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INSTITUT NATIONAL DE RECHERCHE EN INFORMATIQUE ET EN AUTOMATIQUE

Project-Team TRIO

Temps Réel et InterOpérabilité (Real Time and InterOperability)

Lorraine - Rhône-Alpes

THEME 1C

Table of contents

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2. Overall Objectives

The goal of TRIO team is to provide a set of techniques and methods that can be applied to design, validate and scale real time distributed applications. In order to tackle this problem as a whole, our work is structured along three complementary points of view:

- specification of real time on line mechanisms (protocols, schedulers, middleware) offering services to the application with a quality of service that ensures the satisfaction of real time constraints; this includes fault detection, fault indication and fault tolerance,
- modeling process of real time distributed applications in order to analyze these models for verification activities and/or to generate a part of the application,
- verification methods of temporal properties.

The problems to solve are mainly due to three particularities of targeted applications:

- They are discrete event systems with temporal characteristics (temporal performances of hardware support, temporal properties); this increases the complexity of their modeling and of their analysis. So a part of our research objectives is to master this complexity while stating a compromise between the accuracy of a model and its ability to be analyzed.
- A second aspect is the environment of these systems that can be the cause of perturbations. We need to take into account the impact of an uncertain environment (for example, the impact of electromagnetic perturbations on a hardware support) on the required properties. Therefore we have to develop stochastic approaches.
- Finally, the main characteristic of our works is based on the fact that we consider the performances of hardware supports. Consequently, the time that we manipulate is a physical (continuous) time and the studied systems are event driven timed systems.

These three main directions contribute to cover the full spectrum from theoretical modeling and analysis of discrete event systems up to their use in industrial problems, in particular, in the field of in-car electronic embedded systems. Furthermore, some of our results yield to software tools and fruitful collaborations with the automotive industry.

TRIO project team created in 2001 a common research team with PSA Peugeot-Citroën. This team named CARAMELS is a Research Team for Technology (ERT), granted by the French Ministry for Research. Its research topic is the evaluation of dependability characteristics of an embedded communication architecture for X-by-Wire applications.

3. Scientific Foundations

As mentioned before, the TRIO project covers a wide range of scientific domains from modeling techniques and discrete event systems theory to the validation of real time distributed architectures by formal analysis, simulation and/or tests.

3.1.1. Formalism and verification techniques

In order to check for the timed behavior of a distributed systems, the TRIO team developped several techniques based on timed automata and time/timed Petri nets.

To face the combinatorial aspect of the state space which is typical in these kinds of systems, we use on-the-fly techniques for model checking [92] as well as algebraic approaches to describe the evolution of the system [77].

For more general models for discrete event systems, we have developed over the years an expertise in Petri net (PN) theory in both classical PN and the timed PN.

When the features of the system under study are not perfectly known, we use stochastic models, for arrival processes or for error patterns [88]. We consider Markovian and semi-Markovian models but also more general distributions under stationary and ergodic assumptions [76], [75].

3.1.2. Modeling techniques

Starting from a detailed description of a system (hardware description and protocol specifications- software and data exchanges abstraction, distribution), we have to compile a model that can be exploited for formal analysis and / or simulation.

In order to make this compilation easy and automatic, the TRIO team has developed several methodologies according to the domain of application.

All of them use the concept of ADL (Architecture Description Language) [87]. The originality of TRIO is to focus on the time properties and the distributed aspects as well as on the techniques that can be applied to verify these properties. Therefore, the team worked on the conception of such languages (for example, AIL_Transport: Architecture Implementation Language or EAST-ADL) and on the automatic translation into models that can be analyzed (for example, by simulation thanks to OPNET formalism, by formal analysis thanks to Time Petri nets or by schedulability analysis).

3.1.3. Real time services and protocols

As far as the design of discrete event systems is concerned, we mainly use scheduling techniques for real time systems. This means that we have to specify scheduling policies that ensure the respect of time constraints on line and / or optimize the behavior of the system according to some performance criteria. A new approach to solve these problems was partially developed in our team: the trajectory approach with priority functions. This approach has been used many times to make formal proofs of schedulability results in quite general cases. This approach is also taken by the network calculus techniques which has grown so fast in the last few years. In this domain, we try to get away from static assumptions where everything is fixed before hand. Many current systems can adapt dynamically to the environment [90], [91], [79], [78]. This is why we focus on Weakly-Hard-Real-Time constraints such as (m, k)-firm constraints [78], [82].

In the stochastic framework, we use queuing theory (Markov processes, ergodic theory) to evaluate the performance of distributed systems under uncertainty. When close form computations cannot be obtained, we use optimization techniques (such as optimal control and convex analysis) to find optimal admission control policies or resilient task allocations.

4. Application Domains

Four main application domains can be underlined.

- **Fieldbuses and field equipments.** In this context a previous important contribution of TRIO is the participation to WorldFip protocol specification and evaluation. WorldFip Fieldbus is an IEC standard (2000) and is the only field-bus in the world which has been certified (Safety Integrity Level 3) in 2001 according to the IEC 61508 standard. Recently a new field of investigation has been started for error management mechanisms for CAN Networks [19], [20], [22].

- **In-car embedded systems.** A lot of work developed in TRIO is oriented towards these particular applications. They mainly cover two points. The first one is the specification of what must be modeled in such a system and how to reach a good accuracy of a model; this yield to investigate topics like Architecture Description Languages and automatic generation of models. The second point concerns the verification of dependability properties and temporal properties required by these applications and, consequently, the development of new fault tolerant on-line mechanisms to include in an application or in a standard middleware.
- **Evaluation of the quality of services (QoS) of protocols.** In many application domains, the evaluation of the quality of services provided by the used communication protocols is a way to ensure the respect of dependability properties. In this context, we model and analyze some protocols for home automation application and aim to define analytically the optimal configuration of their characteristics; for example, we investigate different protocols available in Power Line Communication systems / PLC (REMPLI Project / 5th EC FP) and in wireless communication. In the same field we specify mechanisms for guaranteeing on line a required QoS.
- **Remote monitoring.** The research in remote monitoring has a main objective, the computer aided diagnosis and maintenance (other teams of the LORIA are involved in these projects: L&D and MAIA). The applications are : on one hand, the health and more precisely, the monitoring of chronic patients (kidney disease, cardiac decompensation) and, on the other hand, the remote monitoring and remote maintenance of physical processes. Both of these applications need real time data acquisition, modeling of the considered "objects", data fusion and decision, and obviously communication and distribution policies analysis. They are good subjects for applying results and identifying new problems or new challenges. The interest for TRIO is the broadening of communication protocols studies and applications, and of interoperability requirements [48], [49].

