

# Experimental Characterization of QoS in Commercial Ethernet Switches for Statistically Bounded Latency in Aircraft Networks

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**Abstract** - Aircraft networks are used to service mission-critical avionics systems as well as cabin systems such as in-flight entertainment. These networks require that the switches used offer line-rate switching as well as bounded latency and jitter. Gigabit Ethernet offers an interesting replacement to traditional proprietary networks because of its high performance and low cost. In this paper we develop a framework for analyzing the abilities of Gigabit Ethernet switches to provide probabilistic guarantees for reliably low latency using Quality of Service (QoS) controls. From the perspective of control capabilities, management complexity, and implementation success we compare the strengths and weaknesses of three modern Ethernet switches. These switches exhibit a broad range of configuration options and are representative of the different levels of QoS implementation available today. We use the performance metrics of latency, jitter, and packet loss to characterize the success of a service policy. The results from a variety of network, load, and traffic scenarios are presented in terms of these metrics. Through the results, we are able to gain insight into the individual switch implementations of QoS.

## I. INTRODUCTION

Key applications for future cockpit and cabin avionics systems promise to drive the performance and reliability requirements of their integrated networking infrastructure to ever-increasing levels. Avionics networks are used to connect mission-critical systems, and therefore have strict performance requirements [1]. The switches used in these networks must be able to operate at line-rate while providing bounded latency and jitter, as well as offer a robust QoS scheme. Specifically, reliably low latencies are essential to handle the growing amounts of critical data. The need for higher bandwidth combined with the importance of cost makes commercial off-the-shelf (COTS) networking technologies desirable. Among the most promising network protocols and technologies to provide these capabilities are those of Ethernet. The economy of scale advantages of Ethernet have led to low equipment costs and ever-increasing line rates. While Gigabit Ethernet is currently under consideration, 10-Gigabit and 40-Gigabit Ethernet are also possible future choices. As the link rates increase, new switches and network interface cards will be required, but the network will remain interoperable with older equipment due to protocol backward compatibility.

The standard implementation of Ethernet makes no provision for treating individual traffic groups in distinct ways. Using QoS, Ethernet switches can identify certain

types of traffic and perform actions on the traffic if necessary. The development of Gigabit Ethernet has allowed significantly increased levels of performance with much higher data rates compared to the previous generation of Ethernet and an increasing degree of support for QoS. However, most QoS mechanisms have been developed to assure bandwidth and reduce packet loss instead of explicitly providing reliably low latency [2-3]. Further, the choice of implementation algorithms and management features changes the granularity and success of the quality of service implementation. Although committed bandwidth and low packet loss are important, avionics networks also require consistently low latency. Mission-critical systems such as navigation may require low latency, while other systems such as in-flight entertainment may require high bandwidth.

Our study analyzes three QoS-enabled Ethernet switches from the perspective of control capabilities, management complexity, and service implementation success. These switches were selected because they represent a range of prices and supported QoS abilities. The control capabilities and management complexity were examined qualitatively. The effectiveness of QoS controls is analyzed statistically in a variety of specific transmission scenarios. Combining these three perspectives, conclusions about the ability of modern COTS Ethernet switches to deliver desired performance guarantees for critical traffic, especially in an avionics setting, will be drawn.

The BayStack 5510-48T from Nortel Networks is an inexpensive 48-port Gigabit Ethernet switch. The switch supports several QoS features including 802.1p user priority and DiffServ. The BayStack can also be stacked to provide up to 384 Gigabit Ethernet.

The Catalyst 2970 from Cisco Systems offers 24 ports of inexpensive Gigabit Ethernet. This switch represents the entry-level Gigabit Ethernet switch from Cisco. It has support for all of the QoS features that will be tested in this study. The Catalyst also implements the shaped round-robin (SRR) queuing method, a modified form of weighted round-robin (WRR) queuing that most switches implement.

The E300 switch from Force10 Networks is the most versatile switch that was tested. The switch has 6 removable line cards that can be replaced to upgrade the network hardware. The switch has 400 Gbps of non-blocking backplane bandwidth, and both 802.1p priority and DiffServ are supported. This switch is designed to be used in high-

bandwidth, mission-critical systems such as internet exchanges or campus backbones.

The organization of the paper is as follows. Section 2 is an overview of QoS terminology and standards for Ethernet. Section 3 describes related work in QoS guarantees. Section 4 provides an overview of our experimental framework and procedure. Section 5 presents the results and analysis from our experiments. Finally, Section 6 contains the conclusions drawn from the study as well as future work.

## 2. BACKGROUND

Typically, Ethernet provides no performance guarantees and therefore operates on a best-effort basis. Although QoS can have many definitions, our key interest is in the study of performance-centric network QoS [2]. That is, this paper is interested in the ability of a network to provide specific performance guarantees. In fact, the primary focus of this study is to examine the ability of a network to provide reliably low latency to critical data.

