PROJECT PERIODIC REPORT

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[2] The home page of the website should contain the generic European flag and the FP7 logo which are available in electronic format at the Europa website (logo of the European flag: http://europa.eu/abc/symbols/emblem/index_en.htm ; logo of the 7th FP: http://ec.europa.eu/research/fp7/index_en.cfm?pg=logos). The area of activity of the project should also be mentioned.

Declaration by the scientific representative of the project coordinator[1]

I, as scientific representative of the coordinator[1] of this project and in line with the obligations as stated in Article II.2.3 of the Grant Agreement declare that:

- The attached periodic report represents an accurate description of the work carried out in this project for this reporting period;
- The project (tick as appropriate):
  - X has fully achieved its objectives and technical goals for the period;
  - ☐ has achieved most of its objectives and technical goals for the period with relatively minor deviations[3];
  - ☐ has failed to achieve critical objectives and/or is not at all on schedule[4].
- The public website is up to date, if applicable.
- To my best knowledge, the financial statements which are being submitted as part of this report are in line with the actual work carried out and are consistent with the report on the resources used for the project (section 6) and if applicable with the certificate on financial statement.
- All beneficiaries, in particular non-profit public bodies, secondary and higher education establishments, research organisations and SMEs, have declared to have verified their legal status. Any changes have been reported under section 5 (Project Management) in accordance with Article II.3.f of the Grant Agreement.

Name of scientific representative of the Coordinator[1]: Kim G. Larsen & Brian Nielsen

Date: 28/04/2010.

Signature of scientific representative of the Coordinator[1]:

[3] If either of these boxes is ticked, the report should reflect these and any remedial actions taken.

[4] If either of these boxes is ticked, the report should reflect these and any remedial actions taken.

Contents

1. Publishable summary

The objective of the Quasimodo project is to develop theory, techniques and tool components for handling quantitative constraints in model-driven development of real-time embedded systems. These real-time, hybrid and stochastic constraints involve the resources that a system may use (computation resources, power consumption, memory usage, communication bandwidth, costs, etc.), assumptions about the environment in which it operates (arrival rates, hybrid behaviour), and requirements on the services that the system has to provide (timing constraints, QoS, availability, fault tolerance, etc.).

More specifically, the project aims at:

1. Improving the modelling of diverse quantitative aspects of embedded systems.
2. Providing a wide range of powerful techniques for analysing models with quantitative information and for establishing abstraction relations between them.
3. Generating predictable code from quantitative models.
4. Improving the overall quality of testing by using suitable quantitative models as the basis for generating sound and correct test cases.
5. Applying the techniques to real-life case-studies and disseminating the results to industry.

By enabling early and automated analysis, design, and test of embedded systems with quantitative constraints, the results of Quasimodo will increase the competitiveness of European embedded systems industry and will help establish Europe as a leader in design of complex embedded systems.

Quasimodo applies and evaluates its research ideas and tools on the following challenging case studies:

1. The Accumulator Charge Controller (provided by HYDAC),
2. The self-balancing scooter (provided by CHESS),
3. A Wireless Sensor Network (provided by CHESS), and
4. The attitude and orbit control software for the satellites Hershel and Planck (provided by TERMA).
5. Adaptive data-paths in photocopiers/printers (provided Océ)
6. Design space exploration for motion control applications implemented on packet switched multi-processor platforms (provided by ASML).

Significant work has been made on all case studies. Especially we emphasize the achieved results on validation of the CHESS WSN. Not only did we find problems in the original clock-synchronization protocol as designed by CHESS, we also managed to identify a revised algorithm that satisfies the relevant properties. Furthermore, we studied trade-offs between energy consumption and collision probabilities resulting from different internal timing parameters.

During the second year we have also worked extensively on algorithms for analysing quantitative models. For instance, significant progress has been achieved in model checking of (Markov and timed automata based) models with continuous time and probabilistic behaviour, and different extensions thereof with non-determinism, process, parameters, and energy constraints. Similarly, we have significantly advanced techniques for abstraction and compositional verification and refinement checking. Also during the second year, we have made substantial progresses in algorithmic methods for the synthesis with bounded resources like memory, energy and costs. Finally we have developed new algorithms for offline and online testing of real-time testing.

In general these advanced algorithms and required data-structures are available in the extensive set of tool components developed by Quasimodo, see the tools section on the Quasimodo web-site. Several new tool components have been developed, and several features have been added to the Uppaal-Tiga tool. Thus, substantial progress has been made on development of individual tool components which are continuously being refined and improved.

The work is also reported in a very large number of scientific publications. Overall the project has made significant scientific progress and we find the project in overall good shape. We thus have a very good foundation for the future work on tool-integration, test generation, and further application to case studies, evaluation, and dissemination.

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Quantitative System Properties in Model-Driven-Design of Embedded Systems

2. Project objectives for the period

The overall second year objective is to develop algorithms for quantitative analysis, synthesis and testing, implement these in tool components, and to perform a first application of these to case studies. A special focus has been on developing techniques for implementation synthesis, and applying developed validation techniques on the Quasimodo case-studies.

The objectives are detailed through the description of milestones M4, and M5.

Milestone M4 is to be verified though the availability of (M4.1) implemented data-structures for symbolic representation and manipulation of state spaces for quantitative models, and (M4.2) verified algorithms and experimental implementation for quantitative analysis, abstraction/refinement, controller-synthesis and testing.

Milestone M5 is to be verified though the availability of (M5.1) first implementation of tool components, (M5.2) first tool trial: integration of selected tool components with industrial tool chains and application to case studies.

Additional goals are model-process improvement (Task 1.1-D1.3), dissemination – especially towards end-users, and to initiate work on the industrial handbook.

Reaching these objectives will give a very good foundation for the future work emphasizing tool-integration, testing, and further application to case studies, evaluation, and dissemination.

The next section details how we have reached these objectives. Section 3.7 gives a summary comparing with the milestones and these objectives.

3. Work progress and achievements during the period

3.1 *WP1: Modelling and Specification*

Wp1 aims at improving modelling and specification of quantitative properties of embedded systems.

Our work in **T1.1 (Model Process improvement)** aims at developing methods for obtaining adequate and faithful models of embedded systems. The current approach can be characterized as "model-hacking" and very ad-hoc. We identified 7 properties that a "good" formal model should have. These properties have emerged from our and others extensive experience in applying formal modelling and analysis. To gain further experience with these properties, we reviewed our modelling effort on the Quasimodo case studies, and identified a number of situations where satisfaction of these properties lead to good models, and where their violation resulted in less usable models. It is our belief that a systematic and explicit check of these properties will lead to better and more usable models. Interestingly, this review also identified a number of notation and tool limitations that hindered a smooth modelling process.

The aim of **T1.2 (Modelling of Quantitative System Aspects)** is to integrate timed, hybrid and stochastic aspects of models. We have worked on the four different topics mentioned in the *Description of Work*, stochastic component-based modeling, probabilistic timed modeling, stochastic hybrid modeling, and resources modeling. We have extended the work developed during Y1 in several aspects/directions

- Parametric DTMC (Discrete Time Markov Chains). To enable modelling and exploration of variations of systems it is very useful to use parameters explicitly, rather than using fixed values. The solution to an analysis problem becomes a function of these parameters, whose ranges can then be explored and optimized. We have developed practical techniques for computing the parametric unbounded reachability probability for PDTMCs (with reward extensions and initial results for non-deterministic models).
- We have identified Interactive Markov Chains as an elegant and effective vehicle for developing compositional reasoning and abstraction techniques for probabilistic models for performance analysis, and have based on this developed promising

simulation preserving abstraction techniques. We also introduce Constraint Markov Chains as a foundation for compositional component-based design of probabilistic systems.

- To enable compositional verification of large timed systems we have developed a complete interface theory for timed input/output automata. This framework supports constructs for refinement checking, consistency checking, logical and structural composition, and quotienting. Tool support is implemented on top of Uppaal-Tiga.
- For the *combined* Probabilistic Priced Priced Timed Automata formalism we have developed and implemented new algorithms for cost-bounded probabilistic reachability analysis.
- Inspired by the Hydac case we have developed an alternative semantics of Priced Timed Automata (PTA) where the accumulated cost (energy) must be kept within a lower and upper bound, and studied how algorithms can be developed. In particular we studied untimed lower bound problem, the timed (1 clock) lower bound problem, and extended the setting with exponential rate prices.
- Furthermore, we have proposed a new notion of cost-optimality for PTAs for infinite runs ("optimal mean cost in the long run") using a discounting semantics that potentially enable efficient analysis algorithms.
- We have developed theories and techniques for model checking Continuous Time Markov Chains (CTMC) against timed automata specifications.

Our work on **T1.3 (Design Notations and Tools)** aims at describing quantitative aspects syntactically in design notations for embedded systems with accompanying tool support. Developing a quantitative notation that is intuitive to use for designers, that has a precise semantics, that allows it to be preserved when transformed into the formalisms supported by current analysis tools is a quite challenging task. Important results are:

- a stochastic extension of Statecharts "StoCharts". This extension adds a probabilistic choice operator, random delays, and decoration with costs. The extension is accompanied by a clean and compositional semantics. A prototype tools allows this notation to be translated into the MoDeSt formalism and analysed using the Quasimodo tools.
- a translater for a subset of state charts into Uppaal timed automata. In particular, UML comments are translated into Uppaal declarations enabling simple but effective way of modelling analyzable timed systems using Statecharts.
- a Markov decision process extension for Statemate that enable dependability analysis.
- extensive work on the Architecture Analysis and Design Language (AADL), in particular in adding support for analysis of probabilistic faults, error handling and recovery. The underlying probabilistic extension is based on interactive Markov chains. This gives a solid basis for the tools for dependability and performance analysis that are currently being developed.

This work has thus progressed well during Y2, and is on track. Future work includes work on modelling tools, an investigation of methodological and tool support model management, a chapter on the modelling process in the industrial handbook, and a feasibility study of adding quantities to Simulink/Stateflow.