5. Software

5.1. Diatélic

Participant: Jean-Pierre Thomesse.

After having developed (in 2002) the well-suited structure for the deployment of the "Diatélic" service in Lorraine, this year has been dedicated to the installation of about 80 patients in the remote monitoring operation. This deployment has been very rich in experience for extending an innovative system at a wide scale. The non-profit association in charge of the operation should be changed in a « Groupement d'Intérêt Sanitaire » during the next year. In terms of medical results, the first months show the same tendencies as the first experiment with 30 patients, i.e. best control of weight, of blood pressure, less consumption of drugs and important decreasing of the hospitalization duration. The results of this operation will be published later when more patients will be monitored during a more important period [10], [50], [47].

The current works are related to two actions:

- Dial-Hémo is a so-called « development action » of INRIA with the participation of the following companies: Diatélic SA and Gambro. This action aims at extending the current system (done for peritoneal dialysis) to the haemodialysis therapeutic.
- DEPIC is a project under the aegis of the RNTS (Réseau National des Technologies de Santé) with the objective to define a new sensor and an intelligent associated system for the prevention of skin infection. This research runs in cooperation with the laboratory LPM located in Lyon.

Both of these operations are carried in cooperation with the MAIA team of LORIA. Regarding the publications on these actions, nothing is published because the protection strategy is oriented towards patent registration.

5.2. EAST-ADL

Participants: Orazio Gurieri, Olivier Barrière [IRCCyN, EC-Nantes].

Within the context of ITEA EAST-EEA project, a tool has been developed for the specification of EAST-ADL Language. This tool is based on GME 2000, developed at Vanderbilt University (USA) and, for the present implements the meta-model supporting the description of a functional architecture and of the corresponding software one. The realization of the prototype is done by TRIO team in cooperation with the team "Real Time" of IRCCyN [58], [62], [60].

6. New Results

6.1. Real time services and protocols

In this topic, we developed, on one hand, policies for managing the quality of service of operating support (mainly, networks and protocols) in order to meet the properties required by real time applications (hard real time, weakly hard real time) and, on the other hand, strategies for scheduling activities and admission control.

6.1.1. Quality of Service of real-time communication systems

Key words: *Real-time*, *QoS*, *Fieldbus*, *Powerline communication*, *automotive embedded systems*.

Participants: Raul Brito, Bruno Gaujal, Liping Lu, Nicolas Navet, Françoise Simonot-Lion, YeQiong Song, Cédric Wilwert.

6.1.1.1. Power line communication protocols(PLC)

PLC has undergone a tremendous development during the last fives years. Faced to the competition of wireless communication, if the deployment of PLC as the last-mile solution is now questionable in Europe (because of the much more stringent regulation on the EM emission than in other parts of the world), its use for the remote meter reading and telecontrol (IEC60870-5-xx, IEC1107, M-Bus) is justified since the equipments are already connected by power distribution networks and moreover most of the meters to read are located in closed environments with metallic obstacles (reinforced concrete walls and tubes) making inaccessible the radio signal.

Within the REMPLI EU project (www.rempli.org) we are developing a new communication infrastructure based on PLC technology to provide not only high date rate but also QoS in terms of reliability (meter reading) and real-time responsiveness (remote control). The time varying communication channel characteristics, the dynamic network topology (load, switching), the large covering distance for low voltage and mid voltage segments (need of repeating and routing) constitute the main obstacles and make the protocol design task very challenging.

In [35] we first analyzed the real-time QoS of the two main PLC MAC protocols for in-home LAN, then address the performance problem of TCP Westwood over PLC by simulation. This simulation study revealed the impact of the packet loss rate on TCP performance. We also discussed the importance of coordinating TCP's RTO estimation with the ARQ of the underlying PLC MAC protocols. This result will be extended to further include the dynamic repeater number in the communication path and applied to the performance evaluation of the Master-slave based polling as well as the peer to peer communication within REMPLI project.

6.1.1.2. Dependability of communication architecture supporting in-car embedded systems

In the next years will emerge the X-by-Wire technology that intends to replace mechanical or hydraulic systems by electronic ones even for critical function as braking or steering. This requires a stringent proof that these new vehicles will ensure the safety of driver, passengers, vehicle and environment. An key point for the dependability of an embedded system is the communication architecture. Within the Research Team for Technology, CARAMELS, a comparative study between networks (TTP/C, FlexRay, TTCAN) that are candidates to support X-by-Wire application has been done. The result is a clear and fair classification of their functions and of the services that they provide to ensure dependability properties. To reach this goal, we

developed a model that allows to identify, at each layer (according to the OSI model of ISO), fault tolerant services that are relevant for satisfying the application requirements [52], [53].

6.1.2. Dynamic Real-time QoS control according to (m,k)-firm model

Key words: *(m, k)-firm*, *Real-time QoS*, *Dynamic scheduling*, *WFQ*, *Network*.

Participants: Anis Koubâa, Enrico Poggi, YeQiong Song, Wang Zhi.

For (m,k)-firm real-time guarantee, two families of (m,k)-firm scheduling algorithms have been proposed: static priority assignment [91], [89] and dynamic priority assignment according to the recent history of the system state [82], [93].

We only focus on the dynamic algorithms as, in general, they provide more effective resource utilization than the static ones and also as we are interested in providing real-time QoS in adaptive real-time systems [84] including real-time networks. Moreover (m,k)-model can be directly used to measure the QoS levels ranging from (k,k)-firm to (m,k)-firm [18].