In a physical (non-theoretical) network, performance guarantees are traditionally specified probabilistically [2]. In order to accomplish this task, the metrics of latency, jitter, and packet loss are used. Jitter is defined as the standard deviation of measured latencies.

In QoS, control mechanisms are specified and implemented to provide performance guarantees. In general, QoS mechanisms are categorized according to several key classifications: time scale, granularity, control carrier, and location of control [2]. QoS can work on multiple time scales. A switch can implement QoS on a per-packet basis, or QoS could be provided on the round-trip time scale by providing flow control. The granularity of QoS can be used to assign priorities based upon varying levels of information. QoS could be classified using a low-layer MAC address or using higher-layer information such as a destination port for a TCP packet. Finally, the control can be stored by a switch, or the information can be embedded inside of a packet header.

This paper focuses on packet-level QoS: mechanisms such as classifiers, markers, and shapers that improve packet transfer performance. Classifiers are elements of a system that determine what level of service should be given to a specific packet. Markers use the results of the classifier to mark the packet header permanently to pass the classification to the next switch. Finally, shapers moderate the packet to provide the proper level of service inside the switch. Fig. 1 shows the process that a switch uses to implement QoS.

There are two general levels of granularity of the control state of a QoS control mechanism: per-flow and aggregate. A per-flow control state provides different service for each *flow*. A flow is defined by an IP source and destination address, source and destination port, and protocol field. Aggregate control states combine several flows together and provide each flow in the group equal service to match the desired group profile [4-5]. Thus, the level of flow aggregation greatly affects the fidelity and complexity of the QoS implementation.

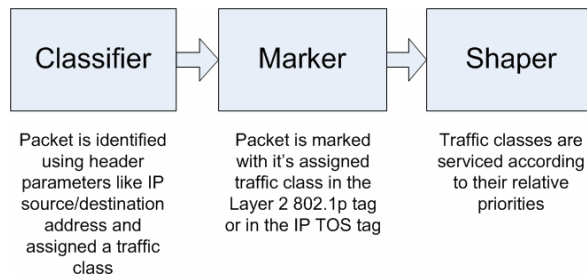


Fig. 1. Classification, marking, and shaping.

The final category of QoS classification is the location of the control. Almost all current Ethernet QoS implementations use the switch to store control state information [3, 6]. For this study, the switch is the sole location of control.

A number of Ethernet QoS standards have been developed to provide sophisticated control over switching performance. First, a relatively simple system, the IEEE 802.1p standard, was created as part of IEEE 802.1D [6]. 802.1p uses three bits from the Layer-2 tag to differentiate 8 levels of service. Therefore, in a complex network many different types of traffic must be aggregated into a single 802.1p service class.

The differentiated services (DiffServ) standard extends the three-bit 802.1p marking to six bits to provide 64 different classes of services [3]. DiffServ also specifies certain per-hop behaviors that can be implemented to assure service to each class. While the Class of Service field for an 802.1p packet is part of the MAC header, the DiffServ classification uses the Type of Service (ToS) field located in the IP header. DiffServ stores the QoS information inside of the packet header, allowing QoS packets to pass through network components that do not implement QoS.

In general, most switches implement both 802.1p and DiffServ and treat traffic of both types in a consistent manner. Most switches implement some variation of a priority queuing system to provide quality of service control. Ingress and egress queues are serviced according to internal priority mappings and queuing schemes. The priority mapping is used to map priority bits from any supported type of QoS to the proper destination queue for an incoming packet. All three of the switches analyzed in this study follow this pattern. Fig. 2 is a graphical representation of the generic implementation of switch-based QoS. Traffic is mapped into the appropriate priority queue and then shaped based on the priority scheme to empty the queues.

## 3. RELATED WORK

A number of recent studies have explored QoS guarantees. Most of these papers concentrate on absolute guarantees in

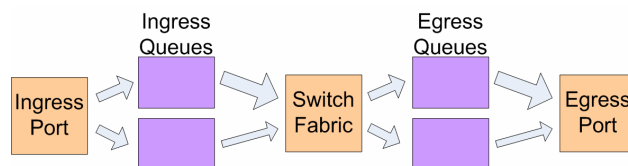


Fig. 2. Generic packet-based QoS prioritization.

theoretical networks, but a few also discuss probabilistic guarantees in a real network. A. Jarayya, *et al.*, developed an integrated service protocol in [7] as well as evaluated the importance of resource allocation and scheduling. Using a reservation-based protocol, their study measures the effects of different scheduling protocols, such as weighted fair queuing or strict priority queuing, on different types of traffic.

