INRIA

INSTITUT NATIONAL DE RECHERCHE EN INFORMATIQUE ET EN AUTOMATIQUE

# *Project-Team TRIO*

# *Temps Réel et InterOpérabilité (Real Time and InterOperability)*

*Lorraine - Rhône-Alpes*

THEME COM

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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 [78].

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 [87]. We consider Markovian and semi-Markovian models but also more general distributions under stationary and ergodic assumptions [77], [76].

### *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) [85] and components. 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 Timed Automata 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], [80], [79]. This is why we focus on Weakly-Hard-Real-Time constraints such as $(m, k)$-firm constraints [79], [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.
- **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 follows two objectives: on one hand, the monitoring of chronic patients (kidney disease, cardiac decompensation) and, on the other hand, the remote monitoring and 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. In this filed, The interest for TRIO is the broadening of communication protocols studies and applications, and of interoperability requirements [55][74], [94].

# 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.

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

**Participant:** Orazio Gurrieri.

Within the context of ITEA EAST-EEA project, a tool has been developed for the description of in-vehicle embedded systems, in EAST-ADL Language. The meta-model defining the language and the tool are based on GME 2000, developed at Vanderbilt University (USA). This tool allows a description of an embedded system at each level of its development process and for each required view. The realization was initiated in 2002, by TRIO team in cooperation with the team "Real Time" of IRCCyN. The last version of the prototype is used by the industrial members of the EAST-EEA project [65], [33], [34].

# 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 Powerline communication systems*

**Keywords:** *Fieldbus*, *Powerline communication*, *QoS*, *Real-time*.

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

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 (http://www.rempli.org) we are developing a new communication infrastructure based on PLC technology to provide not only high data 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 very challenging.
In [59] we firstly analyzed the QoS constraints imposed by the REMPLI applications and then discussed how these constraints can be guaranteed by the PLC network. As the results, traffic classes have been proposed; lower and upper bounds on data transfer delay are evaluated. We also concluded that slave node initiated protocol must be added to the master/slave model in order to provide shorter communication delay. This document will be used to guide the protocols/services design of the REMPLI network and especially the QoS management mechanisms. The network and management layers protocols are proposed in [73] which take into account the specific characteristics of the PLC physical layer. We mainly contributed to the dispatcher concept which is used at each master node to schedule the traffics generated by the different classes of traffic under different QoS requirements [59]. The primary role of the dispatcher is to decide what is the next packet to send among: 1) periodic polling packets, 2) aperiodic request packets coming from transport layer (or already queued), 3) consequent network layer request packets generated by a confirm/response packet sent by a slave node. Simulations have shown its usefulness for providing the required QoS.

### *6.1.2. Network analysis*

**Participants:** Bruno Gaujal, Eric Thierry.

The article [29] presents a theoretical modeling of a small but characteristic scenario that shows a great inequity in medium access between nodes using the IEEE 802.11 DCF mode. In this configuration, two terminals evolve independently and are almost never synchronized, which results in a serious performance issue for a third emitter in between. The results are compared to simulation results and are followed by a discussion on the different performance loss causes.

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

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

**Participants:** Jiming Chen, Jian Li, Anis Koubâa, YeQiong Song.

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], [95].

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 [93].

The Matrix-DBP algorithm we proposed [88] has been extended to take into account the distance to exit failure states during the dynamic priority assignment. Dynamic failure ratio and delay are evaluated. Simulation results revealed the effectiveness of this extension to provide better QoS [31]. Another extension has also been proposed which consists to also deal with aperiodic streams. The idea is to replace the period by the average inter-arrival time. Again with the simulations, we reduced the dynamic failure ratio [30].

The dynamic QoS control according to the (m,k)-model in packet switching network is one of our main applications. For this purpose we defined the concept of “loss-tolerant QoS with graceful degradation” that consists in guaranteeing an acceptable level of QoS for loss-tolerant real-time applications in overload situation. Our approach is mainly applied to multimedia networks assuring the delivery of real-time loss-tolerant multimedia flows such as MPEG video broadcast, Voice over IP, audio streams, etc. Those objectives have been achieved by the definition of a novel scheduling algorithm called (m,k)-WFQ to provide loss-tolerant QoS with graceful degradation. This algorithm has been validated through different and complementary techniques: network calculus based analysis, Opnet simulation and implementation in test bed platform under linux software router (Click Modular developed by MIT) [45], [43],[44],[8], [54], [9], [18].

