Abstract

Energy efficiency by scheduling, which involves the distribution of tasks so that the total energy consumption of a system is reduced, has gained importance recently among researchers, but its theory is far from developed. Though scheduling theory has attracted much interest for many years, most of its work has been focused on objectives related to time (primarily makespan). Energy efficiency by scheduling is yet to see a similarly robust development. Whatever little work has been done on scheduling for energy efficiency is mostly confined to specific domains (such as computer processors and networks). A general theory of energy-efficient scheduling is still awaited. This thesis builds a theoretical foundation for the problem of energy efficient scheduling and provides algorithmic solutions for the same. We show that energy-efficient scheduling is a generalization of minimum makespan scheduling, and is thus a hard problem in general.

The system model proposed here is very close to the behavior of practical systems as we have considered both the power required for task execution as well as the power dissipation of machines when idle which is not the case in prior works on energy-efficient scheduling. The power consumptions of various machines are considered to be distinct and independent of other machines. We provide a classification of systems from the perspective of energy-efficient scheduling. The systems considered in our work comprise interconnected machines with similar capabilities but different working- and idle-state power consumptions. Depending upon the types of jobs, we classify the problems of energy-efficient scheduling into three broad categories — jobs which are (i)
divisible and independent; (ii) non-divisible and independent; and (iii) non-divisible and have precedence constraints. These three problem classes have to be tackled through different approaches because of differences in nature and complexity. Our results show that for energy efficiency, we sometimes should use only $r$ of $m$ machines, where $1 \leq r < m$, letting the rest remain idle.

When jobs are divisible, we are able to compute the minimum energy that a system would consume to complete a given set of jobs. Also, we can generate the minimum-energy schedule for such a set of jobs in linear time and give exact scheduling algorithms which do this.

When jobs are non-divisible, we prove that scheduling is NP-hard and also give approximation algorithms for the same along with their bounds. The bound for the case where machines have identical speeds is $4/3$, while for the case where machines can have different speeds it is $19/12$.

When jobs are non-divisible and have precedence constraints, energy-efficient scheduling is an NP-hard problem, and we propose three different heuristic algorithms for scheduling. Each of these algorithms has its own strengths and limitations, and, depending upon the requirements of a particular domain, any one of them can be chosen. The first is a genetic algorithm (Plain GA) that quickly searches for an energy-reducing schedule. The second (CA+GA) uses cellular automata (CA) to generate low-energy schedules while using a genetic algorithm (GA) to find good rules for the CA. On one end, it gives the most accurate results, yet, on the other, it is the slowest when it comes to processing. The third (EAH) is a simple and fast heuristic and is based on FIFO ordering which gives preference to high-efficiency machines in allocation. We have tested our algorithms on well-known program graphs and compared our results with other state-of-the-art scheduling algorithms which confirm the efficacy of our approach. Our work also gives insight into the time-energy trade-offs in scheduling.