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YARTISS: A Tool to Visualize, Test, Compare and Evaluate Real-Time Scheduling Algorithms

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YARTISS: A Tool to Visualize, Test, Compare and Evaluate Real-Time Scheduling Algorithms

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Abstract—In this paper, we present a free software written in Java, YARTISS, which is a real-time multiprocessor scheduling simulator. It is aimed at comparing user-customized algorithms with ones from the literature on real-time scheduling. This simulator is designed as an easy-to-use modular tool in which new modules can be added without the need to decompress, edit nor recompile existing parts. It can simulate the execution of a large number of concurrent periodic independent task sets on multiprocessor systems and generate clear visual results of the scheduling process (both schedules and tunable metrics presentations). Other task models are already implemented in the simulator, like graph tasks with precedence constraints and it is easily extensible to other task models. Moreover, YARTISS can simulate task sets in which the energy consumptions is a scheduling parameter in the same manner as the Worst Case Execution Time (WCET).

I. INTRODUCTION

In order to evaluate the efficiency of a new approach in real-time systems, software simulation against other algorithms are commonly used. Due to the lack of a standard simulation tool approved by the real-time community, most of the researchers tend to create their own. This situation raises some concerns. In one hand, the presented results are hard to be validated without careful examination of the simulation tool, so those results might be biased toward the proposed approach ; either by adapted generation of testing tasks, or biased implementation against the compared algorithms. On another hand, reasons as out-of-date simulation tools, or lack of good documentation force others to create new tools, which will lead to repetitive algorithms' implementations, specially the common algorithms (e.g. RM, DM, EDF) while consuming the time and effort of researchers. Moreover, if a standard platform succeeds to emerge, one can compare its own policy with a very complicated one without having to understand the very specificity and optimizations of this one. Finally, the simulation protocols could be standardized, and more easily describable by the use of such a reference tool.

In this paper, we introduce YARTISS, a new simulation tool for real-time systems. Generality is its main feature, by which we hope to overcome the previous problems mentioned before. New users are allowed to add their own implemented algorithms easily, with no need to understand how the simulator is built or works. We do not pretend to propose a perfect simulator, however we tried during its development

to learn from our past tries [1], [2]. YARTISS is written in the Java programming language, which is very popular nowadays and offers valuable attributes regarding portability. In order to ensure independence between the different features of the simulator and to reduce the possibilities of massive failures among them, we used modern programming paradigms, like module oriented programming and Java unit tests (JUnit) oriented development.

We tried to develop YARTISS keeping in mind that in order for a simulator to become a reference tool, it should have the following properties: 1) the software must be available under an open source license which gives any researcher the freedom to analyze, verify or modify its implementation ; 2) the *Application Programming Interface* (API) of the software must be well documented and the developer who wants to add or modify an algorithm should not have to read the entire source code in order to understand its behavior ; 3) each part of the simulator (its core, the tasks generator, the results analyzer, ...) must be independent from each other, and easily replaceable by an external module ; and 4) the simulator has to be easy to use in a way that a non-developer researcher can be able to use it. Due to its generality and modularity, we hope that YARTISS makes a valuable contribution to the long process of developing a standard simulation tool recognized by the real-time scheduling research community.

We expose our motivations in Section II. We review related works in Section III. Section IV presents the simulator functionalities. The program architecture is described in Section V. Case studies which demonstrate the extensibility of the tool are presented in Section VI. How to get the tool is explained in Section VII. Future works are discussed in Section VIII and finally we conclude in Section IX.