### 6.1.4. Error Confinement

**Participants:** Bruno Gaujal, Nicolas Navet.

The network CAN is a standard in the car industry. We analyzed in [13] 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 two states and have identified some issues with the existing mechanisms (reaching times of states “bus-off” too short, 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.

### 6.1.5. Scheduling

**Keywords:** *EDF*, *Round-Robin et battery model*, *low-power*, *scheduling*.

**Participants:** Guillaume Huard [IMAG], Bruno Gaujal, Mathieu Grenier, Nicolas Navet, Gaurav Singhal, Eric Thierry, Denis Trystram [IMAG], Cormac Walsh, Olivier Zendra.

*6.1.5.1. Scheduling for grid*

We have studied the new paradigm of convex scheduling (which is seen as a promising alternative to classical strategies to carry computations over grids) over simple structures (trees, acyclic graphs) to assess its theoretical complexity. This was presented in [35].

*6.1.5.2. Scheduling under energy consumption minimization*

Embedded systems have a growing need of computational power. For increasing autonomy and reliability, all these systems will benefit from techniques reducing the consumption by varying the clock frequency of processors in function of the needs since the dissipated power is at least the square of the frequency.

In [15] and [63], we have shown how to compute the best clock frequency for a processor in order to execute a set of tasks. Our algorithm runs in the worst case in O(N) (where N is the number of tasks) if tasks have FIFO constraint [15] and in O(KN2) in the general case [63] where K<<N depends on structural property of the task set and is thus an improvement over the classical algorithm of Yao *et al* that runs in O(N3). Furthermore, we provide a probabilistic analysis of the complexity when the tasks are random [63]. For Poisson arrivals and exponentially distributed latencies, we show that the asymptotic complexity is O(N2 log(N)) and always lower than O(N2 sqrt(N)) whatever the distributions involved. This 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. These latter algorithms are linear in the number of tasks and these complexities are shown optimal [15]. 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 [15].

In [28], 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.

We analyzed the recovery and rate capacity effect for batteries used in embedded systems in [52] for understanding the battery recovery behavior, which help to determine an optimum discharge profile and hence result in significant improvement in battery lifetime. This lead us to propose [52] a stochastic battery model which has been shown to be very accurate on several experiments.

In [38], we present a quadratic time algorithm using dynamic programming to compute the set of $N$ speeds that a processor should use to minimize its energy consumption while meeting real time constraints. This computation is based on the energy consumption as a function of the clock frequencies and a statistical knowledge of the likelihood of using any frequency in the range from zero to the maximal possible frequency.

*6.1.5.3. New scheduling policies*

We proposed in [64] a schedulability analysis technique that can be applied to a large class of real-time scheduling policies that are important in practice, namely the "time independent scheduling policies" [86]. Using a stochastic search algorithm inspired from Hill Climbing, we explored this class of policies and found new policies that behaves well in terms of feasibility, mean response times and under transient overloads. This study have been conducted in the preemptive and non-preemptive case for concrete and non-concrete tasks.

### *6.1.6. Real-time middleware*

**Keywords:** *TDMA*, *X-by-Wire*, *design pattern*, *embedded system*, *fault tolerance*, *frame packing*, *real time*, *scheduling*.

**Participants:** Bruno Gaujal, Nicolas Navet, Ricardo Santos Marques, Françoise Simonot-Lion, YeQiong Song, Cédric Wilwert.

*6.1.6.1. Middleware Configuration*

In 2003, we identified a reference model of an in-vehicle embedded middleware in terms of design pattern. This year we specified a deploiement method for this reference model instantiation. More specifically, we

identified the active objects (tasks, frames) deduced from this pattern and pertinent with regards to an optimal configuration of the middleware; furthermore, we defined how to deploy the different methods in middleware tasks. Presently we are developping heuristic for an optimal configuration of the middleware in terms of scheduling attributes for tasks and frame-packing and scheduling attributes for frames [72]. Implementation constraints, such as not exceeding 16 tasks on OSEK/VDX OS or minimizing the CPU load, are taken into account.