Several studies have also focused on using simulation or experimental analysis on performance guarantees. V. Laatu, *et al.*, experimentally analyzed the effects of a specific DiffServ mechanism on flows of similar priorities using latency and throughput as metrics [8]. Certain types of traffic were found to be more sensitive to the QoS policies than others. C. Bouras, *et al.*, used estimation to provide theoretical performance guarantees and then use simulative results to assess the accuracy of their predictions [9]. In [10], V. Firoiu, *et al.*, provided a framework for evaluating traffic engineering using modeling and then validated the model using simulation.

The use and development of performance metrics is a considerably large area of study. T. Chahed discussed in more detail performance metrics in [11]. Also, for a more complete study, refer to the Internet Protocol Performance Metrics (IPPM) RFCs. A good starting point is a “Framework for IP Performance Metrics” [12].

Previous work [1] compared several Gigabit Ethernet switches using latency and jitter as metrics. It was found that best-effort service between under-subscribed nodes exhibits low latency and line-rate switching. A very simple priority system was introduced, but latency was only measured on a single switch.

#### 4. EXPERIMENTAL FRAMEWORK

In order to evaluate the capability of a switch to provide probabilistic performance guarantees, both the management features and performance of each switch are evaluated. The fidelity and complexity of control mechanisms can vary considerably from switch to switch. For each switch, a short description of the management capabilities and the granularity of control is provided in Section 5. In particular, we evaluate to what degree the switch can be configured to match our chosen scenarios and then generalize our conclusions to how well the switch configuration can solve any arbitrary QoS problem.

In our experiments we concentrate on the goal of evaluating the ability of COTS Ethernet switches to provide reliably low latency for high-priority streams in a congested network. Specifically, our experiments attempt to develop a better understanding of under what conditions a switch can provide the requisite performance of statistically low latency and jitter. The metrics of mean latency and jitter will be critical to identifying expectations of performance. Furthermore, we use the variation of measured mean latencies to analyze the reliability of the observed results.

Fig. 3 shows the general setup for the experimental case studies in this paper. Several key many-to-one contention

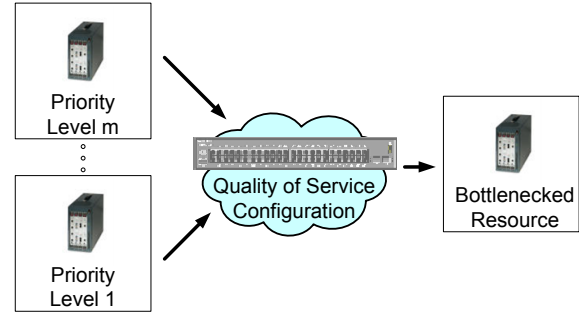


Fig. 3. Conceptual diagram of case studies.

scenarios are used to study the ability of QoS controls in the switches to provide performance guarantees to specific flows.

To analyze latency and jitter at the packet level, an Ixia 400T Traffic generator with 12 Gigabit Ethernet ports was used [4]. The Ixia 400T is capable of measuring received latency to the nearest 20 nanoseconds. The Ixia chassis and ports were configured using a custom Tool Control Language (Tcl) script designed to accurately measure real-time latency and packet loss. This approach also permitted the automation of tests to facilitate data collection. The latency was measured from the time the first bit of the packet leaves the Ixia transmission port until the time that same bit reaches the Ixia receive port.

These scenarios are abstract models of more complex real QoS problems where many different flows compete for a limited number of resources. In the first two cases, the traffic is formed in a many-to-one configuration where seven source nodes are simultaneously sending traffic at some prescribed load and priority to a single destination node.

First, each switch under test was configured to give all flows best-effort service to provide a control set for our later measurements. This approach provides a baseline so that the results with QoS enabled can be put into a proper context. This test case will be referred to as the best-effort case.

For consistency, streams with an 802.1p priority of 7 will be referred to as *platinum streams* for the remainder of this paper. Streams with a priority of 6 will be called *gold streams*. Streams with a priority of 5 will be called *silver streams*. Streams with a priority of zero will be referred to as *best-effort streams*.

In the next case, a single *platinum* stream was given highest priority while leaving the other six streams at lowest priority. The 802.1p priority was set by the switch based on the source address of the incoming packets. The platinum stream models a single flow of critical data competing with less critical data for access to an egress port. This test case will be referred to as the single platinum stream case.

In the second two cases, a larger scale experiment was conducted using 24 ports. For this experiment, only the BayStack 5510 and Catalyst 2970 were used. The 24-port test was designed using information about different traffic patterns in avionics networks included in a previous report to Rockwell Collins [13]. There are two high-bandwidth streams which are given platinum priority. In addition, there

are four gold streams which transmit at a much lower rate. There are also five silver streams that transmit at an even lower rate. 12 PCs are used to generate additional traffic with best-effort priority. These computers are separated into two groups of six. Each computer in a group communicates to another computer in the same group, and one computer transmits to the receive port on the Ixia traffic generator.

