A Rule-Based Approach for Consistent Proportional Delay Differentiation

(Extended Abstract)

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Abstract. Proportional delay differentiation (PDD) aims to maintain pre-specified packet queueing-delay ratios between different classes of traffic at each hop. Existing rate-allocation approaches for PDD services assume the average queueing delay of a class is inversely proportional to its service rate. This assumption may not be valid in a non-heavily loaded system. In this paper, we present a rule-based approach to provide *consistent* PDD services under various load conditions. In this approach, the service rate of a class is adjusted according to a set of control rules. Simulation results demonstrate that, in comparison with other rate-allocation approaches, the rule-based approach is able to provide PDD services under light, moderate, and heavy load conditions consistently.

1 Introduction

Proportional delay differentiation (PDD) service model is to maintain pre-specified queueing delay ratios between different classes [2]. In existing rate-allocation approaches for PDD services, the service rate of a class is adjusted periodically based on current system states [1, 2, 4]. For example, in backlog-proportional rate (BPR), a class's service rate is adjusted according to its backlogged queue length [2]; in joint buffer management and scheduling (JoBS), the service rate is set based on delay predictions of its backlogged traffic [4]. In [1], the authors proposed a linear feedback control approach (referred to as LFB in the rest of this paper), in which a class's service rate is adjusted according to the difference between its normalized head-of-line delay and the average of all backlogged classes. These approaches assume that the average queueing delay of a class is inversely proportional to its service rate. This assumption is valid only during busy periods of the system. These approaches thus are unable to deliver PDD services in a non-heavily loaded system because of the existence of idle periods. In this paper, we present a rule-based rate-allocation approach that relies on a general relationship between the amount of allocated rate and queueing delay to providing PDD services consistently.

2 Design of The Rule-Based Approach

The rule-based rate-allocation approach is based on fuzzy control theory to provide consistent PDD services under various workload conditions. Let W_i denote the average delay of class i computed during a sampling period, and δ_i its pre-specified differentiation parameter. For class i and class j in the system, PDD requires W_i/W_j equals to δ_i/δ_j. In the rule-based approach, the service rate of a class in sampling period $k+1$, denoted by $u(k+1)$, is adjusted according to its error $e(k)$ (*i.e.*, difference between the target delay ratio and the achieved one) and change of error $\Delta e(k)$ in sampling period k. Such adjustment is controlled by a set of rules about heuristic knowledge described by fuzzy logic methods. Figure 1 shows the control structure of the rule-based approach. The rule-base contains quantified control knowledge about how to adjust a class's service rate according to the $e(k)$ and $\Delta e(k)$. The fuzzification interface converts controller inputs into certainties in numeric values of the "triangle" membership functions that are defined for the inputs. The inference mechanism activates and applies rules according to fuzzified inputs, and generates fuzzy conclusions for defuzzification interface. The defuzzification interface converts fuzzy conclusions into the change of service rate of a class in numeric value using "center average" method.

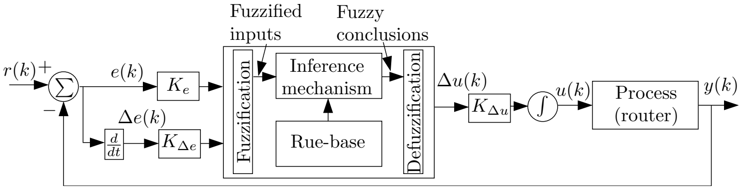


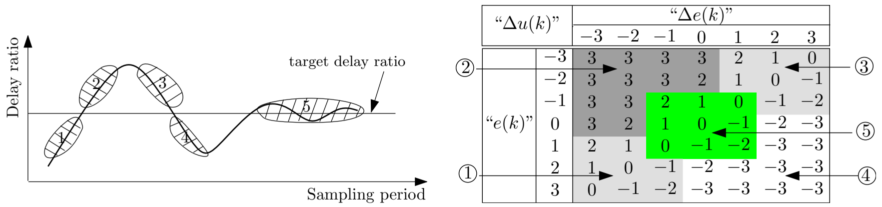
Fig. 1. The control structure of the rule-based approach.

In the approach, class 1 is selected as the base class. A control loop is associated with every other class. In the control loop of class i, the reference input for kth sampling period $r_i(k)$ is $\delta_i(k)/\delta_1(k)$. The output of the loop is the achieved delay ratio of class i to the base class. The error $e_i(k)$ and the change of error $\Delta e_i(k)$ are therefore defined as $\delta_i/\delta_1 - W_i(k)/W_1(k)$ and $e_i(k) - e_i(k-1)$, respectively. The output of the controller is $\Delta u_i(k)$, the rate adjustment of class i. As shown in Figure 1, there are three control factors in the controller. Thus, the inputs of the controller are $K_e e(k)$ and $K_{\Delta e}\Delta e(k)$. The output $u(k) + K_{\Delta u}\Delta u(k)$ is a class's service rate for sampling period $k+1$.

The control rules is defined using linguistic variables and values from fuzzy control theory. The linguistic variables are used to describe each of the controller inputs and output. The linguistic variables assume linguistic values, which are represented using integers. We have "3" ("-3") describes positive (negative) large in size; "2" ("-2") represents positive (negative) medium in size; "1" ("-1") describes positive (negative) small; and "0" is zero in size.

