

# Dynamic Voltage Scaling and Power Management for Portable Systems

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## ABSTRACT

Portable systems require long battery lifetime while still delivering high performance. Dynamic voltage scaling (DVS) algorithms reduce energy consumption by changing processor speed and voltage at run-time depending on the needs of the applications running. Dynamic power management (DPM) policies trade off the performance for the power consumption by selectively placing components into low-power states. In this work we extend the DPM model presented in [2, 3] with a DVS algorithm, thus enabling larger power savings. We test our approach on MPEG video and MP3 audio algorithms running on the SmartBadge portable device [1]. Our results show savings of a factor of three in energy consumption for combined DVS and DPM approaches.

## 1. INTRODUCTION

Battery-operated portable systems impose tight constraints on energy consumption. Portable systems often consist of one or more microprocessors and a set of devices with multiple low-power states. Many microprocessors support dynamic clock frequency adjustment, and some newer devices also support dynamic supply voltage setting [4]. Thus at system level it is possible to reduce energy by changing the frequency and voltage level of the microprocessor (dynamic voltage scaling) and by transitioning components into low-power states (dynamic power management).

In this work, we extend the DPM model presented in [2, 3] with a DVS algorithm, thus enabling larger power savings. The algorithm is implemented for the SmartBadge portable device [1]. The SmartBadge consists of a StrongARM processor, memory, RF link, and display. All components have four main power states: active, idle, standby and off. In addition, the processor can operate over a range of frequencies. For each frequency, there is a minimum allowed voltage of operation. If the processor is run at the minimum frequency and voltage required to sustain the performance level required by the application, it is possible to save power even when the system is active, in addition to the savings that can be obtained by DPM during idle periods. This principle is exploited by the recently announced Transmeta's Crusoe processor [4].

A DVS algorithm sets the microprocessor voltage and frequency at run time depending on the behavior of applications currently running. Early DVS algorithms set processor speed based on the processor utilization of fixed intervals [5, 6]. The individual require-

ments of the tasks running were not considered, resulting in poor behavior for more complex workloads [13]. There has been a number of voltage scaling techniques proposed for real-time systems. The approaches presented in [7, 9, 8, 10] assume that all tasks run at their worst case execution time (WCET). The workload variation slack times are exploited on task-by-task basis in [11], and are fully utilized in [12]. Work presented in [14] introduces a voltage scheduler that determines the operating voltage by analyzing application requirements. The scheduling is done at task level, by setting processor frequency to the minimum value needed to complete all tasks. For applications with high frame-to-frame variance, such as MPEG video, schedule smoothing is done by scheduling tasks to complete twice the amount of work in twice the deadline.

In all DVS approaches presented in the past, scheduling was done at the task level, assuming multiple threads. The prediction of task execution times was done either using worst case execution times, or heuristics. Such approaches neglect that DVS can be done within a task or for single-application devices. For instance, in MPEG decoding, the variance in execution time on frame basis can be very large, a factor of three in the number of cycles [15], or a range between 1 and 2000 IDCTs per frame [16] for MPEG video.

The first contribution of this work is to develop and verify a stochastic model for prediction of execution times for streaming multimedia applications on a frame-by-frame basis. Our model is based on the change-point detection theory used for ATM traffic detection among other applications [17]. We compare our model to perfect prediction and to exponential moving average used in [14]. The prediction algorithm developed is then used as a part of a power control strategy that merges DVS and DPM.

As opposed to DVS, power management algorithms aim at reducing energy consumption at the system level by selectively placing components into low-power states during idle periods. DPM algorithms presented in the past can be classified into deterministic and stochastic [2]. Deterministic algorithms include basic timeout and predictive schemes. Stochastic models can give optimal DPM policies, as long as the basic assumptions made in the formulation of the model are true. A simple stochastic model for DPM assumes that idle times for system resources follow exponential distributions. Unfortunately, it has been shown in [2] that approaches purely based on exponential distributions do not model well real system behavior.

Two stochastic approaches recently presented allow usage of general distributions instead of just exponential. As a result, large power savings were observed. The first approach is based on renewal theory [2]. This model assumes that the decision to transition to low power state can be made in only one state. Another method developed is based on the Time-Indexed Semi-Markov Decision Process model (TISMDP) [3]. This model is more complex, but also has wider applicability because it assumes that a decision to transition into a lower-power state can be made from any number of states. Both approaches assume a single system active state and

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**Emre Salman, Eby G. Friedman**



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## **Table of Contents Dynamic Voltage Scaling And Power Management For Portable**

1. Understanding the eBook Dynamic Voltage Scaling And Power Management For Portable
  - The Rise of Digital Reading Dynamic Voltage Scaling And Power Management For Portable
  - Advantages of eBooks Over Traditional Books
2. Identifying Dynamic Voltage Scaling And Power Management For Portable
  - Exploring Different Genres
  - Considering Fiction vs. Non-Fiction
  - Determining Your Reading Goals
3. Choosing the Right eBook Platform
  - Popular eBook Platforms
  - Features to Look for in an Dynamic Voltage Scaling And Power Management For Portable
  - User-Friendly Interface

4. Exploring eBook Recommendations from Dynamic Voltage Scaling And Power Management For Portable
  - Personalized Recommendations
  - Dynamic Voltage Scaling And Power Management For Portable User Reviews and Ratings
  - Dynamic Voltage Scaling And Power Management For Portable and Bestseller Lists
5. Accessing Dynamic Voltage Scaling And Power Management For Portable Free and Paid eBooks
  - Dynamic Voltage Scaling And Power Management For Portable Public Domain eBooks
  - Dynamic Voltage Scaling And Power Management For Portable eBook Subscription Services
  - Dynamic Voltage Scaling And Power Management For Portable Budget-Friendly Options
6. Navigating Dynamic Voltage Scaling And Power Management For Portable eBook Formats
  - ePub, PDF, MOBI, and More
  - Dynamic Voltage Scaling And Power Management For Portable Compatibility with Devices
  - Dynamic Voltage Scaling And Power Management For Portable Enhanced eBook Features
7. Enhancing Your Reading Experience
  - Adjustable Fonts and Text Sizes of Dynamic Voltage Scaling And Power Management For Portable
  - Highlighting and Note-Taking Dynamic Voltage Scaling And Power Management For Portable
  - Interactive Elements Dynamic Voltage Scaling And Power Management For Portable
8. Staying Engaged with Dynamic Voltage Scaling And Power Management For Portable
  - Joining Online Reading Communities
  - Participating in Virtual Book Clubs
  - Following Authors and Publishers Dynamic Voltage Scaling And Power Management For Portable
9. Balancing eBooks and Physical Books Dynamic Voltage Scaling And Power Management For Portable
  - Benefits of a Digital Library
  - Creating a Diverse Reading Collection Dynamic Voltage Scaling And Power Management For Portable
10. Overcoming Reading Challenges
  - Dealing with Digital Eye Strain
  - Minimizing Distractions
  - Managing Screen Time
11. Cultivating a Reading Routine Dynamic Voltage Scaling And Power Management For Portable
  - Setting Reading Goals Dynamic Voltage Scaling And Power Management For Portable
  - Carving Out Dedicated Reading Time

12. Sourcing Reliable Information of Dynamic Voltage Scaling And Power Management For Portable
  - Fact-Checking eBook Content of Dynamic Voltage Scaling And Power Management For Portable
  - Distinguishing Credible Sources
13. Promoting Lifelong Learning
  - Utilizing eBooks for Skill Development
  - Exploring Educational eBooks
14. Embracing eBook Trends
  - Integration of Multimedia Elements
  - Interactive and Gamified eBooks

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