Journal of
Information Technology & Software Engineering

Chetto, J Inform Tech Softw Eng 2013, 3:3
DOI: 10.4172/2165-7866.1000e122

Editorial Open Access

EDF Option for Scheduling Real-Time Jobs in Energy Harvesting Systems

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Abstract

The introduction of energy harvesting functionalities into an embedded system such as wireless sensor network raises many design questions. The central one is how to smartly use harvesting abilities so as to optimize performance and lifetime of the system? How to dynamically adapt the processing activity and schedule the real-time jobs with deadline constraints so as to subsist perpetually on a given energy source? Researchers are currently striving to design scheduling techniques which adapt to requirements of real-time energy harvesting computing systems. This paper reports very recent results that prove that the well-known Earliest Deadline First scheduler still remains an efficient option for online scheduling in these new generation computing systems.

Introduction to Energy Harvesting Systems

Embedded systems can scavenge regenerative energy from human activity, ambient heat, light, radio, or vibrations [1]. So-called Energy Harvesting (EH) is a technology that allows to capture otherwise unused energy and convert it into electrical energy. Electricity can be used immediately or later through an energy reservoir such as battery or super-capacitor. The EH approach extends the life of batteries (or eliminates them entirely) and decreases maintenance. Real-Time Energy Harvesting (RTEH) systems encompass various application areas such as military, transport and medical ones. The system we target in this paper consists of a single processor unit and a rechargeable energy storage device in charge of executing a set of independent jobs with deadlines. So the problem we have to deal with is: How can we schedule the jobs so as to guarantee their timing constraints perpetually by suitably exploiting both the processor capacity and the available ambient energy.

Main Definitions

- **Definition 1:** A scheduling algorithm is optimal if it finds a valid schedule (where all deadlines are satisfied) whenever one exists.
- **Definition 2:** A scheduling algorithm is online if it makes its decision at run-time.
- **Definition 3:** A scheduling algorithm is clairvoyant if it has an a priori knowledge of the jobs arriving in the system and profile of the energy produced by the source.
- **Definition 4:** An online scheduling algorithm is lookahead-L if L is the length of time interval that the scheduler can foresee at any time.
- **Definition 5:** A scheduling algorithm is idling if it is allowed to keep the processor idle even when there are jobs waiting for execution.

Scheduling in Classical Real-Time Systems

A number of authors have studied the problem of devising algorithms for scheduling time critical jobs on a single processor computing system with no energy consideration. The most popular online scheduling algorithm was introduced by Liu and Layland in 1973 [2]. According to Earliest Deadline First (EDF) which is preemptive and dynamic priority driven, a ready job with the earliest deadline is executed first. Dertouzos [3] proved that EDF is optimal among all scheduling algorithms on a uniprocessor machine. Consequently, if a set of jobs cannot be scheduled by EDF, then this set cannot be scheduled by any other algorithm. Liu and Layland stated a very simple necessary and sufficient schedulability condition for EDF under the assumption that jobs are the instances of periodic tasks with relative deadlines equal to periods. The EDF strategy is consequently a very desirable approach for scheduling independent jobs preemptively when there is no energy limitation and no processing overload. A survey on EDF scheduling can be found in [4].

System Model under Consideration

In this paper, we explore the issue of scheduling for platforms that consist of three components: a processing element with unique voltage and frequency, an energy harvester and a rechargeable energy storage unit. We consider a set of real-time jobs i.e. units of work that need to be executed on the processing element with guaranteeing their deadlines. All jobs can be preempted and later resumed at any time and there is no time or energy loss associated with such preemption. Furthermore, jobs are independent of each other.

Each job is characterized by arrival time, worst case execution time (normalized to processor computing capacity), worst case consumption energy and absolute deadline. In that description, the job needs to receive its units of execution and its units of energy between arrival time and deadline. We assume that the actual energy consumed by a job is not necessarily proportional to its execution time. So, a job consumes energy with arbitrary consumption rate. In what follows, this model will be called RTEH model.

Scheduling in Energy Harvesting Systems

The first works on real-time scheduling with energy constraints mainly focus on shutdown techniques and variable speeds of processors respectively known as Dynamic Power Management (DPM) and Dynamic Voltage Frequency Scaling (DVFS). These works disregard three important aspects: rechargeability of the storage device, variability

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Received November 18, 2013; **Accepted** November 18, 2013; **Published** November 24, 2013

Citation: Chetto M (2013) EDF Option for Scheduling Real-Time Jobs in Energy Harvesting Systems. J Inform Tech Softw Eng 3: e122. doi:10.4172/2165-7866.1000e122

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of the source power and variability of the instantaneous consumption power of the jobs in execution.

Few papers have been devoted to emerging harvesting systems which need to operate perennially thanks to the environmental energy. There is a key consideration that affects power management and scheduling in such systems: the system operates in an energy neutral mode by never consuming more than the harvested energy.

Scheduling algorithms dedicated to RTEH applications exhibit the same important drawbacks: First, they need idling capabilities. Second, they are clairvoyant, i.e., they need to know the future harvested energy precisely. Third, their actual performance in terms of deadline satisfaction mainly depends on the accuracy of the prediction strategies. LSA and EDeg are examples of such scheduling algorithms with idling and clairvoyance requirements [5,6].

EDF Scheduling with Energy Harvesting Constraints

In that section, we report results we have recently established about online scheduling for the RTEH model:

- **Theorem 1:** Optimal non-clairvoyant online scheduling algorithm cannot exist for the RTEH model. Theorem 1 says that energy starvation -situation which results from insufficient energy for executing the jobs timely-should be imperatively anticipated to build an optimal schedule. In other terms, optimal scheduling requires clairvoyance i.e. knowledge on the jobs that will arrive in future and require to be processed and in addition knowledge on the available energy that will be harvested and stored in future [7].
- **Theorem 2:** No lookahead-L scheduling algorithm is optimal for the RTEH model if $L < D$. In theorem 2, we state that energy starvation should be anticipated enough early to avoid a deadline missing. More precisely, an optimal schedule can be produced any current time only if the scheduling algorithm has knowledge at the current time about future on at least the next D time units. D represents the highest relative deadline of jobs that may occur in the application [7].
- **Theorem 3:** EDF is optimal in the class of non-idling online algorithms for the RTEH model. Theorem 2 excludes EDF scheduling to be optimal for the RTEH model since EDF is totally non-clairvoyant by nature. Nonetheless, EDF remains the best online non-idling algorithm according to theorem 3. [8].

Conclusion

Today, only non-idling scheduling capabilities are offered by the great majority of real-time operating systems. Using them in energy harvesting applications will imply to modify the kernel and integrate idling and clairvoyance capabilities for optimal performance objectives. However, optimal scheduling presupposes first to implement very efficient methods for environmental energy prediction and second to prohibit energy source with a highly unstable or stochastic profile. Another option is to call for the EDF scheduler. Even sub-optimal, EDF remains the best option under non-idling settings in an energy harvesting context [9].

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