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Frame-counter scheduler: A novel QoS scheduler for real-time traffic

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Abstract

Real-time traffic communication has Quality of Service (QoS) requirements such as end-to-end bandwidth and delay guarantees. We propose a novel frame-based QoS Scheduler, *the frame-counter scheduler*, for connection oriented packet switching networks. The frame-counter scheduler significantly reduces the end-to-end delay bound and buffer requirements provided by other frame-based schedulers. A fixed amount of buffer is required per node for no packet-loss operation. There is no need for frame synchronization or inter-node communication. The scheduling complexity of frame-counter scheduler is O(1) which makes it possible to implement it for high-speed networks. The required input traffic shape is not more restrictive than the traffic shapes used by the other schedulers.

In this paper, we present the proof for the end-to-end delay bound and the buffer requirement for the frame-counter scheduler. We also provide simulation results to demonstrate the average performance which show that the average end-to-end delay and delay variation (jitter) of the packets is much lower than the end-to-end bound.

Keywords: QoS; Real-time traffic; Frame-based scheduler

1. Introduction

The end-to-end Quality of Service (QoS) for the real-time communication includes bandwidth, delay, and jitter guarantees. Connection admission control and traffic shapers at the network edge are required for QoS support. The switches must use traffic scheduling algorithms to serve packets carrying real-time data in the network. Such traffic scheduling algorithms should have low implementation complexity and simple connection admission control to be able to operate at high speed. Processing and scheduling packets at high line speeds need to be completed in the order of nanoseconds. This short time period increases complexity and limits the scalability of switching systems. Thus, providing end-to-end QoS guarantees for real-time traffic in a scalable and low-complexity fashion is an important issue in high-speed communication networks.

Many QoS schedulers that can support different QoS guarantees have been proposed in the literature. These algorithms include Weighted Fair Queuing (WFQ) [1], Self-Clocked-Fair-Queuing (SCFQ) [2], Delay-Earliest-Due-Date (D-EDD) [3], Rate-Controlled-Static-Priority (RCSP) [4], Traffic-Controlled Rate-Monotonic Priority Scheduling (TCRM) [5], Stop-and-Go (S&G) [6], Hierarchical Round-Robin (HRR) [7], Continuous Framing (CF) [8] and Budgeted Weighted Round-Robin (BWRR) [9].

In this paper, we propose a novel frame-based QoS scheduler called the *frame-counter scheduler*. The frame-counter scheduler can provide tighter end-to-end delay bound than other frame-based schedulers. The amount of buffer required for no-packet-loss operation is also small. The frame-counter scheduler does not need any inter-node frame boundary synchronization or communication yielding a low implementation complexity.

Hence, the proposed frame-counter QoS scheduler can provide end-to-end delay and bandwidth guarantees for

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real-time traffic in high-speed networks in a scalable fashion.

Following this introduction, in Section 2, we present background information and a literature survey of the traffic schedulers for QoS support. In Section 3, we describe the problem formulation and explain the design principles. In Section 4, we describe the operation of the frame-counter scheduler. We prove that it satisfies a certain end-to-end delay bound, and works a certain buffer size limit. We also discuss the scheduling complexity of the frame-counter scheduler. In Section 5, we present simulation results to demonstrate the average performance of our algorithm. Finally, we give conclusions in Section 6. The proof of the correct operation and the provided QoS guarantees of the frame-counter scheduler is based on the construction of a state machine model which is presented in Appendix C.

2. Background

In this section, we first introduce the input traffic specification (i.e., packet arrival pattern at the source node), and the operation principles of different QoS schedulers. Then we discuss the performance metrics for these schedulers such as implementation complexity, required buffer space in each switch, and the provided QoS guarantees.

We consider connection-oriented networks for real-time traffic transport. The switches that are on the end-to-end path of a connection can allocate resources to provide performance guarantees. A connection admission process is required to check if it is possible to deliver the required QoS to the new connection without any service degradation for the existing connections. Two main approaches for the QoS Schedulers are sorted-priority and frame-based schemes.