The test was conducted using two different sets of traffic patterns. The *Average Traffic* scenario is meant to show the network during normal conditions. The receive port on the Ixia chassis is approximately 90% utilized. In this case, the two platinum streams each transmit at 250 Mbps, the four gold streams each transmit at 20 Mbps, and the five silver streams each transmit at 10 Mbps. PCs are used to generate an additional twelve ports of best-effort traffic, transmitting at 140 Mbps each.

In the *Peak Traffic* scenario, the line rates of all streams are increased. This is meant to simulate points in time when there is an unexpected jump in the amount of data being transferred. The Peak Traffic scenario causes the receive port to be over-utilized, but the high-priority traffic is less than 1 Gbps. In this scenario, platinum streams each transmit at 300 Mbps, gold streams each transmit at 50 Mbps, and silver streams each transmit at 25 Mbps. PCs are again used to generate an additional twelve ports of best-effort traffic, transmitting at 250 Mbps each.

Latencies were measured for successfully received packets only; dropped packets do not affect latency measurements. For the 24-port tests, traffic for twelve ports was generated using PCs with Intel PRO/1000 MT Gigabit Ethernet adapters, while the Ixia 400T chassis was used to generate 11 additional ports of traffic and 1 port was used to receive. The computers used were 1.33 GHz Athlon-based machines with 256 MB of DDR PC2100 RAM. Packet sizes of 128, 512, and 1518 bytes were used although only the results of 128- and 1518-byte runs are shown in Section 5 to conserve space. Only 128-byte packet data is shown for the 24-port tests. The line rate of the transmitting ports was varied from 0% to 30%. Trials were conducted 3 times for each data point. There were no significant variations between trials except where noted in Section 5.

## 5. RESULTS AND ANALYSIS

The following sections analyze the performance and abilities of three COTS Gigabit Ethernet switches. In Section 5.1, we analyze each switch qualitatively for management capabilities. Section 5.2 analyzes the performance differences between the separate test beds.

### 5.1 Switch analysis

Intended as an edge switch rather than a core router, the BayStack 5510 offers fairly straightforward QoS control [5]. The 5510 supports both 802.1p and DiffServ classification and marking. The switch enforces policies using 8 egress queues which can be configured to have a strict priority or WRR queue emptying scheme. Strict priority will always

favor packets with the highest 802.1p value, while the WRR approach will give some access to the lower-priority queues. Each queue can be assigned a specific amount of bandwidth to be given in order to provide more fidelity to the QoS implementation. Depending on the packet's 802.1p/DiffServ priority, the packet is mapped to one of the queues by a configurable mapping.

The switch by default disables QoS but has a simple priority mapping in memory to make setting up a WRR priority scheme simple. A WRR scheme is usually preferred so that lower priority streams do not starve under heavy loading conditions. Since the hypothetical platinum stream represents critical data in an avionics network, the highest priority is allocated to the stream. At the same time, the low-priority traffic should not starve whenever the platinum stream is transmitting. Based on the requirements of the platinum stream, network engineers could adjust the WRR queuing. Since the 5510 only has 8 queues, all traffic must be grouped into 8 classes of service for shaping.

The Catalyst 2970 features a slightly more complicated QoS control than the BayStack 5510 in terms of possible configurations. Like the 5510, the Catalyst 2970 features 802.1p and DiffServ classification and marking. The switch offers the ability to queue the packets at ingress according to priority as well as at the egress port. Two ingress queues and four egress queues are available at each port. Using the packet's 802.1p/DiffServ priority, the packet is mapped to one of the queues based on the current priority mapping.

The Catalyst 2970 has a configurable SRR priority scheme to empty each buffer at both the ingress and egress queues. The SRR algorithm specifies a maximum amount of bandwidth that a queue may use. However, if other queues are empty, the bandwidth may be shared. The control over the queues is more complicated than the configuration of the BayStack 5510, but also has greater fidelity since it is possible to specify both the SRR scheme and also the size of each queue. Multiple ingress queues would be useful for distinguishing between different flows that arrive on the same port, but with only 4 egress queues, multiple flows must be aggregated into a single class of service for shaping.

The Force10 E300 is quite different from the other two switches in our study. Intended as a core switch with multiple 10-Gigabit Ethernet ports, the E300 has large buffers capable of storing up to 200 milliseconds worth of data [14]. As in the Catalyst 2970, after classification, the switch chooses which packets to send from the ingress queues based on priority and congestion avoidance. Congestion avoidance consists of Random Early Drop (RED) or Weighted RED (WRED). These methods eliminate packets before a port reaches saturation in order to protect high-priority streams from packet loss. Then, the packet is placed in one of 8 egress queues where egress traffic is also shaped. All of the mappings are configurable with a default that satisfies simple QoS problems.