II. MOTIVATIONS: A BRIEF HISTORY OF YARTISS

Our first try in writing a real-time system simulator was called RTSS [1] and developed between 2005 and 2008. The tool was first developed to test some algorithms to handle temporal fault tolerance and was later extended in order to test aperiodic tasks handling algorithms [3], [4]. Lot of the modifications was made in a hurry and making assumptions on the behavior of existing classes without documentation. Then modifying anything could result in errors in another completely not connected parts. Moreover, if the tools was

initially programmed in Java, it began to rely more and more on bash scripts to be launched and to transform output in human readable files. Based on this first tool, a second one, RTMSim [2], was developed between 2008 and 2011 in the purpose to simulate multiprocessors platforms [5]. The general key ideas was kept, but the first tool had become such a gasworks that it had to be restart from scratch. Of course, all validated parts of RTSS which was of no interest at that specific time was not reimplemented and so were lost (e.g. an implementation of D^{OVER} [6]). A third try was made in early 2011, RTSS v2 [1], which was basically a rebuild of RTSS including energy consuming tasks and used for [7]. Unfortunately, even if it is more usable today than the first RTSS, it suffers from the same lack of documentation and modularity, and usability to simulate and exploit results of large scale simulations. Moreover, it seems difficult to extend it to simulate multiprocessor platforms.

We so came to the development of a new software: YARTISS. From the start, we aimed to produce a tool where the task model, the number of processors and behavior such as the energy consumption model are as easy as possible to modify. The second point where we focus our attention on is the usability of the user interface to produce human readable traces. Our goal was to develop a simulator to produce evaluations but also one that helps us to debug our energy-related algorithms. When we wanted to use YARTISS for an another purpose, namely the simulation of directed graph model of real-time tasks which is a model of tasks with precedence constraints and concurrency (see [8]), this was done without any problems, validating its extensibility.

III. RELATED WORKS

It exists a lot of tools to simulate or visualize instrumented real-time systems execution traces. Due to space limitation, we cannot produce here an extensible list of existing tools. For the instrumented execution analyzer tools, one can refer to [9], [10]. Among open simulation tools, we can cite MAST [11], Cheddar [12], STORM [13] and FORTAS [14]. MAST permits to model distributed real-time systems and offer tools to e.g. test their feasibility or perform sensitivity analysis. Cheddar is written in Ada, handles the multiprocessor case and provides many implementations of scheduling, partitioning and analysis algorithms. It also comes with a user-friendly *Graphical User Interface* (GUI). Unfortunately, no API documentation is available to help the implementation of new algorithms. Moreover, the choice of the Ada language reduces the potential additional developer number. Finally, FORTAS and STORM are tools which, as YARTISS, are written in Java, had modular architectures and permits to simulate task sets on multiprocessor architectures. They both represent very valuable contributions in the effort to provide open and modular tools and could be good candidates in our opinion to be widely used. Unfortunately, even if it is in its current state more usable than our previous tools, FORTAS seems to suffer from the same issues. Its development is not open to other developers for now. We can only download *.class* files. No

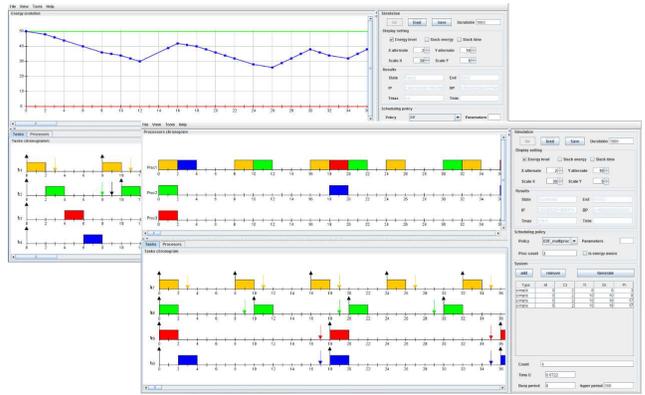


Figure 1. Energy and Multiprocessor Simulation views

documentation is yet provided. It seems that no new version have been released to public since its presentation last year in WATERS.

IV. FUNCTIONALITIES

The two main features of our simulator are the simulation of the execution of one task set scheduled by a specific scheduling policy and the large-scale comparison of several scheduling policies in different scenarios, which implies its third feature: the randomly task sets generation.

A. Single Task Set Simulation

Through the GUI, we can load a task set from a file, randomly generate one, or manually enter its parameters. We can parametrize the desire simulation and then a button permits to run it. Several views are then proposed. The simulation parameters are the task set, the number of processors, the scheduling algorithm and the energy profile.

