How to Make Fast DVFS Beneficial in Mobile Devices

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A processor dynamic voltage and frequency scaling (DVFS) is essential for energy saving in modern computing devices. It is believed that finer-grained control of voltage and frequency with minimum overhead is essential to maximize energy efficiency. In this regard, most processor vendors are struggling to achieve this goal with a variety of improved DVFS techniques such as fast DVFS. On the other hand, as the proportion of leakage power and the number of cores increase, smart dynamic power management (DPM) is strongly demanded to cope with the diminishing returns of DVFS in modern mobile devices. In this study, we show that the fast DVFS alone is not beneficial and thus to be enhanced considering its operation environment and the trade-offs between performance and energy consumption. We analyze an ineffective case when applying the fast DVFS, and suggest several considerations for the fast DVFS to be beneficial in mobile devices.

Actually, operating system (OS) periodically monitors the processor performance to determine the optimum frequency and voltage of the processor. For multi-core processors, a per-core based DVFS would be the best solution, however, there are several challenges such as expensive on-chip regulators and PLLs, complicated thermal management, and severe on-chip variations when applying per-core DVFS to mobile devices. Therefore, cluster based DVFS control (e.g. ARMs big.LITTLE) is prevalent in mobile devices. Even though ARM, the dominant mobile CPU vendor, has announced new energy management techniques such as intelligent power allocation (IPA) and energy aware scheduling (EAS), DVFS in mobile devices still depends largely on the centralized control under OS. Thus, a hardware-assisted DVFS control is necessary to overcome the slow speed of DVFS control caused by SW burden.

To validate fast DVFS in mobile devices, we build an OS level power simulator that support quad CPU cores. Two representative benchmarks are used: one is Templerun2, a pervasive mobile game, and the other is Bbench3.0, a web browsing benchmark application. We use interactive governor and on-demand governor, because they are mostly used in modern mobile devices. While changing DVFS control period from 30 ms to 1 ms, we observe the variation of performance and energy consumption of a quad-core CPU application processor (AP) when running Templerun2 and Bbench3.0. As a result, contrary to expectation, fast DVFS unnecessarily increased performance but consumed more energy.

Energy Oriented Governor: Performance was slightly improved but wasting more energy when reducing the DVFS control period in our experiments. This is because prevalent governors, i.e. on-demand governor and interactive governor, are designed by putting more emphasis on performance rather than energy. Even though Android OS provides energy-oriented governors, they have not been verified completely whether to meet strict deadlines required in mobile devices. However, since the goal of DVFS is to achieve the highest energy efficiency without harming user experience, an energy-oriented governor is worth to be implemented in mobile devices.

Collaboration of OS and Processor Architecture: Without hardware assistance, frequent changes in frequency and voltage inevitably cause additional energy consumption. To alleviate the problem, Intel has recently announced an energy friendly architectures in their CPU products by collaborating with Microsoft to be used for Windows 10. In this manner, such a hardware assisted DVFS technique will be engaged by both mobile OS and mobile CPU companies near future.

Per-Core DVFS Control: Although there exist a number of challenges to overcome, per-core DVFS control is still a strong candidate in maximizing the energy efficiency. With the advancement of analog circuit techniques and a hardware assisted voltage and frequency control, per-core DVFS control will provide more synergetic result.

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http://dx.doi.org/10.1145/nnnnnnn.nnnnnnn