We showed in [41] that DBP (Distance Based Priority, see [82]) combined with EDF (EDF for making choice among tasks/messages of the same priority assigned by DBP) cannot always provide good performance in a multiple input queues single server non-preemptive model because it does not take into account neither the stream timing parameters (period, deadline, service time in server) nor its relationship with other streams sharing the same server. Taking into account these additional parameters, two necessary schedulability conditions are derived and an enhancement of DBP called matrix-DBP is proposed. The performance under overload situation has been improved.

The dynamic QoS control according to the (m,k)-model in packet switching network is one of our main applications. We proposed in [32], [34] and [18] an algorithm called (m,k)-WFQ which extends WFQ server to consider (m,k)-firm temporal requirements. In fact, many multimedia real-time flows are under (m,k)-firm constraint. The transmission of those flows (e.g. MPEG sources for digital video distribution over the internet) uses the Guaranteed-Rate servers, such as WFQ and its variants, to give mainly bandwidth guarantee and consequently delay guarantee for real-time flows provided that their arrivals are upper-constrained. Problems may arise if a bursty traffic with a small service share needs a specific short delay. The higher the service share is, the lower the delay the flow gets. However, WFQ and its variants are only share-driven servers and no explicit temporal constraint is considered in the scheduling process. For (m,k)-WFQ, analytic expressions using Network Calculus theory are derived to give deterministic upper bound on delay provided by (m,k)-WFQ. Theoretical Results and simulations show lower average and maximum delays when using (m,k)-WFQ, without much degrading bandwidth fairness.

6.1.3. Error Confinement

Participants: Bruno Gaujal, Nicolas Navet, Gülgün Alpan.

The network CAN is a standard in the car industry. Last year, we have analyzed in [81] the efficiency of its mechanisms of error confinement which aim at preventing a faulty station to disturb the whole network by disconnecting (state “bus-off”) a faulty station or by reducing its prerogatives like the signaling of faults (state "error passive"). We have proposed a Markovian analysis of the reaching times of the states “bus-off” and "error passive" and we have identified some problems with the existing mechanisms (reaching times of states “bus-off” too short, too much memory of the faults in past transmissions, the transmission faults are by hypothesis non-correlated ...). We have proposed in some new mechanisms which use the quantity of information brought by the result of the last transmission to decide the distance or the advance towards the states “bus-off” and "error passive". These mechanisms may adjust online to an evolution of the perturbation level in the bus. A Markovian analysis has shown really better performances than the existing mechanisms in terms of time of detection of a faulty station as well as probability of detection of a non-faulty station.

In a more general framework, we have studied in collaboration with Pr. Yalcin from Florida State University in Tampa, the effects of bad functioning (partial or total faults) of captors on the controllability of a discrete event system. We use the language generated by the automata model of the system for the specification of the faults of captors. An application on a system of automated production is presented to illustrate the results.

6.1.4. Scheduling

Key words: *scheduling*, *reservation*, *anytime task*, *EDF*.

Participants: Bruno Gaujal, Fabrice Jumel, Nicolas Navet, Françoise Simonot-Lion.

6.1.4.1. Anytime tasks scheduling

A large number of applications in such areas as diagnosis or path planning, use more and more anytime algorithms for which the quality of results increases with computation time. Two types of anytime algorithm exist, that is interruptible and contract algorithms. An interruptible algorithm can be stopped at any time, while for a contract algorithm, a mandatory computation time is required. Using this type of algorithm in a real time application introduces a new set of timed constraints (e.g. deadlines). We propose the definition of a new entity called Resource Manager. Its aim is to share the processor among the different types of tasks (non-anytime, anytime interruptible or anytime with contract) so that every deadlines are respected. This algorithm uses an acceptation test based on Earliest Deadline First policy, without explicit computation of the response times [31].

6.1.4.2. Scheduling under energy consumption minimization

Present embedded systems have a growing need of computational power. It involves some electronic components running at high frequency and consuming a lot of energy (the dissipated power is about the square of the frequency in usual cases). All these systems may benefit from techniques reducing the consumption by varying the clock frequency of processors in function of the needs. In [61] and [28] we have shown how to compute the best clock frequency for a processor in order to execute a set of task under FIFO real-time constraints. Our algorithm runs in linear time and is thus an improvement over the classical algorithm of Yao *et al*. It was made possible by considering the problem as a shortest path problem. We also propose an algorithm for the case where the processor possesses only a limited number of clock frequencies. We extend this algorithm to provide the minimum number of speed changes, which is important when the speed switching overhead cannot be neglected. All our algorithms are linear in the number of tasks if the arrivals and deadlines are sorted and need O(N logN) time otherwise and these complexities are shown optimal.

Some extensions to cases with a limited set of available speeds, and cases with non-convex cost functions and infinitesimal tasks, are also presented in [28].

In [56][26], we study low-power scheduling under the Round-Robin policy which is widely available since it is part of the Posix1003.1b standard. An algorithm that computes the minimum processor speed for scheduling a job set under Round-Robin is provided. It relies on an efficient feasibility test that is also a contribution of this study. Finally, we present mechanisms that are necessary for ensuring schedulability at run-time and that reduces consumption when jobs do not require their worst-case execution time.

6.1.4.3. Resource Reservation In Advance

Some applications, especially in the field of multimedia computing, require a firm guaranty to obtain a given quantity of resource (CPU time or network bandwidth) before a deadline (classical real-time need) and, in the same time, they need that the quantity of resource they obtain is uniformly distributed over time (need related to multimedia). We study scheduling policies for resource reservation in advance (RERA) that fulfill these two requirements. The constant rate policy, which is generally used in such systems possesses the drawback that an important percentage of the requests are rejected and thus the resource is not fully used. By accepting the principle that the uniform repartition can be degraded, we define in [15], [8] three policies that offer different trade-off between resource utilization and uniformity in the execution of the tasks. The proposed policies are based on shaping strategies applied to the placement of the reservations. In one case, the request is distributed the most uniformly as possible with regard to the existing reservations while, for the other policies, the load is spread over time in order to smooth the load reserved on the resource. The performances of the policies have been assessed by simulation with regard to the rate of rejection and the uniformity of the quantity of resource obtained for each request and these policies proved to be very effective in comparison with the constant rate strategy.

6.1.5. Real-time middleware

Key words: *scheduling*, *frame packing*, *real time*, *fault tolerance*, *X-by-Wire*, *embedded system*, *TTP/C*.

