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Design and Experimental Evaluation of an SDN-Based QoS Practice Model for Student Learning

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Abstract

Teaching Quality of Service (QoS) in networking courses is difficult when students practice only in conventional environments that make traffic differentiation and bottleneck behavior hard to observe. This study proposes an SDN-based QoS practice model implemented with Mininet and compares it with a conventional QoS practice model in a quasi-experimental design. A valid sample of 108 students was analyzed, including 54 students in the control group and 54 students in the experimental group. Learning outcomes were measured using a theory pre-test, a theory post-test, and a combined practice test. The pre-test showed no significant difference between the two groups, whereas the experimental group achieved significantly higher post-test and practical test scores after the intervention. These findings indicate that the proposed model can improve both conceptual understanding and hands-on performance in QoS learning.

Keywords: QoS Practice Model, SDN, Mininet, Networking Education, Quasi-Experimental Study, Student Learning Outcomes

1. Introduction

Quality of Service (QoS) is an important but difficult topic in networking education because students must understand traffic classes, congestion, bottlenecks, and service differentiation at the same time. In many conventional laboratories, these phenomena are difficult to observe clearly, especially when the practice environment is not designed for repeatable mixed-traffic experiments.

Software-defined networking (SDN) offers a useful setting for QoS learning because it separates the control plane from the data plane and allows traffic behavior, link capacities, and forwarding policies to be organized more explicitly. In a Mininet-based SDN environment, instructors can recreate the same topology and traffic scenarios across student groups, making QoS effects easier to observe and compare.

This study therefore proposes a new SDN-based QoS practice model and evaluates it against the conventional QoS practice model used previously. The aim is not to claim that one platform is universally superior, but to determine whether the proposed learning environment produces better student outcomes in the context of QoS practice.

The proposed model uses a compact enterprise-style SDN topology, mixed real-time and best-effort traffic, and three load levels to support observation of bottlenecks and QoS behavior under controlled conditions.

The study addresses three questions: whether the proposed model improves overall learning outcomes, whether it improves understanding of traffic classification and bottleneck behavior, and whether it improves practical ability in QoS-related laboratory tasks.

2. Materials and Methods

2.1 Research Design and Participants

This study employed a quasi-experimental design with a control group (CG) and an experimental group (EG). Both groups studied the same networking course, were taught by the same instructor, and completed the same general learning objectives. The difference was the practice model: the CG used the conventional QoS practice model, whereas the EG used the proposed SDN-based QoS practice model.

For the analyses reported in this paper, the valid sample consisted of 108 students, including 54 students in the CG and 54 students in the EG. This balanced sample was used for the pre-test, post-test, and combined practice test comparisons.

2.2 Conventional QoS Practice Model

The conventional QoS practice model represented the traditional laboratory environment used before the intervention. It provided basic QoS practice in a non-SDN setting and allowed students to perform foundational configuration tasks, but it offered limited support for observing mixed traffic, deliberate bottlenecks, and policy behavior under progressively changing load conditions.

As a result, the conventional model was useful for introductory practice but less effective for helping students interpret traffic differentiation and the effect of QoS policies in a structured and repeatable way.

2.3 Proposed SDN-based QoS practice model

2.3.1 System Architecture Design

The proposed model was designed as a compact enterprise-style SDN laboratory environment for QoS learning. The topology contains one core switch, two distribution switches, four access switches, and eight hosts, with an external controller communicating through OpenFlow 1.3. This structure is small enough for classroom use while still preserving a clear network hierarchy.

The model was implemented with Mininet, Open vSwitch, and a Ryu controller. This setup allows instructors and students to observe SDN behavior directly and to repeat the same topology and traffic scenarios across practice sessions.

Link capacities were assigned deliberately to make bottlenecks visible during practice. Host-to-access and access-to-distribution links were set to 10 Mbps, while distribution-to-core links were set to 20 Mbps. This arrangement makes congestion more likely at the edge and intermediate layers, which is useful for QoS observation.

The main technical elements of the proposed model are summarized in Table 1. The topology diagram is shown in Figure 1.