3.2 *WP2: Analysis*

T2.1 (State space representation and model checking) focuses on models with multiple quantitative aspects, such as continuous time, costs, and probabilities. In this task, significant progress has been achieved in model checking of models with continuous time and probabilistic behaviour, in particular continuous-time Markov chains (CTMCs), and a variant thereof that includes non-determinism: CTMDPs. Besides, much progress has been achieved in the verification of priced timed automata, both extended with discrete probabilities, and with energy constraints (that can be interpreted as negative and positive costs).

CTMC model checking has been enriched with the first algorithm for the verification of CTMCs against linear real-time specifications that are given as deterministic timed automata. The main technical achievement has been a reduction of this model-checking problem to the computation of probabilistic reachability properties in a piecewise deterministic Markov process.

For CTMDPs model checking, an investigation and classification of timed schedulers have been made. In this setting, time-abstract schedulers that are used for MDPs are insufficient, and the main question is which time information is important for timed schedulers to yield maximal (and minimal) reachability probabilities. It has been established that total time-positional schedulers suffice. Such oracles need the current state together with the total time that has elapsed so far to steer their decisions.

For priced timed automata, several contributions have been made to the verification of energy constraints: the accumulated cost during any execution must stay between a given upper and lower bound. A connection to mean pay-off games has been established, exponential prices have been considered (where costs grows exponentially rather than linear with elapsed time). In addition, for probabilistic PTA, undecidabiliy results have been obtained for cost-bounded reachability and a prototypical tool (named Fortune) has been realised which involves several improvements to the underlying data structures of PTA model checking.

The work in this task is on schedule.

The activities in T2.2 (Abstraction, Refinement and Compositionality) have focused on exploiting compositionality in abstraction. Here, the idea is exploit abstraction in a component-wise manner, thus avoiding the generation of the state space of the entire model. This principle has been successfully applied to timed automata, as well as interactive Markov chains, basically CTMCs equipped with separate action transitions.

For monolithic abstraction, it has been shown that game-based abstraction is optimal (in the sense of an abstract-interpretation setting), and that abstraction of infinite CTMCs is practically feasible.

The base for abstraction is a formal notion of equivalence of pre-order between processes. In that respect, we have achieved quantitative versions of trace inclusion, trace equivalence, and (bi)simulation in a setting in which propositions are interpreted quantitatively. Further, polynomial-time algorithms have been developed for checking language equivalence of labeled Markov chains, and it is shown that this problem for labeled MDPs requires schedulers with infinite memory.

Finally, very useful results have been obtained for parametric model checking of DTMCs and MDPs, where the focus is on which parameter ranges ensure the validity of a given desired quantitative property.

The work in this task is (as in last year) ahead of schedule.

In **T2.3 (Approximate Analysis Techniques)** discrete-event simulation (DES) techniques have been further refined, realised, and experimented with in the setting of CSL model checking of CTMCs. By means of extensive experiments, the drawbacks and benefits of DES compared to hypothesis testing have been investigated, and reported.

3.3 *WP3: Implementation*

The main research objectives of WP3 are twofold. First, within task T3.1, our objective is to improve the understanding of synthesis problems defined on rich models suited for the modeling of embedded systems. Second, within task T3.2, our objective is to study the transfer of properties established on abstract models into concrete implementations automatically, and the process of automatically generating executable codes from high level mathematical models.

In **task 3.1 (Controller Synthesis and Scheduling)** we study models suited for modeling quantitative aspects of embedded systems and algorithms to reason on those models. In particular, we want to study synthesis problems for models where quantitative aspects of those systems can be modeled adequately. For example, models should allow us to specify and solve algorithmically scheduling problems. For that purpose, we are studying synthesis problems on finite state game structure, timed game structures defined timed automata, automata models extended with probabilities, and automata models extended with costs. In the future, we also plan to study the combinations of those features. During the second year of our project, we have made substantial progresses in algorithmic methods for the synthesis with bounded resources, and extended timed automata models for scheduling. The main results in this line of research are as follows:

- Bounded memory strategies. We developed an extension of ATL, a temporal logic which can express controllability properties. Roughly, ATL extends CTL by replacing the usual (existential and universal) path quantifiers with strategy quantifiers, which may be used to express that there is a strategy for the controller to keep the system within a safe set of behaviors. Our extension can express the extra requirement that the strategy should only use a limited amount of memory on the history of the computation.
- Games with imperfect information. Last year, we have presented algorithms for solving games with imperfect information. This year, we have improved those algorithms by designing compositional and symbolic algorithms for synthesizing controllers with imperfect information. Those compositional and symbolic algorithms extend substantially the practical classes of concrete problems on which our methods apply.

- Games with energy constraints. We present energy games, i.e., games played on a weighted graph where the weights represent energy consumption or storage, and where the aim is to never run out of energy. These games have been first defined within the QUASIMODO consortium in order to model the HYDAC case study. The algorithmic study of the numerous variants of this problem is still in progress, and we report here our preliminary results. Combination of energy games with imperfect information is part of the future works that we plan for next year.

- Optimal adaptive scheduling with UppAal Tiga. Timed game automata extends standard timed automata by marking edges as either controllable or uncontrollable. They define two player games with on the one side the controller (choosing the controllable edges) and on the other side the environment (choosing the uncontrollable edges). Winning conditions of the game can be specified through TCTL formulas: then the controller has to ensure that the formula holds for every execution. A classical and simple case consists in considering reachability questions: the controller has to reach some given winning states (or conversely to avoid some bad state). Those methods are implemented in the UppAal Tiga tool and have been successfully applied to challenging industrially relevant adaptive scheduling problems.

- Stopwatches automata for scheduling. A stopwatch is a clock that can be stopped and restarted. Contrary to clocks that progresses continuously with time elapsing and can only be reset, a stopwatch can be stopped temporarily and it can be used to measure the accumulated time spent in a given set of locations during an execution. This extension is very powerful and leads to undecidability of reachability. On the other hand, it is very well adapted to the modeling of scheduling problems with preemption. Semi-decision algorithms have been developed and shown usable in practical applications. Further theoretical developments are currently done.

- Analysis of timed bounded reachability probabilities in continuous-time Markov decision processes. Continuous-time Markov chains are one of the most important models in performance and dependability analysis. They are exploited in a broad range of applications, and constitute the underlying semantical model of a plethora of modeling formalisms for real-time probabilistic systems. Continuous-time Markov decision processes (CTMDPs), also known as controlled Markov chains, have been used for, among others, the control of queueing systems, epidemic, and manufacturing processes. The analysis of CTMDPs is focused on determining optimal schedulers for criteria such as expected total reward and expected (long-run) average reward.

Those results and their related publications are summarized in the deliverable D3.4 and D3.5. The objectives that were identified in our research proposal for task T3.1 for year 2 have been met and several new perspectives have been open for the sequel of the project.

Second, within **task T3.2 (Implementability and Code Generation)**, our objective is to study the transfer of properties established on abstract models into concrete implementations automatically. This problem is particularly challenging for timed models. Indeed, in timed models time elapsing is measured using real-valued variables while in implementations, time elapsing is measure by counting ticks of a discrete clock with finite precision. The theoretical background has been developed by several teams of the QUASIMODO project. Theoretical progresses have been made last year and reported into deliverable D3.1 (year 2008). During 2009, a practical algorithm based on the zone data-structure for analysis behavior of timed automata has been developed.

- Zone based algorithm for robustness checking. We propose a practical algorithm for the analysis of robustness of timed automata, that is, the correctness of the model in the presence of small drifts on the clocks. The algorithm is an extension of the region based algorithm of Puri and uses the idea of stable zone of Daws and Kordy. The algorithm is a depth first search based on on-the-fly reachability using zones. The current version of our algorithm is able to handle a subclass of timed automata. We are looking to extend it to the full class of timed automata.

Those results and their related publications are summarized in the deliverable D3.2. The objectives that were identified in our research proposal for year 2 have been partially met some additional effort has to be devoted to the robustness checking algorithm with zones in order to make it complete for the all class of timed automata. The result will again be implemented with the tool UppAal.

Third within **task 3.2**, we also study how to generate codes from high level mathematical models. In particular, we plan to study the problem of code generation first on untimed models and then on timed models. In Deliverable D3.6, we report on preliminary results for untimed models. Here is a summary.

Model-Driven Development (MDD) is a software development technique in which the primary software artefacts are models providing a collection of views. Within MDD, programming is replaced by modeling. The question, however, is how to transform a high level model to efficient low-level programming code. We are thus interested in effective implementation mappings (code generation) from abstract models onto concrete platforms with guarantees that correctness properties established of the models also hold of the resulting implementation.

Task WP3.6 studies the problem of the code generation from untimed models. This task is a prerequisite to deliverable 3.7 (due at the end of the project i.e., month 36) where code generation for timed models will be studied.

The solution that we propose for untimed models take as input PROMELA models and produces JAVA code. To develop a solution, we faced several challenges: the different granularity between the two languages, how to translate non-deterministic statements (that abound in Promela), how to translate blocking of statements, etc …

In order to maximize the concurrency in the produced code, we have decided to use JAVA threads to implement PROMELA processes. In particular Java 5 offers several powerful additional features that can be used for programming concurrent applications, and clearly these features are of great value when generating concurrent Java code from PROMELA models.

Our solution will be implemented in a compiler called P2J, which stands for

“PROMELA to Java”. This work is ongoing. A working prototype of the P2J compiler is not yet operational. The front end (i.e. lexical analyser and parser for PROMELA) of the P2J compiler has been developed using ANTLR and is completed. For walking the resulting abstract syntax tree, an ANTLR tree walker has been specified. The back end of P2J (i.e., the code generator) is still missing though. The current version of the P2J compiler can be retrieved from http://ewi.utwente.nl/˜ruys/p2j/

3.4 *WP4: Testing*

Task 4.1 Test Generation. During the second year, WP4 has made significant contributions on the topic of off-line and on-line test theories for real-time systems (T4.1, D4.2). In particular, timed games have proved to be a fruitful setting for testing: test case generation can be formulated in terms of winning strategies in a game where the tester plays against, or in some cases cooperation with, the system. Then test case generation algorithms can be obtained from algorithms for solving timed games. These game-theoretic algorithms have been exploited, refined, and extended for this purpose and they have been implemented in the real-time model checker Uppaal-Tiga. Practical applicability of these methods has been demonstrated in a variety of practical case studies.