The E300 allows the bandwidth percentages assigned to each egress queue to be set in the configuration of the switch.

The granularity is 1%, so using the bandwidth percentage command does not give quite as much control to the network engineer. Also, it is possible to specify the committed, peak, and burst rates allowed for each ingress and egress class so that a more complicated scheme can be created.

### 5.2 Performance comparisons

This section presents the QoS performance comparisons between the Nortel Networks BayStack 5510, the Cisco Systems Catalyst 2970, and the Force10 Networks E300. The switches are compared on their performance in terms of average latency, jitter, and packet loss. Sections 5.2.1 and 5.2.2 compare best-effort performance below saturation and above saturation, respectively. Section 5.2.3 evaluates the performance when a single platinum stream is used. Section 5.2.4 evaluates performance in a complex, 24-port test. By comparing the performance of the switches, insight into the algorithms that control QoS can be gained.

#### 5.2.1 8-port best-effort below saturation

Most often, a switch operates below saturation. Therefore, the ability of a switch to provide reliably low latencies and low jitter below saturation are of particular interest. Fig. 4 and 5 show the best-effort average latencies for small and large packets for all three switches in this study.

Notice that the BayStack 5510 and the Catalyst 2970 have similar latencies but the E300 has consistently higher

latencies. Although the E300 has the highest latencies measured, the difference between the E300 and the other switches is less for larger packet sizes, indicating that the Force10 switch favors larger packet sizes.

Comparing the jitter below saturation under best-effort conditions shows that all three switches provide relatively consistent latencies. Fig. 6 and 7 show that the E300 jitter is slightly higher than the other two switches but not by the same relative differences as found in latency given in Fig. 4 and Fig. 5. The BayStack 5510 typically has at least 5 microseconds lower jitter than the other switches for large packet sizes. The exception is at 10% line rate where the Catalyst 2970 has a slight edge. Without QoS controls enabled, the BayStack 5510 is able to provide the lowest jitter compared to the other switches, although the Catalyst 2970 is only slightly behind.

#### 5.2.2 8-port best-effort behavior after saturation

As each switch reaches saturation, packet loss becomes a problem and thus latency can no longer be measured. Packet loss on each switch occurred when the line rate of each of the seven transmitting streams was greater than 143 Mbps (i.e. 14.3% line rate). The packet losses for the BayStack 5510 and E300 were roughly equivalent, with the E300 having slightly lower packet loss.

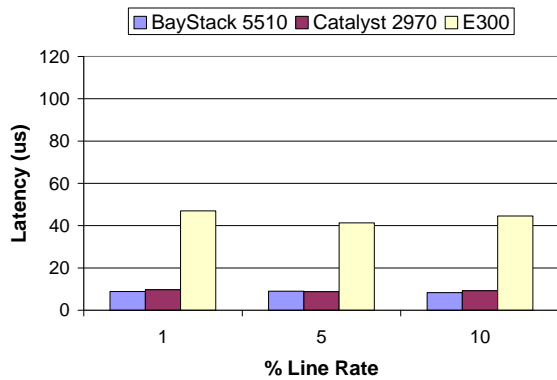


Fig. 4. Best-effort 128-byte packet average latency.

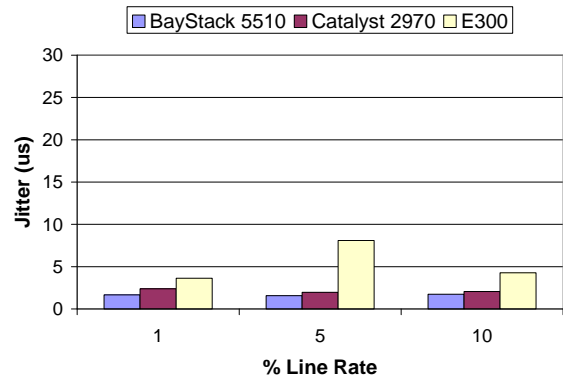


Fig. 6. Best-effort 128-byte packet jitter.

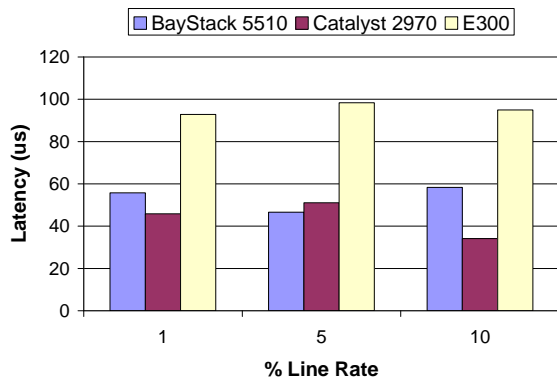


Fig. 5. Best-effort 1518-byte packet average latency.

