FusionClock: WCEC-Optimal Clock-Tree Reconfigurations (Artifact)

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Abstract

Numerous embedded real-time systems have, besides their worst-case execution time (WCET) requirements, strict worst-case energy consumption (WCEC) constraints that must be satisfied. The core hardware component of modern system-on-chip (SoC) platforms to configure the tradeoff between time and energy is the system's clock tree, which provides the necessary clock source for each connected device (i.e., memory, sensors, transceivers). Existing energy-aware scheduling approaches have limitations with regard to these modern, feature-rich clock trees: These shortcomings concern the (re-)configuration of the clock tree with the associated penalties, which are a non-negligible part of dynamic frequency/voltage scaling or power-gating devices in addition to the influence of available sleep modes.

This artifact evaluation covers the work on FusionClock, an approach that exploits a fine-grained model of the system's temporal and energetic behavior. By means of our developed clock-tree model, FusionClock processes time-triggered schedules and finally generates optimized code for a system where offline-determined and online-applied reconfigurations lead to the worst-case–optimal energy demand while still meeting given timing-related deadlines. For statically determining these energy-optimal reconfigurations on task level, FusionClock builds a mathematical optimization problem based on the tasks' specifications and the system's resource-consumption model. Specific components like transceivers of SoCs usually have strict requirements regarding the used clock source (e.g., phase-locked loop, RC network, oscillator). FusionClock accounts for these clock-tree requirements with its ability to exploit application-specific knowledge within an optimization problem. With our resource-consumption model for a modern SoC platform and our open-source prototype of FusionClock, we are able to achieve significant energy savings while still providing guarantees for timeliness, as our evaluations on a real hardware platform (i.e., ESP32-C3) show.

2012 ACM Subject Classification Computer systems organization → Real-time systems

Keywords and phrases energy-constrained real-time systems, worst-case execution time (WCET), worst-case energy consumption (WCEC), energy-aware real-time scheduling, static whole-system analysis, time/energy tradeoff, clock tree, system on chip

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1 Scope

The scope of this artifact has the scope of validating the evaluation results of the related FusionClock paper [1]. The paper presents evaluations based on specific hardware components. The data sets of the energy measurements are available in the artifact in order to reproduce the respective figures. For the generation of the data, FusionClock uses a custom printed circuit board (PCB) and an energy-measurement unit, namely the JouleScope JS220 [3]. The artifact contains this pre-gathered data; the process of generating the data goes beyond the scope of this artifact evaluation. Additionally, in order to give researchers the possibility to produce the raw data, we publicly release the schematics for FusionClock's circuit board as open-source hardware: `https://gitlab.cs.fau.de/fusionclock/pcb`

2 Content

The artifact package includes:

1. An extended and modified version of the `Platin` analysis toolkit [5], from the `T-Crest` project [6], originally available at `https://github.com/t-crest`
2. A modified version of `LLVM` (from `T-Crest`) with backend support for the ESP32-C3 RISC-V–based target architecture
3. Quadratic program (QP) formulator & machine-code generator with hardware model
4. Data of the energy measurements from FusionClock's circuit board

Besides the parts directly included in the artifact's virtual machine, the evaluations require the mathematical solver `Gurobi` [2]. The detailed description of the artifact gives insight into the setup of `Gurobi` as part of the `README.md` of the artifact.

3 Getting the artifact

The artifact endorsed by the Artifact Evaluation Committee is available free of charge on the Dagstuhl Research Online Publication Server (DROPS). The VM image can be downloaded at `https://sys.cs.fau.de/research/data/watwa/ecrts23/Ubuntu.ova`. In addition, the in-depth description of the artifact (i.e., `README.md`), its scripts and further necessary links for setting up the environment, is also available at:

`https://gitlab.cs.fau.de/fusionclock`.

4 Tested platforms

To enable a high degree of portability, we installed the required software inside a virtual-machine image, which is executable using the `VirtualBox` hypervisor [4]. While the size of the artifact requires around 30 GiB of disk space, the self-contained virtual-machine image avoids the necessity to install and configure the multitude of required tools (e.g., `LLVM`, `Platin`, `esp-idf`). `VirtualBox` is available for all common platforms, thereby reducing the hardware requirements for running the artifact to a minimum. The image itself contains a Linux distribution (Ubuntu).

5 License

6 MD5 sum of the artifact

ecdf806fe3717cb98484fc7a9de4bd41

7 Size of the artifact

13 GiB

References

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6 Martin Schoeberl, Wolfgang Puffitsch, Stefan Hepp, Benedikt Huber, and Daniel Prokesch. Patmos: a time-predictable microprocessor. *Real-Time Systems*, 54(2):389–423, 2018. `doi:10.1007/s11241-018-9300-4`.