*6.1.6.2. Fault-tolerance on TDMA-based applications*

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 [47][14], 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. This is proved by using majorization techniques. Finally we show how these ideas can be adapted for the TTP/C protocol [14] with possesses a clique avoidance algorithm that interferes with the analysis made in the general TDMA case.

*6.1.6.3. In-car middleware*

On the one hand, we analyzed in [71], the properties of different middlewares embedded in a vehicle (OSEKCom, OSEK FTCom, Volcano). On the other hand, we studied and compared the fault tolerance services that are furnished by the most currently used in-vehicle embedded networks (CAN, TTP/C and FlexRay) and identified what has to be done at middleware level for providing the same level of dependability to the communication functions [19][71][48][51].

### *6.1.7. Routing in networks of queues*

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

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

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 [61][62][36][37].

## 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*

**Keywords:** *Real time data*, *data acquisition component*, *integration platform*, *interoperability management*, *maintenance*.

**Participants:** Eric Hennequin, Philippe Hubert, Gregory Jacquier, Kamil Karbowiak, Mohamed Khalgui, Xavier Rebeuf, Jean-Pierre Thomesse, Laurent Vallar.

The PROTEUS project aims to create an integration platform for the maintenance of industrial process. Within this 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 2004 with the definition of the objects involving in the Data Acquisition Server. These objects and their relations are used to define a part of the global onthology [55][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 2004, we first focus on a methodology to define and deploy the different services over the platform. We specified the platform configuration at run time and compile time and defined a database to store relations between Web Services. Such database has to be compliant by construction with the defined model (the onthology). Therefore, we proposed a Web Service checking the consistency of the database with regard to the onthology. Finally, we focused on the definition of composed Web Services. They partially automate the maintenance scenario. [39][53][55].

In the Schneider Electric context, the design and the maintenance onthology is deduced from a design tool called LBT. Such tool allows to build a unique hierachy of concepts. Each concept is defined by a set of views. Based on this definition, we proposed to construct low coupled components. We have adapted the PROTEUS platform to exploit such characteristics [75][67].

### *6.2.2. Component based approaches*

**Keywords:** *Real Time Component*, *contracts*, *off-line composition*, *on-line composition*.

**Participants:** Philippe Hubert, Mohamed Khalgui, Yacine Moussouni, Xavier Rebeuf, Françoise Simonot-Lion, Francesco Zampognaro.

This work can be divided into two studies. The first one deals with critical components where composition is done statically off-line [70]. The second study deals with contract mechanism occuring at run-time to ensure time properties.

The first study is based on the Function Block approach, which is one of the most used component standard in Real Time industry. A Function Block is a reactive module implementing one functionality. Actually, this standard provides a static description of components. We propose to enrich the Function Block description in order to provide a priori (model-checking) and a posteriori (test) validation of time properties. The key point is to abstract the behavior of the component in terms of required and offered services.

We model the component behavior as well as the hardware ressource thanks to timed automata [42]. Therefore, properties can be checked using the model checker UPPAAL. We define composition rules for function block in order to validate a function block network. Finally, we define a schedulability condition on the Function Block ensuring its correct execution on a device. Such condition guarantees that no input event

of a Function Block will be discarded. Note that such situation can occur with regard to the standard but is not suitable in a critical application [41].

The second study deals with contract mechanism at run-time. We focus on the OPC protocol which allows a remote monitoring of PLC and SCADA. The protocol defines contracts between components to obtained periodic values, for example. Note that such protocol is based on Web services. Therefore, there is no guarantee on the response time . We propose a mechanism to analyse and predict the network behavior. Then, we propose a re-negociation at run-time to adapt the contract to the network capabilities if possible. A small prototype has been developed to show the interest of such solution into a distributed environment [74].

### 6.2.3. Modeling of the implementation architecture for automatic control applications

**Keywords:** *distribution*, *performance evaluation*, *real-time*, *robustness*.

**Participants:** Fabrice Jumel [CITI, Lyon], GianCarlo Massari, Nicolas Navet, Françoise Simonot-Lion, YeQiong Song, Cédric Wilwert.

