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Delay bounds for a network of guaranteed rate servers with FIFO aggregation

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Abstract

To support quality of service guarantees in a scalable manner, aggregate scheduling has attracted a lot of attention in the networking community. However, while there are a large number of results available for flow-based scheduling algorithms, few such results are available for aggregate-based scheduling. In this paper, we study a network implementing guaranteed rate (GR) scheduling with first-in–first-out aggregation. We derive an upper bound on the worst case end-to-end delay for the network. We show that while for a specific network configuration, the derived delay bound is not restricted by the utilization level on the GR, it is so for a general network configuration.

Keywords: Flow aggregation; Aggregate scheduling; Differentiated services; Delay bound; Guaranteed rate scheduling

1. Introduction

To support quality of service guarantees in a scalable manner, aggregate scheduling has attracted a lot of attention in the networking community. For example, in the Differentiated Services (DiffServ) framework [2], a required per-hop behavior (PHB) is provided on aggregate basis. However, while there are a large number of results available for flow-based scheduling algorithms, few such results are available for aggregate-based scheduling. In a recent work done by Charny and Le Boudec [6], a delay bound is derived (as Theorem 1 in [6]) for a network implementing aggregate scheduling. In the considered network in [6], each node implements aggregate class-based strict priority (SP) scheduling and the considered traffic class is the priority class which has priority over all other traffic classes. The bound derived in [6] has been adopted in [4,16,17]. Also, it has been extended without proof in [1] to obtain an upper bound on end-to-end delay of an expedited forwarding (EF) packet achieved by a DiffServ network with arbitrary topology where each node can be a guaranteed rate (GR) server. However, we will demonstrate by a simple example that while the bound derived in [6] is correct under the fluid

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Nomenclature

f	an EF flow
p^k	the kth packet of the flow
a^k	the arrival time of packet p^k
l^k	the length of packet p^k
$L^{\max}$	the maximum packet length among all network packets
ρ_f	the average arrival rate of flow f
σ_f	the burst size of flow f
$A_i(t, t+\tau)$	the amount of flow (or aggregate) i traffic in $[t, t+\tau]$
C_h	the speed of link h
I_h	the number of incoming links at the node of link h
P_h	the sum of all EF traffic incoming links' speeds at the node of link h
$\mathscr{F}_h$	the set of EF flows on link h
g_h	the EF aggregate on link h
R_h	the offered rate on link h to EF traffic
ρ_h	the average arrival rate of EF traffic on link h
σ_h	the burst size of EF traffic on link h
$A_h(t, t+\tau)$	the amount of EF traffic in $[t, t+\tau]$ on link h
$\alpha_h(\geqslant \sum_{f\in\mathscr{F}_h} \rho_f/R_h)$	the EF traffic utilization level of R_h on link h, where ρ_f is the average arrival rate of flow f when entering the network
$\beta_h(\geqslant \sum_{f\in\mathscr{F}_h} \sigma_f/R_h)$	the EF traffic burstiness tolerance level on link h as compared to R_h, where σ_f is the burst size of flow f when entering the network
$\mathscr{A}(t)$	an arrival curve
$\mathscr{S}(t)$	a service curve

model assumption, for packetized networks, it needs to be improved.

In this paper, we study a network of arbitrary topology which implements GR scheduling [12] with first-in–first-out (FIFO) aggregation. We derive an upper bound on the worst case end-to-end delay for the network using a similar method as adopted in [6]. We show that while for a specific network configuration, the derived delay bound is not restricted by the utilization level on the GR, it is so for a general network configuration. Since many scheduling disciplines proposed in the literature belong to GR, the considered network in this paper is more general than the one considered in [6].

The rest of the paper is organized as follows. In Section 2, we present the model of the considered network. In Section 3, we derive an end-to-end delay bound for the considered network using a similar method as adopted in [6]. In Section 4, we review some related work. Finally in Section 5, we conclude the paper.

2. Network model

Consider a network of arbitrary topology. Assume that all nodes in the network are output-buffered and implement aggregate class-based GR scheduling [12]. In the network, traffic is classified into different classes. In this paper, we consider a traffic class that is offered by the GR server at each hop h a rate guarantee R_h with latency E_h [1,12]. For simplicity, we will refer to this considered traffic class as EF class throughout the paper. At each node in the network, packets belonging to the EF class are aggregated and queued in the FIFO manner in a separate EF queue. The buffer size for the EF queue is assumed to be infinite. The total traffic of all EF flows sharing a particular output link is referred to as an EF aggregate. We assume that each end-to-end EF flow f is constrained by a leaky bucket with parameters (σ_f, ρ_f) when it arrives to the ingress node, where σ_f is the burst size and ρ_f is the average rate. Note that a flow can itself consist of a number of microflows sharing the same end-to-end pair, but we do not make any assumption on how these microflows are shaped. In addition, the aggregate of all flows entering a certain ingress node can be additionally aggregately shaped regardless of their egress nodes, but bounds presented in this paper do not depend on such aggregate shaping. Moreover, we adopt the convention that a packet has been received/trans-