1) *Task Models*: YARTISS offers an open architecture that greatly facilitates the integration of different task models. The current version proposes two models. The first one is the Liu and Layland task model augmented with energy related parameters. All the tasks are independents and one task is characterised by its WCET C_i , its worst case energy consumption E_i , its period T_i and its deadline D_i . The second one is the Graph task model which is a common real-time task model on multiprocessor systems. It is used to implement systems consisting of number of missions in which there exists dependencies controlling their execution flow. In this model, a graph G_i is a collection of real-time tasks $\{\tau_{i,1}, \tau_{i,2}, \tau_{i,q}\}$, sharing the same deadline D_i and period P_i of the graph, and they differ in their WCET $C_{i,j}$. The directed edges between the tasks of the graph determine their precedence constraints, and since each task in the graph might have more than one successor and predecessor, concurrent execution can be generated. We will see in Section VI that it is easy to propose another task models.

2) *Uniprocessor / Multiprocessors*: Using the simulator, one can implement and test its own multiprocessors algorithms and partitioning policies. Some multiprocessors scheduling

algorithms was implemented to test this feature like EDF and FP. Figure 1 shows the user interface.

3) *Energy Profile*: Unlike many other simulators, this one permits to model the production and the consumption of energy in the system. It permits the user to model an energy harvester like a battery or a capacitor with limited or unlimited capacity. It can also model a renewable energy source by a charging function. The user can implement and use its own energy profiles. Figure 1 shows the user interface. Note that the view used to print the energy level can easily be augmented to print other metrics, such as system slack times for example.

a) *Energy Source Model*: We have implemented an energy source profile that models a renewable energy source represented by a battery with limited capacity and a linear charging function. This model is not the only possible one, the user can add its own profile by implementing the interface and injecting it into the engine of the simulator in few lines of code and without needing to open packages. An example is given in Section VI.

b) *Consumption Model*: It is important to note that for some works, energy consumption of a task must be modeled independently from its WCET [15]. This is why our simulator provides the ability to specify a consumption profile for each task of the system or choose one global profile applied to all tasks. A consumption model is represented by a function and must be able to provide the amount of energy consumed between two dates during the tasks execution i.e. the integral of the consumption function. Implemented models so far are: *Linear consumption* (not realistic but permits to establish some interesting preliminary conclusions) and *Early instantaneous consumption* where all the energy cost of a task is consumed as soon as a task is scheduled. This later model is assumed to represent the worst case scenario. As the energy source profile, a new consumption model can be added without having to open the simulators packages. An example is given in Section VI.

4) *Scheduling Policy*: The main purpose of the simulator is to test scheduling algorithms, compare them and show their performances and efficiency. Much attention has been focused on the design of this part of the simulator to make it as generic as possible so that users can add, override and inject new scheduling policies easily. There are currently twenty algorithms implemented including classic algorithms (RM, DM, EDF uni and multiprocessors), heuristics for the energy constrained scheduling problem and policies for precedence graph model based on *Least-Laxity-First* LLF. As with other parameters of the run-time environment of the simulator, the user can add and link his own algorithms in some lines of code without open core packages. An example is given in Section VI.

B. Run Large Scale Simulations

A major utility of the simulator is the large scale comparison of several algorithms or scheduling policies. It is done in the same way than a simple single simulation but on a large set of systems on different scenarios. The comparison is based