Last year, we developed a simulator, based on Matlab/Simulink, allowing to analyze quantitatively how the implementation of a functional automatic control application influences the quality parameters of a controlled system. The initial purpose was to compare some scheduling policies [40]. In 2004, we refined this approach in order to evaluate the dynamic reliability of X-by-Wire applications. The former simulator is integrated to SimulinkCar, a simulator of the vehicle behaviour (developped at PSA Peugeot-Citroën). This simulator is used for the quantification of the tolerable failures at the communication level (loosed messages, delayed messages) for TDMA based protocol (TTP/C, FlexRay) [57][23].

### 6.2.4. Architecture Description Language for in-car embedded applications

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

**Participants:** Orazio Gurrieri, 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 aims to capture all information needed for the development, from early analysis (vehicle view, functional views, design view) to implementation (logical view, hardware and technical views, operational view), to master the variation points at each level and to meet specific automotive requirements such as support for automatic code generation, traceability, validation and verification. However, the language defines the artifacts in a unique and consistent way. [65], [34], [33], [11], [32]. EAST-ADL specification is available on the web site of ITEA EAST-EEA http://www.east-eea.net.

## 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. Supervisory control in Petri nets

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

**Participants:** Bruno Gaujal, Alessandro Giua [University of Cagliari, Italy].

The latest (and most complete) version of our result on throughput of continuous Petri net is now available in [12], where the minimal assumptions for existence of throughputs are given.

The case of discrete timed Petri nets is much more complicated and is studied in [27]. We give a method to compute the throughput in a timed live and bounded free-choice Petri net under a total allocation. We

also characterize the conflict-solving policies that achieve the smallest throughput in the special case of a 1-bounded net. It does not correspond to a total allocation, but "almost".

### *6.3.2. Evaluation of the reliability of distributed automatic control applications*

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

**Participants:** GianCarlo Massari, Nicolas Navet, François Simonot [IECN, UHP Nancy I], 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?

We analysed such systems embedded in vehicle, especially "steer-by-wire" systems and we developped a method for the evaluation of their dependability, that depends on the communication subsystem. The studied "steer-by-wire" systems are those for which the order (steer angle, steer speed) given by the driver is transmitted to the control laws implemented on redundant micro-controllers thanks to a communication network (redundant bus). This leads to an unavoidable delay between the production of the order and its consumption by the control law. In a first step, thanks to a continuous model of the whole system (control law and controlled system), developped by PSA Peugeot-Citroën, a parameter is computed that provides a QoS level for the application. For ensuring an acceptable behaviour of the vehicle, this QoS parameter has to be more or equal a given value. SO, we evaluate the value of the QoS parameter for several delays between the production and the consumption of the driver's order and we determine the greatest age of the driver's order, termed the "Worst tolerable delay", at its consumption point by the control law, that gives a tolerable behaviour of the vehicle. This is used for the specification of a "TDMA round" ensuring that, at its consumption point, the value of a driver's order will never be too old.

Furthermore, we extend this approach in order to verify the respect of the dependability of the X-by-Wire system under randomly arrived perturbations (e.g. EMI). For this purpose, we firstly derived the error period length for a given perturbation period, in terms of the number of communication cycles (time is thus discrete), thanks to this we obtained the expression for evaluating the behavioural reliability, defined as the probability of exceeding the "worst tolerable delay". The technique to obtain this probability is based on the mathematic results of the consecutive-k-out-of-n:F systems [81]. 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.

### *6.3.3. Response time evaluation techniques for real-time QoS guarantee*

**Keywords:** *Network calculus*, *Response time evaluation*, *Worst-case analysis*.

**Participants:** Anis Koubâa, YeQiong Song.

For real-time QoS performance evaluation, we have mainly focused on analyzing the upper bound of response time for deterministic real-time guarantee. 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 or majoring 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 which gives the worst-case response time for a given set of periodic or sporadic sources scheduled with fixed priority. The second approach, termed "Network Calculus" gives an upper bound on delay for a set of message streams constrained by $(\sigma,\rho)$. In [17],

we compared the bounds of both approaches for periodic and sporadic arrival processes with Fixed Priority scheduling. For this purpose, a relationship is given between the jitter and the maximum burst size for an optimal transposition from the classical task model to ($\sigma$,$\rho$)-constrained model. We also proposed a hybrid method to optimise 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.