WP4 has also developed mechanisms for test coverage and test selection (T4.1, to be reported in the future deliverable D4.3). We have put forward a framework of risk-based testing, which takes into account the severity of the faults and the probability of their occurrence. In this framework, we can not only compute test coverage or risk, but also to construct the best (= lowest) test suite for a within a given cost budget. Details will be presented in D4.3.

To enable testing of hybrid systems with mixed discrete and continuous signals we are working on the approach of combining our real-time online testing tool with Simulink aiming at exploiting the strengths of each formalism and tool. We have made successful initial integrations of the tools. To enable testing from timed probabilistic models we basing our work on the semantic framework of probabilistic Timed Automata as implemented in Uppaal-Pro, although tangible results have yet to emerge.

WP4 has been active in dissemination: in particular, we have used the model-based testing tool TorX and Uppaal TRON in our MSc courses on Testing Techniques. This allows students to get acquainted with state-of-the-art research in model-based and quantitative testing theories.

Finally, we note that, as reported in D4.1, WP4 developed off-line and on-line quantitative testing also during year 1: in the first year, WP4 developed a quantitative extension of ioco-theory. D4.1 reports on the extension of ioco-theory with measure inaccuracies, together with off- and online test case generation algorithms for these extensions.

Task 4.2 Approximate Testing. This task has yet to officially start, but as is evident from the previous paragraph progress has already been made.

Overall this, WP is on track.

3.5 ***WP5: Case Studies, Tools, Dissemination and Exploitation***

Work package WP5 is concerned with case studies (T5.1), tools (T5.2), and dissemination and exploitation (T5.3).

Case Studies

In T5.1 (case studies), Quasimodo has been working on a series of case studies, provided by the industrial partners in Quasimodo and by two external collaborators. In these case studies various modeling formalisms are used for (quantitative) analysis, code generation, and test generation. The case studies are used to demonstrate and challenge the usefulness of the developed methods and tools, and to assess their strengths and weaknesses. The case studies that were selected are close in spirit to products that are under development by the industrial partners.

Four case studies were initially identified and provided by the Quasimodo industrial partners:

1. the Accumulator Charge Controller (ACC), provided by HYDAC;
2. the Self-Balancing Scooter, provided by CHESS;
3. a Wireless Sensor Network (WSN), provided by CHESS;
4. Attitude and orbit control software for satellites Hershel and Planck, provided by TERMA.

In addition, two case studies were selected from external industrial collaborators in other projects:

5. adaptive scheduling of data paths , provided by OCE;
6. a Rapid Input-Output (RIO) packet switch, provided by ASML.

In the first year the original four case studies were described, and challenges and research questions were identified; see Deliverable D5.2 "Preliminary description of case studies". Two of the case studies, viz. the Accumulator Charge Controller (HYDAC) and the Wireless Sensor Network (CHESS) were elaborated during the first year. Deliverable D5.5 "Case studies: Models" describes the approaches to modeling and analyses of these cases and the first results.

During the second year Quasimodo has mainly worked on the cases Wireless Sensor Network (CHESS), attitude and orbit control software (TERMA), Rapid Input-Output packet switch (ASML), and adaptive scheduling of data paths (OCE). The Deliverable D5.7 “Case Studies: Validation” describes the main results. Papers were published or submitted about the Accumulator Charge Controller (HYDAC), Wireless Sensor Network (CHESS; two papers), adaptive scheduling of data paths (OCE), and the Rapid Input-Output packet switch (ASML). Here, we briefly report on the status of all six case studies.

1. Accumulator Charge Controller (HYDAC)

For the ACC several Simulink and Stateflow models (Matlab), Timed-Gamed Automata models (UPPAAL-TIGA), and PHAVER-models were developed for simulation, synthesis, and verification, respectively. We were able to enforce safety properties (e.g., pressure is always within safe margins) in an efficient way such that the ACC consumes almost the least possible amount of energy. The Quasimodo-synthesized controllers improve the performance of the original HYDAC controllers (33-45% for various versions). This case study shows that the Quasimodo method and tools have reached a level of maturity that makes it possible to work on, and be successful with relevant industrial control problems.

During 2009, Quasimodo worked on validating and refining the models, obtaining more accurate results, and publishing and presenting the experiences and results (on the conference on Hybrid Systems: Computation and Control 2009).

The ACC is part of a product under development by HYDAC. HYDAC plans to implement the results of this case study in a concrete product at the end of the year. On the basic of these experiences HYDAC intends to use model-driven software engineering for some upcoming projects.

2. Self-Balancing Scooter (CHESS)

The self-balancing scooter provided by CHESS is a meta-stable system with interesting control challenges in mechanics, electronics, and software. From the CHESS point of view the most interesting part of the scooter is the high-level control: when to switch on the scooter, when to start riding, when to stop, and how to stop. This part, however, resembles more a traditional, qualitative design problem and not so much a quantitative analysis and verification problem. Initial models of the high-level control have been built and analyzed in UPPAAL for a couple of qualitative properties. The lack of quantitative properties, however, made that progress in this case study is limited.

3. Wireless Sensor Network (CHESS)

Within the Wireless Sensor Network the Medium Access Control layer protocol (gMAC) was analyzed by means of model-checking with UPPAAL. It was shown that with the original clock synchronization protocol designed by CHESS a static, fully synchronized WSN network may eventually become unsynchronized when using the median synchronization algorithm. In addition, a full, parametric analysis of the protocol for the special case of cliques (networks with full connectivity) was performed, from which constraints on the parameters were derived that are necessary and sufficient for correctness. These results were checked with the proof assistant Isabelle. This case study shows that clock synchronization is a very challenging for quantitative formal methods. Extensions are desirable with respect to more powerful abstractions, probabilistic properties, e.g., for radio communication, etc. which we plan to tackle in the third year.

A demonstrator was developed to show the loss-of-synchronization issue with real nodes. This demonstrator was shown during the Quasimodo Workshop at the FMweek in Eindhoven (NL), November 6, 2009.

The MoDeST models of the gMAC protocol, developed during the first year, were used to analyse, using discrete event simulation, probabilities of collision rates, the effectiveness of the collision detection mechanism, and how this affects performance and energy consumption also taking into account the number of active slots. This work was not continued during the second year.

During the second year, an activity on model-based testing (MBT) for WSN was started. The goal is to perform a protocol conformance test of the gMAC protocol entity using MBT, i.e., a model of the required behaviour of gMAC is built and tests are automatically generated from this model and then executed on the gMAC protocol stack of a WSN node using the Quasimodo MBT tools UPPAAL-TRON, ToRXakis, and JTorX. A first model and a test environment was developed, and automatic testing with ToRXakis was performed on testing of the gMAC software in a simulated host environment in simulated time. Future activities will extend this set-up to testing on the target hardware and testing in real-time.

4. Attitude and orbit control software (TERMA)

This case study considers the ACC ASW software, a system for satellite attitude and orbit control used within the Herschel and Planck satellite systems. During year 2, work was performed on schedulability analysis, which Terma has so far performed using classical worst-case response-time analysis. The goal has been to apply the Quasimodo model-based approach allowing schedulability analysis to be carried out as a model-checking problem, and to compare this with the classical approach, which may be over-pessimistic.

A new approach in which tasks, resources, and scheduling principles are modeled as timed (stop-watch) automata made it possible to do this more precise analysis leading to the conclusion that all configurations are schedulable, which was not possible using the classical approach. Moreover, the method turned out to be very efficient with possible deadlock violations visualized by Gantt charts. This case study shows that the UPPAAL model checker can be applied for schedulability analysis

Plans for year 3 include further validation of the Timed Automata models, scaling-up by distributed model-checking with UPPAAL, and the take-up of the method within TERMA.

5. Adaptive scheduling of data paths (OCE)

The OCE case study, which was added to our selection of cases at the end of the first year, comes from the Octopus project in which, among others, OCE, ESI/RU, and ESI participate. It concerns the data path of a printer/copier encompassing the complete path of the image data (the bit stream) from source (e.g., the network) to target (the imaging unit). Due to its complexity, it provides an excellent challenge for the new analysis and synthesis techniques that are being developed within Quasimodo.

UPPAAL was used to make detailed models of the data path of a new machine that is currently under development at OCE. We focused on a Timed Automata model reflecting uncertainty, which is due to the fact that the arrival time of new printer jobs is typically unknown. Arrival times are the most significant source of uncertainty in this application domain. As far as we know, this is the first application of Timed Automata technology to an industrial scheduling problem with uncertainty in job arrivals. UPPAAL-TIGA was applied to automatically compute optimal adaptive scheduling strategies.

6. Rapid Input-Output packet switch (ASML)

Another case study that was added to the set of case studies, is a Rapid Input-Output packet switch provided by ASML in the context of the ESI project WINGS. The project concerns a multi-processor platform where processors are interconnected by Rapid Input-

Output (RIO) packet switches. The main challenge is how to map a specific application on the platform such that periodic timing constraints (all packets are delivered in time) are met. The first model in the language POOSL developed in WINGS was used for functional and performance analysis with simulation based techniques leading to approximate results for worst-case and average case latencies. However, because of the criticality also formal verification of worst-case latencies as well as functional logics was desired by ASML. For this, we transformed the model to a network of Timed Automata in order to verify worst-case latencies and functional logics with UPPAAL. We are currently exploring if this approach is also applicable to best-case and average-case latencies, and we are comparing the results with those obtained via POOSL. During the last year, we intend to work on scalability of the approach, improving abstractions in the UPPAAL model, and comparing UPPAAL and POOSL models by means of model-based testing.

Altogether, WP5 has made good progress in quantitative modeling, analysis, verification, and synthesis in five (out of six) case studies. The most significant results of T5.1 are:

- In the Accumulator Charge Controller (HYDAC) a controller was synthesized that outperforms the original HYDAC controller;
- An important clock synchronization error was detected in the WSN gMAC protocol (CHESS) using model-checking;
- Schedulability of tasks for the ACC ASW software (TERMA) was shown, which was not possible with classical methods;
- Results for worst-case latencies of the RIO packet switch (ASML) obtained via simulation were confirmed with model-checking.