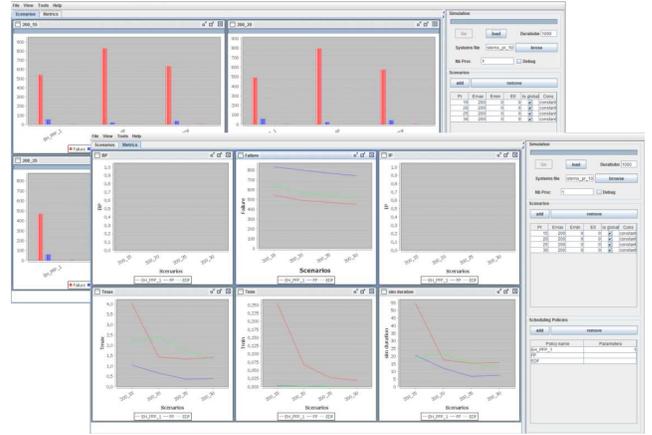


Figure 2. Concurrent large scale simulations: histogram and curves views

on statistics that currently can be the number of failure or missed deadlines, the system lifetime, the amount of time spent at maximum energy level E_{max} and minimum level E_{min} and the average duration of idle period and busy periods. One can add its own metrics as demonstrated in Section VI. Multiple simulations are run concurrently by using the java multi-threading concept and so the duration of simulations is hardly reduced, taking advantages of hardware parallelism. We show in Figure 2 examples of charts which can be displayed with YARTISS.

C. Task Sets Generation

Performing large-scale test requires a large set of tasks systems. To be credible, we have to use sufficiently varied systems to cover the possible tasks systems space. The simulator provides the ability to choose its generator according to scenarios and algorithms to be tested. The current version includes a generator inspired by the UUniFast-Discard algorithm [16] adapted to energy constraints. This algorithm generates a task set that respect the CPU utilization ($U = \sum \frac{C_i}{T_i}$) and the energy utilization ($U_e = \sum \frac{E_i}{T_i \times Pr}$) imposed by the user. The basic version is not energy aware. We had to adapt it to produce time feasible and energy feasible systems. The principle is to distribute the load imposed on the tasks that compose the system. When we add energy cost to the task and an energy load to the system we end up with two parameters to vary and two conditions to satisfy. The algorithm in its current version distribute U and U_e in the same way on the tasks then tries to find the pair (C_i, E_i) which satisfies all the conditions namely U_i, U_e and $Pr < \frac{E_i}{C_i} - Pr < E_{max}$. The operation is repeated a few times and keeps the couple that approaches most the imposed conditions, and so the algorithm returns a time potentially¹ energy feasible system. The user can use the described generator as it can write and use its own one.

¹until now there is no feasibility test that takes into account energy constraints, we hope to have the possibility to present some key ideas to RTSOPS, conjointly organized with ECRTS and WATERS

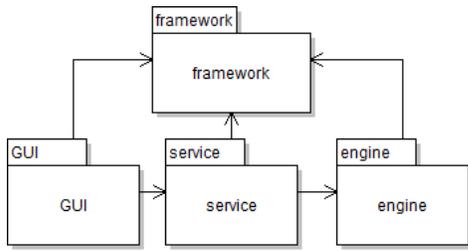


Figure 3. Modules connexion UML Diagram

D. Graphic User Interface

To facilitate the use of the simulator by a large number of users, we equipped the application with a graphical interface to make available the features mentioned above in interactive and intuitive way. After the simulation of a single system with an energy profile and a scheduling policy the user can follow and analyze the schedule on three different views: a time chart, a processor view and the energy curve which shows the evolution of energy (as mentioned before, other data can be monitored and print on this view).

In order to run simulations and get the results of a comparison of scheduling policies, the application offers a view that allows the user to select the scheduling policies to be compared, the energy scenarios and to run simulations. Thus the user can see the results as graph per scenario or per comparison criterion. This view offers also a debugging tool in which the user can analyse the result of comparison system by system and can optionally display the time chart of each system and in each scheduling policy. This can help to detect behaviors that differ in one algorithm to another. Then this simulator can produce results on a large scale of randomly generated task systems in order to evaluate a scheduling policy, but also easily explore properties of a new algorithm, find counter examples on hypothesis we can make by easily isolating degenerate cases. For example, in the case of energy scheduling, no optimal algorithm exists yet. If you think your algorithm is, you can first run it on a large number of task systems, and ask the simulator to present you only systems where your algorithm fails whereas another heuristics succeed.

