Project no.:	**318490 (FP7-ICT-2011-8)**
Project full title:	**Self Energy-Supporting Autonomous Computation**
Project Acronym:	**SENSATION**
Deliverable no.:	**D3.2**
Title of Deliverable:	**Energy Optimal Scheduling**

Contractual Date of Delivery to the CEC:	**31 OCT 2013**
Actual Date of Delivery to the CEC:	**29 NOV 2013**
Organisation name of lead contractor for this deliverable:	**SAU**
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Participants(s):	**AAU, INR, RWT, SAU**
Work package contributing to the deliverable:	**WP 3**
Nature:	**R (report)**
Version:	**0.5 (DRAFT)**
Total number of pages:	**10**
Start date of project:	1. Oct. 2012 **Duration:** 36 month

Project co-funded by the European Commission within the Seventh Framework Programme (2012-2015)

Dissemination Level		
PU	Public	**X**
PP	Restricted to other programme participants (including the Commission Services)	
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Abstract:

This deliverable describes core contributions to the objective 3.1 of SENSATION revolving around energy optimality. It is based on five research papers published within the first year of SENSATION.

Keyword list: Optimal Control, Energy Games, Statistical Model Checking, Imperfect Information, Automotive Control, Power Grid Stabilization.

Contents

1 Introduction

This deliverable summarises the tangible advances made by the SENSATION project partners on the topic of energy optimal scheduling, reporting on the first year of the SENSATION collaborative efforts. The research efforts were crucially driven by the industrial case studies of SENSATION.

The first three results we report on in this deliverable are of direct relevance for the case provided by GOMSPACE. Section 2 describes how to derive and ensure "capacity" bounds of winning strategies in multiweighted and parametrised energy games. These can be interpreted as battery capacities of orbiting sattelites, and the work provides conroller strategies ensuring transmission of data to earth in the context of on-board solar energy harvesting. Section 3 discusses statistical model checking to effectively arrive at approximately optimal control strategies, where the scenario considered involves energy level of batteries, with the objective of identifying parameter settings that will maximize battery lifetime or time between required battery recharges. In Section 4 we describe a new method for synthesizing controllers under imperfect information in a time- and cost-restricted setting. The method identifies a subset of predicates sufficient for control and whose cost is minimal. In the context of GOMSPACE, this method can be applied to designing scheduling strategies using a cost-optimal collection of sensors.

Section 5 turns to a novel combination of probabilistic model checking and efficient constraint-solving. This investigation is driven by the needs of the academic case study, and constitutes a first stepping-stone towards deployment techniques for SADF specifications, in that it provides an effective approach to systematically explore the design space of SW/HW mappings to determine energy-optimal deployments. Section 6 looks into distributed scheduling of large-scale energy systems with SENSATION technology. It consider the problem of power grids becoming less stable the more renewable micro-generation of power is attached to them. The control strategies devised in this work are based on probabilisitic parametric energy models. They reverse the present situation to the converse: The more renewable power, the better for the power grid stability.

2 Optimal Bounds for Multiweighted and Parametrised Energy Games

Participants:

- Line Juhl and Kim Guldstrand Larsen (Aalborg University)
- Jean-François Raskin (Université Libre Bruxelles)

Contribution Multiweighted energy games are two-player multiweighted games that concern the existence of infinite runs subject to a vector of lower and upper bounds on the accumulated weights along the run. In this work [5] we assume an unknown upper bound and calculate the set of vectors of upper bounds that allow an infinite run to exist. For both a strict and a weak upper bound we show how to synthesize this set by employing results from previous works, including an algorithm given by Valk and Jantzen for finding the set of minimal elements of an upward closed set. Additionally, we consider energy games where the weight of some transitions is unknown, and show how to synthesize the set of suitable weights using the same algorithm.

Perspective The problem of synthesizing upper ”capacity” bounds allowing for the existence (and synthesis) of winning strategies ensuring infinite runs within these bounds is highly relevant for the SENSATION case study provided by GOMSPACE. Here the bounds corresponds to the capacity of batteries and the strategies ensuring infinite runs, while be based on suitable scheduling of transmission of data to earth given information about possibility of harvesting energy from solar energy.

