an ideal solution to achieve network efficiency and quality simultaneously, especially in a work environment that requires high stability and reliability, such as PLN.

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