Computers and Electrical Engineering 000 (2017) 1–13

Contents lists available at ScienceDirect

Computers and Electrical Engineering

journal homepage: www.elsevier.com/locate/compeleceng

Energy efficient non-clairvoyant scheduling for unbounded-speed multi-core machines☆

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ARTICLE INFO

Article history:
Received 10 March 2017
Revised 27 November 2017
Accepted 2 December 2017
Available online xxx

Keywords:
Speed scaling
Power management
Online non-clairvoyant scheduling
Competitive analysis
Significance-based flow time

ABSTRACT

With the increasing consumption of energy in data centers, the demand for energy efficient multiprocessor job scheduling is growing dramatically. Besides flow time, energy conservation has become a significant issue and drawn enormous interest. In this paper, an online non-clairvoyant scheduling algorithm Significance-based Multiprocessor Round Robin (SbMRR) is proposed. SbMRR utilizes the unbounded speed model, where the range of the speed of any processor is from zero to infinity. To validate the effectiveness of the algorithm, mathematical and simulation-based analysis are conducted which demonstrates that SbMRR provides the minimum sum of significance-based flow time and energy consumed. SbMRR is $O(\alpha)$-competitive, more precisely $((\alpha+1)/((1-1/\alpha\beta)))$-competitive, where $\beta \geq 4$ a constant. The competitive ratio of SbMRR is least to date. SbMRR provides the minimum sum of energy consumed and significance-based flow-time.

1. Introduction

In data centers, the requirement of energy is growing gradually [1]. The growth in energy consumption and price hike has become one of the most important design factors for machines in data centers. The online job scheduling for uniprocessor or multiprocessor is one of the fundamental optimization problems in computer science. The simple standard objective in such problems is to minimize the total flow time for a set of jobs, where processor executes up to the maximum speed. In recent years, the energy consumption of processors has become a prime concern. The dynamic speed scaling (DSS) plays a vital role in energy management. In DSS, a processor can regulate its speed to save energy. At low speed, the processor finishes jobs slower and saves energy, whereas at high speed, the processor finishes jobs faster but consumes more energy. In the available literature, to achieve a better quality of service and low energy consumption, the objective considered is to minimize the sum of flow time and energy. If the jobs come along with significance or priority, the objective considered is to minimize the sum of significance-based flow time and energy. The power consumed by a processor, using speed scaling, is a function of speed *Power* $P = speed^{\alpha}$, where $2 \leq \alpha < 3$. *Weight, priority* and *significance* of a job are used as synonyms. The general speed scaling problem comprises of two components: first, which job to execute next; second, the execution speed of a processor. In multiprocessor systems, there is an additional component that decides the allocation of a new job to some processor.

The ONCSP are more natural and realistic, where jobs are released over time, each job arrives with significance and its processing time is known only when the job completes. Motwani et al. [2] introduced the study of non-clairvoyant settings.

☆ Reviews processed and recommended for publication to the Editor-in-Chief by Guest Editor Dr. R. C. Poonia.

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https://doi.org/10.1016/j.compeleceng.2017.12.012
0045-7906/

The theoretical study of scheduling was initiated by Yao et al. [3]. There are different objectives available in literature and a plenty of research is conducted using them. Albers and Fujiwara [4] introduced the problem of minimizing the flow time plus energy, in the DSS approach. Pruhs et al. [5] studied the scheduling of dynamically released jobs for the objective of flow time plus energy. Chan et al. [6] initiated the study of non-clairvoyant speed scaling.

The objective of minimizing the flow time on uniprocessor or multiprocessor is considered by [7–9]. The objective of minimizing the significance based flow time is adopted by [10–12]. In the past few years, the problem of online scheduling for the objective of minimizing the total significance based flow time plus energy in DSS model is studied extensively under clairvoyant setting [4,13,14–16]. A less literature is available on the study of online non-clairvoyant scheduling problem for the objective of minimizing the significance-based flow time plus energy. There are different scheduling algorithms available in literature with various parameters [17–22].

To date, the online scheduling problems are studied extensively using clairvoyant settings, where the processing requirement of jobs is known at their release time. Less extensively studied, online non-clairvoyant scheduling problems (ONCSP) are more natural and realistic. In ONCSP, the jobs are released over time, each job arrives with significance and its processing time is known only when the job completes. In this paper, a speed scaling scheduling problem is considered for multiprocessor system. The objective of minimizing the significance-based flow time plus energy is considered using online non-clairvoyant settings. The unbounded speed model and traditional power function is used for potential function analysis of proposed algorithm SbMRR. In SbMRR, the significances of jobs are computed on the basis of the processed size of concerned job.