V. ARCHITECTURE

To meet the requirements specified in Section II, we have ensured that the design is as generic and open as possible by applying the appropriate design patterns and modular programming practices. We cut the project in four main modules: the engine or core module, the services module responsible to connect the engine with outside, a module for GUI and finally a framework module that contains general tools necessary for the application. This module separations follows the classical *Model-View-Controller* design pattern (see Figure 3) which permits to isolate the core application part from its presentation and thus permits to the engine to be generic and easily integrable in other tools.

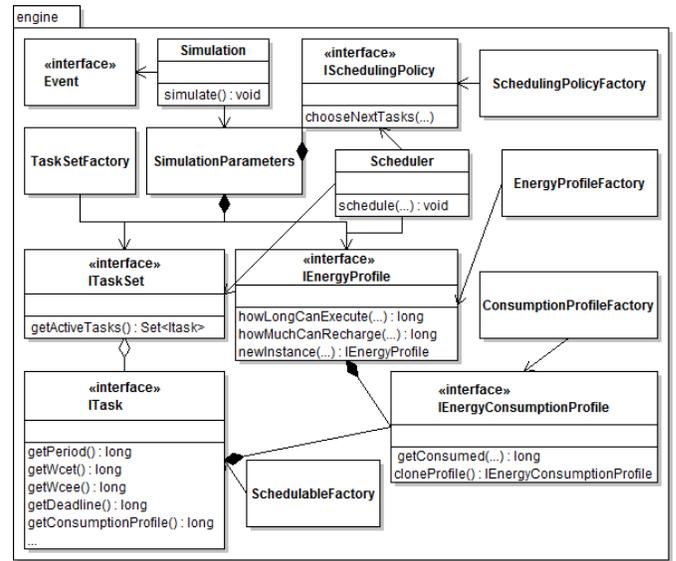


Figure 4. The engine module UML diagram

A. Engine Module

The *Simulation* class, responsible of running a simulation, takes as parameter a container that contains a scheduling policy, an energy profile and a set of tasks. An UML diagram of this module is given by Figure 4. The simulator being based on events, on receipt of an event the scheduler is called to update the running tasks, it then call the scheduling policy to choose the tasks to execute and the associated processors. This module so defines interfaces needed to execute, i.e. the scheduling policy, the energy source model and tasks energy consumption model. The interface implementation is not directly linked to the simulation object. In order to build an energy profile, for example, one have to register an instance of this class in a factory. This factory is responsible to create new instances when needed and completely obfuscates the implementation. This allows anybody to create its own scheduling policy or its own task consumption model in a transparency way: one only have to write the model code and register an instance of its class by calling a method of the factory in order to make the new class available through the graphical interface. Case study are give in Section VI in order to demonstrate this assertion.

B. Service Module

This module makes the interface between the simulator core and the potential user interfaces. It permits to give the necessary data to the GUI and to get back the user modifications from it. It also permits to prepare the simulation parameters, or to set up a large scale test. This module component has been made in such a way that it permits to reuse the same classes for an other GUI, such as a textual user interface for example.