Participants: Bruno Gaujal, Nicolas Navet, Ricardo Santos Marques, Rishi Saket, Françoise Simonot-Lion.

6.1.5.1. Frame Packing

The set of frames of an in-vehicle application must meet two constraints: it has to be feasible from a schedulability point of view and it should minimize the network bandwidth consumption. The latter point is crucial for enabling the use of low cost electronic components and for facilitating an incremental design process. In a first study [43], we proposed two heuristics for the NP-complete problem of generating a set of schedulable frames that minimizes the bandwidth usage. The proposed strategies are complementary. The first one can be applied to large size problems (in the context of in-vehicle applications) while the second one, more efficient in our experiments, is limited to small size problems (less than 12 signals emitted by each stations). Our proposals have proved to be efficient in comparison with other possible strategies such as "one signal per frame" or the"First fit Decreasing" and "Best Fit Decreasing" heuristics from the bin-packing field [43], [42].

In [71], a new algorithm is presented that performs much better in terms of bandwidth consumption than the one from [43] for large size problems. However, the algorithm from [43] still remains very competitive for feasibility.

6.1.5.2. Robustness of redundant functions on TDMA

A Fault-Tolerant Unit is a set of stations that perform the same functions, thus the application can tolerate the loss of one or several stations composing the FTU. In [36][27], we showed how one can use Fault-Tolerant Units (FTU) in an optimal way to make a TDMA network robust to bursty random perturbations. We consider two possible objectives. If one wants to minimize the probability of losing all replicas of a given message, then the optimal policy is to spread the replicas over time. This is proved using convexity properties of the loss probability. On the contrary if one wants to minimize the probability of losing at least one replica, then the optimal solution is to group all replicas together [27]. This is proved by using majorization techniques. Finally we show how these ideas can be adapted for the TTP/C protocol [27] with possesses a clique avoidance algorithm that interferes with the analysis made in the general TDMA case [37].

6.1.5.3. In-car middleware

A aim of the ITEA EAST-EEA project, is the specification and the validation of an in-vehicle middleware the main objective of which is to allow portability and re-use at source code level. In [59], we first identified for each car domain the building blocks that could be support the EAST-EEA middleware. With our partners, we then specified [55] the services of a middleware specific for the powertrain domain which is currently being implemented.

6.1.6. Routing in networks of queues

Participants: Bruno Gaujal, Emmanuel Hyon, Alain Jean-Marie [LIRMM].

Key words: *admission control*, *multimodularity*, *Sturm words*.

Our aim is to minimize some cost functions linked to the average sojourn time of customers in parallel networks modeled by networks of queues. The control is an open-loop control which means that the controller does not know the state of queues when routing, he only knows the parameters of the system. This type of control has many applications in networks, usually when the service time is really shorter than the time required to gather the information. This happens in particular in long range networks or optical networks. The minimization of the sojourn time is done by an admission control which enables to balance the loads and thus to optimize the use of the resources provided by the network.

Our approach consists in finding mathematically the optimal policies. The class of optimal policies is known: they correspond to Sturmian words. Given some parameters, our work aims at providing the right optimal policy in this class. Two axes have been followed.

In the first one, the parameters (inter-arrivals and services) are deterministic but the networks we consider are composed of tandem queues. The properties of the mean waiting time enable us to use the algorithm of

discrete convex descent. In that case, we can compute the optimal policy which is periodic and fractal. We carry on with this work to generalize these results to the admission in parallel $(max, +)$ networks.

On the other hand, for networks composed of a unique queue, we try to take into account exponential inter-arrivals and exponential services. If the mean waiting time has a fractal behavior in function of the proportion of admitted clients, the weighted mean waiting time is convex and we can apply a planned searching algorithm which enables to find the optimal policy. All these works providing a computation of the optimal policy have been gathered in the PhD thesis of Emmanuel Hyon [83] and are being improved both on the theoretical and the computational aspects.

6.2. Modeling techniques

To build a model of a distributed application according to a language or formalism that support verification analysis requires skills both in the used formalisms and in the application domains. Usually one person has only one of these skills. This fact is a bar for applying formal methods and quantitative analysis based verification in industry. In order to bring a solution to this problem, some of our works aimed to define architecture description language suited for real time distributed applications and to provide a way for designing a distributed real time application by integration of real time components.

6.2.1. Real time data specification for maintenance applications

Participants: Eric Hennequin, Philippe Hubert, Xavier Rebeuf, Jean-Pierre Thomesse.

Key words: *Real time data*, *maintenance*, *data acquisition component*.

Within ITEA Proteus Project, the WP3 work-package is dedicated to the specification and the design of a generic data server as an image of any process monitored by a SCADA or controlled by any DCS or PLC system. The main goal is to provide to the maintenance engineers and operators the data (real time data and historic data) necessary for the maintenance operations. A very important work has been carried in 2003 for the analysis and specification of the necessary data, of the required quality of data. The characteristics of data acquisition components have been specified comparing SCADA systems, PLC systems, DCS, Condition monitoring Systems, Computer aided production data collection, and field devices. This analysis leads to the definition of data acquisition objects, which have been defined according to a UML formalism. And one of the most important result is the definition of an ontology structure [24].

The WP6 work-package focuses on the integration of the different tools (SCADA, ERP, CMMS) on a unique platform. The challenge is to ensure interoperability between these components. In 2003, our work can be divided into two parts: the definition of the platform, and the methodology to design services.

We choose to construct the platform thanks to web services technology. It is divided into several parts. First, the Central Service Application containing services responsible for the platform management. Then, each existing tool is wrapped by a component called Interface Core Adapter. The adapter is responsible for translating the specific tool services into standardized ones.

In order to check interoperability between the standard services, we propose to use structured UML class diagrams. In such diagram, each work-package defines the interface of the offered and required services including the exchanged data definition. In order to be webservices compliant, we impose some structure and restriction to this diagram. Then, we automatically generate WebServices interfaces (in Web Service Description Language). Once the elementary services are defined, we have to adapt Maintenance process scenarios. We propose to specify them thanks to UML use case and UML sequence diagram. Thanks to these documents, it is possible to define workflows handled by a choreography server. Finally, in order to guarantee coherency between the different ontologies used by existing documents and applications, we define a dynamic database ensuring the link between an equipment and its documentation [70], [69], [74], [66].