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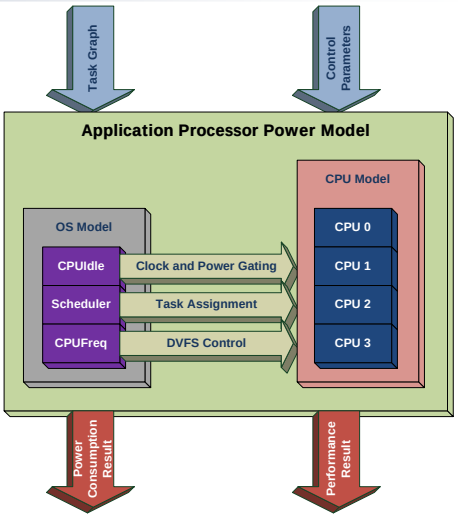
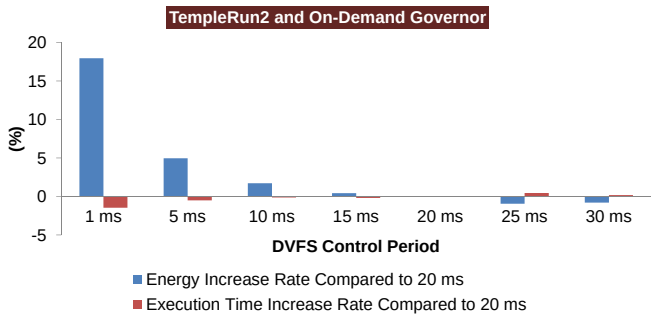
Motivation

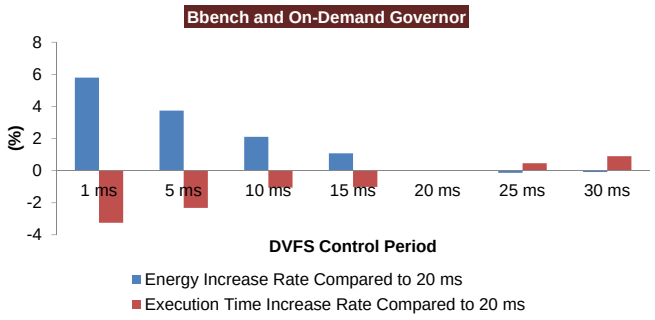
- **Fast DVFS**
  - ✓ **Definition** : Frequent frequency and voltage scaling(20 ms → a few ms or shorter)
  - ✓ **Question** : Can fast DVFS improve energy efficiency even with large overhead in mobile devices?
- **Power Simulator for Mobile Devices**
  - ✓ Realistic Power Model
    - Android OS with on-demand governor and interactive governor
    - Quad Coretex-A57 Cores
  - ✓ Swing DVFS control period from 30 ms to 1 ms with a step of 5 ms
    - Power and performance measurement against 20 ms (Default value of OS)

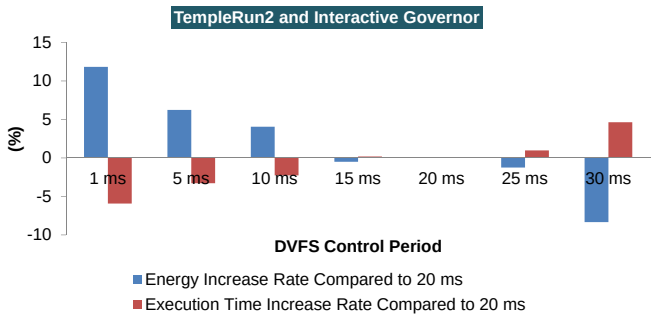


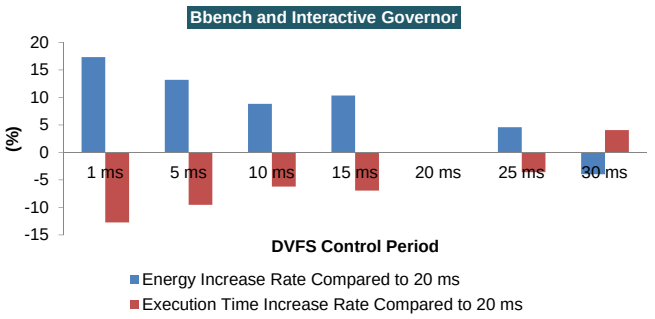
Experimental Results

Faster DVFS Consumes More Energy!









Discussion