**Real-Time Task Scheduler with Dynamic Voltage and Frequency Scaling**

**Implementation and Analysis Report**

This report is an elaborative explanation of the implementation and analysis of a real-time task scheduler incorporating Dynamic Voltage and Frequency Scaling (DVFS) for energy efficiency. The system implemented four different scheduling algorithms: Rate-Monotonic (RM), Earliest Deadline First (EDF), and their power-efficient variants, respectively (EE-RM and EE-EDF).

**System Design and Implementation**

**Scheduling Algorithms**

The scheduler was developed in Python, with a modular design that separates the management of tasks from the scheduling logic. It implements the main scheduling algorithms with support for preemption.

**Rate-Monotonic (RM) Implementation**

The RM scheduler assigns fixed priorities based on task periods, where shorter periods receive higher priorities. There is a pool of tasks sorted in priority order according to their periods. For the input tasks, the order of priorities was:

* w4 (Period: 200s)
* w2 (Period: 220s)
* w5 (Period: 300s)
* w3 (Period: 500s)
* w1 (Period: 520s)

The scheduler achieved an idle rate of 7.9% with a total energy consumption of 575.62J when running at maximum frequency (1188 MHz).

**Earliest Deadline First (EDF) Implementation**

The EDF scheduler dynamically assigns priorities depending on absolute deadlines. The implementation maintains task deadlines and will update the priorities at runtime. This results in a different execution pattern from RM, thus giving an idle rate of 6.1% while the total energy is 586.88J at maximum frequency.

**Energy-Efficient Implementations**

**Frequency Selection Algorithm**

For energy-efficient variants, the scheduler implements a sophisticated frequency selection mechanism. For each task, it:

1. Calculates available time until deadline
2. Determines valid frequencies that can complete the task within deadline
3. Computes energy consumption for each frequency option
4. Selects the frequency that minimizes energy consumption while meeting the deadline

The available frequencies were:

* 1188 MHz (625 mW)
* 918 MHz (447 mW)
* 648 MHz (307 mW)
* 384 MHz (212 mW)

**Results Analysis**

**Energy Efficiency Comparison**

The energy-efficient variants demonstrated significant energy savings:

1. Standard RM vs EE-RM:
   * Standard RM: 575.62J, 7.9% idle time
   * EE-RM: 288.32J, 7.9% idle time
   * Energy Reduction: 49.9%
2. Standard EDF vs EE-EDF:
   * Standard EDF: 586.88J, 6.1% idle time
   * EE-EDF: 288.27J, 6.1% idle time
   * Energy Reduction: 50.9%

**Scheduling Pattern Analysis**

Both EDF and RM preserved their essential scheduling properties while being energy efficient. The key trend observed was that the 648 MHz setting was used predominantly by most EE variants, intermittently switching to higher frequencies when driven by deadline constraints.

Notable observations:

1. Task w4, despite having the shortest period, could often execute at lower frequencies due to sufficient slack time.
2. The system maintained similar idle times between standard and EE variants, indicating that energy savings came from frequency scaling rather than execution time adjustments.
3. EDF showed slightly lower idle time compared to RM, suggesting more efficient CPU utilization.

**Algorithm Effectiveness**

The implemented schedulers demonstrated several key strengths:

1. Deadline Adherence: All variants maintained deadline compliance while achieving energy efficiency.
2. Energy Optimization: The EE variants achieved approximately 50% energy reduction while maintaining timing constraints.
3. Preemption Handling: The scheduler successfully managed preemption at period boundaries, particularly evident in the RM implementation where higher-priority tasks (w4) preempted lower-priority ones.

**Conclusion**

The implementation showed the effectiveness of DVFS in real-time scheduling systems. Energy-efficient variants save a significant amount of energy without losing scheduling properties and deadline guarantees of their base algorithms. Slightly different idle times between EDF and RM implementations point to fundamental differences in their respective scheduling approaches, where EDF performs marginally better CPU utilization.

These results suggest that applying DVFS to real-time systems can indeed provide substantial energy savings without compromising the task scheduling requirements. Future improvements might be related to more dynamic strategies in frequency adjustment and better handling of variability in the time of execution for tasks.