6.2.2. Modeling of implementation architecture for automatic control applications

Key words: *robustness*, *performance evaluation*, *real-time*, *distribution*.

Participants: Fabrice Jumel, Nicolas Navet, Françoise Simonot-Lion.

In this study, we developed a method for the performance evaluation of automatic control applications implemented onto a distributed hardware architecture. For this purpose, we furnished a simulator, based on Matlab/Simulink, thanks to which we can analyze quantitatively how the implementation of a functional automatic control application influences the quality parameters of a controlled system. We describe how to model a computer based implementation and how to design a model that integrates both the controlled system, the functional view of the control law and its implementation on a distributed computer based architecture. We apply these principles on a case study and exhibit some results obtained by simulation. Thanks to this modeling approach and by using the developed simulator, we show that, if several regulations share the same processor, the quality of these regulation is better when using a policy that alternates the priorities than with a Fixed Priority Protocol policy [30].

6.2.3. Architecture Implementation Language for in-car embedded applications

Key words: *embedded systems*, *architecture implementation language*, *meta-modeling*, *UML.*

Participants: Paolo Castelpietra [PSA Peugeot-Citroën], Orazio Gurrieri, Gerardo Satriano, Françoise Simonot-Lion.

Within the ITEA EAST-EEA project, we participate actively to the definition of EAST-ADL, the common description language for architectural models in the automotive domain. The approach adopted by the members of the project is to make the definition of this language compliant to UML2. EAST-ADL seeks to capture all information needed for the development, from early analysis to implementation and evolution and meets specific automotive requirements such as support for automatic code generation in the context of common automotive hardware [60]. Six views on an in-vehicle embedded system are supported: the Vehicle View (VV) describes the mix of electronic functionalities implemented for a particular vehicle, the Functional Analysis Architecture (FAA) takes those functionalities and describes the functional decomposition with data exchanges, the Functional Design Architecture (FDA) adds further description of interface aspects, the Logical Architecture (LA) is the low-level flat software description, the Hardware Architecture (HA) describes the physical elements of the vehicle, the Technical Architecture (TA) includes hardware related communication and system management components and describes the environment in which the application software runs and finally, the Operational Architecture (OA) models the mapping of software components of the Logical Architecture onto the components of the Technical Architecture. A progression through these models is implicit, but as there is overlap between the architectures, the path through them can be adapted to the needs of the different domains and companies. However, the language defines the artifacts in a unique and consistent way. The description of the language elements is divided into parts corresponding to different language domains: the structure specifying structural relation, the behavior describing behavioral models, the requirements modeling requirements (functional and non functional ones) and their relations to other entities, the V&V elements describing entities related to testing and verification [63]. Finally, on the one hand, the language provides a support for the versioning and configuration management and, on the other hand for variant handling [58], [62].

6.3. Verification and performance evaluation

TRIO project team works on different techniques that allow to represent the physical time and the fact that the considered systems are subject to an uncertain environment. This includes time, timed Petri nets, timed automata, queuing systems as they are classically used as well as algebraic approach for dealing with these models. Furthermore, as the problem is often not only to prove the feasability of an application but also to find the best solution according to different criteria, we have to deal with discrete optimization techniques.

6.3.1. Timed automata analysis

Key words: *TIOSM*, *timed automata*, *verification*, *graph.*

Participants: Mohamed Khalgui, Xavier Rebeuf, Françoise Simonot-Lion.

We extend the method proposed in [85] to a priori validate a property on a system. In our framework, system and property are modeled by TIOSM containing cycles. The hard point is to identify matching cycles on both

automata. In this case, the classical TIOSM verification algorithm leads to combinatorial explosion. Therefore, we classically transform each Strongly Connect Component of each state machine into single cycles. Then, we show that it is possible to structure the verification to avoid combinatorial explosion [65].

6.3.2. Supervisory control in Petri nets

Key words: *supervisory control*, *routing*, *linear programming*, *formal languages*, *synthesis of Petri networks*.

Participants: Gülgün Alpan, Bruno Gaujal, Alessandro Giua [University of Cagliari, Italy], Mohsen A. Jafari [Rutgers University, USA].

In 2001, we have provided a technique to control Petri nets thanks to routing functions. In 2002, this technique has been used to study timed and routed continuous Petri nets (RPCTR). First, we have given linear programs which enable to compute the stationary speed of RPCTR with some hypotheses of minimal structures (we just suppose the existence of a "stationary regime") Then, we have used a new version of this linear program to compute the optimal routing functions (which gives the highest stationary speed). On going work includes the computation of rates, in general bounded, and live nets under stochastic and/or deterministic routings. As a second step, we have applied this technique to solve a concrete problem of optimal scheduling of buses in a town under some constraints on the resources and with some synchronizations.

Another application of this work was the design of discrete controller which ensures a structural specification (the absence of starvation) and another type of performance (the increase of the flow). The problem was solved in the framework of discrete time continuous Petri nets. However the change to a discrete controller brings many difficulties. In [23], we present the different difficulties and we propose a heuristic which gives a discrete controller from the continuous model.

6.3.3. Analysis of functional programs

Key words: *computation of functions*, *the halt problem*, *memory space*.

Participants: Bruno Gaujal, Jean-Yves Marion [Loria], Jean-Yves Moyen [Loria].

We have shown that we can use Petri nets to model the computation of a recursive function and thus to develop some tools to evaluate the memory space needed to achieve the computations. These results are presented in the PhD thesis of Jean-Yves Moyen which should be defended on December 17, 2003.

6.3.4. Evaluation of the Quality of Service in wireless communication systems

Key words: *Wireless networks*, *Quality of Service*, *Semi-Markovian processes*.

Participants: Claude Chaudet [INRIA-INSA Lyon], Bruno Gaujal, Isabelle Guérin [INRIA-INSA Lyon], Eric Thierry.