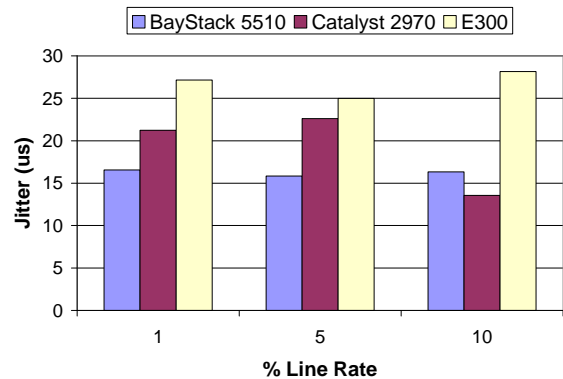


Fig. 7. Best-effort 1518-byte packet jitter.

### 5.2.3 8-port single platinum stream behavior

The platinum stream latencies are shown for all three switches in Fig. 8 and Fig. 9. After QoS is enabled, the below-saturation latencies of the BayStack and Catalyst are 1 microsecond less than the best-effort case for small packets. However, the latency of the E300 is approximately 10 microseconds lower for small packets at 5% and 10% line rate. Large packet sizes saw considerable reductions in latency from using QoS except in the Catalyst 2970.

The BayStack 5510 latency was reduced by an average of 7 microseconds for the large packet sizes. While the Force10 switch has higher latencies, it also benefits more from the use of QoS below saturation.

The results in Fig. 8 indicate that the BayStack and Catalyst vastly outperform the E300 in latency above saturation for small packets. The BayStack and Catalyst latencies increase slightly after saturation while the E300 nearly triples. Fig. 9 shows that the relative difference is not quite as serious in larger packets, but small packets can be important to an avionics network [1]. The Catalyst performs slightly better above saturation at reducing the latency.

The single platinum stream jitter results are shown in Fig. 10 and Fig. 11. For 1518-byte packets, the jitter is reduced greatly after applying QoS for the Catalyst and E300. The BayStack jitter is also reduced by 5 microseconds, but exhibits the highest jitter observed.

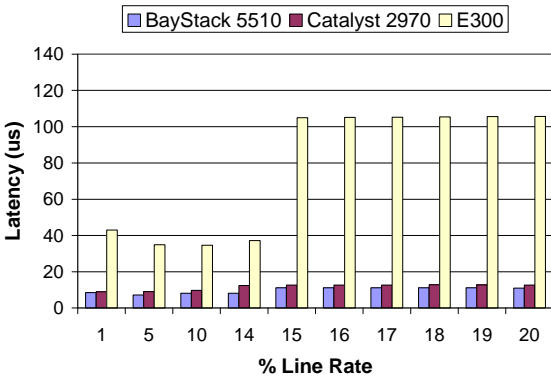


Fig. 8. Single platinum stream 128-byte packet latency.

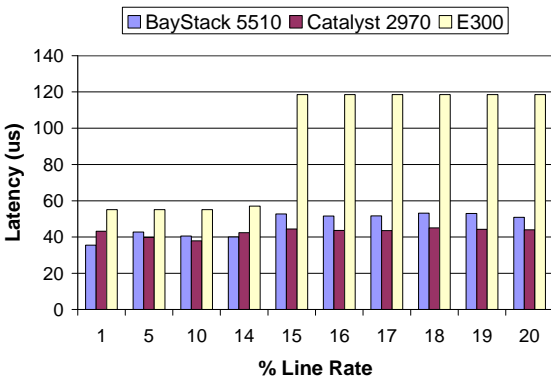


Fig. 9. Single platinum stream 1518-byte packet latency.

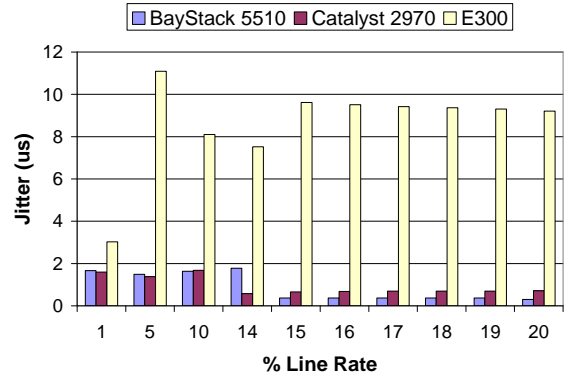


Fig. 10. Single platinum stream 128-byte packet jitter.