Tools

For tools (T5.2), the ambition is to develop tools, tool-plug-ins and tool-chain integration between tools developed by partners and external and industrially applied tools. Last year's deliverable **D5.4: "Plan for integration of tool components"** formulated the plan for development of tools as:

- A number of tools aiming at probabilistic and stochastic analysis for Markovian models of probabilistic extensions of timed automata, and
- A collection of branches of the tool UPPAAL for verification, scheduling, controller synthesis and testing for timed automata and timed game models.

During the second year eight new tools have been put forward the Quasimodo partners. Three of the tools aim at support for analysis of (priced) probabilistic timed automata using different techniques (discrete time, zone-based analysis and use of general polyhedra). Several of the probabilistic tools allow exchange of models between themselves and with the external tool PRISM.

Four tools for validation and analysis of real-time systems have been put forward during year 2, providing support for worst-case-execution-time (WCET) analysis of C-programs executing on ARM9 processors, schedulability analysis of safety-critical Java programs as well as off-line and on-line testing. Three of these tools are using the UPPAAL verification engine as back-end, which has itself been extended with a number of new features (including Live Sequence Charts).

For the real-time tools based on UPPAAL, interaction with external UML-based tools as well as Matlab/Simulink has been continued. In particular, systematic transfer of strategies synthesized by UPPAAL-Tiga as S-functions of Simulink are planned to be demonstrated at the upcoming CPSWeek, April, Stockholm. Also, initial success in linking UPPAAL-Tron and Simuling to obtain (co-)simulations of timed automata models in the context of more complex continuous behavioral components has been made.

The significant development of tools and tool components made during the reporting period are all summarized in Deliverable D5.8. D5.8 also gives a short status of tool integration providing a preliminary to the upcoming Deliverable D5.9. Besides integrating with UML and Simulink we will also investigate the possibility of integrating the Quasimodo plug-ins with Scicos. We are confident that Quasimodo will be able to deliver a useful tool environment for model-based analysis, implementation, and testing of quantitative system properties.

Dissemination and Exploitation

The activities and plans for dissemination and exploitation (T5.3) are described in Deliverable D5.6 "Dissemination and Exploitation”. Different activities have, and will be organized in this respect. In addition to much activity in maintaining the website, organizing conferences, symposia, (summer-) schools, workshops, and in giving invited talks, academic and industrial courses, related projects and networks, the following items are particularly mentioned:

1. A Quasimodo workshop was organized during the FM week, November 6, 2009, in Eindhoven (NL), with participants from academia, industry, and Quasimodo itself. A keynote was given by Prof. Rance Cleaveland (University of Maryland), and the workshop was concluded with an industrial panel with members from Reactive Systems, Philips, OCE, and ESI/ASML.
2. A final Quasimodo symposium is planned for the autumn of 2010.
3. The first Quasimodo demonstrator was shown during the Quasimodo Workshop on November 5, 2009. The demonstrator is based on the CHESS Wireless Sensor Network (WSN) case; see above.
4. Work has started on a joint effort of writing a “Handbook on Quantitative Model-Driven Development for Embedded Systems” to be published at the end of the project.
5. HYDAC plans to implement the results of the case study in a concrete product at the end of the year. Moreover, on the basic of the experiences in Quasimodo, HYDAC intends to use model-driven software engineering for some upcoming projects.
6. The results obtained in the WSN case study are used in the current WSN design and development of CHESS. In addition, CHESS intends to set-up a conformance testing activity for WSN nodes using the Quasimodo approach.
7. Transfer of Quasimodo model-based testing methods and tools into other CHESS business lines was initiated.

8. Based on the results of the schedulability analysis for attitude and orbit control software, plans for take-up of this method within TERMA are initiated.

3.6 *Use of Resources*

The following table shows the planned and real (actual) staff (person month) usage per work package per partner for ***staff being paid*** from the Quasimodo budget. P=planned, R=real person months. Remark that much more effort is put into the project than reflected in this table.

Year 2

	WP0		WP1		WP2		WP3		WP4		WP5		Total	
Partner	P	R	P	R	P	R	P	R	P	R	P	R	P	R
AAU	6	4	0	0	3	2	2	2	4	2	2	2	17	12
ESI	0	0	8	6	5	4	2	2	4	2	9	10	28	24
CNRS	0	0	0	0	3	8	6	8	0	0	2	1	11	17
RWTH	0	0	2	2	6	5	0	0	0	0	3	3	11	10
SU	0	0	2	4	5	5	0	0	0	0	4	4	11	13
CFV	0	0	0	0	2	0	9	11	0	0	2	0	13	11
Terma	0	0	0	0	0	0	0	0	3	1	0	6	3	7
Chess	0	0	2	2	0	0	0	0	0	0	0	1	2	3
Hydac	0	0	1	0	0	0	0	0	2	0	0	1	3	1
Total	6	4	15	14	24	24	19	23	13	5	22	28	99	98
Total Y1	6	5	12	5	20	15	20	9	3	9	28	25	89	68
Total Y3	6	0	6	0	10	0	6	0	13	0	40	0	81	0
Total	18	9	33	19	54	39	45	32	29	14	90	53	269	166

Total y1+y2

	WP0		WP1		WP2		WP3		WP4		WP5		Total		Remain
Partner	P	R	P	R	P	R	P	R	P	R	P	R	P	R	
AAU	18	9	2	2	6	4	6	6	6	2	14	4	52	27	25
ESI	0	0	16	6	11	4	6	2	14	9	25	17	72	38	34
CNRS	0	0	0	0	8	11	13	12	0	0	7	2	28	25	3
RWTH	0	0	4	3	14	11	0	1	0	2	10	4	28	21	7
SU	0	0	5	5	11	9	0	0	4	0	11	7	31	21	10
CFV	0	0	0	0	4	0	20	11	0	0	4	0	28	11	17
Terma	0	0	2	0	0	0	0	0	3	1	5	7	10	8	2
Chess	0	0	2	2	0	0	0	0	0	0	8	9	10	11	-1
Hydac	0	0	2	1	0	0	0	0	2	0	6	3	10	4	6
Total	18	9	33	19	54	39	45	32	29	14	90	53	269	166	103
Total Yr	18	9	33	19	54	39	45	32	29	14	90	53	269	166	
Remain	9		14		15		13		15		37		103		

A total of 99 person months has been planned for the second year, and 98 was delivered, hence the effort is in balance with the expected. Note however, that we have yet to catch up on the less-than-planned effort (caused difficulty of hiring in hiring staff from the beginning of the project) invested in Y1. Given the staff now hired we see no problems in delivering the promised effort.

All partners are active in the project, and are delivering within reasonable tolerances the planned effort.

Regarding management, we had planned to spend 6 pm's but have reported 4 in actual usage. However, the actual number is 1.5 person months higher. But the budget allocated for technical coordination at AAU has already been spent. The discrepancy is caused by a wrong estimation of the costs of senior scientific personnel when the original budget was planned. Qualified and responsive coordination will of course still take place in the coordinators and assisting coordinators own time. The time of the administrative coordinator is unaffected.

We remark that Chess has already delivered more than the planned effort. They delivered 11 person months where 10 was planned. Similarly, they have exhausted their personnel budget. Nevertheless, Chess remains active in the project at their own expense, and has promised to continue supporting its case studies.

We also remark that CNRS only has 3.5 person month left. This is however, aligned with the work plan that states that they are somewhat less involved than the previous years. We expect that the remaining time is sufficient for CNRS to complete its tasks.

Somewhat less effort than planned was put into WP4; however this is outbalanced by the extra effort invested in Y1. Oppositely, a little more effort was put into WP5 than planned, but this offsets the less effort used in Y1. We take this an expression of an increased interest in applying the developed technique in the case studies.

In total 98 person months (equalling nearly 8 person years) has been delivered by Quasimodo. The deliverables and milestones have all been met, and in addition the work has resulted in more than 80 refereed scientific (conference or journal) publications.
The project meetings have had a very high attendance rate (30-50 researchers). Thus the support by the EC has produced a lot of good quality research on quantitative system properties, especially compared to the budget.

3.7 *Summary of Milestones*

The overall second year objective is to develop algorithms for quantitative analysis, synthesis and testing, implement these in tool components, and to perform a first application of these to case studies. The objectives are detailed through the description of milestones M4, and M5.

A very large set of algorithms and data-structures for representation and manipulation of state spaces for quantitative models have been designed and implemented.

We have developed symbolic techniques for model-checking and probabilistic reachability analysis of discrete and continuous time Markov chains and Markov decision processes, and parametric model checking of DTMCs. Discrete event simulation based techniques have been developed as well. To support reachability analysis of timed automata, probabilistic timed automata, as well as probabilistic priced timed automata, we have developed significant extensions of the state-of-the art zone-based techniques to manipulate zones and zone federations with prices and probabilities (one clock priced zones are an interesting case).

To reduce the state-explosion problem we have developed quantitative abstraction/refinement techniques to support compositional analysis. Results include definition of quantitative refinement relations, CEGAR for probabilistic systems, abstract interpretation techniques for concurrent probabilistic programs, and refinement and consistency checking for timed i/o automata.

To support synthesis, we have developed novel efficient symbolic algorithms for controller synthesis based on timed game automata, robustness checking, and test generation taking into account partial observability and bounded resources. Finally, we have designed efficient techniques for symbolic state-set representation and manipulation for online testing and monitoring.

Most of these techniques are implemented in prototypes enabling experimental validation resulting in a large set of (nearly 20) implemented unique quality tool-components. They are described in deliverable 5.8, and are available via the Quasimdo web-page. Several of these have already been applied to Quasimodo case studies. CHESS case: MoTor, Uppaal, TorXakis. Hydac case: Uppaal-Tiga with partial observability. Terma case: Uppaal with timed automata templates for scheduling, Oce: Uppaal, ASML: Uppaal

The first integrations of the Uppaal-suite and the industrial tool chain Simulink have been made. In the context of the Hydac case we have imported Tiga-synthesized strategies into Simulink. We are working on a general systematic method for doing this. Further, we have a first functioning prototype of Uppaal-TRON connected to Simulink for co-simulation and refinement testing. Finally, a large subset of UML state-chart models made in eg., the Rational Systems Developer case tool can be converted into Uppaal-timed automata. This is applied in an external industrial case study.