3 Optimizing Control Strategy Using Statistical Model Checking

Participants:

- Alexandre David, Kim Guldstrand Larsen, and Marius Mikučionis (Aalborg University)
- Axel Legay (INRIA Rennes)
- Dehui Du (ECNU Shanghai)

Contribution This contribution [2] proposes a new efficient approach to optimize energy consumption for energy aware buildings. Our approach relies on stochastic hybrid automata for representing energy aware systems. The model is parameterized by several cost values that need to be optimized in order to minimize energy consumption. Our approach exploits a stochastic semantic together with simulation in order to estimate the best value for such parameters. Contrary to existing techniques that would estimate energy consumption for each value of the parameters, our approach relies on a new statistical engine that exploits ANOVA, a technique that can reduce the number of runs needed by the comparison algorithm to perform the estimates. Our approach has been implemented and our experiments show that we clearly outperform the naive approach.

Perspective This method is useful for efficient synthesis of near-optimal parameters for parameterized strategies, and will be useful for the SENSATION case study related to GOMSPACE. In this case we are considering scheduling strategies parameterized by threshold parameters involving energy level of batteries, with the objective of identifying parameter settings that will maximize battery lifetime or time between required battery recharges.

4 Controllers with Minimal Observation Power applied to Timed Systems

Participants:

- Peter Bulychev, Alexandre David, Kim Guldstrand Larsen (Aalborg University)
- Franck Cassez (NICTA, Sydney)
- Jean-François Raskin (Université Libre Bruxelles)
- Pierre-Alain Reynier (Marseille University)

Contribution In this contribution [1] we consider the problem of controller synthesis under imperfect information in a setting where there is a set of available observable predicates equipped with a cost function. The problem that we address is the computation of a subset of predicates sufficient for control and whose cost is minimal. Our solution avoids a full exploration of all possible subsets of predicates and reuses some information between different iterations. We apply our approach to timed systems. We have developed a tool prototype and analyze the performance of our optimization algorithm on two case studies.

Timed automata by Alur and Dill is one of the most popular formalism for the modeling of real-time systems. The literature on timed automata contains a number of successful applications that have motivated progresses both in theory and tool support. One such application is controller synthesis, i.e. the automatic synthesis of a controller strategy that forces a system to satisfy a given specifi- cation. For timed systems, the controller synthesis problem has been first solved in Maler et al, and progress on on-the-fly algorithms were obtained by David et al now implemented in the Uppaal-Tiga tool, and applied to several case studies. The on-the-fly algorithm of assumes that the controller has perfect information about the evolution of the system during its execution. However, in practice, it is com- mon that the controller acquires information about the state of the system via a finite set of sensors each of them having only a finite precision. This motivates to study imperfect information games. In practice, the observations are naturally defined by the values of a finite set of state predicates, that we call observable predicates. Observable predicates correspond, for example, to information that can be obtained through sensors by the controller. In previous work an on-the-fly algorithm for computing observation-based strategies has been proposed, and implemented in Uppaal-Tiga. However it is assumed that the set of observable predicates is fixed, and the algorithm solves the game of imperfect information for this fixed set of observable predicates only. In the current contribution, we further develop this approach and consider a set of available observation predicates equipped with a cost function. Our objective is to synthesize a winning strategy that uses a subset of the available observable predicates with a minimal cost. Clearly, this can be useful in the design process when we need to select sensors to build a controller. Our algorithm works by iteratively picking different subsets of the set of the available observable predicates, solving the game for these sets of predicates and finally finding the controllable combination with the minimal cost. Our algorithm avoids the exploration of all possible combinations by taking into account the inclusion-set relations between different sets of observable predicates and monotonic properties of the underlying games. Additionally, for efficiency reasons, our algorithm reuses, when solving the game for a new set of observation predicates, information computed on previous sets whenever possible. This algorithm has been implemented in a prototype tool, and we analyze the effectiveness of various parameters of the algorithm by applying this tool to two case studies.

Perspective The devised method may prove useful for the GOMSPACE case study in designing scheduling strategies using a cost-optimal collection of sensors.