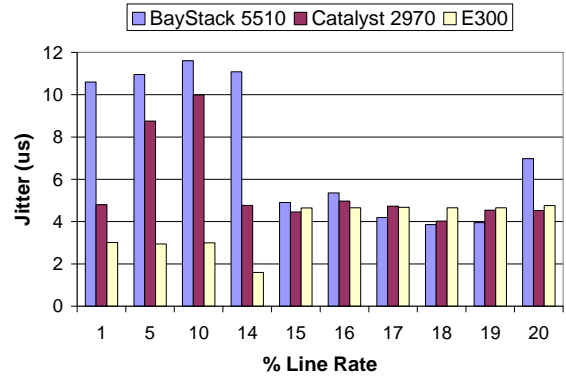


Fig. 11. Single platinum stream 1518-byte packet jitter.

Above saturation, the small-packet jitter is very low for the BayStack and Catalyst, while more considerable but manageable for the E300. However, the large-packet jitter has all three switches having about the same jitter after saturation and the E300 having lower and more consistent jitter below saturation. The E300 was designed with 10GigE operation in mind. Therefore, it may be optimized for larger packet sizes to get the best use from faster operation because of the effects of the inter-packet gap.

The packet loss for all three switches was 0% for the platinum stream. Thus, all three are capable of properly preventing packet drop with QoS for critical data.

### 5.2.4 24-Port experimental results

Without QoS enabled, both of the tested switches show similar results for the 24-port experiment. The latency results of the Average Traffic case for 128-byte packets are shown in Fig. 12. The platinum streams receive the lowest average latency on both switches, and the gold streams receive higher latency. The silver streams receive lower latency on the BayStack, but similar latency to the gold stream on the Catalyst.

With QoS enabled, the BayStack 5510 decreases average latency for the platinum streams, increases average latency for the gold streams, and does not affect the average latency of the silver streams. The platinum streams experience a

lower maximum latency when QoS is enabled, resulting in a lower amount of jitter, as seen in Fig. 13.

The Catalyst 2970 decreases average latency for the platinum and silver streams, but increases the average latency for the gold streams. All of the streams have reduced maximum latency when QoS is enabled. The silver streams benefit the most from the use of QoS controls on the Catalyst 2970, due to the significantly lowered maximum latency.

In the Peak Traffic case, packet loss will occur on all streams if QoS is not enabled. We will only look at the QoS-enabled case. The latency of every stream is higher than in the Average Traffic case on both switches. However, no packet loss is experienced. The average latency values for each stream are shown in Fig. 14.

Fig. 15 shows the jitter values for the various streams on the BayStack 5510 and Catalyst switches. The QoS controls of the BayStack 5510 are able to control jitter in a predictable way. Higher priority streams have less jitter than lower priority streams when the receive port is over-saturated. The Catalyst 2970 jitter is lowest for the silver streams, 1.7 us. This behavior is due to the way the switch treats streams with a priority level of 5.

The silver streams on the Catalyst 2970 demonstrate that the switch treats packets with an 802.1p or IP precedence value of 5 as the highest priority. This switch is configured by default to provide QoS for Voice over IP (VoIP) streams. VoIP streams usually have a priority level of 5. This

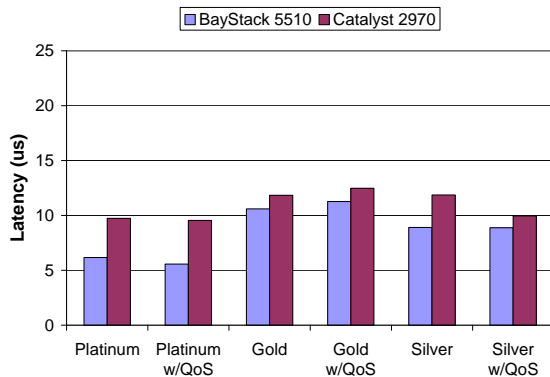


Fig. 12. 24-Port Average Traffic latency results.

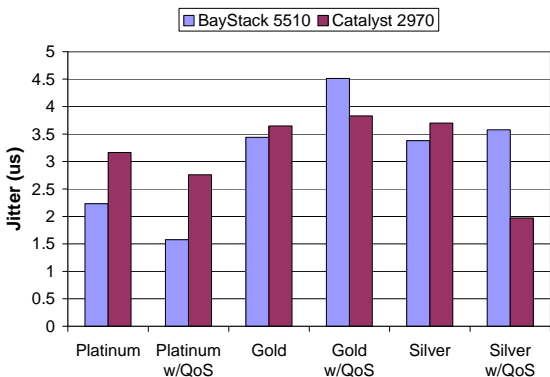


Fig. 13. 24-Port Average Traffic jitter results.