In the framework of our involvement in the AIR&D consortium, we have studied an asymmetric system (with hidden stations) of three stations in line which communicate through a wireless network with respect to the 802.11b protocol. This study shows that the asymmetry between the hearings for receptions and the interferences of emissions implies a quasi-starvation phenomena for the station in the middle of the two other ones. The modeling with a semi-Markovian process confirms the simulations which show that the central station can access the medium only 1% of the time. Using semi-Markovian processes in a very rigorous way to evaluate the performances of the 802.11b protocol has not been achieved yet in the literature, we are developing such an approach to provide a general and rigorous evaluation in the symmetric case (with no hidden station) and in the asymmetric case when stations are connected by a tree.

6.3.5. Evaluation of the reliability of distributed automatic control applications

Key words: *reliability*, *dependability*, *distributed control systems*, *fault tolerant architectures*, *TDMA*, *X-by-Wire*.

Participants: Fabrice Jumel, Nicolas Navet, Françoise Simonot-Lion, YeQiong Song, Cedric Wilwert.

Computer based control systems are real time systems. Models defined by automatic control specialists usually make strong assumptions: null processing time, synchronous activities. Most implementations do not fulfill

these hypothesis; in fact they induce a lot of temporal faults such as losses, delays or jitters. The different questions to answer are:

- in which ways the implementation influences the behavior of the controlled system?
- how to define the required functional and temporal characteristics?
- how to avoid temporal faults that might degrade the system functioning?

In [8], we propose some contributions in order to improve the design of computer based control systems with regards to the above identified issues. For evaluating the performances of an implementation, when analytical studies are not possible, we applied the modeling principles presented in paragraph 6.2.2 and used the simulator that implement them [64]. We obtained some counter-intuitive results such as the fact that a controlled system is more dependent on average response time than on some deadline missings. Another contribution of [8] consists in proposing scheduling techniques that increase predictability and are well-suited to automatic control applications presented in section 6.1.4.3. Finally, we proposed in [31] a general method for evaluating the reliability of a computer based control applications under perturbations. This method based on Markov chain analysis enables the designer to find an implementation support (hardware, redundancies, distribution) that meets the specified constraints in terms of probability of fault occurrence.

Steer-by-wire systems must meet not only reliability but also real-time requirements. Some studies initiated in CARAMELS Research Team for Technology, developed an integrated approach for evaluating both the temporal performance and the behavioral reliability of Steer-by-wire systems taking into account the delay variation introduced by network transmission errors [46],[45]. The considered temporal performance is the Quality of Service perceived by the user, i.e. the vehicle stability. Tests in vehicles and simulations have been realized to estimate the maximum tolerable response time of the system, and to evaluate the impact of this delay on the Quality of Service. We quantify then the worst case response time of the system for a generic architecture based on TDMA protocol but independent of the communication network (could actually be TTP/C or FlexRay), and apply these generic results to a case study. We further define the notion of "behavioral reliability" as the probability that "the worst case response time is less than a given threshold" [54]. We applied this technique to a real case study provided by PSA Peugeot-Citroën. In this case the behavioral reliability was evaluated and linked to the Safety Integrity Levels defined in IEC61508-1 standard. Based on this behavioral reliability concept, the final objective of our work is now to propose a new dependability analysis method for X-by-Wire systems by taking into account both dynamic performance, fault-tolerance mechanisms and static redundancy of the system .

6.3.6. *Response time evaluation techniques for real-time QoS guarantee*

Key words: *Ethernet switch*, *delay evaluation*, *Markov Process*, *Network Calculus*.

Participants: Anis Koubâa, Liping Lu, Anatoli Manita [Université d'État Lomonossov - Moscou], François Simonot [IECN - UHP Nancy 1], YeQiong Song, Zhi Wang.

For real-time QoS performance evaluation, we mainly focused on evaluating the probability distribution of the response time for probabilistic real-time guarantee and analyzing the upper bound of response time for deterministic real-time guarantee.

Concerning the evaluation of the probability distribution of the response time we have been interested in an Ethernet switch as the switched Ethernet is more and more considered as an alternative to replace partially fieldbuses in factory automation communication systems. In [68] we proposed an exact mathematical model of an Ethernet switch based on a multi-dimensional Markov process. We discussed both continuous and discrete time variants of the proposed model. We put forward the problem of asymptotic analysis of steady-state distribution of the workload (from which we can easily deduce the response time distribution) to evaluate the performance of the system. This approach is deeply related with the recent results on large deviations in Markovian systems. We provided a comprehensive study of a particular model called symmetrical geometric. For the special case of Binomial input flow, the asymptotic approach is compared with the exact recurrent formulae highlighting the numerical efficiency of the asymptotic approach.

Unlike the response time probability distribution which is interested in stochastic trajectories, the response time upper bound evaluation is mainly based on the worst case trajectory analysis. There are two main approaches developed to perform the analysis of the upper bounds. The first one is issued from Liu and Layland theory [86], and gives what is called the worst-case response time for a given set of periodic or sporadic sources scheduled with fixed priority. The second approach made by Cruz [80] gives an upper bound on delay for a set of message streams constrained by (σ,ρ). When industrial switched Ethernet is considered, as the main part of the traffic is periodic or sporadic, both approaches could be used. In [33] we compared the bounds of both approaches for periodic and sporadic periodic arrival processes with Fixed Priority scheduling. For this purpose, a relationship is given between jitter and the maximum burst size for an optimal transposition from the classical task model to (σ,ρ)-constrained model. We also proposed an hybrid method to optimize upper bound given by Cruz's approach. A comparison study showed the advantage of our method and how presented results are useful to improve backlog estimation in a multi-hop network.

6.3.7. Schedulability analysis under (m,k)-firm policies

Key words: *(m, k)-firm*, *EDF*, *Distance Based priority protocol*.

Participants: Anis Koubâa, Jian Li, YeQiong Song, Zhi Wang.

Compared to the traditional hard real-time guarantees that are equivalent to $(k, k) - firm$ constraints, guarantying m out of any k consecutive instances of a recurrent task induces less demand on the system processing capacity. However for taking advantage of this lower processing requirement, one has to find a schedulability condition specific for $(m, k) - firm$ guarantee.

Existing schedulabilty analysis [91], [89] considered the scheduling under the FPP policy. In [67], we derived a sufficient schedulability test for deterministic $(m, k) - firm$ guarantee under NP-DBP-EDF (Non Preemptive - Distance Based Priority - Earliest Deadline First) scheduling.