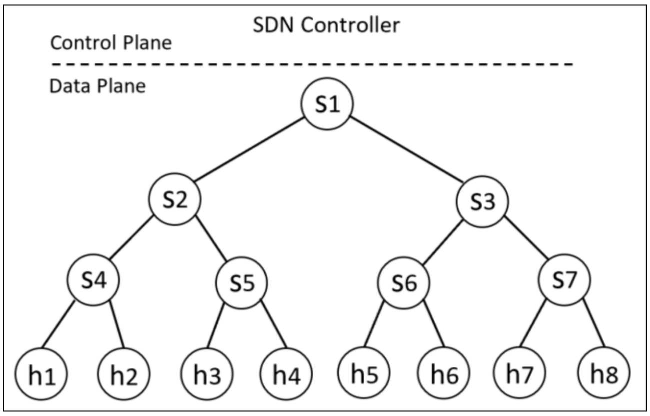

Fig 1: Topology of the proposed SDN-based QoS practice model

Table 1: Technical Specification of the Proposed SDN-based QoS Practice Model

Component	Description in the proposed SDN-based QoS practice model
Switch set S	S = {s1, s2, s3, s4, s5, s6, s7}.
Host set H	H = {h1, h2, h3, h4, h5, h6, h7, h8}.
Host-access links	Nominal bandwidth of 10 Mbps.
Access-distribution links	Nominal bandwidth of 10 Mbps.
Distribution-core links	Nominal bandwidth of 20 Mbps.
Intended bottlenecks	Primarily located on the 10 Mbps links at the edge and intermediate layers.
Controller role	The controller runs outside the data-plane topology and manages switches through OpenFlow 1.3.

2.3.2 Traffic design

The traffic design combines real-time traffic and best-effort traffic so that students can observe competition for shared network resources. The overall flow set includes RT-UDP, BE-UDP, and BE-TCP, allowing students to compare the behavior of delay-sensitive traffic with non-adaptive and adaptive background traffic.

Traffic was organized into three profiles: low load, medium load, and high load. These profiles were used to show baseline behavior, emerging contention, and pronounced congestion, respectively. By keeping the same traffic logic across repeated runs, the model supports consistent observation and instruction.

Flow placement was also controlled so that a substantial portion of traffic traversed the 10 Mbps links, where bottlenecks were expected to appear. This design made the effects of QoS policies easier to observe during practice. Table 2 summarizes the traffic classes used in the model, and Table 3 explains the instructional meaning of the three traffic load levels.

Table 2: Traffic Classes Used in the Proposed SDN-based QoS Practice Model

Traffic class	Implementation	Modeling purpose	Main characteristic
RT	UDP	Represents real-time traffic with a high share in the traffic mix	Sensitive to delay, jitter, and loss; sending rate is explicitly prescribed
BE-UDP	UDP	Represents continuous background load	Tends to consume bandwidth aggressively without transport-layer adaptation
BE-TCP	TCP	Represents adaptive background traffic	Throughput depends on the network state and transport behavior

Table 3: Interpretation of the Three Traffic Load Levels for QoS Practice Activities

Load level	Resource-contention characteristic	Educational use in QoS practice
Low	Background load exists but does not saturate most 10 Mbps uplinks	Suitable for observing baseline QoS behavior under near-noncongested conditions
Medium	Competition becomes visible at selected edge and intermediate links	Suitable for analyzing emerging competition between RT and BE traffic and discussing service differentiation
High	Multiple bottlenecks appear simultaneously and queueing effects become pronounced	Suitable for examining congestion, bottleneck effects, and QoS-policy behavior under heavy mixed-load conditions

2.3.3 Practice scenarios and QoS learning tasks

The proposed model was used to organize practice into progressively more complex tasks. Students first identified topology roles and traffic paths, then generated mixed traffic, compared low-, medium-, and high-load behavior, and finally interpreted the impact of QoS policies on bottlenecks and service differentiation.

These tasks required both technical execution and interpretation, so students were expected not only to configure the environment but also to explain the observed network behavior.

2.4 Instruments and Data Collection

Learning outcomes were evaluated with three instruments: a theory pre-test, a theory post-test, and a combined practice test. The pre-test measured initial knowledge before practice, the post-test measured knowledge after the intervention, and the combined practice test measured broader hands-on competence in the course context.

In addition to these tests, the instructional design considered whether students could more clearly observe traffic differentiation, bottlenecks, and QoS policy effects during laboratory activities.

2.5 Statistical Analysis

The data were analyzed using independent-samples t-tests. Pre-test, post-test, and combined practice test scores were compared between the two groups. A significance level of 0.05 was adopted, and the practical meaning of differences was interpreted alongside the statistical results.

