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Approximation and Online Algorithms

Second International Workshop, WAOA 2004
Bergen, Norway, September 2004
Revised Selected Papers

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Preface

The 2nd Workshop on Approximation and Online Algorithms (WAOA 2004) focused on the design and analysis of algorithms for online and computationally hard problems. Both kinds of problems have a large number of applications arising from a variety of fields. WAOA 2004 took place in Bergen, Norway, from September 14 to September 16, 2004. The workshop was part of the ALGO 2004 event which also hosted ESA, WABI, IWPEC, and ATMOS.

Topics of interests for WAOA 2004 were: applications to game theory, approximation classes, coloring and partitioning, competitive analysis, computational finance, cuts and connectivity, geometric problems, inapproximability results, mechanism design, network design, routing, packing and covering, paradigms, randomization techniques, and scheduling problems. In response to our call we received 47 submissions. Each submission was reviewed by at least 3 referees, who judged the paper on originality, quality, and consistency with the topics of the conference. Based on the reviews, the Program Committee selected 21 papers. This volume contains the 21 selected papers and the two invited talks given by Yossi Azar and Klaus Jansen.

We thank all the authors who submitted papers to the workshop and we also kindly thank the local organizers of ALGO 2004.

November 2004

G. Persiano
R. Solis-Oba

WAOA 2004

September 14–16 2004, Bergen, Norway

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Online Packet Switching

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Abstract. We discuss packet switching for single-queue, multi-queue buffers and CIOQ buffers. We evaluate the algorithms by competitive analysis. We also mention the zero-one principle that applies to general switching networks.

1 Introduction

Overview: Packet routing networks, most notably the Internet, have become the preferred platform for carrying data of all kinds. Due to the steady increase of network traffic, and the fact that Internet traffic volume tends to constantly fluctuate, Quality of Service (QoS) networks, which allow prioritization between different traffic streams have gained considerable attention within the networking community. As network overloads become frequent, intermediate switches have to cope with increasing amounts of traffic, while attempting to pass forward more "valuable" packets, where values correspond to the required quality of service for each packet. We can measure the quality of the decisions made within a network by considering the total value of packets that were delivered to their destination.

Traditionally, the performance of queuing systems has been studied within the stability analysis framework, either by a probabilistic model for packet injection (queuing theory, see e.g. [11, 18]) or an adversarial model (adversarial queuing theory, see e.g. [5, 12]). In stability analysis packets are assumed to be identical, and the goal is to determine queue sizes such that no packet is ever dropped. However, real-world networks do not usually conform with the above assumptions, and it seems inevitable to drop packets in order to maintain efficiency. As a result, the competitive analysis framework, which avoids any assumptions on the input sequence and compares the performance of online algorithms to the optimal solution, has been adopted recently for studying throughput maximization problems.

Single-Queue: In general we assume that all packets have a fixed size and each is associated with a value. We are given a FIFO queue with bounded capacity. At each time step new packets arrive to the end of the queue, and the packet at the head of the queue is transmitted. The goal is to maximize the total value of

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transmitted packets. We distinguish between two models: preemptive and non-preemptive. The former allows to discard packets stored in the queue, while the latter does not, i.e. whenever a packet is accepted to the queue it has to be eventually transmitted. In both cases a packet can be dropped at its arrival.

Aiello *et al.* [2] initiated the study of different queuing policies for the 2-value non-preemptive model in which each packet has a value of either 1 or $\alpha > 1$. Andelman *et al.* [4] later showed tight bounds for this case. The preemptive 2-value single-queue model was initially studied by Kesselman and Mansour [14], followed by Lotker and Patt-Shamir [17] who showed almost tight bounds. The general preemptive single-queue model, where packets can take arbitrary values, was investigated by Kesselman *et al.* [13], who proved that the natural greedy algorithm is 2-competitive (specifically $2\alpha/(1+\alpha)$-competitive where $\alpha \geq 1$ is the ratio between the largest value to the smallest one).

The natural greedy preemptive admission control strategy for a single queue studied in [13] is defined as follows: Enqueue a new packet if the queue is not full, or a packet with the smallest value in the queue has a lower value than the new packet. In the latter case a smallest value packet is discarded.

Kesselman *et al.* [15] were the first to show a preemptive algorithm whose competitiveness is strictly below 2, followed by Bansal *et al.* [10] who presented a 1.75-competitive algorithm.

Multi-Queue: The multi-queue QoS switching model that was originally introduced in [7]. In this model we have a switch with m incoming FIFO queues with bounded capacities and one output port. At each time step new packets arrive to each of the queues. Additionally, at each time step the switch selects one non-empty queue and transmits the packet at the head of the queue through the output port. As before, the goal is to maximize the total value of transmitted packets.

The results for a single queue were generalized for multi-queue switches with arbitrary number of input queues in [7], by a general reduction from the multi-queue model to the single-queue model. Specifically, a 4-competitive algorithm is presented in [7] for the weighted multi-queue switch problem. An improved 3-competitive algorithm was shown in [9]. The 3-competitive algorithm is the natural greedy which works as follows. Use the greedy single-queue policy in all m incoming queues to handle admission control. At each time step, transmit the packet with the largest value among all packets at the head of the queues.

The multi-queue switch model has been also investigated for the special case of unit-value packets, which corresponds to IP networks. First, the result from [7] shows that any algorithm that transmits any packet if exists is 2-competitive. Albers and Schmidt [3] showed that any greedy algorithm for the unit-value problem is not better than 2-competitive. In addition, they introduced a deterministic 1.89-competitive algorithm for this problem; A randomized 1.58-competitive algorithm was previously shown in [7]. Recently, a deterministic 1.58-competitive algorithm was shown in [6], for the case where the size of the queues is quite large compared with their number.