6.3.8. Stochastic discrete systems

Participants: Bruno Gaujal, Eric Thierry.

Key words: *stochastic process*, *social sciences*.

We have collaborated with Laszlo Gulyas, researcher at the "Computer and Automation Research Institute of the Hungarian Academy of Sciences". The problem submitted to the TRIO team was the study of a stochastic process which is present in complex discrete systems modeling some growth processes in social sciences. We are currently writing down the mathematical results we obtained, they confirm simulation results previously done by Laszlo Gulyas.

6.3.9. Partially ordered sets

Participants: Anne Bouillard, Bruno Gaujal, Eric Thierry.

Key words: *2-dimension*, *partially ordered sets*, *probabilistic method*, *lattice*, *trace group*.

6.3.9.1. 2-dimension of partially ordered sets

A bit-vector encoding of a partially ordered set $P = (X, \leq)$ consists in associating with each element x in P a subset $code(x)$ of a fixed set $S = \{1, ..., k\}$ such that the order on P corresponds to subset inclusion, namely $x \leq y$ if and only if $code(x) \subseteq code(y)$. Given a partially ordered set $P = (X, \leq)$, the cardinality of the smallest set S such that there exists a bit-vector encoding of P using S, is called the 2-dimension of P. In our work, we study the computational aspects of the 2-dimension and of the corresponding encodings. In particular, we provide new approximation results [14].

Moreover, the only upper bound known today for the 2-dimension of an ordered set $P = (X, \leq)$ has been: $dim_2(P) \leq |X|$. We have found a new bound using a probabilistic method: $dim_2(P) \leq 2e(|D(P)| + 1) \ln(|X|)$ where $D(P) = \{y \in X | y \leq x\}$ [72].

6.3.9.2. Lattices of tilings

By introducing a new transformation on lattices, we give a new interpretation of known results on lattices of tilings by dominos and we extend these good properties to some other spaces admitting a lattice structure [57].

6.3.9.3. Integer partitions

We have studied a transformation defined on integer partitions which consists in decrementing each integer of the partition and then add a new integer which is the sum of removed values. We study the dynamics obtained when iterating this transformation and we show that it converges to partitions P close to $(1, 2, ..., n)$ [40].

6.3.9.4. Trace group

The trace group (monoïd) is the quotient of a free group (monoïd) by commutation relations between some pairs of generators. We show that the Mœbius inversion formula known for the trace monoïd (and proved by Cartier et Foata in 1969) has an analogue for the trace group [25] and we provide some extensions of this formula [9].

7. Contracts and Grants with Industry

7.1. PSA-Peugeot Citroën contracts - Safety of embedded networks

Participants: Fabrice Jumel, Nicolas Navet, Françoise Simonot-Lion, YeQiong Song, Cédric Wilwert.

A collaboration between TRIO and PSA Peugeot-Citroën takes place in CARAMELS Research Team for Technology. Its aim is to develop a methodology in order to evaluate the dependability characteristics of an embedded communication architecture for X-by-Wire applications. Last year, we provided a comparative analysis of classical embedded protocols. This year we studied how to formally link the performances and Quality of Services evaluated at communication system level to the dependability and more specifically the safety required at vehicle level. The main purpose is to contribute to a certification method that guarantees a "Safety Level" of an embedded electronic system. This last point is one of the future trends of TRIO [29], [54].

8. Other Grants and Activities

8.1. National Grants

8.1.1. CNRS Specific Actions

TRIO members participate actively to several CNRS Specific Actions in 2003.

- AS CNRS 195 - Composants et architectures temps réel : In this research group, we study how to design a distributed real time application thanks to an approach "Components / Architecture". The first point is to identify what is a component in the context of real time application and the second one to specify models and / or methods for their modeling, their validation at component level and at composition of components level.
- AS CNRS 124 - Etudes de commandes de systèmes tolérants aux fautes : The main topic of this research group is concerned by fault tolerance of automatic control system thanks to active methods. The following aspects are studied: instrumentation architecture, identification of the links between failure detection and control activities, mastering the methods complexity regarding to real time implementation.
- AS CNRS 106 - Conception faible consommation : Lowering the energy consumption becomes a major issue in the design of embedded systems. This problem can be tackled at different levels: hardware design, architectural choices, assembly code generation, scheduling policies, etc The aim of the low-Power Design group is to allow researchers from all these fields to identify the critical issues where research efforts have to be placed and to share their experience.
- AS CNRS 80 - Systèmes dynamiques et modélisation en algorithmique

8.2. European Projects

8.2.1. European ITEA Project EAST-EEA

Participants: Orazio Gurrieri, Nicolas Navet, Gerardo Satriano, Françoise Simonot-Lion.

This project(2001 - 2004) is supported, in France by the French Under-Ministry for Industry) - *Embedded Electronic Architecture for the European Automotive Industry* - The partners are Audi, BMW, Centro di Richerche Fiat, Daimler Chrysler, ETAS, Finmek Magneti Marelli, Opel Powertrain, PSA Peugeot-Citroën, Renault, Robert Bosch, Siemens VDO Automotive, Valeo, VECTOR Informatik, Volvo, ZF Friedrichshafen, CEA-LIST, IRCCyN, INRIA, Linköping University of Technology, Mälardalen University, Paderborn University, Royal Institute of Technology, Technical University of Darmstadt, ECOO/LORIA, TRIO/LORIA). To define on the one hand, a EAST Architecture Description Language and a coordinated approach for embedded architecture validation and test, and, on the other hand, a common embedded real time middle-ware are the two main objectives of this project [62], [58], [60], [59], [55], http://www.east-eea.net.

8.2.2. European ITEA Project PROTEUS

Participants: Eric Hennequin, Philippe Hubert, Xavier Rebeuf, Jean-Pierre Thomesse.