5 Model-Based Energy Optimization of Automotive Control

Participants:

- Joost-Pieter Katoen, Thomas Noll and Stephen Wu (RWTH Aachen University)
- Thomas Santen and Dirk Seifert (ATL Microsoft)

Contribution Reducing the energy consumption of controllers in vehicles requires sophisticated regulation mechanisms. Better power management can be enabled by allowing the controller to shut down sensors, actuators or embedded control units in a way that keeps the car safe and comfortable for the user, with the goal of optimizing the (average or maximal) energy consumption. This work [6] proposes an approach to systematically explore the design space of SW/HW mappings to determine energy-optimal deployments. It employs constraint-solving techniques for generating deployment candidates and probabilistic analyses for computing the expected energy consumption of the respective deployment. Fig. **??** gives a more detailed overview of our approach. We use the FORMULA tool to automatically generate deployment candidates, i.e., mappings of software to hardware components that satisfy the given requirements. The computation of the expected energy consumption (lower box) is essentially based on two inputs. The first is the usage profile, specified as a discrete-time Markov chain (DTMC; upper left box) over mode configurations. The second is the set of deployment candidates (upper middle box) as provided by FORMULA (Formal Modeling Using Logic Programming and Analysis) [4]. The outcome is the optimal deployment, in the sense that the expected energy consumption (for the given usage profile) is minimal.

Perspective This work is a first stepping-stone towards deployment techniques for SADF specifications, as required by the academic case study. It is a novel combination of probabilistic model checking and efficient constraint-solving.

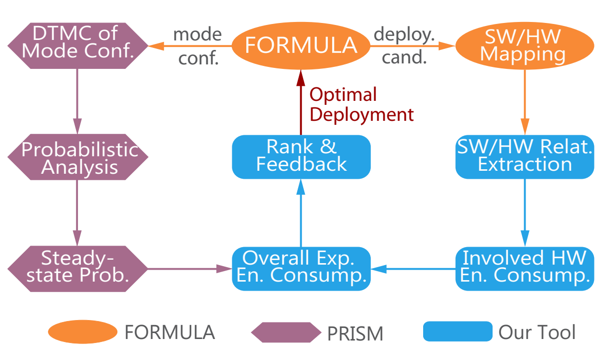

Figure 1: Overview of our approach towards energy optimization of deployment candidates

6 Decentralized Power Grid Stabilization Strategies

Participants:

- Arnd Hartmanns and Holger Hermanns (Saarland University)

Contribution The electricity markets in Europe, Asia, and the Americas are evolving towards decentralized structures, essentially rooted in political decisions to counter the worldwide climate change. The increase of production based on renewable energy like wind and photovoltaic power generators implies drastically higher fluctuations in available electricity. The problem has two challenging facets, namely power grid stability and economy of power production/supply. The stability of the distribution grids is a priority concern because reliable distribution is a prerequisite for economic use of power, whether or not renewable. This asks for improved and better coordinated diagnostic and prediction techniques, as well as orchestrated demand-side mechanisms to counter critical grid and/or generation situations.

In this work [3] we discuss on formal behavioural models of power grids with a substantial share of photovoltaic microgeneration. Simulation studies show that the current legislatory framework in Germany can induce frequency oscillations. This phenomenon is indeed recognised by the German Federal Network Agency responsible for overseeing the national power grids, and new regulations are currently being identified to counter this phenomenon. We study the currently valid proposal, and compare it with a set of alternative approaches that take up and combine ideas from communication protocol design, such as additive-increase/multiplicative-decrease known from TCP, and exponential backoff used in CSMA variations. We classify these alternatives with respect to their availability and goodput. The models are specified in the modelling language Modest, and simulated with the help of the modes simulator. Some of the controllers devised in this SENSATION work provide distinguished stability to a power grid, by harvesting randomisation: To date, the grid becomes less stable the more renewable microgeneration of power is attached to it, while with the controllers we devise the situation is the converse: The more renewable power, the better for the power grid stability.

Perspective The power grid stability domain as a very fruitful and inspiring area for further energy-aware scheduling research. The controller devised within these SENSATION activities provide distinguished and provable stability. Still, the challenges in this domain are highly intriguing, and ask for inclusion of further quantities, so as to enable the inclusion of further metrics, such as voltage stability.

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