The organization of the paper is as follows: Section 2 describes some related scheduling algorithms and their results. In Section 3, the notations used in the paper and definitions necessary for discussion are explained. An online non-clairvoyant algorithm SbMRR is proposed and compared against an optimal offline algorithm using amortized analysis (potential function), in Section 4. The working of the proposed algorithm SbMRR is simulated and compared with the best known algorithm in Section 4. The next Section 5 provides concluding remarks and future scope of the work.

2. Related work

Fox et al. [23] proposed an online non-clairvoyant algorithm Weighted Latest Arrival Processor Sharing with Energy (WLAPS + E) for the objective of minimizing the significance-based flow time plus energy. They showed that WLAPS + E is $(1+6\Delta)$-speed $(5/\Delta^2)$-competitive when it schedules the late arrival parallelizable jobs. In WLAPS + E, every job uses the machine proportional to the job significance, where $0 < \Delta \leq 1/6$. WLAPS + E does not use all available machines, rather it spares some machines to save energy. WLAPS + E is analyzed using potential function analysis along with speed scaling approach and traditional power function. Im et al. [24] studied a problem of scheduling online jobs using non-clairvoyant approach for unrelated machines. The objective considered is to minimize the significance based flow time plus energy. They proposed $O(\alpha^2)$-competitive scheduling algorithm Selfish Migrate-Energy (SM-E) using the traditional power function. In SM-E, a virtual queue is maintained on every processor, where the new or migrated jobs are added at tail. The jobs migrate selfishly until equilibrium is gained. Im et al. simulates Sequential Best Response (SBR) dynamics and they migrates each job to the machine that is provided by Nash equilibrium. Like LAPS and WLAPS, in SM-E the larger speed is allotted to the jobs residing in the tail of the queue. In SM-E, every processer is using a variant of Weighted Round Robin (WRR). Azar et al. [25] considered a problem of scheduling non-migratory jobs using online non-clairvoyant settings. They proposed an algorithm NC-PAR for the identical parallel machines for the objective of minimizing the significance-based flow time plus energy. NC-PAR is $(3+\frac{1}{\alpha-1})$-competitive using traditional power function and unbounded speed model. In NC-PAR, jobs are having uniform densities (*i.e. weight*/*size* = 1). In NC-PAR, a global queue of unassigned jobs is maintained in FIFO order. A new job is assigned to an idle machine and the speed of a processor using NC-PAR is based on the total remaining significances of the active jobs.

In this paper, a problem of scheduling online non-clairvoyant jobs on multicore/multiprocessor machines is studied for the objective of minimizing the significance-based flow time plus energy. An algorithm SbMRR is proposed using traditional power function and unbounded speed model. SbMRR is $(\alpha+1/(1-1/\alpha\beta))$- competitive, i.e. the competitive ratio $c \leq 3.428$ for $\alpha = 2$ and $\beta \geq 4$. Usually, the significances of jobs are system generated, allotted to jobs at their arrival time and remains fixed for their life time. In SbMRR, scheduler calculates and allocates the significance of a job using the processed size of a job. The total flow time plus energy is calculated by summation of flow time multiplied by computed significance and energy. Unlike computation of total flow time, the computation of total weighted/significance-based flow time depends on significances of jobs multiplied by flow time. The summary of results is given in Table 1.

3. Definitions and notations

In this paper, an online non-clairvoyant job scheduling is studied using P_t processors. Online jobs arrive over time and before the arrival of jobs there is no prior information about the arrival-sequence of jobs. In non-clairvoyant model, the size of a job j is known only when a job j completes. Pre-emption is allowed with no penalty. All jobs are sequential in nature and non-migratory. The total potential value of all P_t processors at time is t $\Phi(t)$ *or* Φ. t *or* C_t is the current system time. ω is a constant depends on α, i.e. $\frac{1}{\alpha}$. The traditional power function and unbounded speed model are adopted. A schedule S_{hd} of any job set X is considered. At any time t, a job j is active if arrival time $a_t(j) \leq t$ and remaining size of job j $Rmg(j,\ t) >$

Please cite this article as: P. Singh, Energy efficient non-clairvoyant scheduling for unbounded-speed multi-core machines, Computers and Electrical Engineering (2017), https://doi.org/10.1016/j.compeleceng.2017.12.012