> *Milestone M4 is to be verified though the availability of (M4.1) implemented data-structures for symbolic representation and manipulation of state spaces for quantitative models, and (M4.2) verified algorithms and experimental implementation for quantitative analysis, abstraction/refinement, controller synthesis and testing.*

> *Milestone M5 is to be verified though the availability of (M5.1) first implementation of tool components, (M5.2) first tool trial: integration of selected tool components with industrial tool chains and application to case studies.*

Considering the above mention results, we are confident that we have met milestones M4 and M5. In addition, we remark that partners are very willing to contribute to the industrial handbook.

Some additional effort has to be devoted to getting a fully working prototype of the P2J compiler, and to make the zone based algorithm for robustness checking complete for all timed automata. We would also like to see further involvement from the end-user-panel.

4. Deliverables and milestones tables

Deliverables (excluding the periodic and final reports)

Year 2 deliverables are highlighted using a bold-faced font.

TABLE 1. DELIVERABLES[5]

Del. no.	Deliverable name	WP no.	Lead beneficiary	Nature	Dissemination level	Delivery date from Annex I (proj month)	Delivered Yes/No	Actual / Forecast delivery date	Comments
D1.1	Modeling quantitative system aspects	1	ESI/RU	R	PU	12	Y	12	
D1.2a	Design Notations	1	SU	R	PU	12	Y	12	1)
D1.2b	Design Notations	**1**	**SU**	**R**	**PU**	**12**	**Y**	**24**	
D1.3	Model process improvement	**1**	**ESI/RU**	**R**	**PU**	**24**	**Y**	**24**	
D1.4	Modeling tools	1	ESI/ESI	R+P	PU	36			
D2.1	Model checking real-time probabilistic models	2	AAU	R+P	PU	12	Y	12	P)
D2.2	Symbolic data structures and analysis of models with multiple quantitative aspects	**2**	**CNRS**	**R+P**	**PU**	**18**	**Y**	**24**	**2) P)**
D2.3	Abstraction	**2**	**RWTH**	**R**	**PU**	**24**	**Y**	**24**	
D2.4	Abstraction-refinement	2	ESI/RU	R+P	PU	30			
D2.5	Approximate Analysis	2	SU	R+P	PU	36			
D3.1	Transfer of correctness properties from model to implementation	3	ULB	R	PU	12	Y	12	

[5] For Security Projects the template for the deliverables list in Annex A1 has to be used.

D3.2	Tool for implementability checking	**3**	**ULB**	**P**	**PU**	**18**	**Y**	**24**	**2) P)**
D3.3	Model checking of controllability properties	3	ULB	R+P	PU	12	Y	12	4)
D3.4	Synthesizing controllers with bounded resources	**3**	**CNRS**	**R+P**	**PU**	**24**	**Y**	**24**	**P)**
D3.5	Extended timed automata for scheduling	**3**	**CNRS**	**R+P**	**PU**	**18**	**Y**	**24**	**2) P)**
D3.6	Code generation from untimed specifications	**3**	**ESI/TW**	**R+P**	**PU**	**24**	**Y**	**24**	**P)**
D3.7	Code generation from timed specifications	3	AAU	R+P	PU	36			
D4.1	Quantitative Testing Theory	4	ESI/TW	R	PU	12	Y	12	
D4.2	Algorithms for off- and online quantitative testing	**4**	**AAU**	**R+P**	**PU**	**24**	**Y**	**24**	**P)**
D4.3	Test selection and coverage	4	AAU	R+P	PU	30			
D4.4	Approximate testing	4	ESI/TW	R	PU	30			
D4.5	Final Algorithms and evaluation	4	ESI/TW	R	PU	36			
D4.6	Online hybrid/stochastic testing	4	ESI/TW	R+P	PU	30			
D5.1	Quasimodo Website	0	AAU	O	PU/CO	1	Y	1	
D5.2	Preliminary description of case	5	SU	R	PU/CO	6	Y	12	2)
D5.3	Dissemination and use plan	5	ESI	R	PU	6	Y	12	2)
D5.4	Plan for integration of tool components	5	AAU	R	PU	12	Y	12	
D5.5	Case Studies: models	5	RWTH	R	PU	12	Y	12	
D5.6	Dissemination and Exploitation	**5**	**ESI/ESI**	**R+D**	**PU**	**24**	**Y**	**24**	**D)**
D5.7	Case studies: validation	**5**	**SU**	**R**	**PU/CO**	**24**	**Y**	**24**	
D5.8	Tool components	**5**	**AAU**	**R+P**	**PU/CO**	**24**	**Y**	**24**	**P)**
D5.9	Tool components and tool integration	5	AAU	R+P	PU	30			
D5.10	Final report on case studies and	5	RWTH+SU	R+P	PU/CO	36			

	tool integration								
D5.11	Final report on Dissemination and Exploitation	5	ESI/ESI	R	PU	36			
D5.12a	Industrial Handbook vers. 1	**5**	**ESI/ESI**	**R**	**PU**	**24**	**Y**	**24**	
D5.12b	Industrial Handbook final	5	ESI/ESI	R+D	PU	36			

1) Concerning D2.1 on design notations which we find only partially completed due to the uncertainty of the partner replacement, we propose to write an updated version by month 24. This will be reflected in our proposal for an updated Description of Work.
2) These deliverables were submitted to the commission by the end of the reporting period (M24) in agreement with the project officer

D) Demonstrator concerns the de-synchronization of the sensor network as described in the report.

P) A prototype tool component is delivered with this deliverable as described in the following table

Deliverable	Description	Availability by
D2.1	A model checker for probabilistic timed automata. The component named UPPAAL-Prob is a branch of the UPPAAL model-checker extended with probabilities.	Contacting the developers (Kim G. Larsen kgl@cs.aau.dk). It is in working condition but is still being matured before its public release expected by June 2009.
D3.3	Model-checking of implementability of timed automata models (robustness analysis) and controller synthesis.	These functionalities are available in the latest developer snapshot of UPPAAL (version 4.1) and UPPAAL-Tiga available at www.uppaal.com. The improved algorithm described in D3.1 section 3 will be available in the next developer snapshot (version 4.1.1) forseen in March 2009.
D2.2	Fortuna is a model checker for priced probabilistic timed automata able to compute the maximal probability by which a state can be reached under a certain cost-bound (and time-bound). Further, we extensively use DBMs (difference bound matrix) to represent and manipulate clock zones.	A first release (v0.2) of Fortuna is available at http://www.cs.ru.nl/J.Berendsen/fortuna/ The Uppaal DBM library is downloadable from the Uppaal website www.uppaal.com
D3.2	Model checking of implementability (rubustness) of timed games using a zone based algorithm.	An experimental version is implemented in Uppaal Tiga and can be found at http://www.cd.aau.dk/~adavid/uppaal-dev.zip
D3.4	Controller synthesis under partial observability and bounded resources.	An extended uppaal Uppaal-Tiga supporting partial observability, büchi acceptance conditions, and synthesis of non-zeno strategies is implemented, and available in the latest developer version of Uppaal-TiGa. (http://www.cs.aau.dk/~adavid/tiga/
D3.5	Extended timed automata schedulabiilty analysis using stop watches.	Timed Automata Templates are available by contacting the developers (Jacob Illum Rasmusssen illum@cs.aau.dk). Stop watches are implemented in Uppaal.

D3.6	Code Generation from high-level formal languages (promela2java)	The current (incomplete) version is available at http://ewi.utwente.nl/~ruys/p2j
D4.2	Prototype implementation of test generation algorithms for on-line and offline real-time testing.	Online real-time testing is available in the tool Uppaal-TRON http://www.cs.aau.dk/~marius/tron/ Offline test generation is available either through Uppaal or Uppaal-TIGA (http://www.cs.aau.dk/~adavid/tiga/)
D5.8	A large set of tool components supporting formal analysis and synthesis of probabilistic, timed, priced, timed probabilistic systems have been developed.	The Quasimodo Website maintains a list of available (currently nearly 20) Quasimodo tool compontents http://www.quasimodo.aau.dk/tools.html

Milestones

TABLE 2. MILESTONES

Milestone no.	Milestone name	Work package no	Lead beneficiary	Delivery date from Annex I	Achieved Yes/No	Actual / Forecast achievement date	Comments
M1	Project Start	All	AAU	M1	Yes	15+16 Jan'08	Kickoff meeting
M2	Definition Phase	All	ESI	M6	Yes	M8	
M3	Modelling Formalisms	All	SU	M12	Yes	M12	
M4	**Algorithm Design**	All	CNRS	M18	**Yes**	**M18**	
M5	**Tool Components**	All	RWTH	M24	**Yes**	**M24**	
M6	Tool Integration and case studies	All	ESI	M30			
M7	Project Closure	All	AAU	M36			

1. Milestone M1 is to be verified through a kick-off meeting. The Quasimodo kick-off meeting was held 15+16 january 2008 at Aalborg University, Denmark.
2. Milestone M2 is to be verified through availability of 1) a precise descriptions of case studies, 2) a plan for tool components and their integration in industrial tool chain.
3. Milestone M3 is to be verified through the availability of 1) a semantic foundation of quantitative models in terms of labelled transition systems including semantics of composition of models, refinements between models, 2) a formal definition of conformance and robustness between quantitative models and implementations, 3) first models of case studies, and 4) quantitative extensions identified by the needs of case studies.
4. Milestone M4 is to be verified though the availability of 1) implemented data-structures for symbolic representation and manipulation of state spaces for quantitative models, and 2) verified algorithms and experimental implementation for quantitative analysis, abstraction/refinement, controller synthesis and testing.
5. Milestone M5 is to be verified though the availability of 1) first implementation of tool components, 2) first tool trial: integration of selected tool components with industrial tool chains and application to case studies.
6. Milestone M6 is to be verified though the availability of: 1) final version of tool components, Well documented APIs and XML exchange formats for all tool components available, 2) Case studies completed including modeling, analysis, testing and code generation using developed tool components integrated with industrial tool chains.
7. Milestone M7 is to be verified though the availability of: 1) Final reports evaluating case studies, tool components and their integration and applicability, and 2) Dissemination of results of the project via tool demonstrators and the ”Quasimodo Handbook”.

We believe that we have reached these milestones M1-M5 as discussed in Section 3.7.