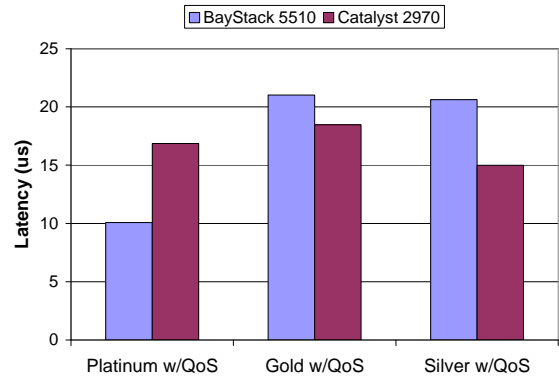


Fig. 14. 24-Port Peak Traffic latency results.

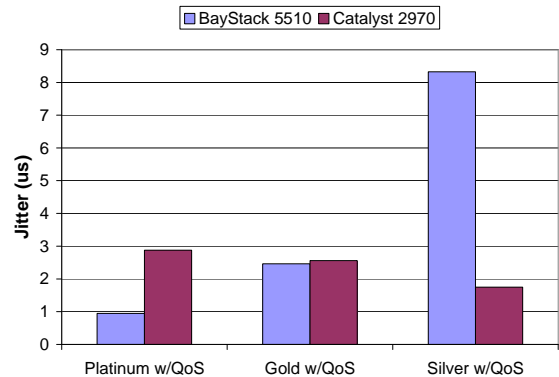


Fig. 15. 24-Port Peak Traffic jitter results.

behavior could be changed by remapping the priority levels to specific high-priority buffers [15].

The Catalyst 2970 has only four egress queues and must therefore combine certain priorities into specific queues. Streams with a priority level of 6 or 7 are combined into the same queue, while streams with a priority level of 5 are given their own independent queue intended for VoIP traffic. The silver streams have lower jitter caused by lower amounts of traffic and a dedicated queue, while the platinum and gold streams generate a significantly greater amount of traffic and have a shared queue.

## 6. CONCLUSIONS

Aircraft networks demand both high bandwidth and low latency within bounds. For this reason, switches built for these networks were usually custom-designed for each generation of network. Current Gigabit Ethernet switches offer high throughput and low latency in over-provisioned cases. With the use of QoS-enabled switches, these benefits can be extended to cases where the network is slightly under-provisioned. Therefore, COTS switches with QoS controls offer a low-cost solution for avionics networks. This paper presents a comparative performance evaluation of three such switches: the Nortel Networks BayStack 5510, the Cisco Systems Catalyst 2970, and the Force10 Networks E300.

Each switch provides a reasonable amount of QoS control with options for creating a full solution to match desired performance capabilities. Latencies and jitter for all switches decreased dramatically for critical data as long as it is given sufficient priority. However, these switches have not yet reached their potential in terms of matching the versatility of QoS standards. Although each switch implements DiffServ classification and tagging, none of the three switches examined had the ability to differentiate between 64 separate traffic classes for purposes of queue shaping. Thus, network engineers are given fewer options to implement complicated priority schemes.

The BayStack 5510 from Nortel Networks featured very impressive latency and jitter performance, especially for smaller packets. The switch was capable of assuring jitter for critical data below 2 microseconds for small packet sizes. Further, the BayStack configuration utility was easy to use while providing a good amount of QoS control to create more powerful QoS solutions. The Nortel Networks has 8 egress queues, which allows for a variety of traffic profiles.

The Catalyst 2970 from Cisco Systems also featured low latency and jitter for small packets. For large packet sizes, QoS controls decrease large-packet jitter by at least 10 microseconds compared to the best-effort case. The QoS configuration of this switch allows the user to have control over all aspects of the QoS policies. The ability to shape at the ingress queue is a significant difference, which would possibly help packets that have already been classified by a previous switch. This switch also implements WRED and other congestion avoidance techniques that are useful for protecting critical data.

The E300 from Force10 Networks also featured low jitter, but its latency was much higher than the other two switches. For low traffic loads, the E300 has jitter of approximately 3 microseconds for large packet sizes. The E300 is intended as a core switch for high-end applications. The large amount of QoS control however means that the E300 can implement the most diverse set of policies of any of the switches analyzed.

As future work, simulation models will be built and used to extend the experimentally gathered data. The simulations will investigate the use of new QoS services that are beyond the capabilities of the current experimental testbed. Various network, traffic, and load scenarios will be analyzed for the QoS mechanisms under study. The simulations will provide probability distributions of arrival latencies for different QoS algorithms. The models will be verified against the experimental data that has already been gathered. This data will provide a comprehensive analysis of the relation between current and emerging QoS services and switch technologies in terms of statistically bounded latencies.

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