C. Framework Module

This is a toolbox module that contains generic classes and functions in order to facilitate the code writing. This module

```

1 public class MainDemoSP {
2     public static void main(String[] args) {
3         SchedulingPolicyFactory.registerPolicy(new LLF());
4         DesktopMain main = new DesktopMain();
5         main.setVisible(true);
6     }
7 }
8
9 class LLF extends AbstractMultiProcSchedulingPolicy {
10    @Override public String getPolicyName() {
11        return "LLF";
12    }
13    @Override public ITaskSet createTaskSet() {
14        return new AbstractTaskSet(new Comparator<ITask>() {
15            @Override public int compare(ITask t1, ITask t2) {
16                long laxity1 = t1.getDeadline() - t1.getRemainingCost();
17                long laxity2 = t2.getDeadline() - t2.getRemainingCost();
18                int cmp = (int) (laxity1 - laxity2);
19                if (cmp==0)
20                    return (int) (t1.getPriority() - t2.getPriority());
21                return cmp;
22            }
23        });
24    }
25    @Override public SortedSet<ITask> getActiveTasks(long date) {
26        SortedSet<ITask> activeTasks = new TreeSet<ITask>(comparator);
27        for (ITask t : this)
28            if (t.isActive())
29                activeTasks.add(t);
30        return activeTasks;
31    }
32 }
33
34 @Override public Processor[] chooseNextTasks(
35     Processor[] processors, ITaskSet taskSet,
36     IEnergyProfile energyProfile, long date,
37     EventGenerator evGen) {
38     int i=0;
39     for (ITask task : taskSet.getActiveTasks(date)) {
40         if (i<processors.length){
41             long hlcet = energyProfile.howLongCanExecute(task);
42             if (hlcet <= 0) {
43                 evGen.generateEvent("energy_failure", task, date, null);
44                 processors[i].setNextTask(null);
45             }
46             else {
47                 evGen.generateEvent("check_energy_state", task, date + 1, null);
48                 processors[i].setNextTask(task);
49             }
50             i++;
51         }
52     }
53     for (;i<processors.length; i++){
54         processors[i].setNextTask(null);
55     }
56     return processors;
57 }
58
59 @Override public ISchedulingPolicy newInstance() {
60     return new LLF();
61 }

```

Listing 1. How to add a scheduling policy

permits to accelerate the execution of several simulations by using the capacities of modern multiprocessors architecture, using the JAVA concurrency API. It follows the *producer consumer* design pattern in order to permits for example to run several simulations in the same time, sending the result of each one to the consumer which compute statistics and update the GUI. This is also used for the task set generation. Several producers can run in concurrency, sending the produced tasks to consumers which write them in files. This permits to speed up the generation and simulation of large scale tests.

D. View Module

This module contains the necessary classes for the GUI. We do not detail it here.

VI. CASE STUDIES

We demonstrate in this section that it is easy to tune the simulator to address specific needs.

A. Adding a Scheduling Policy

To add a new scheduling policy, e.g. LLF, one first need to add the simulators *.jar* files to a new project in its favorite

```

1 public class MainDemo {
2     public static void main(String[] args) {
3         SchedulingPolicyFactory.registerPolicy(new LLF());
4         ConsumptionProfileFactory.registerConsumptionProfile(new LogConsumption());
5         DesktopMain main = new DesktopMain();
6         main.setVisible(true);
7     }
8 }
9
10 class LogConsumption implements IEnergyConsumptionProfile {
11    @Override public String getName() {return "log";}
12    @Override public List<Double> getParameters() {return null;}
13    @Override public void setParameters(List<Double> params) {}
14
15    @Override public long getConsumed(long wceet, long wceee,
16        long remainingTimeCost, long duration) {
17        double a = wceet - remainingTimeCost;
18        double b = a + duration;
19        if (b > wceet) b = wceet;
20        if ( (b-a) <= 0 )return 0;
21        long result = (long) Math.log(b/a);
22        if (result > wceee )result = wceee;
23        return result;
24    }
25
26    @Override public IEnergyConsumptionProfile cloneProfile() {
27        return new LogConsumption();
28    }
29 }

```

Listing 2. How to add a new energy profile

IDE and then provide an implementation of the interface *ISchedulingPolicy*. The policies are named to identify them among all others. The method *getPolicyName()* must so return the policy's name. To allow the scheduling policies factory to instantiate the new class, one must implement the method *newInstance()* that returns a new instance of its policy class. Then he specifies the task set model by implementing the method *createTaskSet()*, having the choice to use the available task models or to create its own one according how tasks must be sorted. *ITaskSet* is an iterable of *ITasks* that sorts tasks and give a sorted set of activated tasks at time *t*. For LLF tasks must be sorted by their laxity. To decide which task execute and on which processor the method *chooseNextTasks()* must implemented. Listing 1 gives the whole code needed to use LLF as an external module with the simulator.