5. Project management

5.1 *Consortium management tasks and achievements;*

The day-to-day management of Quasimodo is handled by the management team, which consists of the Coordinator, Co-coordinator and Administrative Project Manager. The agreed procedures have been followed thus securing efficient day-to-day support of the consortium members.

During the second project period, the main management tasks have included:

- Organization of three project meetings, Bruxelles February 17-19, 2009; Nijmegen June 11-12, 2009; and Paris 24-26 February.
- Organization and conduction of General Assemblies in conjunction with the project meetings.
- Follow-up on project review.
- Completion of amendment, including producing an update Description of Work.
- Organization of Quasimodo dissemination day at FM-Week in Eindhoven, November 6 2009.
- Adoption of two additional case studies, as agreed in the General Assembly.
- The research in the work packages have been coordinated primarily via mail and telephone, in addition to the project working meetings; the communication within and between work packages works well.
- Continuous update and development of the Quasimodo project website.
- Marielle Stoelinga (ESI/Twente University) has taken over the WP4 leader task from Arne Skou (AAU), whom has been re-allocated to other AAU projects.
- Ensuring efficient communication within the consortium.
- Distributing financing to all partners.
- Updating contact information
- Project reporting, monitoring and review.
- AAU was elected for EC financial audit which took place December 2009. The preliminary information that we have received indicates that only minor remarks will be made.
- Quasimodo welcomes its fourth project officer.
- Invitation of SciLab to the project meeting in Paris.

Moreover, the management team endeavours to assist the consortium on day-to-day management issues and to communicate information and guidelines from the EC.

Finally, it is the impression of the management team that the consortium performs well, and the individual WPs interacts satisfactorily and in general the progress is according to schedule.

The conclusion from the Y1 review meeting was that the project has made good progress, and made very impressive scientific contributions. The reviewers made some recommendations to the consortium:

Recommendation 1: We would like to suggest to the Consortium that they would be more effective in integrating the project results if they focus on the process, i.e. what is needed, and also by trying to define an interchange format, for example based on the format that already exists for Uppaal, to minimise the number of required transformations.

Recommendation 2: From the industry perspective, we would like you to consider how to involve the architectural modelling perspective, in addition to the behavioural aspects.

Recommendation 3: It would be good to increase collaboration with the End User Panel.

Recommendation 4: While the presentations during the review meeting were excellent, future deliverables would benefit from more effort to make them more readable and self-contained.

Details:
Addition to recommendation 1: In the situation that resulted from the withdrawal of Inchron and the related delay of the delivery on design notations (D1.2), the focus of D1.2 should now be on addressing the feasibility of embedding results into common modelling notations. The proposed use of an interchange format may not only serve this purpose but may also serve as integrating glue between the partners and their respective approaches. Such efforts will likely increase the access to project results for researchers and engineers outside the core expertise of the Quasimodo project and thus improve the impact in the embedded systems community.

Addition to recommendation 4: For future deliverables, the technical content should be self-contained in the document. Abbreviations and domain-specific terms should be explained to the extent practically possible. Progress reports should refer to partner names in addition to the name of the individuals involved in visits and project actvities.

R1. We are working on several fronts to support this recommendation. First, we aim at embedding our notations in UML such that a tool may translate such extended UML models into our internal tool format. Such an extension and translator has already been built for timed automata. Further, we will study the feasibility of linking our notations to Simulink Stateflow.

For purely probabilistic models, the file format in the Prism tool functions as an de-facto exchange format. Timed models, especially all Uppaal variants (for timed automata, timed games, priced timed automata, probabilistic timed automata) already share an XML-based exchange format. Uppaal now also supports generation of concrete time simulation traces / counter example traces, and an XML export feature for these is under development.

Further, we are considering developing translator for (a data-less) subset of the Uppaal-Pro format to bridge the gap between the timed and purely probabilistic tools.

R2. We believe our work on Arcade and the Architectural Description Language (AADL) as described in deliverable 1.2 address this recommendation.

R3. We have updated the end-users-panel and invited them to the Quasimodo dissemination event in the FM Week held in Eindhoven. Not as many particitates as we would have liked. We will invite them again for the final Quasimodo symposium planned towards the end of the year. We also foresee more involvement in Y3 by asking for feedback for the Industrial Handbook.

R4. We made an effort in making the Y2 deliverables more explanatory and self-contained by reminding the authors of the deliverables of this recommendation.

5.2 *Problems and solutions*

The process of partner substitution, and update of DOW and reallocation of budget, unfortunately made slow progress, both due to delays in writing it and due to substitution of project officer(s). One issue that took time was a clarification of how/how not subcontracting could be used to involve external experts on tool integration with Simulink. As time passed we made progress within the consortium, and the submitted DOW reflects that we do not need subcontracting. The amendment was ready for submission after summer holidays when Quasimodo's project officer changed job. A request for a pre-check was sent to the new project officer in November. Following appointment of another new project officer, we formally submitted the amendment in December and approval is expected primo February 2010.

Another issue occurred when we invited the end-user-panel to the Quasimodo dissemination event. It turned out that several had changed position in the company, and a few were no longer affiliated with the project. Hence, we sought suitable updates. The updated panel is listed in the new DOW.

5.3 *Changes to the consortium*

Since the beginning of the project all parties have changed their administrative contact person. In relation to the amendment just completed, the contact information has been updated in the Grant Preparation Forms.

Some minor changes: Francois Laroussine (CNRS) was replaced by Nicolas Markey from CNRS as scientific and technical contact person. CNRS decided to recruit a post-doc as an extra person is needed because of the work in the project is more complicated than anticipated. The project officer, Berta Ferrer Llosa was informed and approved the change. Also ULB recruited a post-doc to work on the project.

5.4 *Project meetings*

In this Y2 reporting period two regular Quasimodo workshops have been arranged, in addition to a Quasimodo dissemination day.

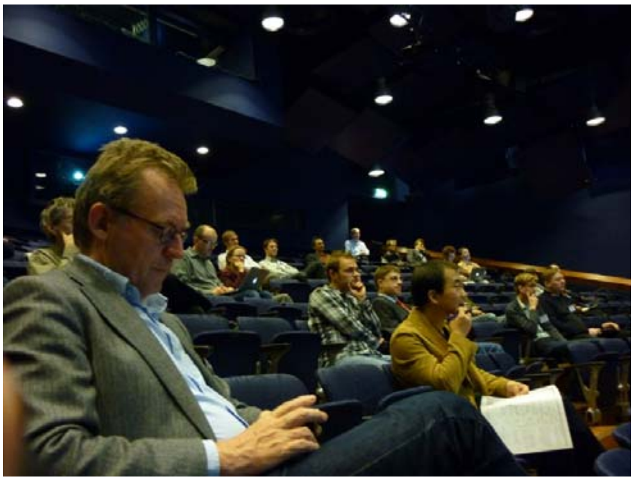
Meeting 3 was held in Brussels 17+18 of February 2009 and organized by ULB. The workshop featured 17 technical/scientific presentations related to the work packages. 46 international researchers associated with the partners were present showing an enormous interest in the Quasimodo project. Also, a management board meeting took place. Minutes and slides from the meeting and general assembly are available at the internal Quasimodo website.

Meeting 4 was held in Nijmegen, NL, on June 11-12, 2009 organized by ESI/Radboud University. The workshop featured 11 scientific presentations related to the work packages. In addition, half a day was set aside to focusing on discussing the case studies and presenting progress on these. Nearly 35 participants were present. Also, a management board meeting took place. Minutes and slides from the meeting and general assembly are available at the internal Quasimodo website.

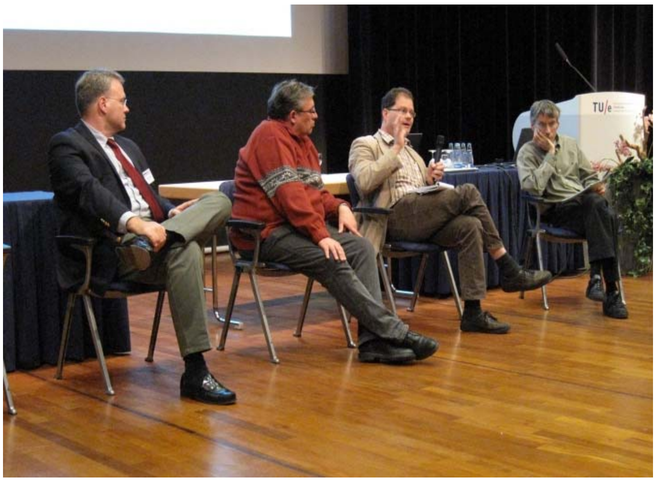
Meeting 5 will be in Paris, 24-26 of February 2010.

Quasimodo Dissemination Event held in Eindhoven, November 6 2009 in conjunction with the "Formal Methods Week". The purpose of this workshop arranged by Quasimodo was to disseminate Quasimodo work and research results, and to bring researchers, practitioners and industry together to discuss the issues, challenges and latest solutions for the design of complex embedded systems with quantitative constraints. The workshop was especially targeted towards practitioners in the field but was open to everybody interested. The *end-user-panel* was invited.

The program featured a keynote talk by Professor Rance Cleaveland, University of Maryland, on bringing formal methods into practice. He gave an excellent talk that provided a lot of valuable and provoking advice strongly supported by his experiences from commercializing formal methods (model based testing). Rance is a member of the end-users-panel.



Audience in the big distinguished lecture hall.



Panel Discussion

Further, the program contained a short introduction to the Quasimodo project, two sessions with 7 Quasimodo case-study presentations demonstrating on the research and results on case-studies. One of these demonstrated the discovered clock de-synchronization problem in a sensor network by means of a physical setup with 3 sensor nodes. The Workshop concluded with a short panel discussion on the topic *"What are the* *industrial needs for quantitative methods and tools? -What is lacking ? -What challenges to you pose to the scientific community?"* The panelists were

- Lou Somers, Océ
- Jeroen Voeten, ESI
- Rance Cleaveland, University of Maryland and Fraunhofer Institute
- Leszek Holenderski, Philips

The workshop attracted between 10 to 25 external participants (varied during the day). Although we had hoped for more, we find the participation acceptable. Originally we decided to collocate the event with FM-Week, because a number of conferences and industry related events would gather there and thus bring many researchers and practitioner together that potentially would be interested in Quasimodo.