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

**Keywords:** *(m;k)-firm*, *DBP*, *mechanical words*, *schedulability*.

**Participants:** Emmanuel Hyon, Ning Jia, Jian Li, Françoise Simonot-Lion, YeQiong Song.

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.

*6.3.4.1. Schedulability analysis of non pre-emptive DBP-EDF*

We addressed in [46] the problem of deterministic guarantee of (m,k)-firm real-time requirement for a set of periodic or sporadic jobs sharing a common server. DBP has been choosen for its interesting feature of dynamically assigning priorities, based on the recent state of the system (k-sequence). So it is suitable for QoS management in adaptive real-time systems and networks. Our main contribution is the expression of the sufficient condition under non pre-emptive DBP-EDF scheduling for deterministically guaranteeing (m,k)-firm constraint. This result is necessary for the system server capacity dimensioning. It could be implemented as an admission control procedure, within IP networks (e.g. Internet-based control systems, Remote control and monitoring systems based on Internet and power line networks such as what has been proposed in REMPLI project) for dynamically managing real-time QoS according to (m,k)-firm model.

*6.3.4.2. Schedulability analysis using properties of mechanical words*

In [68] we showed a new method for the schedulability analysis of the task sets under (m,k)-firm constraints using the properties of the mechanical words. We are only interested in the scheduling problem under fixed (m,k) patterns. First, we proved that the patterns defined in the literature can be characterized in the form of the mechanical words with which the schedulability proofs are largely simplified. Then, by identifying the defaults of these patterns, we propose a new way, based on the cellular line, to determine the (m,k) patterns of the tasks. The simulation results showed that our approach achieves an improvement of the schedulable region.

### 6.3.5. Partially ordered sets

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

**Participants:** Anne Bouillard, Bruno Gaujal, Eric Thierry.

*6.3.5.1. 2-dimension of partially ordered sets*

Bit-vector encodings of a poset $(P, \leq_P)$ consist in associating to each vertex $x$ of $P$ a subset $code(x)$ of a fixed set $S = \{1, ..., k\}$ such that the order on $P$ coincides with subset inclusion, i.e., $x \leq_P y$ if and only if $code(x)$ is included in $code(y)$. Given a poset $(P, \leq_P)$ the cardinality of the smallest set $S$ such that there exists a bit-vector encoding of $(P, \leq_P)$ using $S$ is called the 2-dimension of $(P, \leq_P)$. In this paper, we investigate computational aspects of this parameter and the generation of compact bit-vector encodings. It contains a survey of previous results, as well as new complexity results and new open problems. This is published in [16].

*6.3.5.2. Trace group*

Traces are a nice theoretical tool to study discrete event systems with parallel features.

A trace group (monoid) is the quotient of a free group (monoid) by relations of commutation between some pairs of generators (traces). We prove in [10] an analog for the trace group od the Möbius inversion formula for the trace monoid (Cartier and Foata, 1969) .

# 7. Contracts and Grants with Industry

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

**Participants:** Nicolas Navet, François Simonot, 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. The main objective of this contract is to formalize the link between the performances and Quality of Services evaluated at communication system level and 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 [57].

## 7.2. Schneider Electric Industries

**Participants:** Philippe Hubert, Yacine Moussouni, Xavier Rebeuf.

Since September 2004, a collaboration between TRIO and Schneider Electrics aims to define and experiment an integration platform for the monitoring of processes controled by Schneider equipement. Such platform is partially based on results of the PROTEUS project. But contrary to the Proteus approach, the design of the process itself as well as its maintenance definition relies on a global component based approach. Each components is defined thanks to a set of coherent views [67].Such design methodology allows to deploy low coupled components on the platform. Moreover, we propose to handle QoS through contract management between components [74].

# 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 [70].
- AS CNRS 124 - Etudes de commandes de systêmes 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 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.

## 8.2. European Projects

### *8.2.1. European ITEA Project EAST-EEA*

**Participants:** Orazio Gurrieri, Nicolas Navet, 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 [65], [33], [34], [11], [32], http://www.east-eea.net.

### *8.2.2. European ITEA Project PROTEUS*

**Participants:** Eric Hennequin, Philippe Hubert, Gregory Jacquier, Kamil Karbowiak, Xavier Rebeuf, Jean-Pierre Thomesse, Laurent Vallar.