The project Proteus is supported, in France by the French Under-Ministry for Industry). Its purpose is to specify a generic platform for e-maintenance for industrial process and transport domain. The partners are Cegelec, Cegelec AT, AKN, IBS, IML Cottbus, Schneider Electric, Pertinence Data, ARC Informatique, TIL Technologies, LIP6, IFAK, TU Münich, LAB, L&D/LORIA, LIFC, MAIA/LORIA, TRIO/LORIA. This project intends to define a generic platform for e-maintenance including SCAD systems, IA diagnosis systems, ERP and CMMS systems [24], [70], [69], [74], [66], [73].

8.2.3. European Program IST 2001-825, REMPLI

Participants: Liping Lu, Raul Santos Brito, YeQiong Song.

The major goal of the project is to provide real time collection and control system for the energy distribution and consumption, using power lines and Internet for communication. Another goal is to design and to develop a broadband power line communication system that will be incorporated to a remote meter reading system and let to read data on various kinds of energy consumption over the Internet. In order to achieve the goal, TRIO is working within the following tasks: concept of the broadband power line communication for multi-entity communication systems, design and development of a set of hardware/software solutions implementing the concept, study of the system major characteristics.

8.3. International Cooperations

- PRA SI01-04 on “Analysis and Improvement of High Speed Ethernet in Realtime Capability” is a biannual bilateral research program co-funded by AFCRST in France and the Chinese ministry of the science and technology. The two partners are TRIO team of the LORIA and the National Laboratory of Industrial Control Technology of Zhejiang university. Our activities focus on the development of (m,k)-firm scheduling algorithms and their use in industrial switched Ethernet. As part of this program we received two visiting researchers (Jiming Chen and Zhi Wang) for totally fives months and planned to participate to the final seminar at the end of this year in Zhejiang university.
- TEMPO-QoS is a project INRIA-ICCTI between TRIO and IEETA, (Instituto de Engenharia Electronica e Telematica de Aveiro) whose aim is to study how specify, evaluate and control the temporal quality of service for embedded networks by applying methods classically used in automatic control.

8.4. Visits

In 2003 TRIO has invited the following researchers for short term visits

- Ali Yalcin, Assistant professor, University of Florida in Tampa (USA) (15 days in March 2003),
- Dinard van der Laan , University of Leiden (10 days in June 2003).
- Sergio Junco, Professor, Rosario University, Argentina, (10 days in november 2003)

9. Dissemination

9.1.1. Conference organization, Editing activities

- Eric Thierry was a member of the organization committee of the thematic institute Exystence (ETI) "Discrete and Computational Aspects of Complex Systems", from June 16 until July 4, in ENS Lyon.
- Emmanuel Hyon has organized a conference on "young researchers: which positions in industry?" in collaboration with student associations in Lyon.
- Xavier Rebeuf was co-responsible of the organization committee of MSR'2003 (Metz-october 2003),
- TRIO permanent members participate to the program committee of FET 2003, SICICA 2003, RTS'02, RTS'03, MSR'03, SLENB2003, WODES'04, RTS'04, WFCS'04, ETR'03, ETFA'03, CIFA'04, IEEE Mechatronics 2004
- Gülgün Alpan is an invited editor of the special issue on flexible manufacturing of the *Robotics and Computer integrated Manufacturing Journal.*.
- Françoise Simonot-Lion and Jean-Pierre Thomesse are reviewers for TSI, Françoise Simonot-Lion and YeQiong Song for IEEE Transactions on Industrial Electronics, Gülgün Alpan-Gaujal and Françoise Simonot-Lion for IEEE Transactions on Robotics and Automation, YeQiong Song for Computer Communications and Control Engineering and Practice, Bruno Gaujal for Journal of Discrete Event Dynamic Systems, Nicolas Navet for IEEE Transactions on Computers, IEEE Transactions on Vehicular Technology, Computer Communications and IEE Proceedings Software.
- YeQiong Song organized the one day session on "Distribution, networks and Quality of Service" at ETR'03.

9.1.2. Action for the research community

- Several members of TRIO participate actively to the GDR ARP STRQdS, Ordo and RGE,
- Françoise Simonot-Lion is co-responsible with François Vernadat (LAAS Toulouse) of "Quality of Service of Real-Time Systems" group of GDR ARP,
- Françoise Simonot-Lion is member of steering committee of CNRS - STIC RTP 20 ("Reliability, Diagnostic, Fault tolerance"),
- Françoise Simonot-Lion is member of scientific committee of ACI Sécurité,
- Bruno Gaujal et Gülgün are members of the working group SdC of Grenoble;
- Bruno Gaujal is an elected member of the evaluation committee of INRIA.
- Jean-Pierre Thomesse is member of Scientific Orientation Committee of LORIA,
- Xavier Rebeuf is elected member of the administration board of Institut National Polytechnique de Lorraine.
- Eric Thierry is responsible of "Séminaires du MIM "(Magistère d'Informatique et Modélisation de l'ENS Lyon) (Lien: http://perso.ens-lyon.fr/eric.thierry/SeminaireMIM/)
- Françoise Simonot-Lion is member of the Program committee of INRIA-Lorraine
- YeQiong Song is member of operation committee of QSL action,
- Teaching members of TRIO are elected to CSE of sections 27 and / or 61. Françoise Simonot-Lion was elected member of CNU section 61.

9.1.3. Colloquium, seminars, invitations

- Gülgün Alpan has been invited for one week in the University of Florida in Tampa (Jul. 2003).
- Bruno Gaujal is invited to the Mathematiches Forschunginstitut Oberwolfach for the workshop on Applied Probability (Dec. 2003)
- Françoise Simonot-Lion was invited as keynote speaker at IFAC FET'2003 Conference,
- Nicolas Navet and Françoise Simonot-Lion were invited as keynote speakers at Automotive Engineering Conference,
- Nicolas Navet, Xavier Rebeuf, Françoise Simonot-Lion were chairpersons of FET'2003, RTS'2003, MSR'2003 Conferences.
- Nicolas Navet organized in may 2003 a seminary on "Embedded Systems" in the context of QSL and in december 2003 the seminary "Scheduling" gathering projects Algorille, MACSI and TRIO [39].

9.1.4. Teaching activities

The permanent members of TRIO are teaching in INPL and Université Henri Poincaré-Nancy 1. They participate also to DEA "Informatique de Lorraine", DEA "Algorithmique" of University Paris VI, DEA "Informatique" of ENS-Lyon .

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