However, FM-Week grew to a mega-event, and the Quasimodo event seemed to drown somewhat in the crowd. It is not unusual that small workshops suffer from a low attendance at these mega events as many participants tend to go to the sessions of the conferences instead.

Quasimodo had a session in FMCO which this year was realized as a concertation meeting of European funded projects. Further, 3 Quasimodo research papers were presented in the technical programmes. In addition, a Quasmodo key personnel (Joost-Pieter Katoen, RWTH) gave an invited Talk at the FMWeek Soiree. All together, Quasimodo left a solid fingerprint on the FMWeek.

5.5 *Project planning and status;*

Quasimodo has submitted all required deliverables, and met its main mile stones, and work is in several areas progressing beyond the plan. We see to tasks that are concerningly behind schedule. We expect the amendment request to be approved whilst this document is being studied.

5.6 *Use of foreground and dissemination*

A detailed list of the dissemination activities appears in Deliverable 5.6 (dissemination and exploitation). We refer to this for details.

Quasimodo staff personnel are very active in disseminating the research results. In the reporting period they have been involved in organizing more than 15 local and international workshops, summer-schools, events, and courses related to Quasimodo work. Several are being organized for in 2010. As mentioned, Quasimodo had a strong presence in the FM week in Eindhoven.

In addition to numerous (unlisted) regular scientific paper presentations, more than 30 invited and keynote talks related to Quasimodo work has been given.

Quasimodo very actively collaborates with several other national (including more than 10 industrial projects) and international projects. Especially, we remark the EC projects ARTIST Design NoE, MOAN (Strep), Multiform (Strep), Genesys (Strep), Destecs (Strep), GASSICS (ESF).

The research in Quasimodo has for year 2009 (and known to appear in 2010) resulted in around 87 refereed scientific (conference or journal) publications. The accumulated bibliography (sorted per work package per year) is listed in Section 9. A browsable version is available online at the Quasimodo webpage http://www.quasimodo.aau.dk/publications.html.

6. Explanation of the use of the resources

Beneficiary 1 AAU			
Work Package	**Item description**	**Amount**	**Explanations**
WP 1, 5	Personnel costs RTD	29.081 €	Salaries for 3 researchers
WP 0	Personnel costs MAN	21.506 €	Salaries for co-coordinator and adm. project mananger
WP 0,1,5	Remaining direct costs	16.554 €	Travel, confernce fees, courier services
TOTAL DIRECT COSTS*		67.141 €	

Beneficiary 2 ESI			
Work Package	**Item description**	**Amount**	**Explanations**
WP 1,2,3,4,5	Personnel costs	111.836 €	B.R.H.M. Haverkort: 0,31 pm (person months) G.J. Tretmans: 2,16 pm J. Schmaltz: 8,37 pm J. Xing: 12,00 pm J.P.M. Voeten: 0,09 pm
	Subcontracting	0 €	
WP 1,4,5	Major cost item "X"	7.219 €	Traveling
WP 5	Major cost item "Y"	1.972 €	Hardware + software
TOTAL DIRECT COSTS*		121.027 €	

Beneficiary 3 CNRS			
Work Package	**Item description**	**Amount**	**Explanations**
2,3,5	Personnel costs RTD	74.945 €	salaries for 3 researchers and salary for 1 post-doc for 16,5 person months (10711,5€)
	Remaining direct costs	13.583 €	Travel, conference fees
TOTAL DIRECT COSTS*		88.527 €	

Beneficiary 4 RWTH			
Work Package	**Item description**	**Amount**	**Explanations**
1,2,5	Personnel costs	47.816 €	Hours of one postdoc working on Quasimodo, and hours of Prof. Katoen
	Subcontracting	0 €	
	Major cost item "X"		
	Major cost item "Y"		
	Remaining direct costs	3.656 €	Travel Costs
TOTAL DIRECT COSTS*		51.472 €	

Beneficiary 5 SU			
Work Package	**Item description**	**Amount**	**Explanations**
1, 2, 5	Personnel costs	70.838 €	Hartmanns, Zhang, Bogdoll
	Subcontracting		
1, 2, 5	Major cost item "X"	5.044 €	travel
	Major cost item "Y"		
	Remaining direct costs	0 €	
TOTAL DIRECT COSTS*		75.882 €	

Beneficiary 6 ULB			
Work Package	**Item description**	**Amount**	**Explanations**
	Personnel costs	55.759 €	Ten months of Post-doc (R. Gentilini) + 2 Months of Post-doc (A. Degorre) - WP 3 - Quantitative games with imperfect information.
	Subcontracting		
	Remaining direct costs	1.132 €	
TOTAL DIRECT COSTS*		56.891 €	

Beneficiary 7 TERMA			
Work Package	**Item description**	**Amount**	**Explanations**
WP 5	Personnel costs	63.400 €	Requirements Modelling, Model based testing
	Subcontracting		
	Major cost item "X"		
	Major cost item "Y"		
WP 5	Remaining direct costs	7.734 €	Travel, Project disemination
TOTAL DIRECT COSTS*		71.134 €	

Beneficiary 8 CHESS			
Work Package	**Item description**	**Amount**	**Explanations**
WP1 + WP5	Personnel costs	23.087 €	
	Subcontracting		
	Major cost item "X"		
	Major cost item "Y"		
WP1	Remaining direct costs	1.556 €	Travelling
TOTAL DIRECT COSTS*		24.643 €	

Beneficiary 9 HYDAC			
Work Package	**Item description**	**Amount**	**Explanations**
WP 5	Personnel costs	7.662 €	case study support
WP 5	Travel costs	841 €	Travel expenses (meetings at Nijmegen, Eindhoven and Brussel)
TOTAL DIRECT COSTS*		8.503 €	

Cost-budget follow-up

The following table shows the cost-budget follow-up for Quasimodo (the actual and percentual) spending of the total budget (not EC contribution) for Quasimodo. Most partners have a reasonable budget left do deliver their remaining effort. However, we remark that CHESS and CNRS have exceeded their personnel budget. Similarly, Terma is approaching its budget. We expect all partners to remain active in the project and support its remaining tasks.

Cost Budget Follow-up Table		total budget figures - not EC funding									
Contract no.	214755	Acronym:	Quasimodo			Date:	21-apr-10				
Participants	Type of expenditure (as defined in budget)	Budget	Actual costs (EUR)				Pct. Spent				Remaining budget (EUR)
			Year 1	Year 2	Year 3	Total	Year 1	Year 2	Year 3	Total	
		e	a1	b1	c1	d1	a1/e	b1/e	c1/e	a1+b1+c1/e	e-d1
Partner 01	Total person-month	52	15	12		27	29%	23%		52%	25
AAU	Personnel costs	237.372,33	63.022	50.587		113.609	27%	21%		48%	123.763
	Subcontracting	1.500,00	0			0	0%	0%		0%	1.500
	Other direct costs	82.947,00	6.231	16.921		23.152	8%	20%		28%	59.795
	Indirect costs	192.191,59	41.551	40.504		82.055	22%	21%		43%	110.137
	Total costs	514.010,92	110.804	108.012		218.816	22%	21%		43%	295.195
Partner 02	Total person-month	72	14	24		38	19%	33%		53%	34
ESI	Personnel costs	379.340,03	67.535	111.836		179.371	18%	29%		47%	199.969
	Subcontracting	4.500,00	0			0	0%	0%		0%	4.500
	Other direct costs	36.000,00	7.856	9.191		17.047	22%	26%		47%	18.953
	Indirect costs	249.204,02	45.234	72.616		117.850	18%	29%		47%	131.354
	Total costs	669.044,05	120.625	193.643		314.268	18%	29%		47%	354.776
Partner 03	Total person-month	28	8	16,5		25	29%	59%		88%	3,5
CNRS	Personnel costs	97.500,50	45.094	106.133		151.227	46%	109%		155%	(53.727)
	Subcontracting	78.356,00	0			0	0%	0%		0%	78.356
	Other direct costs	11.072,00	500	13.583		14.083	5%	123%		127%	(3.011)
	Indirect costs	65.143,50	27.356	71.829		99.185	42%	110%		152%	(34.042)
	Total costs	252.072,00	72.950	191.545		264.495	29%	76%		105%	(12.423)

Partner 04	Total person-month	28	11	10		21	39%	36%		75%	7
RWTH	Personnel costs	159.761,52	61.902	47.816		109.718	39%	30%		69%	50.044
	Subcontracting	1.500,00				-	0%	0%		0%	1.500
	Other direct costs	12.090,56	4.831	3.656		8.487	40%	30%		70%	3.604
	Indirect costs	103.111,24	40.039	30.883		70.922	39%	30%		69%	32.189
	Total costs	276.463,32	106.772	82.355		189.127	39%	30%		68%	87.336
Partner 05	Total person-month	31	8	13		21	26%	42%		68%	10
USAAR	Personnel costs	177.042,02	42.418	70.838		113.256	24%	40%		64%	63.786
	Subcontracting	1.500,00	0			0	0%	0%		0%	1.500
	Other direct costs	12.090,56	1.106	5.044		6.150	9%	42%		51%	5.941
	Indirect costs	113.479,54	26.114	45.529		71.643	23%	40%		63%	41.837
	Total costs	304.112,12	69.638	121.411		191.049	23%	40%		63%	113.063
Partner 06	Total person-month	28	0	11		11	0%	39%		39%	17
ULB	Personnel costs	144.532,02	0	55.759		55.759	0%	39%		39%	88.773
	Subcontracting	1.500,00	0			0	0%	0%		0%	1.500
	Other direct costs	12.075,45	1.696	1.132		2.828	14%	9%		23%	9.247
	Indirect costs	93.964,48	1.017	34.135		35.152	1%	36%		37%	58.812
	Total costs	252.071,95	2.713	91.026		93.739	1%	36%		37%	158.333
Partner 07	Total person-month	10	1	7		8	10%	70%		80%	2
Terma	Personnel costs	71.853,25	6.934	63.400		70.334	10%	88%		98%	1.519
	Subcontracting	1.500,00	0			0	0%	0%		0%	1.500
	Other direct costs	10.500,00	1.219	7.734		8.953	12%	74%		85%	1.547
	Indirect costs	71.134,72	7.831	66.162		73.993	11%	93%		104%	(2.858)
	Total costs	154.987,97	15.984	137.296		153.280	10%	89%		99%	1.708