Sorted-priority algorithms compute a timestamp for each arriving packet with respect to the current system state and update the system state accordingly. The scheduler sorts the packets based on their timestamps. The complexity of such algorithms derives from the computation of the timestamp for each packet and from maintaining the priority queues. The required computations have to be performed at the line rate. An increase in the line rate requires faster computation which results in a more expensive implementation. WFQ, SCFQ, D-EDD, RCSP and TCRM are examples for sorted-priority algorithms.

Frame-based approaches provide deterministic delay bounds for the real-time traffic in the packet network. Bandwidth guarantees are provided by splitting time into frames and limiting the amount of traffic that can be transmitted during a frame period [10]. A strict admission policy based on the peak rate of the connections is required to guarantee the bounded end-to-end delay. There might be an additional delay component to smooth the bursts over the frames. Algorithms such as S&G, HRR, CF and BWRR adopt the frame-based approach.

All of the QoS schedulers we mention above provide per-connection end-to-end delay guarantees to traffic streams regulated by a specific traffic model. Traffic specification models for real-time services bound the source traffic so that the number of bits that arrive for a connection during a specified time interval does not exceed a certain amount. Such traffic specifications include (r, T), (σ, ρ), and $(X_{\min}, X_{\text{ave}}, I, S_{\max})$ [11]. In the (r, T) model, the traffic is shaped such that no more than rT bits are transmitted in an interval of length T which is called a frame, where r is a measure of the average rate. Similarly, in the (σ, ρ) model, σ indicates the maximum burst size and ρ indicates the long term bounding rate. In this traffic model, no more than $(\sigma + \rho\tau)$ bits are transmitted during a time interval τ. The $(X_{\min}, X_{\text{ave}}, I, S_{\max})$ model defines the minimum inter-arrival time between packets as $X_{\min}$ and the average inter-arrival time between packets measured over an interval of length I as X_{ave}. The maximum packet size is denoted by $S_{\max}$.

The end-to-end delay bound guaranteed by the QoS schedulers depends on the input traffic specification parameters and the number of hops on the end-to-end path of the connection. The scheduling complexity is either $O(1)$ or depends on the total number of connections to be scheduled (V).

WFQ and SCFQ work with the (σ, ρ) traffic model. They provide an end-to-end delay bound that grows linearly with the number of hops on the end-to-end path. The end-to-end delay bound for the WFQ algorithm is the time to transmit the burst at the allocated rate in addition to the time spent to transmit the largest packet at each node. The scheduling complexity of the WFQ algorithm is $O(V)$ and the required buffer space for no packet loss operation grows at each switch on the path. SCFQ decreases the scheduling complexity to $O(\log V)$ at the expense of increasing the delay bound.

D-EDD and RCSP work with the $(X_{\min}, X_{\text{ave}}, I, S_{\max})$ traffic model and TCRM works with the (σ, ρ) traffic model. They can guarantee bounded link and end-to-end delays which depend on the current state of the connection establishment. They all have a scheduling complexity of $O(\log V)$. TCRM has a connection admission algorithm with a complexity of $O(V)$. Using traffic regulators and assigning static priorities for each connection in these algorithms simplify the implementation. RCSP can operate with fixed buffer size at each node while the required buffer increases at each node on the path for D-EDD.

The proposed frame-counter scheduler is a frame-based QoS scheduler. Next, we explain S&G, HRR, CF and BWRR algorithms which are also frame-based schedulers.

S&G, HRR and CF are frame-based algorithms that are designed for fixed-size packets. They work with the (r, T) traffic model, where T is the used frame size. This traffic shape is maintained throughout the network by these algorithms. There is a difference in the service order of the packets between S&G and HRR. In S&G, packets that are transmitted in the same frame at the network ingress are transmitted in the same frame on all links traversed