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, LD&/LORIA, LIFC, MAIA/LORIA, TRIO/LORIA. This project is based on open technologies like Web Services, ontology definition (protegee), workflows... In this project, TRIO focuses on platform architecture design, interoperability, composed services, models for data acquisition [39][53][55][24][60]. Several prototypes applied to different maintenance domains are currently in development in order to validate the approach (see http://www.proteus-iteaproject.com/).

### *8.2.3. European Program NNE 2001-00825, 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 [59][73].

## 8.3. International Cooperations

- PRA SI03-02 is a biannual bilateral research program co-funded by AFCRST in France and the Chinese ministry of the science and technology. It aims to develop the (m,k)-firm based QoS management in multimedia networks. The two partners are TRIO team of the LORIA and the National Laboratory of Industrial Control Technology of Zhejiang university.
- PAI “Germaine de Staehl” with the Institute of Communication Systems (ICS), EPFL directed by Jean-Yves Le Boudec.
- 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

- Mireille Bousquet (LABRI, one week in June 2004).
- Joël Goossens, Professor, Université Libre de Bruxelles, Belgium, (4 days, May 2004).
- Arie Hordijk (Leiden, two months, March and September 2004).
- Alain Jean-Marie (LIRMM. one week in November 2004).
- Jean Mairesse (LIAFA, one week in October 2004).
- Anatoly Manita, Professor, University of Moscow, Russia (June - July 2004).
- Louiza Medjkoune Bouallouche, Bejaïa University, Algeria (September 2004).
- Flavio Ocquendo, Annecy University (one day in September 2004).
- Gianlucca Rizzo (EPFL, two weeks in June)
- Dieter Zöbel, Professor, Koblenz-Landau University, Germany, (2 days, May 2004).

# 9. Dissemination

### *9.1.1. Conference organization, Editing activities*

- TRIO permanent members participate to the program committee of WODES'04, RTS'04, RTN'04, WFCS'04, CIFA'04, IEEE Mechatronics and Robotics Conference 2004.
- Jean-Pierre Thomesse was chairman of "Industrial Computing" track and organized a special session on "Proteus" project at IEEE Mechatronics and Robotics Conference 2004, Aachen, Germany.
- Françoise Simonot-Lion and Jean-Pierre Thomesse are reviewers for TSI, Françoise Simonot-Lion and YeQiong Song for IEEE Transactions on Industrial Electronics, 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, Asian Journal of Control.
- Françoise Simonot-Lion will chair the subcommittee "Automotive Electronic and Embedded Systems" (part of the Technical Committee on Factory Automation) of the IEEE Industrial Electronics Society.
- Nicolas Navet is Program Chair of the Conference RTS'05 in Paris.
- Nicolas Navet is editor of a special issue on real-time systems of TSI.
- Françoise Simonot-Lion is Member of the Advisory Board of the "Embedded Systems Hanbook" at CRC Press.

### 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 is member 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.
- Jean-Pierre Thomesse is member of Scientific Board of Institut National Polytechnique de Lorraine.
- Xavier Rebeuf is elected member of the administration board of Institut National Polytechnique de Lorraine.
- Françoise Simonot-Lion is member of the Program committee of INRIA-Lorraine
- YeQiong Song is member of operation committee of QSL action.
- Xavier Rebeuf is the Scientific Expert of the Research Program Committee at Schneider Electric Industries.
- Eric Thierry is in charge of the Computer Science Student Seminar at the ENS Lyon. Researchers are invited to present their work to the "Licence" and "Master" students in order to introduce them to the research world in computer science.
- As a member of the evaluation comitee of INRIA, Bruno Gaujal has participated to the admissibility examinations for CR2 DR2 and DR1 of INRIA.
- 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

- Nicolas Navet was invited speaker at "thêmes émergents du chapitre français de l'ACM-SIGOPS" on Embedded Systems in Nantes (October 2004).
- YeQiong Song was invited keynote speaker at the 1st French Taiwanese Conference in Information Technologies, Paris. 2004.
- Jean-Pierre Thomesse was invited keynote speaker at the GISEH Conference, Mons. 2004.
- Nicolas Navet was invited at EPFL (March 2004) in the context of PAI "Germaine de Staehl".

### *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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