Partner 08	Total person-month	10	8	3		11	80%	30%		110%	(1)
CHESS	Personnel costs	62.568,07	46.441	23.088		69.529	74%	37%		111%	(6.961)
	Subcontracting	1.500,00	0			0	0%	0%		0%	1.500
	Other direct costs	10.500,00	2.787	1.556		4.343	27%	15%		41%	6.157
	Indirect costs	43.840,84	29.537	13.853		43.390	67%	32%		99%	451
	Total costs	118.408,91	78.765	38.497		117.262	67%	83%		150%	1.147
Partner 10	Total person-month	10	3	1		4	30%	10%		40%	6
HYDAC	Personnel costs	70.859,79	20.948	7.662		28.610	30%	11%		40%	42.250
	Subcontracting	1.500,00				-	0%	0%		0%	1.500
	Other direct costs	10.500,00	761	841		1.602	7%	8%		15%	
	Indirect costs	72.128,18	21.323	7.799		29.122	30%	11%		40%	43.006
	Total costs	154.987,98	43.032	16.302		59.334	28%	11%		38%	95.654
Total	Total person-month	269	68	98	-	166	25%	36%		62%	103,5
	Personnel costs	1.400.829,53	354.294	537.119	-	891.413	25%	38%		64%	509.417
	Subcontracting	93.356,00	-	-	-	-	0%	0%		0%	93.356
	Other direct costs	197.775,57	26.987	59.658	-	86.645	14%	30%		44%	111.131
	Indirect costs	1.004.198,11	240.002	383.310	-	623.312	24%	38%		62%	380.886
	Total costs	2.696.159,21	621.283	980.087		1.601.370	23%	36%		59%	1.094.789

7. Quasimodo Publications (as of February, 2010)

General

2010

Joost-Pieter Katoen, Advances in Probabilistic Model Checking, in: Verification, Model Checking, and Abstract Interpretation (VMCAI), pages 25, Springer-Verlag, 2010

Christel Baier, Boudewijn R. Haverkort, Holger Hermanns and Joost-Pieter Katoen, Performance Evaluation and Model Checking Join Forces (2010), in: Communications of the ACM

2008

Joost-Pieter Katoen, Perspectives in Probabilistic Verification, in: 2nd IEEE International Symposium on Theoretical Aspects of Software Engineering (TASE), pages 3-10, IEEE CS Press, 2008

Christel Baier and Joost-Pieter Katoen, Principles of Model Checking, MIT Press, 2008

WP1: Modelling and Specification

2010

J. Berendsen, B. Gebremichael, F. W. Vaandrager and M. Zhang, Formal Specification and Analysis of Zeroconf using Uppaal (2010), in: ACM Transactions on Embedded Computing Systems

Kim Guldstrand Larsen, Shuhao Li, Brian Nielsen and Saulius Pusinskas, Scenario-Based Analysis and Synthesis of Real-Time Systems Using Uppaal, in: Proc. 13th Conf. on Design, Automation and Test in Europe (DATE'10), pages "", IEEE, 2010

2009

Marco Bozzano, Alessandro Cimatti, Marco Roveri, Joost-Pieter Katoen, Viet Yen Nguyen and Thomas Noll, Codesign of Dependable Systems: A Component-Based Modeling Language, in: Proc. 7th ACM-IEEE Int. Conf. on Formal Methods and Models for Codesign (MEMOCODE 2009), pages 121-130, IEEE CS Press, 2009

Eckard Böde, Marc Herbstritt, Holger Hermanns, Sven Johr, Thomas Peikenkamp, Reza Pulungan, Jan Rakov, Ralf Wimmer and Bernd Becker, Compositional Dependability Evaluation for STATEMATE (2009), in: IEEE Transaction on Software Engineering, 35:2(274-292).

Patricia Bouyer and Antoine Petit, On extensions of timed automata, in: Perspectives in Concurrency Theory, pages 35-63, Universities Press, 2009

Kim Guldstrand Larsen, Shuhao Li, Brian Nielsen and Saulius Pusinskas, Verifying Real-Time Systems against Scenario-Based Requirements, in: Proc. 16th International Symposium on Formal Methods (FM'09), pages 676-691, Springer, 2009

Benedikt Bollig and Paul Gastin, Weighted versus Probabilistic Logics, in: Proceedings of the 13th International Conference on Developments in Language Theory (DLT'09), pages 18-38, Springer, 2009

2008

Claus Thrane, Ulrich Fahrenberg and Kim G. Larsen, : Quantitative simulations of weighted transition systems, in: Proceedings of Nordic Workshop on Programming Theory, 2008

Hichem Boudali, Pepijn Crouzen, Boudewijn R. Haverkort, Matthias Kuntz and Marielle Stoelinga, Architectural dependability evaluation with Arcade, in: The 38th Annual IEEE/IFIP International Conference on Dependable Systems and Networks, DSN 2008, June 24-27, 2008, Anchorage, Alaska, USA, Proceedings, pages 512-521, IEEE Computer Society, 2008

Tingting Han, Joost-Pieter Katoen and Alexandru Mereacre, Compositional Modeling and Minimization of Time-inhomogeneous Markov Chains, in: Hybrid Systems: Computation and Control (HSCC), pages 244-258, Springer Verlag, 2008

Ulrich Fahrenberg and Kim G. Larsen, Discount-Optimal Infinite Runs in Priced Timed Automata., in: Proceedings of INFINITY 2008 10th International Workshop on Verification of Infinite-State Systems, 2008

Patricia Bouyer, Ulrich Fahrenberg, Kim G. Larsen, Nicolas Markey and Jiri Srba, Infinite Runs in Weighted Timed Automata with Energy Constraints, in: 6th International Conference on Formal Modelling and Analysis of Timed Systems (FORMATS'08), Saint-Malo, France, pages 33-47, Springer, 2008

Patricia Bouyer, Kim G. Larsen and Nicolas Markey, Model Checking One-clock Priced Timed Automata (2008), in: LMCS, 4:2:9

Patricia Bouyer, Nicolas Markey, Joel Ouaknine and James Worrell, On Expressiveness and Complexity in Real-time Model Checking, in: ICALP'08, Reykjavik, Iceland, pages 124-135, Springer, 2008

Pepijn Crouzen, Holger Hermanns and Lijun Zhang, On the Minimisation of Acyclic Models, in: CONCUR 2008 - Concurrency Theory, 19th International Conference, CONCUR 2008, Toronto, Canada, August 19-22, 2008. Proceedings, pages 295-309, Springer, 2008

Kim G. Larsen and Jacob I. Rasmussen, Optimal reachability for multi-priced timed automata. (2008), in: Theoretical Computer Science, 390:2-3(197-213)

Nathalie Bertrand, Patricia Bouyer, Thomas Brihaye and Nicolas Markey, Quantitative Model-Checking of One-Clock Timed Automata under Probabilistic Semantics, in: QEST'08, Saint-Malo, France, pages 55-64, IEEE Computer Society Press, 2008

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Joost-Pieter Katoen, M Bozzanol, G Burte, A Cimatti, M. le Coroller, Viet Yen Nguyen, T Noll and X Olive, System and Software Co-Engineering: Performance and Verification, in: ESA ADCCS Workshop, Noordwijk, The Netherlands, 2008

Mani Swaminathan, Martin Fraenzle and Joost-Pieter Katoen, The Surprising Robustness of (Closed) Timed Automata against Clock-Drift, in: 5th IFIP International Conference on Theoretical Computer Science (IFIP TCS), 2008

Taolue Chen, Tingting Han and Joost-Pieter Katoen, Time-Abstracting Bisimulation for Probabilistic Timed Automata, in: 2nd IEEE International Symposium on Theoretical Aspects of Software Engineering (TASE), pages 177-184, IEEE CS Press, 2008

Publications for topic: WP2: Analysis

2010

Björn Wachter and Lijun Zhang, Best Probabilistic Transformers, in: VMCAI, pages 362-379, Springer Verlag, 2010

J. Berendsen, B. Gebremichael, F. W. Vaandrager and M. Zhang, Formal Specification and Analysis of Zeroconf using Uppaal (2010), in: ACM Transactions on Embedded Computing Systems

Lijun Zhang and Martin R. Neuhäußer, Model Checking Interactive Markov Chains, in: Sixteenth International Conference on tools and algorithms for the construction and analysis of systems (TACAS), Springer, 2010

Ernst Moritz Hahn, Holger Hermanns, Björn Wachter and Lijun Zhang, PASS: Abstraction Refinement for Infinite Probabilistic Models, in: TACAS, 2010

Christel Baier, Lucia Cloth, Boudewijn R. Haverkort, Holger Hermanns and Joost-Pieter Katoen, Performability Assessment by Model Checking of Markov Reward Models (2010), in: Formal Methods in Systems Design

Uli Fahrenberg, Kim G. Larsen and Claus Thrane, Quantitative Analysis of Weighted Transition Systems (2010), in: Logic and Algebraic Programming -- Special Issue of NWPT08

Patricia Bouyer, Uli Fahrenberg, Kim G. Larsen and Nicolas Markey, Timed Automata with Observers under Energy Constraints, in: Proceedings of the 13th International Conference on Hybrid Systems: Computation and Control (HSCC'10), ACM Press, 2010

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Peter Bulychev, Thomas Chatain, Alexandre David and Kim G. Larsen, Checking simulation relation between timed game automata, in: Proceedings of the 7th International Conference on Formal Modelling and Analysis of Timed Systems (FORMATS'09), pages 73-87, Springer, 2009

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Ulrich Fahrenberg and Kim Guldstrand Larsen, Discounting in Time (2009), in: Electr. Notes Theor. Comput. Sci., 253:3(25-31)

Alexandre David, Kim G. Larsen, Thomas Chatain and and Peter Bulychev, Efficient on-the-fly Algorithm for Checking Alternating Timed Simulation., in: In Proceedings of the 7th International Conference on Formal Modeling and Analysis of Timed Systems, pages 73-87, 2009

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