B. Adding an Energy Profile

The same methodology can be applied to add a new energy consumption profile. Listing 2 gives the whole code needed to use a logarithmic consumption profile, still as an external module.

C. Adding a Traffic Model

To add a new task type, one has to implement the interface *ITask* and register the class into the *Schedulable* factory. The current version of the interface describes a standard Liu and Layland task. It can be used in its current state to model an other kind of tasks like we do with graph tasks and task with precedences without open the packages. If it is not sufficient, one can extends it to make it more suitable to its needs. For example, to implement uncertain tasks model where the tasks execution times are specified into an interval, one can implement the interface *ITask* and modify the behavior of some methods to permit the exceeding of WCET by manipulating the *remainingCost()* method and the conditions of jobs end. Due to space limitation, we cannot give the code here, but it will be added to the demonstration package code suite (see Section VII).

D. Using an External Module to Generate Tasks

One of the advantages of the simulator is that it works with files of standard format like XML. It lets us use external tools if needed to generate tasks by converting the output file with XSL transformation to get an input file understandable by our simulator.

E. Adding More Metrics

If one want to count the number of preemptions, for example, he has to modify the class *Simulator* to check each of tasks begin and end events to detect preemptions and increment a counter in the statistics container. Then, to show the new metric on GUI he must modify the class *Metric* to add the new one and the necessary algorithms to compute maximum, minimum and average. Clearly, this is not a good design. This point is discussed in Section VIII.

VII. DISTRIBUTION

The project is available from the GForge collaborative development environment hosted at <https://svnigm.univ-mlv.fr/projects/yartiss/>. This environment provides a subversion (svn) server allowing anonymous checkouts, documentations hosting, RSS feeds subscriptions, and public forums. A web page dedicated to YARTISS is also available at <http://yartiss.univ-mlv.fr>. In addition to a general presentation of the tool, it proposes a demo applet version which allows interested reader to try YARTISS directly from his web browser and an application form to allow anybody to share external modules.

VIII. FUTURE WORKS

The actual release offers many important and expandable features but the simulator is still under development. Some parts of the project have been made in the emergency which has prevented them to be as clean as they could. For example, the implementation of comparison metrics is strangely coupled with simulation classes and if we want to add a new metric we will be forced to open the engine module and modify internal classes as described in Section VI-E. This may be dangerous and not acceptable architecturally. Improvement works are planned to address such weaknesses, like we have done for energy profiles and scheduling policies. Some other future works are planned: 1) We want to provide a command line user interface to allow the use of our simulator without the graphic environment to permits its use inside automated scripts and/or through a distant machine. This should be done easily because of the adopted architecture and responsibilities separation. 2) If we use XML format in mostly all inputs and outputs in order to be able to reuse other external tools functionalities, this feature must be generalized to the simulation results in order to permits their visualization with an external tool (e.g. GRASP[10]). 3) An additional work is needed on the description of processor and we need to add the ability to execute on heterogeneous and independent processors in terms of computational power, memory and energy consumption. This could also lead to integrate research on distributed systems. 4) Finally, concerning the energy part, we must integrate the

Dynamic Voltage and Frequency Scaling (DVFS) model in order to be compliant with most recent works in this area.

IX. CONCLUSION

In this paper we presented YARTISS, a real-time multi-processor scheduling simulator. A consequent effort has been made to make it as extensible as possible. To justify the need for an open and generic tool, we presented the history of YARTISS development. Then we briefly presented existing simulation tools. We have described the three main functionalities of YARTISS: 1) simulate a task set on one or several processors with monitoring the system energy consumption, 2) concurrently simulate a large number of task set and present the results in a user friendly way that permits to isolate interesting cases, and 3) randomly generate a large number of task set. Then, in order to demonstrate the modularity and extensibility of our tool, we presented its architecture and five case studies that shows how to add functionalities, in most cases without having to open the project archive. Finally we gave the instructions to test YARTISS and presented some improvement features we will implement.

We hope that this software can became a first step toward a widely adopted simulation tool through the real-time scheduling community.

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