3. Results and Discussions

3.1 T-test results of pre-test

The pre-test was conducted to determine whether the CG and EG had comparable baseline knowledge before the intervention. Levene's test was not significant (F = .013, p = .911), so the equal variances assumed results were used. The independent-samples t-test showed no statistically significant difference, t(106) = .125, p = .901. The CG obtained a mean score of 7.359 (SD = 2.0443), while the EG obtained a mean score of 7.311 (SD = 1.9538). These results indicate that the two groups were equivalent before practice. This finding supports the internal validity of the comparison because later differences are less likely to be explained by unequal starting knowledge.

Table 4: Group Statistics of Pre-Test

Group Statistics					
	Group	N	Mean	Std. Deviation	Std. Error Mean
Theory Test (Pre-test)	CG	54	7.359	2.0443	.2782
	EG	54	7.311	1.9538	.2659

Table 5: Independent Samples Test Results of Pre-Test

Independent Samples Test										
		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
Theory Test (Pre-test)	Equal variances assumed	.013	.911	.125	106	.901	.0481	.3848	-.7148	.8111
	Equal variances not assumed			.125	105.783	.901	.0481	.3848	-.7148	.8111

3.2 T-test results of post-test

The post-test evaluated knowledge after the practice process. Levene's test was not significant (F = 1.525, p = .220), so the equal variances assumed results were used. The t-test showed a statistically significant difference, t(106) = -5.268, p < .001. The CG obtained a mean score of 6.633 (SD = 1.2797), whereas the EG obtained a higher mean score of 8.013 (SD = 1.4375). This indicates that the proposed model supported stronger post-intervention theoretical learning.

Table 6: Group Statistics of Post-Test

Group Statistics					
	Group	N	Mean	Std. Deviation	Std. Error Mean
Theory Test (Post-Test)	CG	54	6.633	1.2797	.1742
	EG	54	8.013	1.4375	.1956

Table 7: Independent Samples Test Results of Post-Test

Independent Samples Test										
		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
Theory Test (Post-Test)	Equal variances assumed	1.525	.220	-5.268	106	.000	-1.3796	.2619	-1.8989	-.8604
	Equal variances not assumed			-5.268	104.599	.000	-1.3796	.2619	-1.8990	-.8603

A likely explanation is that the proposed model made traffic classes, bottlenecks, and policy effects easier to observe, which helped students connect practical activities with QoS concepts.

3.3 T-test results of combined practice test

The combined practice test was used to compare the hands-on performance of the two groups after the intervention. Levene's test was significant (F = 9.625, p = .002), so the equal variances not assumed results were used. The t-test revealed a statistically significant difference, t(99.286) = -7.283, p < .001. The CG obtained a mean score of 6.85 (SD = 1.379), whereas the EG obtained a mean score of 8.57 (SD = 1.057). These results show that the experimental group outperformed the control group in practical competence.

Table 8: Group Statistics of Combined Practice Test

Group Statistics					
	Group	N	Mean	Std. Deviation	Std. Error Mean
Combined Practice test	CG	54	6.85	1.379	.188
	EG	54	8.57	1.057	.144

Table 9: Independent Samples Test Results of Combined Practice Test

Independent Samples Test										
		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
Combined Practice test	Equal variances assumed	9.625	.002	-7.283	106	.000	-1.722	.236	-2.191	-1.253
	Equal variances not assumed			-7.283	99.286	.000	-1.722	.236	-2.191	-1.253

This result suggests that the proposed model improved not only conceptual understanding but also students' ability to perform QoS-related laboratory tasks.

3.4 Discussion

Taken together, the results show a clear pattern: the two groups started from a similar baseline, but the experimental group performed better after practicing with the proposed SDN-based QoS model. The differences were evident in both post-test knowledge and combined practical performance.

One likely reason is that the proposed model made key QoS problems more visible. Because the topology, traffic classes, and load levels were controlled, students could more easily observe traffic differentiation, bottleneck formation, and the effect of policies under mixed-load conditions.

The findings should still be interpreted within the scope of the study. The intervention combined a new practice model, an SDN setting, and a Mininet-based implementation, so the results support the effectiveness of the integrated learning environment rather than the isolated effect of any single technical component.

4. Conclusion

This study proposed a new SDN-based QoS practice model and evaluated it against a conventional QoS practice model in networking education. The statistical results showed no significant difference at pre-test, but the experimental group achieved significantly better post-test and combined practice test scores after the intervention. These findings indicate that the proposed model can improve both theoretical understanding and practical performance in QoS learning.

The main value of the proposed model lies in its ability to present QoS concepts through a structured, repeatable, and observable SDN environment. Future work may extend the evaluation to additional cohorts, longer-term learning retention, and other QoS-related practice tasks.

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