Evaluation of Embedded System Energy Usage with Extended UML Models

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***Abstract*—Energy consumption as an increasingly important decision criterion has to be included in the search for good architectural and design alternatives to make an embedded system as energy-efficient as possible. The proposed method describes a system with dedicated extended UML models for applications and hardware components and evaluates the energy use via a transformation into an analyzable stochastic Petri net.**

I. Introduction

Energy-efficiency is a so-called non-functional property which is of great importance in the current discussion about resource efficiency. While some components in the industry such as microcontrollers are already being developed with low power consumption, we should draw attention to the fact that an energy-efficient automation system as a whole includes several other components such as a controlled system and a digital control software (on which we concentrate our work for now). There is currently a lack of modeling and estimation procedures which could be applied already in the early design phases for energy consumption observation.

There are different levels of abstraction on which embedded systems can be evaluated for this task [1]. While there are some methods for the quite exact computation of energy consumption, they all require very detailed knowledge of the system under design. The description has to be on a very low level, which is available only in the later phases of the design process.

II. Method description

We propose a modeling and estimation procedure for early design phases, in which major architectural decisions are made, to consider energy consumption. The Unified Modeling Language (UML) [2] is an industry standard for the description of software systems. However, it is not intended to describe system properties equally well as there are no constructs for non-functional properties. Domain profiles of the UML have been developed for this task, namely, the MARTE Profile (Modeling and Analysis of Real-Time and Embedded Systems) [3] as a successor of the UML Profile for Schedulability, Performance and Time (SPT). With its help, non-functional properties like machine utilization, failures, temporal relations etc. can be described. The profile was developed especially for embedded systems and, hence, is suitable for our purposes better than the standard UML alone. In this work, we use state machines to describe the system behavior.

UML models adopting the MARTE profile contain the necessary information for energy consumption estimation. However, they are not usable for a numerical estimation directly, as UML models are not semantically well-defined for a specification of the resulting stochastic process. There is a lack of analysis algorithms. For this work, we propose extended UML models to be transformed into models for which analysis algorithms already exist, so that the behavior and the properties are preserved. Stochastic Petri nets (SPN) [4] are used for this purpose, as they are well adapted for concurrent and synchronized systems and powerful performance evaluation algorithms. This is an extension of an earlier work, in which extended UML statechart models were transformed into uncolored SPNs and analyzed [5]. A similar approach is taken in [6], where the work mentioned is applied to energy consumption evaluation in a different way.

In the proposed procedure, we explicitly address the hardware part of the system, which will be the same for all applications. It is described in an *operational model* and specifies all run modes of a processor (microcontroller), the possible state changes, and their associated power consumption (as well as transition times, if applicable) (Fig. 1 left top). This information can be taken from data sheets and measurements, and the model has to be constructed only once for a specific CPU.

On the other hand, the effect of the controlling software is captured in an *application model*. It describes which steps are taken and what time is spent in which mode and may include stochastic behavior (interrupts, for instance). Thus, it contains information about the

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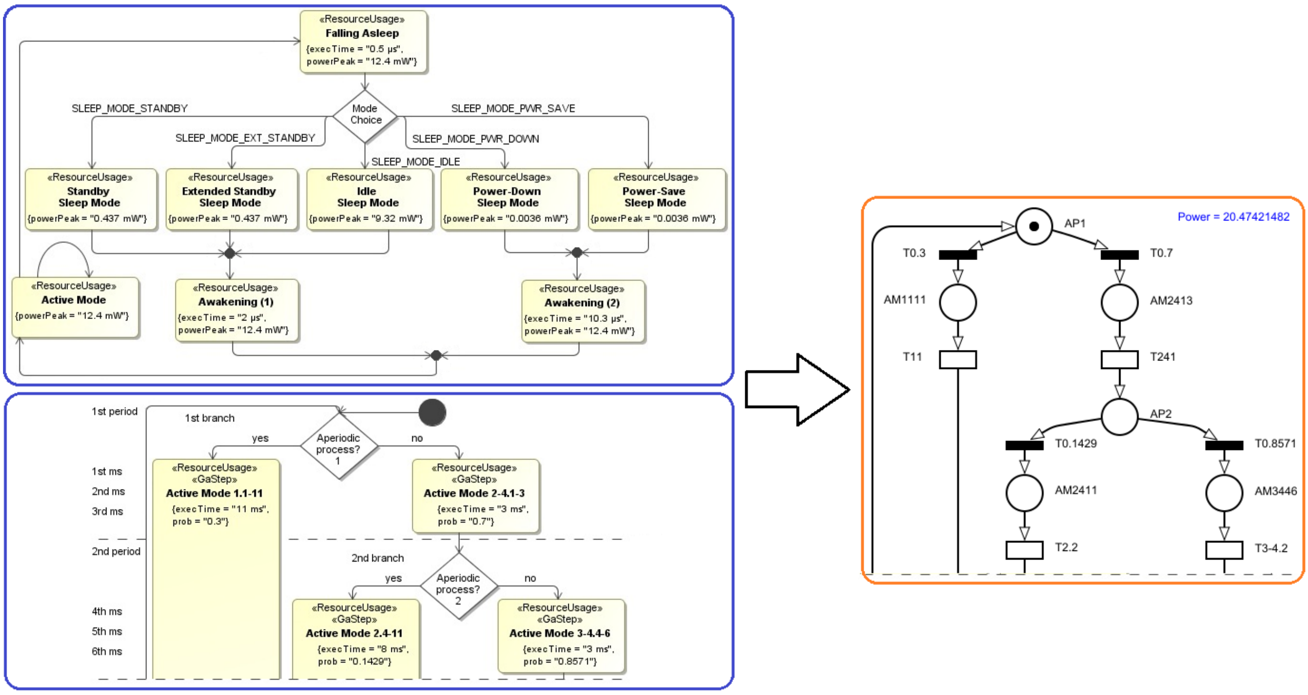

Figure 1: Operational and application UML models and their transformation into a Petri net

operational states used in the specified program and their duration (Fig. 1 left bottom).

Two created UML state machines are combined and converted into a Petri net. The application model is taken as the basic one for this operation. The missing information (missing states, power, duration) is taken from the general operational model. In [7], we presented a detailed example of the method implementation. The procedure overview is presented in Fig. 1. The resulting model can then be used to estimate the power consumption of the system with the help of Petri net tools such as TimeNET [4]. The calculation of the power occurs automatically in the course of the static analysis of the Petri net.

III. Conclusion

This paper presented a methodology for the model-based estimation of energy consumption for embedded systems. The UML language extended with the MARTE profile is used for the modeling process. The main contribution is to describe the overall processor behavior with an independent general operational model, while the software applications are specified in the application model referencing the first one. The two models are converted into a SPN, which is then used for a performance evaluation. Thus, the design process for embedded systems can be supported by predicting the energy consumption. Currently, the automatic transformation of extended UML statecharts into SPNs is being implemented as an extension of TimeNET. Besides, actual lab setups are used to apply and validate the proposed method.

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