We first analyze the effect of the controller on the achieved delay ratio in PDD service provisioning as illustrated in Figure 2(a). In this figure, five zones of different characteristics can be identified. Zone 1 and 3 are characterized with opposite signs of $e(k)$ and $\Delta e(k)$. That is, in zone 1, $e(k) > 0$ and $\Delta e(k) < 0$; in zone 3, $e(k) < 0$ and $\Delta e(k) > 0$. In these two zones, the error is self-correcting, and the achieved delay ratio is moving towards to the target one. Then $\Delta u(k)$ is set to either speed up or slow down the current trend. Zone 2 and 4 are characterized with same signs of $e(k)$ and $\Delta e(k)$.

That is, in zone 2, $e(k) < 0$ and $\Delta e(k) < 0$; in zone 4, $e(k) > 0$ and $\Delta e(k) > 0$. In these two zones, the error is not self-correcting, and the achieved delay ratio is moving away from the target one. Then $\Delta u(k)$ is set to reverse the current trend. Zone 5 is related to situations characterized with rather small magnitudes of $e(k)$ and $\Delta e(k)$. That is, both $e(k)$ and $\Delta e(k)$ are close to zero, and the system is at a steady state. Thus $\Delta u(k)$ is set to maintain current state and correct small deviations from the target delay ratio.



“$\Delta u(k)$”		“$\Delta e(k)$”						
		-3	-2	-1	0	1	2	3
“$e(k)$”	-3	3	3	3	3	2	1	0
	-2	3	3	3	2	1	0	-1
	-1	3	3	2	1	0	-1	-2
	0	3	2	1	0	-1	-2	-3
	1	2	1	0	-1	-2	-3	-3
	2	1	0	-1	-2	-3	-3	-3
	3	0	-1	-2	-3	-3	-3	-3

(a) Illustration of control effect.

(b) The control rules.

Fig. 2. Design of control rules.

The resulted control rules based on the analysis are summarized in Figure 2(b). A general linguistic form of these rules should read as: *If* premise *Then* consequent. For example, assuming that both $e(k)$ and $\Delta e(k)$ are “1”, the rule then is: *If* the error is positive small *and* the change of error is positive small *Then* the change of service rate is negative medium. The detailed design is presented in [5].

3 Experimental Results

We compare the proposed approach with JoBS, BPR, and LFB. The experiments assumed two classes in the system. We assumed distributions of packet inter-arrivals and sizes similar to those in [2]. The packet inter-arrivals followed a Pareto distribution with the shape parameter to be 1.5. In these packets, 40% were 40 bytes, 50% were 550 bytes, and 10% were 1500 bytes. The target delay ratio δ_2/δ_1 was set to 4. The system load changed from 60% to 95% for every 200 sampling periods, which is set to 10,000 departed packets. The control factors of the controller were set as: $K_e = K_{\Delta e} = 0.1$ and $K_{\Delta u} = 1$. Figure 3 presents the experimental results.

First of all, we observe from the figure that the rule-based approach can provide consistent PDD services if the system load is no less than 70%. In comparison, none of the other rate-allocation approaches was able to achieve the goal. JoBS and BPR can guarantee PDD services only when the system load becomes as high as 90%. This is because they adjusted a class’s service rate according to its queueing delay. In systems with moderate load, the idle periods leads to a deviation of the achieved delay ratio from the target.

LFB fails to deliver required PDD services in all test cases. It is because the approach was mainly designed for differentiated service provisioning over busy periods only. In a time interval with mixed busy and idle periods, a small idle time percentage leads to a great performance deterioration. LFB is a rate-allocation approach with feedback control. It, however, adjusts a class’s service rate according to the difference

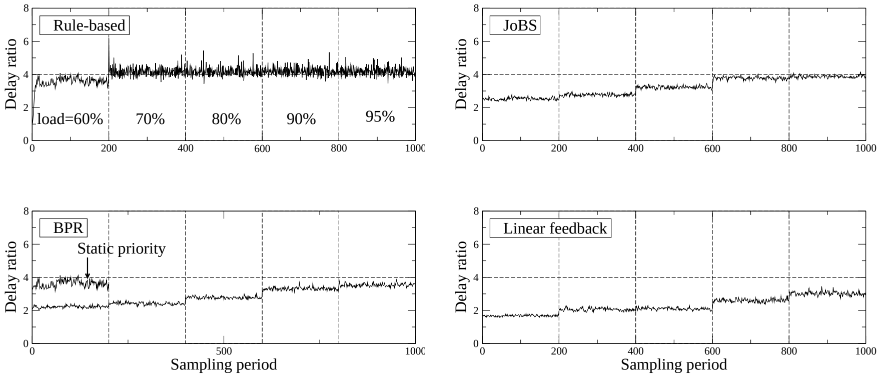


Fig. 3. Comparison with other rate-allocation approaches.

between its normalized head-of-line delay and the average of all backlogged classes. In contrast, the rule-based approach adjusts the service rate according to the error of achieved delay ratio. It approximates the nonlinear relationship between the queueing delay and the service rate by taking advantage of fuzzy control theory.

From the figure, we observe that when the system load becomes lower than 70%, the achieved delay ratio is always smaller than the target ratio. This infeasibility is possible for PDD services in a work-conserving system due to the constraints of conservation law [3]. We conducted an experiment using the static priority approach to obtain the upper bound of the feasible delay ratios for a system of 60% load. From the figure, it can be observed that the rule-based approach can closely approximate the upper bounds. The achieved delay ratios due to other approaches are much smaller than the bounds. This further demonstrates the superiority of the rule-based approach.

4 Conclusions

In summary, we have proposed a rule-based approach for PDD service provisioning in this paper. It adjusts rate allocation between different classes using a set of control rules that quantifies heuristic control knowledge that are valid under various load conditions. In comparison with other rate-allocation approaches, the approach is demonstrated to be effective for provisioning of consistent PDD services.

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