Fully Functional Rate Limiter Design on Programmable Hardware Switches

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CCS CONCEPTS
• Networks → Middle boxes / network appliances.

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P4, Rate Limiter, Network Function

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1 INTRODUCTION
Rate Limiters play a key role in network QoS management such as bandwidth allocation and performance isolation. Rate limiters can be implemented in various locations in the network (e.g., Linux HTB, NIC, switches [4–6]); however, in certain scenarios where network operators have no access to end hosts, a rate limiter can only be implemented on network devices (e.g., mobile core networks, IaaS cloud providing bare mental machines). A recent trend of programmable switches [1] gives an opportunity to implement in-network rate limiters.

In this project, we would explore the approach to implement a rate limiter under the constraints of hardware programmable switches. While the current programmable hardware switch provides some degree of packet processing flexibility, but there still exist constraints:1 (1) the data flow in a switch is uni-direction, and it can only go from the switch buffer to the switching circuit; (2) the programmability is only limited to work on the switching circuit, not available on buffers; (3) the computation on switches is limited, without native support to operations like multiplication and division, and temporal logic; (4) switch memory is scarce to scale to many flows’ processing.

The design space of a rate limiter includes algorithmic choice (leaky bucket v.s. token bucket), excessive traffic policy (traffic shaping v.s. traffic policing [3]), and implementation approach (timer-based v.s. event-based). Due to the limitation on programmable hardware switches, we could only implement the token bucket algorithm with traffic policing.

In the rate limiting algorithm, two parameters committed rate and burst size BS are configured, and a variable token is maintained. The token accumulates with time and is constrained by BS as threshold. For each packet, if there are sufficient tokens (i.e., token >= pkt.size), the packet is sent and the token is reduced; otherwise, the packet is dropped. Note that “the token accumulates with time” can be implemented in two ways: in a timer-based approach, a timer periodically triggers the token update to accumulate the token within the period; in an event-based approach, each packet triggers the accumulation calculation within the duration between the current packet and the previous successfully sent packet (multiplied by the rate).

We first profile the performance of a timer-based and an event-based rate limiter, and show their insufficiency caused by hardware limitations: the timer-based rate limiter is not TCP friendly with throughput oscillation; and the event-based rate limiter is not flexible in rate control. To build a fully functional rate limiter, we propose several improvements and optimizations to achieve a rate limiter on the current program hardware switches with (1) committed rate saturation, (2) low oscillation, (3) rate flexibility, and (4) memory efficiency.

2 PROFILING RATE LIMITERS
We implement the two rate limiters and profile them. The experiment has a switch in the middle and two servers on the edge (a sender and a receiver) with 10Gbps NIC. The RTT on the testbed is less than 100us. We tune the committed rate and burst size as the parameter and measure the throughput and the oscillation (i.e., the standard deviation of the throughput). Figure 1 shows the results, and we observe that both rate limiters can achieve rate control. But each of them has its own insufficient aspects.

The timer-based rate limiter makes TCP flows experience obvious oscillation and the oscillation cannot be improved by tuning burst size. We notice that the refreshment interval is larger than RTT (~4ms v.s. 100us). Within each refreshment interval, there are several rounds of packet round trips, which leads to the final window size (before drop) to be larger and the rate limiter to be easier to drop packets. We also argue that, in most data center networks,

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In details, we cannot program the switch buffer to selectively drop excessive packets, so the leaky bucket algorithm is excluded, and the switch hardware circuit cannot withhold or put packet back to buffer, so traffic shaping is excluded.
We propose the following improvements and optimization for the event-based rate limiter, that is varying with Committed Burst Size (CBS) value in the entry. Since it is not possible to pre-compute products of multiplicand and multiplier in arbitrary granularity and range (e.g., real number domain), it is actually an approximate algorithm. And an analysis of the tradeoff between storage space (i.e., granularity) and accuracy (error in result) is needed. Similarly, we can achieve division with Approximate Division Table (ADT).

**FULLY FUNCTIONAL RATE LIMITER DESIGN**

We propose the following improvements and optimization for the event-based rate limiter to get a fully functional rate limiter.

**Achieving Multiplication.** We present Approximate Multiplication Table (AMT) to overcome limited computation. The key idea of AMT is to pre-compute intermediate results and store in a table, then all computations in the runtime are transformed as table look-ups. For example, if we need to compute $a \times b = c$, we can pre-compute a table with $<a, b>$ as the key to look up and $c$ as the value in the entry. Since it is not possible to pre-compute products of multiplicand and multiplier in arbitrary granularity and range (e.g., CBS (MB), Timer-based)

![Figure 1: Mean values and variances of TCP throughput varying with Committed Burst Size (CBS)](image1)

The event-based rate limiters reduce the oscillation significantly. For example, in the timer-based rate limiter the oscillation is $>30$% when the rate is 40Mbps; but in an event-based rate limiter, that is $\leq 7$% when the rate is 64Mbps. The reason of such improvement is that the packet arrival interval in the event-based rate limiter is usually smaller than the refreshment time interval in the timer-based one, and even smaller than RTT. Thus, the token value can be accumulated, updated, and consumed in a more timely manner, which contributes to a more smooth and precise rate control.

However, the event-based rate limiters are inflexible in rate control. The essential reason is that in the token update, the product of $\text{timeInterval} \times \text{rate}$ requires multiplication $\times$, which is not supported by the current programmable hardware. The best candidate to support such an operation is "shift $<c$", and thus, only limited rate can be configured (i.e., $2^n$Mbps).

![Figure 2: Mean values and variances of TCP throughput varying with Committed Burst Size (CBS)](image2)

**REFERENCES**