CIOQ Switch: To date, the most general switching model that has been studied using competitive analysis is CIOQ (Combined Input and Output Queued) architecture. A CIOQ switch with speedup $S \geq 1$ is an $N \times N$ switch, with N input ports and N output ports. The internal fabric that connects the input and output FIFO queues is S times faster than the queues. A switching policy for a CIOQ switch consists of two components. First, an admission control policy to determine the packets stored in the bounded-capacity queues. Second, a scheduling strategy to decide which packets are transferred from input queues to output queues through the intermediate fabric at each time step. The goal is to maximize the total value of packets transmitted from the switch.

The online problem of maximizing the total throughput of a CIOQ switch was initiated by Kesselman and Rosén in [16]. For the special case of unit-value packets, they proved that the greedy algorithm is 2-competitive for a speedup of 1 and 3-competitive for any speedup. For the general case they obtained non-constant bounds of $4S$ and $\log \alpha$, where α is the ratio between the largest and smallest values. Recently, a constant (about 9) competitive algorithm was presented in [8] for the general CIOQ model.

Multiple-Node Networks: The simplest network one may consider has a topology of a line of length k, where node i is connected to node $i+1$ by a unidirectional link, and contains a fixed-size FIFO queue to store the packets waiting to be transmitted. At each time step new packets may arrive online to the network nodes, each is associated with a value and a destination node. Additionally, each node can transmit the packet at the head of its queue to the next node. The goal is to maximize the total value of packets that were delivered to their destination. The case $k = 1$ corresponds to single-queue. The unweighted version of the line model, in which all packets have unit value, was investigated by Aiello *et al.* [1] who proved that the greedy algorithm is $O(k)$-competitive. This was generalized and improved by [9] that showed that the natural greedy algorithm is $(k+1)$-competitive for the weighted problem.

The Zero-One Principle: While different techniques were used to analyze algorithms in various switching models, there was one common property: analysis of 2-value sequences, in which packets can take only 2 distinct values, was always substantially easier compared with arbitrary packet sequences. Moreover, many results are known only for restricted value sequences, since handling the state of a system containing packets with arbitrary values is significantly more involved. Motivated by this, [9] introduced the zero-one principle for switching networks. This principle applies to all *comparison-based* switching algorithms, that base their decisions on the relative order between packet values. The principle says that in order to prove that an algorithm achieves c-approximation it is sufficient to prove that it achieves c-approximation with respect to sequences composed solely of 0's and 1's, where ties between packets with equal values may be broken arbitrarily. One might have assumed that without loss of generality there are no 0-value packets in the input sequence since those could have been dropped. Indeed, the optimal solution may ignore all 0-value packets, however, the comparison-based algorithm may not, since it only regards the relative order between values. The zero-one principle was applied, among others, to get the 3-competitive algorithm for the multi-queue switch as well as the $k+1$ -competitive algorithm for the line.

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Approximation Algorithms for Mixed Fractional Packing and Covering Problems

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We study general mixed fractional packing and covering problems (MPC_ϵ) of the following form: Given a vector $f : B \to \mathbb{R}_+^M$ of M nonnegative continuous convex functions and a vector $g : B \to \mathbb{R}_+^M$ of M nonnegative continuous concave functions, two M - dimensional nonnegative vectors a, b, a nonempty convex compact set B and a relative tolerance $\epsilon \in (0, 1)$, find an approximately feasible vector $x \in B$ such that $f(x) \leq (1 + \epsilon)a$ and $g(x) \geq (1 - \epsilon)b$ or find a proof that no vector is feasible (that satisfies $x \in B$, $f(x) \leq a$ and $g(x) \geq b$).

The fractional packing problem with convex constraints, i.e. to find $x \in B$ such that $f(x) \leq (1 + \epsilon)a$, is solved in [4, 5, 8] by the Lagrangian decomposition method in $O(M(\epsilon^{-2} + \ln M))$ iterations where each iteration requires a call to an approximate block solver $ABS(p, t)$ of the form: find $\hat{x} \in B$ such that $p^T f(\hat{x}) \leq (1 + t)\Lambda(p)$ where $\Lambda(p) = \min_{x \in B} p^T f(x)$. Furthermore, Grigoriadis et al. [6] proposed also an approximation algorithm for the fractional covering problem with concave constraints, i.e. to find $x \in B$ such that $g(x) \geq (1 - \epsilon)b$, within $O(M(\epsilon^{-2} + \ln M))$ iterations where each iteration requires here a call to an approximate block solver $ABS(q, t)$ of the form: find $\hat{x} \in B$ such that $q^T g(\hat{x}) \geq (1 - t)\Lambda(q)$ where $\Lambda(q) = \max_{x \in B} q^T g(x)$. Both algorithms solve also the corresponding min-max and max-min optimization variants within the same number of iterations. Furthermore, the algorithms can be generalized to the case where the block solver has arbitrary approximation ratio [7, 8, 9].

Further interesting algorithms for the fractional packing and fractional covering problem with linear constraints were developed by Plotkin et al. [13] and Young [15]. These algorithms have a running time that depends linearly on the width - an unbounded function of the input instance. Several relatively complicated techniques were proposed to reduce this dependence. Garg and Könemann [3] described a nice algorithm for the fractional packing problem with linear constraints that needs only $O(M\epsilon^{-2} \ln M)$ iterations.

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